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SAFETY-RELATED REQUIREMENTS FOR PHOTOVOLTAIC MODULES AND ARRAYS

Final Report: Flat-Plate Solar Array Project, Engineering Sciences Area

March 1984

Work Performed Under Contract No. NAS-7-100-955392

Underwriters Laboratories Inc.
Melville, New York

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SAFETY-RELATED REQUIREMENTS FOR PHOTOVOLTAIC MODULES AND ARRAYS

JPL CONTRACT NO. 955392

FLAT-PLATE SOLAR ARRAY PROJECT

ENGINEERING SCIENCES AREA

FINAL REPORT

MARCH, 1984

The JPL Flat-Plate Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of flat-plate solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DOE.

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ACKNOWLEDGEMENTS

R. Sugimura of the Jet Propulsion Laboratory was the Technical Manager for this study and R. Ross, Jr. is the Manager of the Reliability Engineering Development Area of the Flat-Plate Solar Array (FSA) Project for which this study was performed. Their guidance and technical input to this study were deeply appreciated.

ABSTRACT

Underwriters Laboratories has conducted a study to identify and develop safety requirements for photovoltaic module and panel designs and configurations for residential, intermediate, and large scale applications.

Concepts for safety systems, where each system is a collection of subsystems which together address the total anticipated hazard situation, are described. Descriptions of hardware, and system usefulness and viability are included. This discussion of safety systems recognizes that there is little history on which to base the expected safety related performance of a photovoltaic system. A comparison of these systems, as against the provisions of the 1984 National Electrical Code covering photovoltaic systems is made. A discussion of the UL investigation of the photovoltaic module evaluated to the provisions of the Proposed UL Standard for Flat-Plate Photovoltaic Modules and Panels is included.

Grounding systems, their basis and nature, and the advantages and disadvantages of each are described. The meaning of frame grounding, circuit grounding, and the type of circuit ground are covered.

The development of the Standard for Flat-Plate Photovoltaic Modules and Panels has continued, and with both industry comment and a product submittal and Listing, the Standard has been refined to a viable document allowing an objective safety review of photovoltaic modules and panels. How this document, and other UL documents would cover investigations of certain other photovoltaic system components is described.

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APPENDICES

SUMMARY

Underwriters Laboratories Inc. (UL) has followed the developments in photovoltaic module design insofar as commercially available products are concerned and as far as announcements of unmarketed products are concerned, and has engaged in dialogue with photovoltaic module manufacturers and others having an interest in this field. Information obtained, as well as material describing photovoltaic module field performance and input from others including those on the National Electrical Code Ad-Hoc Subcommittee on Photovoltaics has been used to develop suggestions concerning installation procedures. Many of these suggestions appear in Article 690, Photovoltaic Systems, of the National Electrical Code, 1984 (NEC). A copy of Article 690 is appended to this report. An explanation of certain of the Article 690 items relating to array disablement and array ratings was developed. Other suggestions for array installation procedures have been incorporated in the Section on Safety System Schemes which may appear in future specifications for photovoltaic array installations. These schemes appear as a part of this report.

The rationales for system and circuit grounding, or circuit isolation, types of grounding and efficacy of an installed grounding scheme were studied. Suggestions for grounding schemes and isolation schemes are provided.

Concepts concerning acceptable construction and test performances of modules and panels as concerns safety related items were developed. This resulted in the evolution and further development of the UL Proposed Standard for Safety - Flat-Plate Photovoltaic Modules and Panels, UL1703, that forms a part of this report. The prior version of this Proposed Standard was included in Report DOE/JPL 955392-1; DEVELOPMENT OF PHOTOVOLTAIC ARRAY AND MODULE SAFETY REQUIREMENTS, June, 1982. The Proposed UL Standard contains provisions describing items such as insulating materials, current-carrying parts, connection means, corrosion protection, mechanical integrity, accessibility, temperature limits, and dielectric withstand capability.

A complete investigation of the ARCO Solar, Inc. M51 Photovoltaic Module to the provisions of the Proposed UL Standard for Photovoltaic Modules and Panels was undertaken. This investigation was sponsored by ARCO Solar, Inc. and included the optional roof fire test procedure, by which the module was assigned a Class C roof fire rating. This investigation also resulted in the further refinement of the Proposed UL Standard, by identifying test procedures and construction specifications which might have been unreasonable or unnecessary to apply.

UL evaluations of components for use in photovoltaic systems were considered and the particulars by which components, such as connectors, diodes, diode housings, wiring systems, and mounting frames would be judged are described.

1. INTRODUCTION

1.1 General

Research into safety-related proposals for photovoltaic systems was performed for the Jet Propulsion Laboratory's (JPL) Flat-Plate Solar Array (FSA) project. Underwriters Laboratories Inc. (UL) has further identified areas of photovoltaic module installation aspects and construction which may compromise safety of both human life and property. This work has resulted in: advanced concepts for safety systems, module and panel safety related construction specifications in the Proposed UL Standard for Safety - Flat-Plate Photovoltaic Modules and Panels; UL1703, Edition of March, 1984; and guidelines for installation of photovoltaic system components in the form of proposals for revisions, since accepted, for the National Electrical Code (NEC)*.

The Proposed UL Standard is intended to provide guidance to manufacturers concerning features of construction of the product deemed desirable to reduce the risk of fire and shock to an acceptable level. Product compliance to the standard is usually verified by an independent third party. The certification as to compliance of any particular piece of the product may be shown by a mark of the testing agency (third party) affixed to the product.

Further refinement and revision of the Proposed UL Standard resulted from an evaluation and subsequent Listing of the ARCO Solar Inc. M51 module. This work was funded and sponsored by ARCO Solar, Inc.

1.2 Report Format

This report is divided into 6 sections and 9 appendices. The sections reference one or more appendices, which provide details and additional material.

Section 2 describes Safety Systems for Photovoltaic Installations, detailing expected hazard situations, proposed remedies for each, and how the remedies (the subsystems) are combined to form candidate systems. Grounding systems and rationales and the differences between frame and system grounding, and the virtues of isolated and grounded electrical systems are covered. The selection of the "best" systems is described. The Proposed UL Standard for Safety - Flat-Plate Photovoltaic Modules and Panels is introduced.

Section 3 describes the investigation of the ARCO Solar Inc. M51 photovoltaic module for its compliance with the provisions of this Standard, including a discussion of how the investigation resulted in furthering the development of the Standard. This material is provided with the permission of ARCO Solar, Inc.

* - National Electrical Code® and NEC® are Registered Trademarks of the National Fire Protection Association, Inc., Quincy, Massachusetts.

Section 4 describes how photovoltaic system components would be evaluated with respect to the provisions of the Proposed UL Photovoltaic Module Standard and other standards of Underwriters Laboratories Inc.

Section 5 provides explanation that expands on certain of the provisions of Article 690 of the National Electrical Code.

Section 6 provides a summation and recommendations.

A companion report in preparation, DOE/JPL 955392-3; SAFETY REQUIREMENTS FOR WIRING SYSTEMS AND CONNECTORS FOR PHOTOVOLTAIC SYSTEMS, Underwriters Laboratories Inc. covers wiring systems, those now described in the National Electrical Code that would be acceptable in photovoltaic system installations, and new wiring systems developed specifically for photovoltaic installations. Details will be provided on how new wiring materials and termination methods would be evaluated to determine acceptability in photovoltaic systems.

2. SAFETY SYSTEMS

2.1 Introduction

The presence of any energy source creates a potential for hazard. In contemporary electrical systems, the energy source is most often the utility supply, but it can be on-site means such as generators or batteries. To satisfy community interests with regard to protecting (a) the occupants of a building, (b) emergency personnel that may be called to a building, and (c) occupants and owners of adjacent buildings, a utility will generally not provide electric service to any installation that does not meet minimum requirements that have been established to keep the potential for hazard to a prescribed level. These minimum requirements are described in the local electrical code, in many cases based on the National Electrical Code (NEC).

2.1.1 Nature of Hazards

The potential hazards from the use of electricity are two fold, fire and shock.

Electric current through a body if of sufficient magnitude and duration may cause death or serious injury. The magnitude of the current is dependent upon the body impedance and the circuit parameters. In certain cases the duration may be a function of a circuit device.

Fault-currents through unwanted paths, or overcurrents through normal paths may cause arcing or overheating and a resulting fire hazard situation. Typically, in photovoltaic installations, a fire hazard situation may be caused by a current through an unwanted path, which may likely involve arcing.

2.1.2 Historical Data

The extensive installation and use of utility-powered electrical systems have provided data describing their safety performance. This data has shown where modifications were necessary in system specifications to provide the desired level of safety, and over the years such modifications have been made in the provisions of the NEC and its supporting documents.

2.1.3 No Safety Performance Data Base

In the case of photovoltaic systems, no substantial data exists to describe expected system safety performance. What are likely to be the acceptable levels of safety in a photovoltaic system installed between now and 1987 (in other than a utility or Federal Government facility) are described in new Article 690 of the 1984 National Electrical Code, and its supporting documents. Supporting documents would include, by implication and reference, the Underwriters Laboratories Inc. Proposed Standard for Safety - Flat-Plate Photovoltaic Modules and Panels, UL1703, March, 1984, Appendix A of this report and the Draft Standard for Safety - Power Conditioning Units for Use in Residential Photovoltaic Power Systems, April, 1982 Appendix B of this report, and any standards of other organizations involved in listing or labeling devices and materials (see paragraphs 90-6 and 110-2 of the NEC).

Extensive data on system safety performance and installations was not available during the development of the NEC Article 690 because residential, commercial, and industrial photovoltaic systems had not seen widespread use. Thus, the framers of this NEC Article, consisting of people from module manufacturers, system installers, contractors, testing laboratories, and government laboratories had to use judgement based on the best available information to define what photovoltaic module failure modes there might be, what the installer can reasonably do in erecting the installation, and what apparatus is commercially available to be used as a part of the photovoltaic installation. It was on this basis that the proposed provisions for the NEC to cover photovoltaic installations were developed. As is the case with all safety standards, field service records are continually reviewed and are considered when future revisions to the requirements are developed.

2.1.4 Minimum Safety Levels Per 1984 NEC

The text of NEC Article 690 is presented in Appendix C. An examination of this text discloses that a photovoltaic system would be considered acceptable if basically (a) both circuit and conductive frame parts are solidly grounded and (b) primary insulation is provided to prevent personal contact with electrically hazardous parts, and to prevent currents from passing between circuit parts and ground that would constitute a shock hazard to personnel or create a fire hazard situation. A fundamental level of safety is established by the insulation system that prevents current-carrying conductors and devices creating a potential for shock hazard or leading to equipment damage. Additionally, the Article describes connectors (locking or latching type, polarized), source circuit fuses, point of connection to the building supply, disconnecting means, etc., but these do not modify the basic requirement for the use of a single insulation system, without back-up protective devices such as ground-fault detection and response systems or double insulation, as the primary safety system of a photovoltaic installation. Thus a photovoltaic installation represented by the electrical schematic of Figure 2.1.4 would comply with the NEC. NEC Article 690 considered the installation of PV systems using material, components, and devices now commercially available, and the provisions of this Article, in conjunction with the listing of modules to certify their compliance with a safety Standard such as the Proposed UL Standard, represent what is considered to be an acceptable level of safety within the current state of the technology. Field experience will ultimately dictate whether or not additional requirements are needed. For example, fault conditions such as frame-ground arcing, in-circuit arcing, and delamination of encapsulants and superstrates have been observed in some installations, but the extent of any resultant damage has not been assessed. §§

NEC Section 690-18, Disablement of an Array, recognizes that the photovoltaic system is a source that is energized by radiant energy and not readily "turned-off", but does not identify a particular method of accomplishing disablement. (See also Section 5, National Electrical Code Status, for commentary on "Array Disablement".)

§§ - Reference - Materials, Processes and Testing Laboratory Technical Progress and Final Reports: Massachusetts Institute of Technology, Lincoln Laboratory; S. E. Forman, M. P. Themelis, (1) November, December 1980; January, February 1981; (2) July, August, September, October, 1981; (3) Final, 1977-1982.

Any permanent ground path such as A in Figure 2.1.4 in conjunction with single insulation failures and line-ground faults B or C may result in arcs or body currents which can constitute fire or shock hazard situations. Supplementary circuit elements which can be used to arrest such arcing or terminate body ground currents may therefore be desirable for incorporation in a photovoltaic system. Such devices and components, which are now technically feasible and thus readily commercialized if the demand exists, constitute a more advanced system, and is the subject of much of this section.

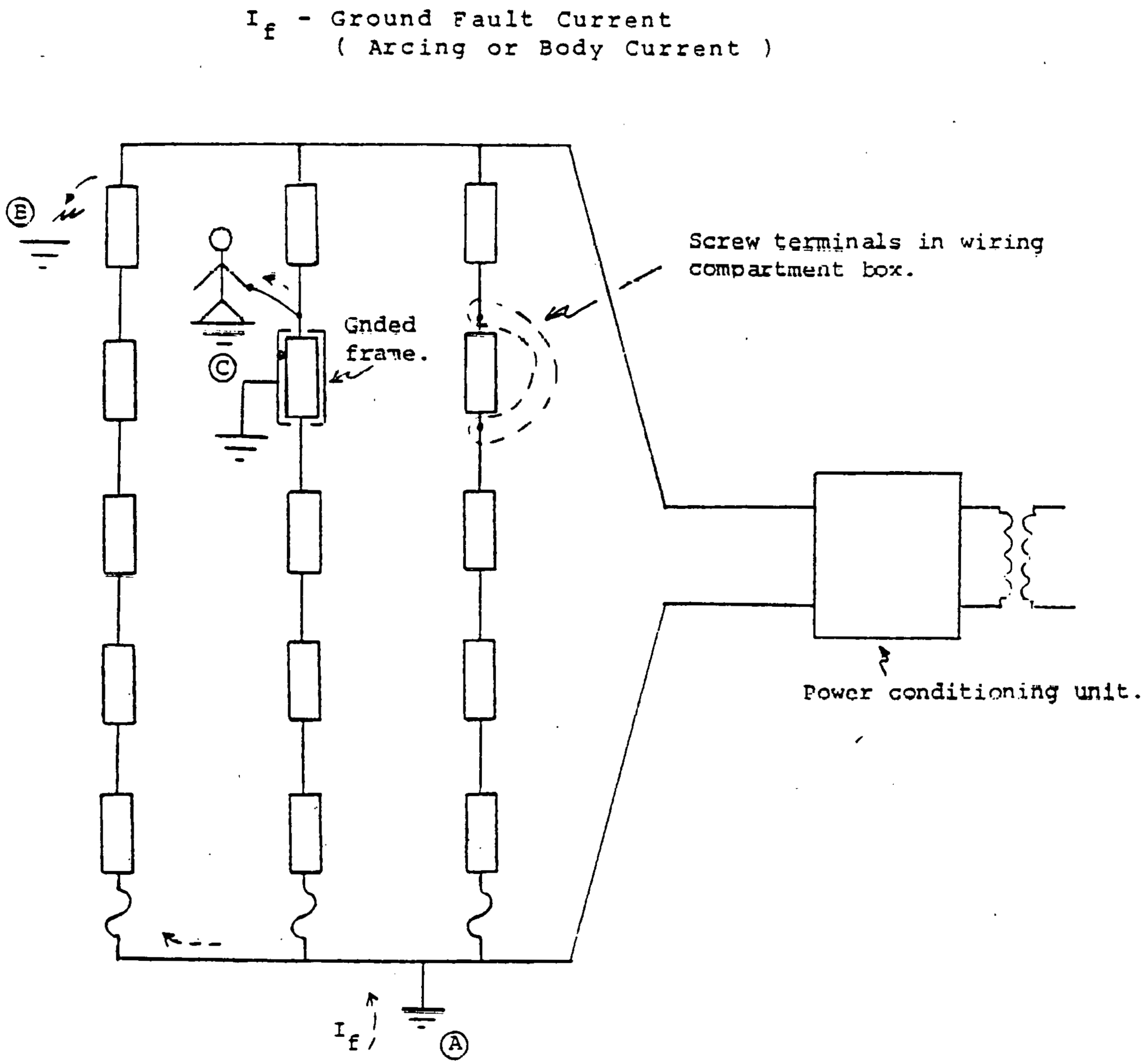


Figure 2.1.4

Photovoltaic System Per NEC Article 690

2.2 Grounding and Ground-Fault Detection/Response Systems

2.2.1 Background

As a backup to the insulation system, additional means can be provided to prevent shock hazard or equipment damage situations from occurring. A key consideration in selecting these means is the ground scheme utilized. This ground scheme constitutes an important part of any "Safety System".

Two aspects of grounding relate to almost all electrical safety systems: (1) grounding of enclosures; and (2) grounding of circuits. In the following, grounding of ac equipment enclosures and ac system grounding is covered in terms of the National Electrical Code requirements, followed by an overview of grounding considerations for photovoltaic systems.

The fine print note under National Electrical Code Section 250-1 states:

> "Systems and circuit conductors are grounded to limit voltages due to lightning, line surges, or unintentional contact with higher voltage lines, and to stabilize the voltage to ground during normal operation. Systems and circuit conductors are solidly grounded to facilitate overcurrent device operation in case of ground faults.
>
> "Conductive materials enclosing electrical conductors or equipment, or forming part of such equipment, are grounded to limit the voltage to ground on these materials and to facilitate overcurrent device operation in case of ground faults."

2.2.2 Enclosure Grounding, AC Systems

In contemporary electrical service systems, the interconnection between the grounding and grounded conductors on the premises is made only at the service, see Fig. 2.2.2. From this point, a grounding conductor (that conductor which in service is provided with a green or green/yellow colored or sometimes no insulation) travels to the utilization equipment (appliances and the like) and is connected to the frame of such equipment to effect grounding of conductive materials enclosing electrical conductors. This grounding of the conductive enclosure limits the voltage between the enclosure and ground in the event of a line-to-enclosure fault in the utilization equipment.

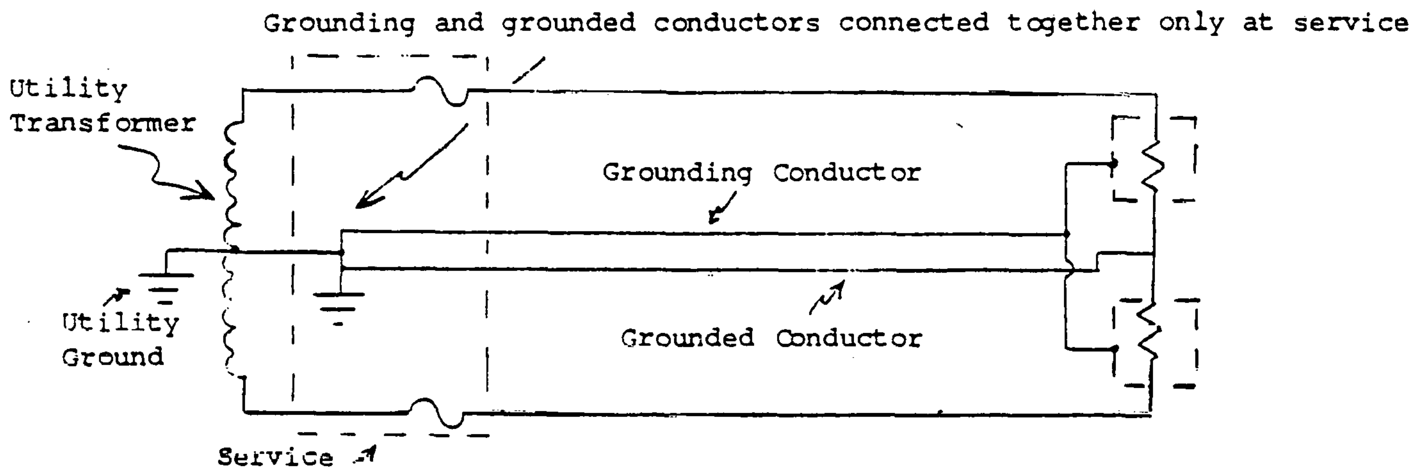


Figure 2.2.2

Grounding - AC Services

A line-to-enclosure fault might cause the full available branch-circuit current to flow through the ungrounded and grounding conductors until the overcurrent protective device (e.g. - the fuse) operates to clear (open) the circuit. Because of this, the conductors (and especially the grounding conductor) must be of adequate ampacity to handle this current without rupturing, excessive temperatures, or expulsion of sparks or arcs, for the duration of the current flow. In addition to its ampacity, the grounding conductor must be installed in proper physical relationship to the current-carrying conductors with which it is associated, so as to invite the ground-fault current to return through it rather than being diverted to other, possibly inadequate paths. In ac systems, the available currents on the source side of the fuses may range from several thousand amperes to tens of thousands of amperes, to and through the one hundred thousand ampere level. Typically, when available current levels on the source side of the overcurrent devices approach the one hundred thousand ampere mark, the overcurrent devices are current-limiting (note that only certain circuit interrupting devices are classed as current-limiting) so that the full peak of the available source current is not available on the load side of the overcurrent protective device. Thus, this high available fault current is never seen by either the circuit conductors to the load or by the grounding conductor.

GLOSSARY:

CURRENT-LIMITING FUSE - A fuse that properly interrupts all available currents within its interrupting rating and, within its current-limiting range, limits the clearing time at rated voltage to an interval equal to or less than the first major or symmetrical current loop duration and limits peak let-through current to a value less than the peak current that would be possible with the fuse replaced by a solid conductor of the same impedance.

CURRENT-LIMITING RANGE (As Applied to Fuses) - That range of rms symmetrical available currents which is equal to and less than the interrupting rating in which the total clearing time at rated voltage and frequency is less than 1/2 cycle.

CURRENT-LIMITING CIRCUIT BREAKER - A circuit breaker that does not employ a fusible element and that when operating within its current-limiting range, limits the let-through I^2t to a value less than the I^2t of a 1/2 cycle wave of the symmetrical prospective current.

CURRENT-LIMITING RANGE (As Applied to Circuit Breakers) - The rms symmetrical prospective currents between the threshold current and the maximum interrupting rating current.

For a high available current, low power factor, ac circuit closed for full current asymmetry (near zero on the voltage wave), a current-limiting fuse or circuit breaker may operate to interrupt the current as shown in Figure 2.2.2A. The grounding conductors must not rupture before the current-carrying conductors, for such rupturing would leave the enclosure at line voltage, resulting in a shock hazard situation. Typically, if the grounding conductor is at least as large as the current-carrying conductors, the overcurrent device will operate on the occurrence of a low impedance line-to-enclosure fault to protect both current-carrying and grounding conductors, and will leave the enclosure with no voltage.

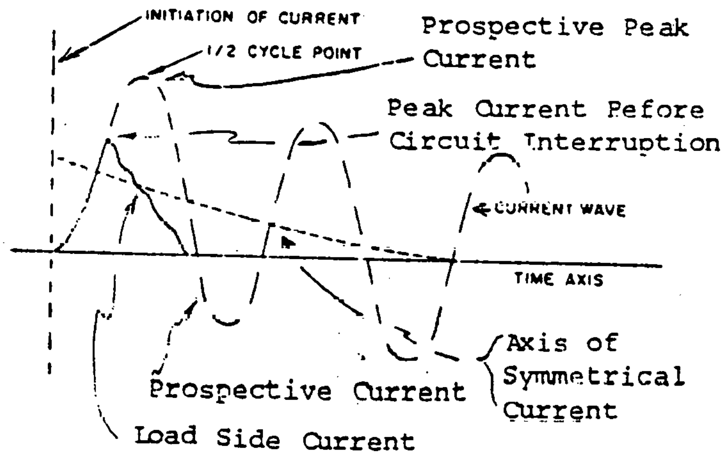


Figure 2.2.2A

Operation of Current-Limiting Circuit Interruption Device

If the line-to-enclosure fault is of high enough impedance so that the current in the fault is insufficient to cause the overcurrent device to operate, then the impedance in the grounding conductor must be low enough, so that under the maximum continuous current that can flow, the voltage between the enclosure and earth does not reach the value considered to be the threshold of shock hazard. Continuous currents are defined as currents with durations of one second or more.

Thus, the enclosure ground, if properly sized, operates to, under all circumstances, limit the voltage on accessible parts, and thereby prevent a shock hazard situation from personal contact with such parts.

2.2.2 Circuit Grounding, AC Systems

In contemporary electrical service systems, the use voltages appearing on circuits in residences, offices, etc., are derived from the secondary of distribution transformers, the primary of which may be in the range 4-13 kV, see Figure 2.2.3. Both the primary and secondary windings of the distribution transformer are grounded by the utility. Should a primary-to-secondary fault occur at the high end of the distribution transformer, the primary voltage, which might otherwise be impressed on the secondary, will be greatly reduced by the secondary circuit ground, and the current through this ground will clear the circuit by causing operation of the transformer primary overcurrent protective device. See Figure 2.2.3A. This requires that the ground faults be of adequate ampacity and low enough impedance so that the current will be adequate to cause the overcurrent device to operate.

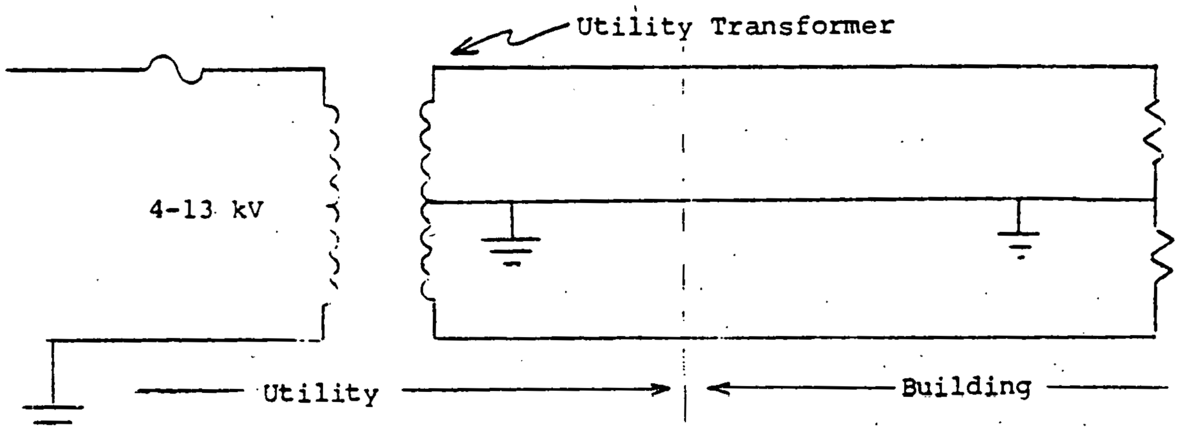


Figure 2.2.3

AC Distribution System

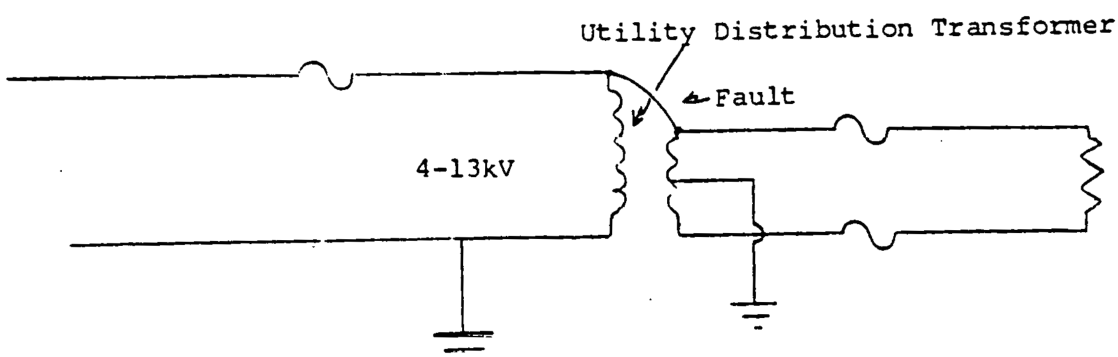


Figure 2.2.3A

AC Distribution System - Fault in Utility Transformer

If the transformer secondary ground is not present, see Figure 2.2.3B, the fault in the distribution transformer would result in the supplied buildings electricity system being brought up to the transformer primary voltage. As neither the spacings or insulation in this system is likely to be adequate for high voltage, a hazard would then exist (1) in any user contact with this system, or (2) from arcs and resulting fires.

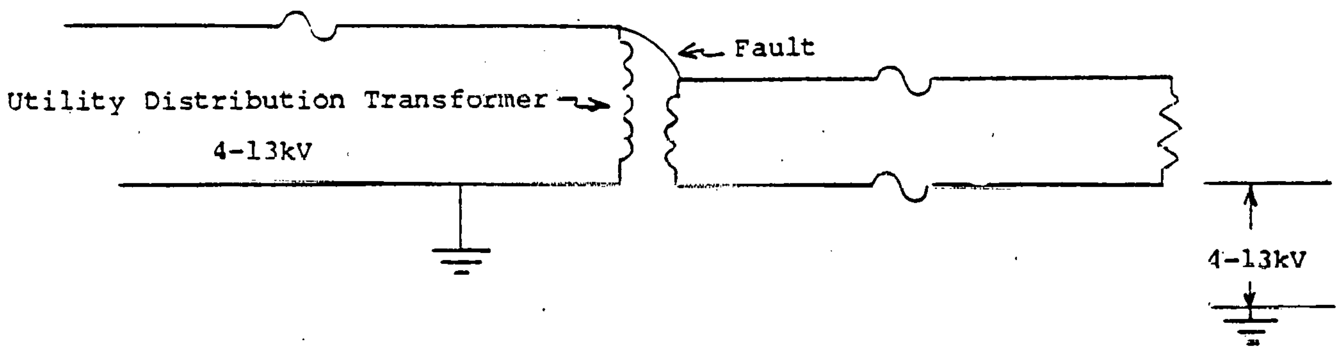


Figure 2.2.3B

Fault in Transformer - Ungrounded Use Network

The system ground also prevents the transformer secondary voltage from rising in voltage, relative to earth, due to induced charges or line surges. Systems are center-grounded so that the voltage between any portion of the circuit and earth is limited to 0.5 (single phase) or 0.57 (three phase) of the total circuit voltage. Also see Section 2.2.6.2, Circuit Grounding and an Alternative.

An important basis for system grounding is that accidental system grounds are generally inevitable, and if the system ground is not deliberately provided, the accidental ground can appear anywhere in the circuit. Accidental grounds would not provide the limited voltage-to-earth protection afforded by a center-grounded system.

2.2.4 Interaction

The utility-provided ground and the buildings service ground are separated by the "neutral" conductor of the service drop or service lateral (conductors between the building's service entrance and the utility low voltage [120-600 volt] distribution network). Unlike the grounding conductor within the building, this neutral conductor will carry current any time the building's load is not balanced between sides or phases, and in carrying current will produce voltage drop along its length. In this circumstance, if the building's ground has significant impedance, while the utility's does not, there will be a voltage difference created between (1) the building's grounding conductors together with all enclosures connected to this conductor, and (2) earth ground at or near the enclosures. If the voltage difference is large enough, considering the environment (e.g. - wet or submerged contact), a shock hazard may be present. See Figure 2.2.4. Solutions to this are to assure that the building's service connection to ground is of low enough impedance, or creating an artificial grounding plane at a potential equal to that of the grounding conductors at the enclosures. Generally, the first option, the low enough impedance is the desired route, because it avoids the need to construct the artificial ground plane and locate the enclosures so that they, and actual earth (differing from the artificial ground plane such as a buried grid) cannot be contacted simultaneously.

Article 250, Section H, paragraph 250-84 of the NEC describes the maximum acceptable resistance of a single grounding electrode (25 ohms). Grounding resistances are relatively easy to measure, an example of such measurements is presented in Appendix D, GROUNDING SYSTEM RESISTANCE AND ASSOCIATED MEASUREMENTS. Detail on methods of measuring grounding resistance is provided in the Standard Handbook for Electrical Engineers, D. G. Fink and J. M. Carroll, McGraw-Hill, 1968.

The work described in Appendix D reports measurements on a known grounding network, but as details of the system grounding were never received by UL, use of these measurements for any purpose was not possible.

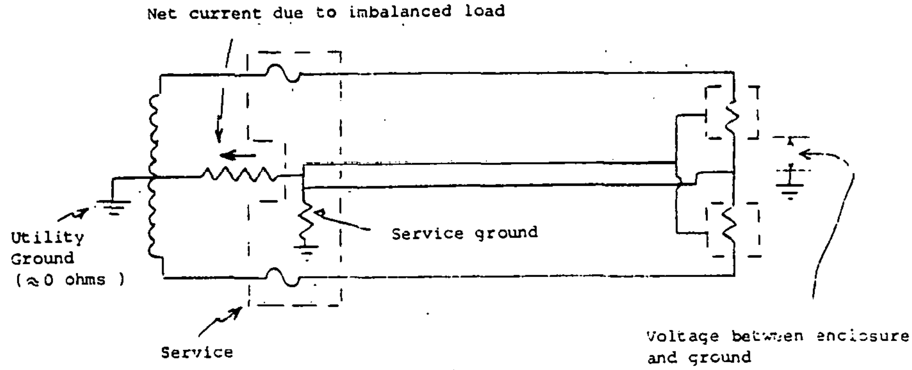


Figure 2.2.4

Inadequate Building Ground

- Equipment Enclosures to Ground Voltages

2.2.5 Connection to Earth

Grounding, in the broad sense need not mean an actual connection to earth. For example, an electrical system on an aircraft is grounded by being connected to the frame of the craft and voltages are referenced to the frame. When an electrical system exists near actual earth, and is connected to earth, the means of making the earth connection is important to ensure that system voltages to ground are low. Details on methods of circuit connection to earth are provided in Section 4 of IEEE Std. 142-1972 "IEEE Recommended Practice For Grounding Industrial and Commercial Power Systems" and thus it is unnecessary to provide all of the same information here. A synopsis of alternate grounding schemes does indicate that where concrete foundations of a building or other structure are provided, the reinforcing rods of such concrete provide a good and ready made grounding electrode, and are better than grounding electrodes directly buried in earth. This is because, for concrete encased rods, the resistivity of the material closest to the electrode (the concrete), is lower than the resistivity of the soil which would otherwise occupy that volume. The resistivity of the material in this volume is the most critical resistivity in establishing grounding resistance. Treated soils can provide the same low resistivity in the area of the grounding electrodes, but maintenance is then needed because the treatment is not permanent.

Where a single electrode does not provide the desired low value of grounding resistance, multiple driven electrodes are used. However, multiple electrodes would not necessarily reduce the grounding resistance as though they were simple parallel current paths, because the voltage gradient patterns created by the electrodes would overlap each other. The greater the distance between the multiple electrodes, the less the overlap and the more effective are the parallel paths.

2.2.6 Grounding As Applied to Photovoltaic Systems

2.2.6.1 Frame Grounding

As with other electrical systems, the noncircuit conductive parts of a photovoltaic system (e. g. - frames, structures) should be grounded to ensure that there will be no voltage between these parts and (earth) ground in the event of insulation failure. And this grounding should take into account possible voltage drops along a neutral conductor as described under Section 2.2.4, Interaction.

The frame grounding means should be such that removal of a module does not interrupt the frame grounding for any other part of the photovoltaic installation. This provision is best included in an installation code (e.g. - the NEC).

In circumstances where the spacing between circuit parts and conductive frame parts is great and the intervening insulation rigorous, so that energization of the conductive structure such as roof gutters or flashing on a photovoltaic equipped roof is unlikely, then these parts can be isolated. No attempt has been made to define what constitutes large enough spacings or rigorous enough insulation, except that some guidance is available from the rules concerning Double Insulation, see Safety Systems, Section 5 and Appendix E, PROVISIONS OF THE STANDARD FOR DOUBLE INSULATION SYSTEMS FOR USE IN ELECTRICAL EQUIPMENT, UL 1097-1978, THAT MAY BE CONSIDERED APPLICABLE TO PHOTOVOLTAIC MODULES AND SYSTEMS.

2.2.6.2 Circuit Grounding and an Alternative

Some of the rationales for a system ground for a utility supply may not exist for a photovoltaic array. For example, in a residential array interactive with the 120/240 volt building wiring by way of a transformer-isolated power conditioning unit, contact of the array circuit with higher voltage systems is unlikely. However, other bases do exist, such as, a need to stabilize the system voltage and define it with respect to ground so that insulation systems will not be overstressed, and the desire to know which circuit point is at ground so that control can be placed over successive grounds to prevent arcing or shock hazard ground-fault currents. If the objectives which are ordinarily met with solid grounding (solidly grounded is defined as grounded through an adequate ground connection in which no impedance has been inserted intentionally,) can be met with other types of ground connections then such other ground connections would be acceptable, for as stated in NEC Article 690:

> "Other methods which accomplish equivalent system protection and which utilize equipment listed and identified for the use shall be permitted" (Exception to Section 690-41).

An alternative to grounding is circuit isolation from ground. An isolated circuit can be a viable option if the circuit is equipped with a ground sensor to monitor the value of resistance between the circuit and ground. When that resistance has dropped below the value which would allow shock-hazard level or arcing hazard level currents in ground faults (a second uncontrolled ground between the circuit and ground), a reaction to the original fault takes place. See details in Section 2.4.4. In an isolated system, system voltage with respect to ground can be stabilized with high resistance (typically 100 kilohm) connections between the array circuit and ground, which for purposes of this document is not considered grounding. As with other circuits, in the situation of an ungrounded circuit, the circuit should be adequately guarded so that circuit parts are not exposed to contact by persons.

Thus, an ungrounded array circuit, properly equipped, can be provided with an adequate level of safety for use in photovoltaic systems.

The condition of a "virtual ground" may be present in a photovoltaic array interactive by way of a transformerless power conditioning unit with a center-grounded utility supply. A virtual ground is that point in the circuit which is at ground potential, but which has no direct connection to ground. See Figure 2.2.6.2 and Subsections 2.4.1.3 and 2.4.1.4. Again, the virtual ground, in conjunction with a high resistance connection to ground to provide a voltage reference when the array is disconnected from the utility, appears to satisfy the reasons for ground of a photovoltaic array.

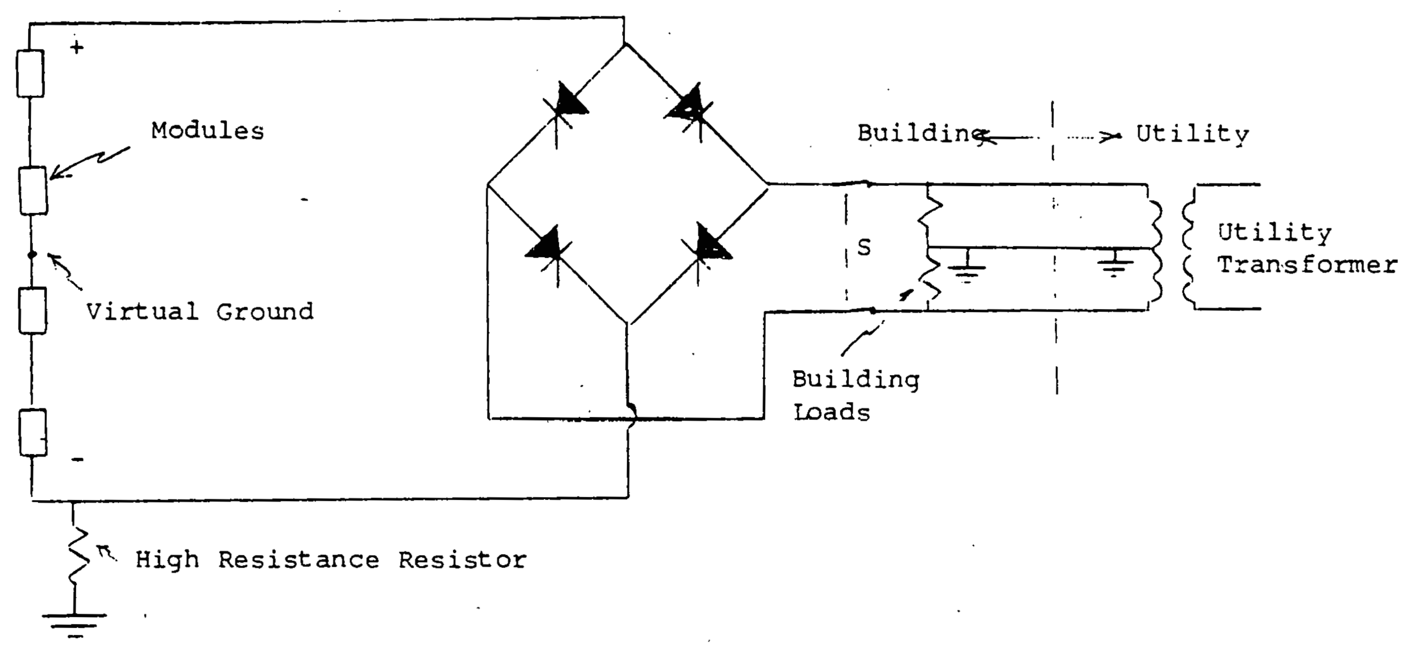


Figure 2.2.6.2

Array With Virtual Ground

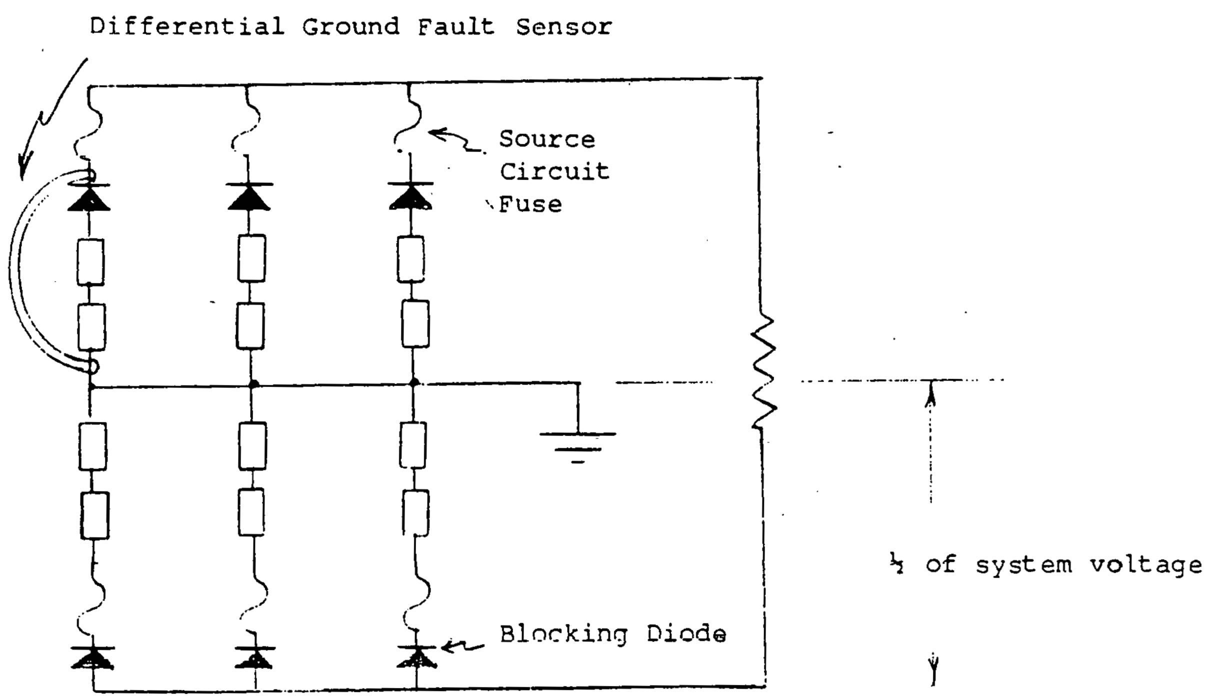


Figure 2.2.6.2A

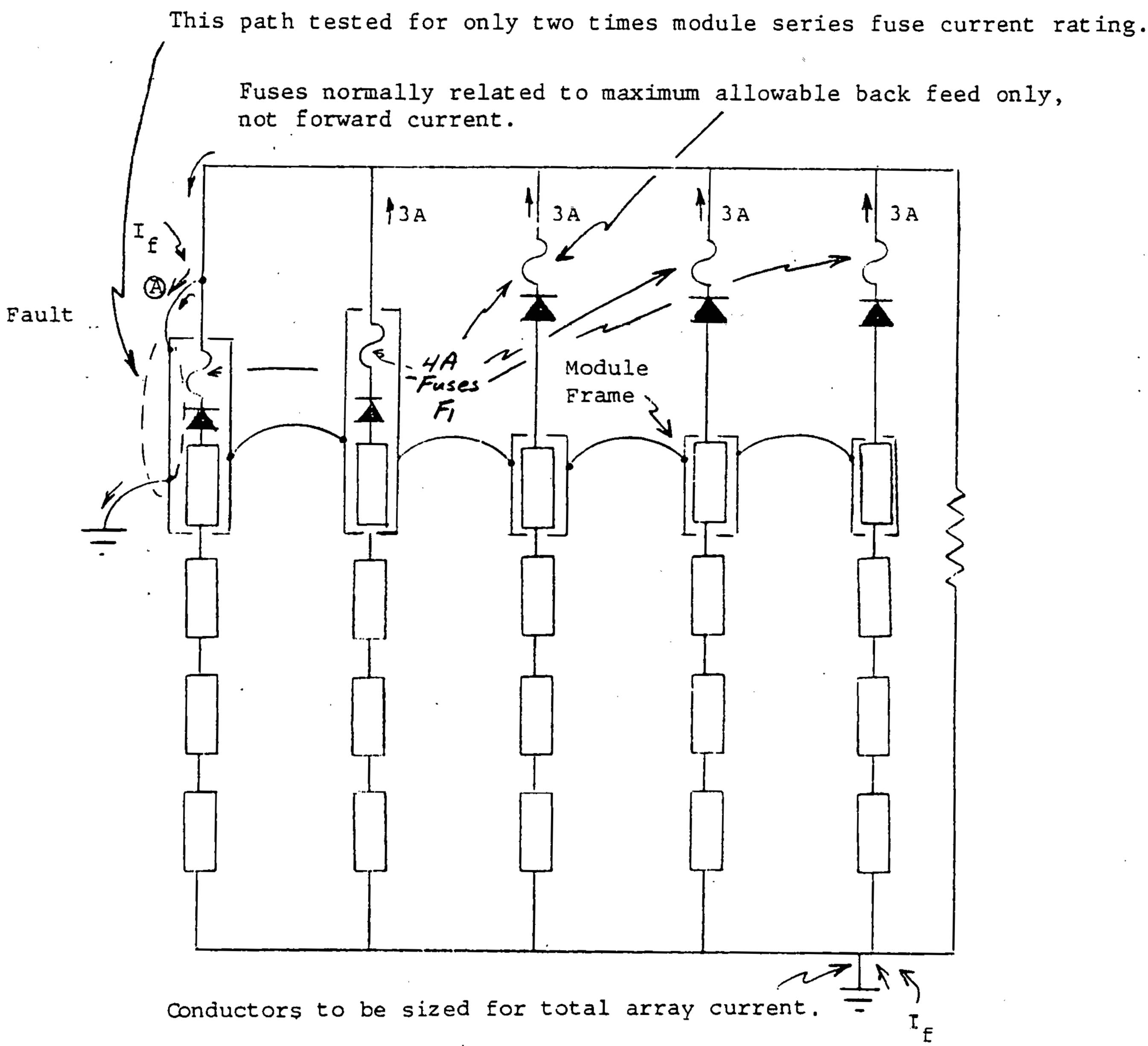
Center Grounding

If, in grounding an electrical circuit, the voltage between any and all parts of the circuit and ground can be restricted to less than the circuit voltage, such should be done. This will lessen the likelihood or severity of electric shock. This is readily achievable by center grounding. However, center grounding of an array circuit does add complexities in applying differential ground fault sensors, blocking diodes, and source circuit fuses. With center grounding each half of the source circuit must be fitted with individual devices. See Figure 2.2.6.2A.

2.2.6.3 Bonding Path Ampacity and Integrity

In the circuit of Figure 2.2.6.3, array source circuits (strings) are connected in parallel. In this circumstance, should a circuit-to-ground fault occur at A, the current faulted to ground would be equal to that from all the parallel connected modules, or 15 amperes in the case shown. This 15 ampere fault current exceeds the 8 ampere value used for the evaluation of the module bonding path (two times module series fuse rating,) per Section 25 "Bonding Path Resistance" of the Proposed UL Standard for Flat-Plate Photovoltaic Modules and Panels. Thus, the adequacy of this module's bonding path to withstand the effects of the ground-fault condition are unknown, and the ground path may be destroyed by the excessive current at any point within the area indicated by the dashed lines in the figure. Destruction of the grounding path while the circuit-to-frame fault is maintained, results in the frames being at array voltage, a hazardous condition.

To alleviate this problem, the Bonding Path Resistance Test, can be modified to represent ground-fault currents due to the maximum number of modules which can be connected in parallel (with a marking on the modules indicating this maximum number); or each fuse designated F_1, normally applied only to protect the modules from hazards due to reverse current, can be sized to protect the module bonding path and located outside of the module as it is in the three right-hand source circuits. In this, the more likely situation, where the fuses are outside of the modules and in the ungrounded end of the source circuit they will provide the needed protection, regardless of the number of source circuits connected in parallel. Modifications for Section 25 of the Proposed Standard are being considered to address this. If diodes were considered an acceptable means of protecting against faults, the blocking diode might also serve to protect the module bonding path if placed outside the module on the ungrounded end of the source circuit.



Bypass Diodes not shown.

Fuses and blocking diodes may be within or external to modules, if special end modules are utilized.

Figure 2.2.6.3

Overburdening Module Bonding Path

2.3 Advanced Safety Systems

2.3.1 Examples

An example of an array incorporating present technology devices that offers a considerably higher degree of safety in terms of protection against both fire and shock hazard situations is presented in Figure 2.3.1. This array maintains a concept of a solid ground (paragraph 690-41 of the NEC), but the solid ground may now be interrupted where necessary, both automatically or manually (leaving only a high resistance path to earth), to terminate ground-fault currents. (This is considered to comply with the NEC by virtue of the exception to the paragraph.) A basic insulation system is maintained around all circuit conductors to constitute a primary safety system. Should this insulation fail, safety subsystem components (e.g. - ground-fault sensing and reaction devices), the installation of which would not be not in conflict with the provisions for the NEC, would provide for the safety of the installation. It is unlikely that all of the safety subsystems shown in Figure 2.3.1 would be found in a single array. A restricted number could cover the fire and shock hazards otherwise associated with:

a) in-current arcing (fire)
b) ground fault arcing (fire)
c) ground fault body currents (shock)
d) overheated components (immediate fire, long term through degradation of materials - fire and shock)
e) short-circuits on utility power line (fire)
f) module replacement

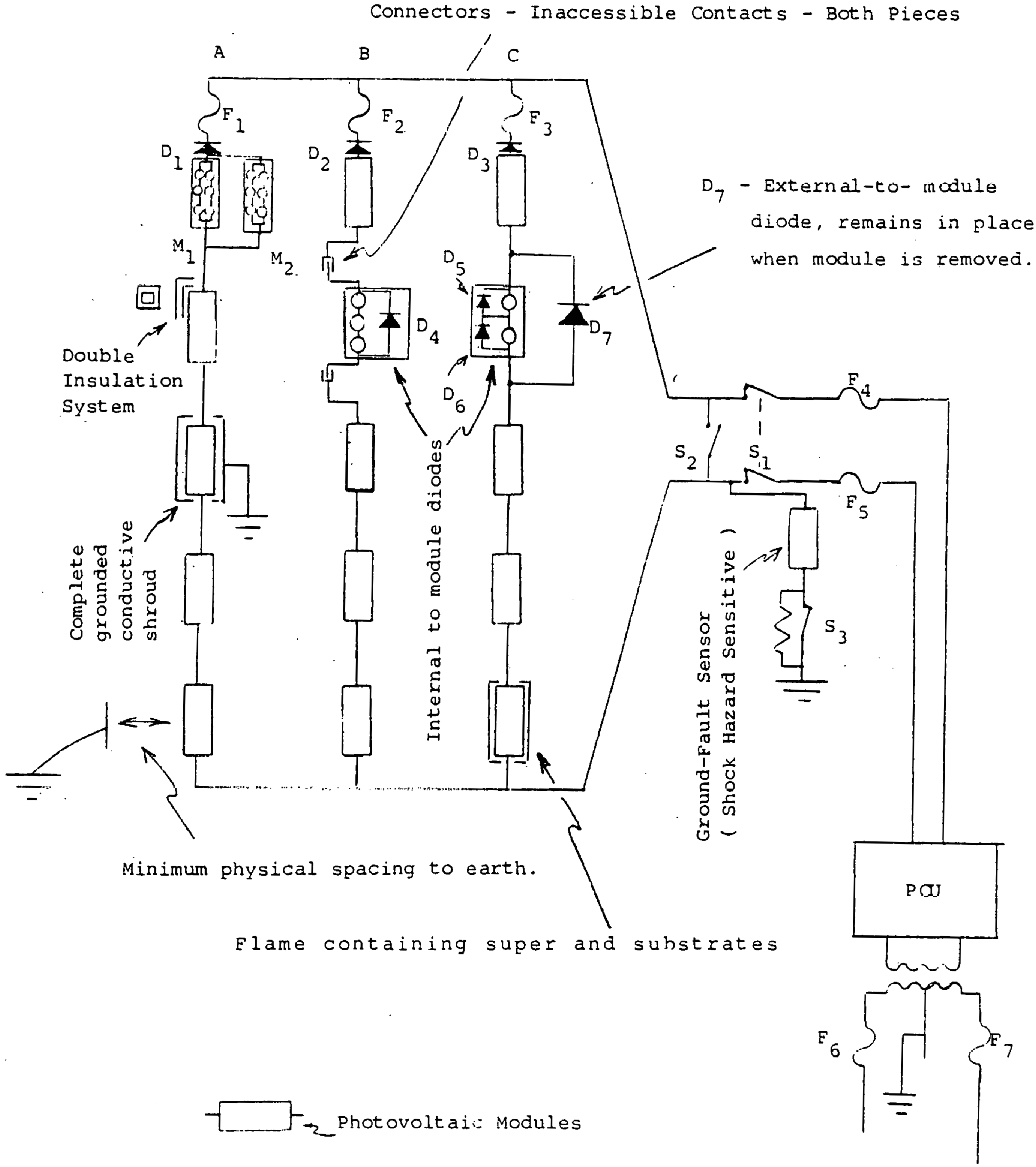


Figure 2.3.1

Safety Subsystems in a Photovoltaic Installation

For the circuit described by Figure 2.3.1, in-circuit arcing is prevented by redundant (parallel-path) circuit paths (as in source circuit A), a hierarchy of bypass diodes (as in source circuit C) or made harmless by flame-containing superstrates and substrates (as in source circuit C). Ground-fault arcing is prevented or made less likely by 'double insulation' (as in source circuit A) or a ground-fault detection and reaction system of either shock or fire hazard sensitivity level (for entire array circuit). Ground-fault body currents are prevented or made less likely by double insulation, complete grounded conductive shrouds, or minimum physical spacings between circuit elements (as in source circuit A). Overheated cells under conditions of reduced cell output (second quadrant operation) are prevented by bypass diodes (D5, D6, D7) around groups of cells (maximum number of cells allowed per diode as elected by manufacturer and confirmed by test, see Section 37 of Proposed UL Module Standard), (as in source circuit C) or numerous cell strings in parallel (as in source circuit A). Overheated cells under conditions of reverse current (fourth quadrant operation) are prevented by blocking diodes and/or fuses (as in source circuits A, B, and C). Short-circuits on utility power line are removed by opening of over-current devices F6 and F7 (as in the power conditioning unit output circuit) presently called for by NEC Article 690 (paragraph 690-9). Module replacement with minimal hazard is facilitated by modules with plug connectors with recessed contacts (see Section 15 of the UL Proposed Standard for Photovoltaic Modules and Panels for the degree of recessing considered necessary) (as in source circuit B) or external-to-module bypass diodes (e.g. - D7) in conjunction with ground interrupt switch S_3 and/or load break switch S_1, array shorting switch S_2, and low (less than 30 volt) voltage modules (as in source circuit C).

While most of the items described in the preceding paragraph will not be required under the provisions of NEC Article 690, some, such as blocking and bypass diodes appear in most arrays for performance purposes. However, for performance purposes it is possible that no account may be taken of the mounting location of, for example, the bypass diodes. Thus, if the diodes were an integral part of the modules, and were removed from the circuit with the module they would be ineffective in restraining voltage levels during module replacement.

2.4 Subsystem Details

Specifics on each of the subsystems proposed is presented in the following. Table 2.5 discloses which hazards each of these systems is intended to protect against.

2.4.1 Ground-Fault Detection and Response Systems

Ground-fault current occurs in a grounded electrical circuit when deteriorated insulation and/or the exposure of live parts, together with the introduction of a conductive path, causes a current between a circuit part and ground. A ground-fault system consists of the sensing device to detect this condition, and reaction circuitry to mitigate any adverse consequences. The ground-fault sensing device may be either of two types. One, the differential type, responds to differences in currents between the two legs of the circuit. This type is commonly used in bathroom and garage receptacles of dwelling units, per Section 210-8 of the NEC. The ac version used in these applications incorporates a differential transformer, consisting of the two circuit leads passing through a toroidal core.

The other type of ground-fault sensing device, the direct ground-current responding type, directly senses a current in the path between the ground and the circuit. It may consist of a simpler detecting element, such as a resistor, across which a voltage is measured. When providing protection in use circuits, the ground-fault system will ordinarily disconnect the circuit from the source. When providing protection in photovoltaic source circuits, the source must be rapidly extinguished as for example by array-short-circuiting, or the ground path opened. In the following examples the ground path is interrupted to terminate the ground-fault currents.

2.4.1.1 Shock Hazard

Where the voltage and available circuit current are above the values which constitute a shock hazard situation, one parameter, the duration of the current through the ground-fault, can be controlled to alleviate the hazards from electric shock. Typically, ground-fault systems for ac circuits will limit the duration of the current to as low as 25-26 milliseconds, which is expected to greatly reduce the risk of electrocution.

Acceptable exposure durations as a function of current for dc and combinations of ac and dc have not yet been formulated. Because of the lower risks from dc (as against ac), these durations may be longer than those permitted for ac.

2.4.1.2 Fire Hazards

Ground-fault arcing (current in an unwanted path), can be arrested by a ground-fault detection and interruption or disabling system.

2.4.1.3 Device Particulars and Application

A differential type ground-fault detector is shown in the photovoltaic system circuit of Figure 2.4.1, a direct-ground-current detection type is shown in the circuit of Figure 2.4.1A.

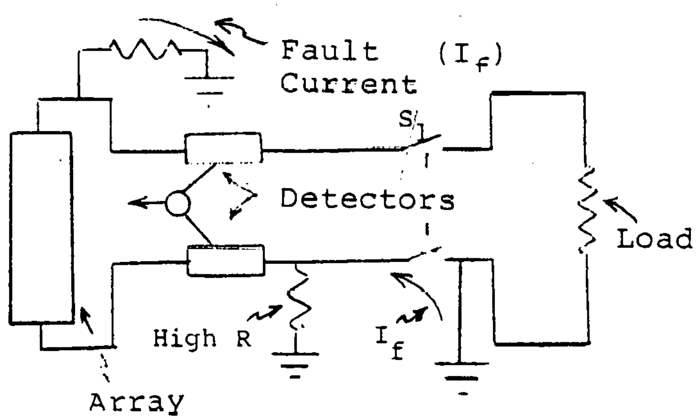


Figure 2.4.1
Differential Ground-Fault Detector

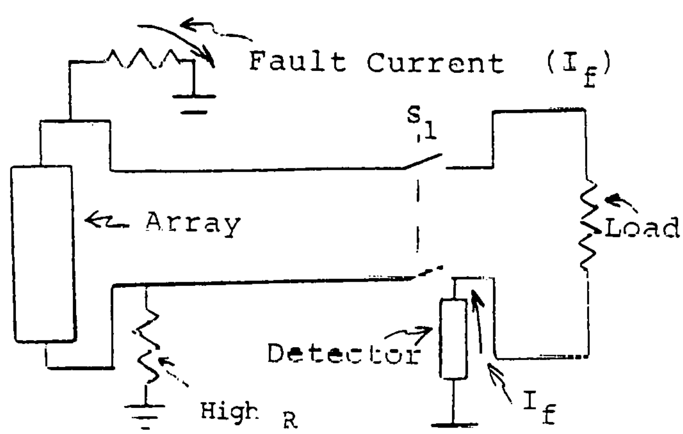


Figure 2.4.1A
Direct-Ground-Current Fault Detector

In utilizing ground-fault systems, the specific areas afforded protection are determined by the location of the circuit grounds and detectors. For the circuit of Figure 2.4.1, ground-fault protection is provided only in the circuit part to the left of the detectors (the array side), and only if there are no low-impedance grounds in the grounded conductor to the left of the detector.

For the circuit of Figure 2.4.1B, (a redrawing of the circuit of Figure 2.4.1 with an added ground) with a ground to the left of the detector (the accidental ground A), a fault current, if it develops, may reenter the normal current path on the source (array) side of the ground fault sensor, resulting in insufficient imbalance for fault-current detection. Further, even if ground faults were detectable, the presence of ground path A would make it impossible to terminate ground currents with the switching used.

It is assumed that deterioration of insulation or misconnection may allow ground connections such as A in Figure 2.4.1B to develop. With this situation, a ground-fault system might fail to operate upon the occurrence of a ground fault.

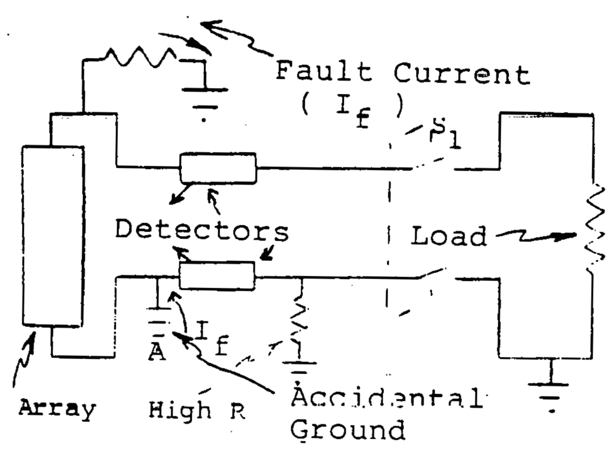


Figure 2.4.1B
Differential-Ground-Fault Detector - Accidental Ground

Because of this, UL requirements for ac ground fault-circuit interrupters state that ground-fault protection shall be provided when the circuit conductor that is normally grounded at the service only, is also grounded at a point in the load circuit of the ground-fault circuit interrupter.

Contemporary differential type ac ground-fault circuit interrupters may achieve this protection capability by including an oscillator circuit which is triggered by the closing of a ground path similar to that of A in Figure 2.4.1B. This oscillator can create a sufficiently imbalanced current through the differential detectors to activate the device. It will do so upon the occurrence of the improper ground (a connection between the grounding and grounded conductors at the protected area) whether or not there is an actual arcing or body path ground-fault, and whether or not there is a load.

DC ground-fault devices built for photovoltaic system use with a directly grounded array, as shown in Figures 2.4.1 or 2.4.1B, may need to include this capability.

For the circuit of Figure 2.4.1A, ground-fault protection is provided throughout the circuit, but only if there is no other ground in the circuit. For the circuit of Figure 2.4.1C (a redrawing of the circuit of Figure 2.4.1A with an added ground), an added ground anywhere will defeat the direct-ground-current detection type ground-fault sensor. Again, the accidental ground also makes it impossible to terminate ground-fault currents with the switching system used. It is necessary to include an oscillator circuit with this type of ground-fault detector to detect the unwanted ground.

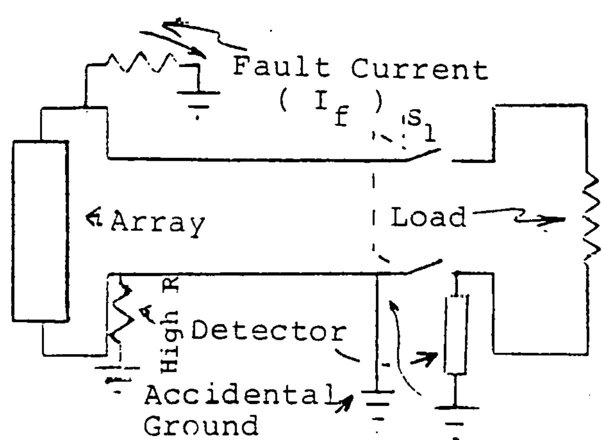


Figure 2.4.1C
Direct-Ground-Current Fault Detector - Accidental Ground

A utility interactive photovoltaic array having a "virtual" rather than solid ground with a transformerless power conditioning unit is shown in segment X of the circuit of Figure 2.4.1D. "Virtual" ground is that point in the array which is electrically at ground, but has no direct electrical connection to ground. With this system, ground-fault currents at the array may be caused by currents from either the array or line source, or both. Differential detectors B_1 and B_2 in conjunction with interruption switch S_2 provide ground-fault protection at any point in the array except at the "virtual" ground.

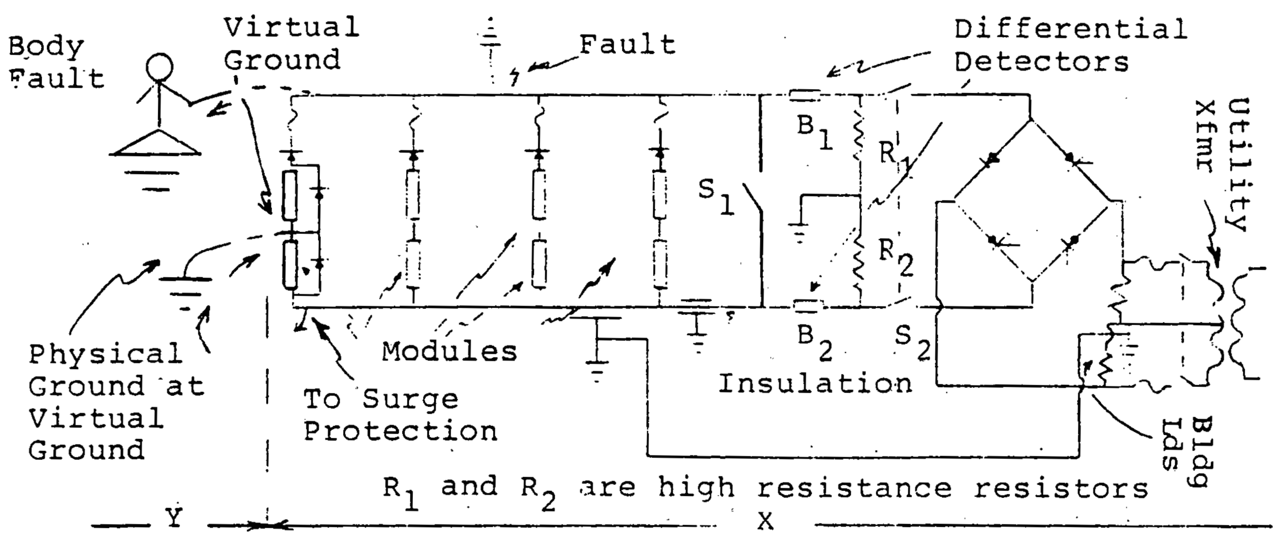


Figure 2.4.1D
Array With Transformerless Interactive Power Conditioning Unit - Differential Ground-Fault Detector

No protection is needed at the "virtual" ground, because no current exists in a fault between points at the same potential, the virtual and real grounds. However, for an effective system, no ground can be permitted to remain at the virtual ground on the array side of differential detectors B_1 and B_2. The adverse consequence of a ground on the array side of detectors is shown in segment Y of the circuit of Figure 2.4.1D, where ground-fault currents may bypass the differential detectors and thus be undetected, thereby defeating the system. Further, interruption of the fault-current path is again impossible. In this scheme, it does not appear feasible to provide an oscillator circuit to cause operation of the ground-fault system in the event of grounding of the virtual ground point. This is because the oscillator would need to force current through the modules and power conditioning unit. This appears to be beyond the capability of the oscillator. However, it is believed that this item can be handled in other ways.

2.4.1.4 Prospect for Grounding of Virtual Ground

In house wiring systems, staples through conductors, plus uninsulated terminals within grounded metal boxes, and the misuse of ground as a neutral, are the primary causes of "grounding" of a neutral conductor at other than the service. With the array and transformerless power conditioning unit of Figure 2.4.1D, only limited lengths of wire and a restricted number of terminals are likely to be at the virtual ground point.

In any series connection of modules, rearrangements of array source circuit (string) shadowing that might occur during a diurnal cycle, together with the bypassing of the shadowed module by its bypass diodes; would cause a rearrangement of voltage within the source circuit. Thus, the voltage zero point (virtual ground) in the source circuit would shift so that no one point remained at the electrical center. Therefore, any likely physical grounding of a point that is nominally the virtual ground of the source circuit would be detected at some time during the daily cycle, when that point is of sufficient voltage away from ground.

However, whether this progression of shadowing will be incorporated in an array either accidentally, inherently, or deliberately, and thus be relied upon to effect the triggering of the ground-fault system upon occurrence of the grounding of the virtual ground is in question. In fact, because it is desired that an array not be shadowed during any part of its power-producing cycle, it is assumed that any steps that can be taken to eliminate any type of shadowing will be taken.

Thus, other means are desirable to eliminate the problem of grounding of the virtual ground point. First, it is considered that a slight imbalance in voltage output of the modules without any module shadowing, may remove the virtual ground from the module terminals, but whether there would be sufficient current to activate the ground-fault system by contact between a terminal near virtual ground, and ground, is questionable. However, the most reasonable candidate system is that with an odd number of modules in a source circuit (series string) where the virtual ground is confined to the center of a module (or modules). If the module voltage is high, contact between any module terminals or wire and ground is likely to activate the ground fault system.

2.4.1.5 Response

When a ground-fault is sensed, the response must terminate any fault currents, whether they are from the array or from any interactive source present. In the circuit shown in Figure 2.4.1D, all current through a ground-fault would be at a minimum value by the opening of double pole switch S_2. In the circuits shown in Figures 2.4.1 and 2.4.1A, all currents would be at a minimum value by the opening of switch S_1. In both of these cases, ground-fault currents are of a low value due to interrupting the ground path. No attempt is made to remove the output of (open circuit) the array source. Since short circuiting an array is considered tantamount to operating an engine at "red-line", this method of resolving hazard situations is reserved for those cases where it is the only feasible method to resolve a hazard situation.

Opening the low resistance ground path to terminate a fault current, if such were the only ground, would leave the array circuit at an undefined voltage from earth. In this condition, the array circuit could "float" to a substantial voltage from earth, and overstress insulation, resulting in the breakdown of such insulation. To prevent this, high resistance resistors are used to stabilize system voltage with respect to earth while keeping any fault currents to low values (e.g. -- in the order of 5 milliamperes maximum).

2.4.1.6 Component Leakage Currents

The response of any ground-fault system is dependent upon a current imbalance. While the purpose of the system is the detection and response to transient currents as occurring through arcs, bodies, etc. the system will also react to standing leakage currents. The larger the standing leakage current, the less sensitive the ground-fault system can be to prevent the standing leakage current from causing the ground-fault system to react. To allow a reasonably sensitive ground-fault system, module leakage (circuit-ground) current levels must be limited. Table 21.1 of the Proposed UL Standard for Flat-Plate Photovoltaic Modules and Panels covers this by requiring no more than a 10 microampere current (based on leakage current from the module operating at system voltage to ground) for parts of a module liable to be connected together (conductive frames, pans). For an end-grounded array this would allow 6000 modules in an array (or portions of an array protected by a single ground-fault device) using a dc ground-fault sensor with a 30 milliampere sensitivity, because in such an application the average module voltage to ground is one-half of the system voltage.

At least 24,000, and probably more modules would be tolerated in a center-grounded system. With a center-grounded system, if modules with equal leakage currents are placed on opposite sides of the ground there will be no standing current through the ground-fault detector, no matter what the number of modules, see Figure 2.4.1.6(a). As leakage current becomes more pronounced on one side of the array ground as against the other side, the net standing current through the ground detector increases, with the limit in detector current being one-eighth (1/8) of the total of the leakage of the assembled modules. See Figure 2.4.1.6(b). The factors combining to generate this 1/8 figure are; 1/2, only one-half of the modules are then involved, and 1/4, the average of the module voltage to ground is one-quarter of the system voltage.

2.4.1.7 Comparison-Differential and Direct Ground Current Type Devices

A differential type ground-fault detector: (a) has the ability to function in circuits whose basic ground is not directly under the installer's control, as for example with a transformerless power conditioning unit and a utility-controlled ground; and (b) permits portions of the array (e.g. - source circuits) to be protected independently of each other. However, the differential type device (a) is more expensive because its circuitry must have the capability of sensing differential currents in the low milliampere range out of total currents in tens or hundreds of amperes, and (b) has the need to keep losses in the detector to a minimum as the normal load current passes through the detectors.

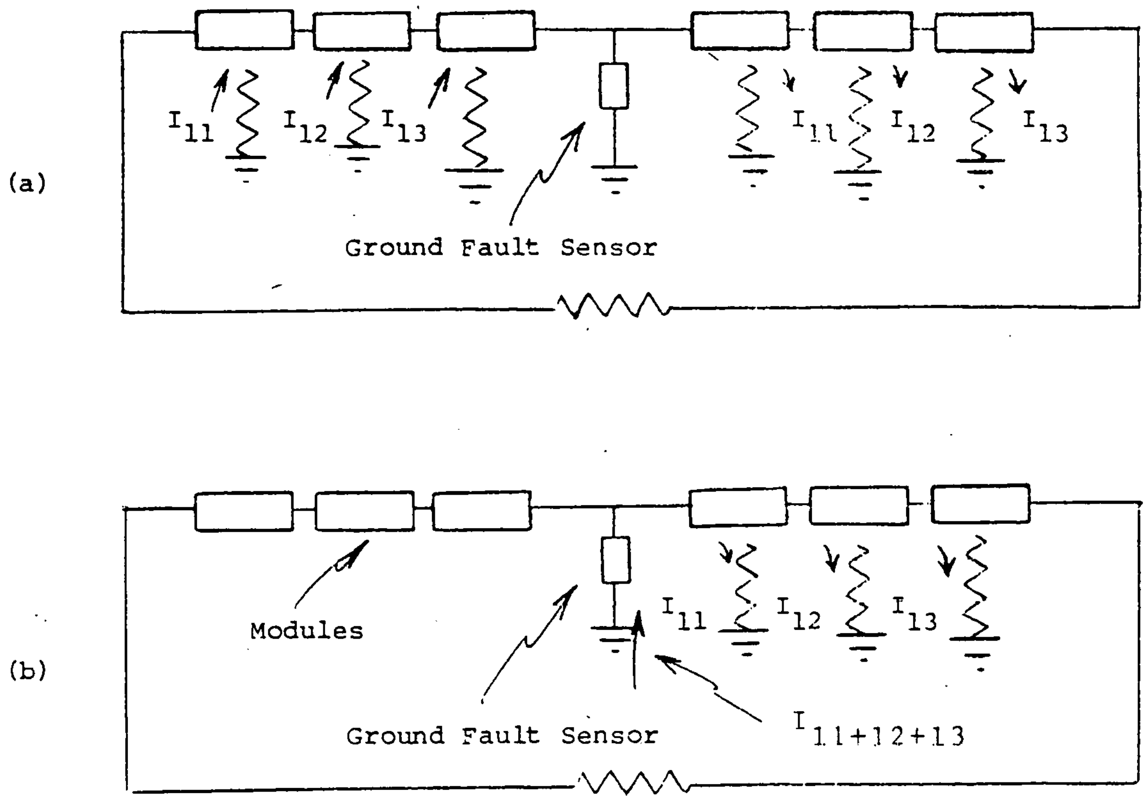


Figure 2.4.1.6
Standing Leakage Currents -
Center Grounded Array Circuit

A direct ground current measuring type: (a) has a low cost, basically because of simplicity of measurement; and (b) does not need to keep losses in the detector low as current is normally not passing through the detector. However, the direct ground type: (a) does not allow as much freedom in the methods of circuit grounding (it is not compatible with a utility interactive system with a transformerless power conditioning unit); and (b) cannot be used were the array circuit is to be divided into separately protected sections.

2.4.1.8 Status

Direct ground-current sensors are already in place in several installations, and their construction and implementation has been reported on. However, no known installation of a differential type dc ground-fault detector in a photovoltaic array exists, yet this type may become the more widespread of the two in residential installations because it is compatible with transformerless power conditioning units. Because of this, Underwriters Laboratories has investigated, built and tested an experimental differential dc ground-fault detector. Details are presented in Appendix F, DEVELOPMENT OF DIFFERENTIAL DC GROUND-FAULT DETECTOR.

2.4.1.9 Conclusion

Based on UL's experimental work and on the reported experience of others, ground-fault detection and response systems appear to be a practicable device for photovoltaic systems.

2.4.2 In-Circuit Arcing-Arc Detection Systems

The breaking of an electrical conductor, along with a maintenance of the electrical source to the conductor, may result in an arc at the point of the break. Because the arc might not cause current in any path outside of the norm*, nor cause excessive current, devices such as ground-fault sensors or overcurrent devices (fuses, circuit breakers) are incapable of sensing the arc.

* The high frequency components of the arc may induce current in metal adjacent to the circuit metal. Any such currents are not included in this consideration.

2.4.2.1 Hazard Problem and Basic Solution

Because substantial arcing can be a fire hazard situation, uncontrolled arcing situations in a photovoltaic installation must be eliminated, or their effects controlled. Four basic methods are envisioned to reduce the risk of fire hazards from electric arcs:

a) keep arc energy limited, below ignition level of adjacent materials,
b) terminate arc after its inception, to reduce likelihood of ignition of adjacent materials,
c) keep flammable materials from arc, or,
d) prevent the occurrence of the arc.

2.4.2.2 Solution Specifics

2.4.2.2.1 Arc Energy Limited

The fire hazard potential of an electric arc, that is, its propensity to ignite materials, is a function of the energy in the arc, the material present, and the material of the electrodes. With a photovoltaic array, the materials will be the encapsulants, superstrates, substrates, wiring compartment enclosures, and the like, but can additionally be debris accumulated about the array. While the materials of the modules can be defined, the material of the debris is not as easily categorized. The debris could be material that is relatively easy to ignite, such as dry leaves. UL has used surgical cotton to represent this readily ignitable debris for test purposes. In the case of the actual installation, the electrodes can be wiring, cell material, or interconnect material. UL suggests that a copper-steel combination is an appropriate representation of these materials.

To determine what might be considered to be a "safe" arc, that is an arc with energy too low to ignite the selected indicator material, a series of tests was performed to determine the minimum open-circuit voltage (V_{OC}) and corresponding short circuit current (I_{SC}) of a circuit that is just capable of producing an arc that will ignite surgical cotton. Details are presented in Appendix G, CURRENT AND VOLTAGE LEVELS ASSOCIATED WITH IN-CIRCUIT ARCING . The outcome of this work produced the curve which appears as Figure 38.1 of the Proposed UL Standard for Flat-Plate Photovoltaic Modules and Panels, UL1703.

Bypass diodes can be utilized to limit voltages across circuit breaks and along with this limited voltage, the likelihood of arcing. See Appendix H, SUPPRESSION OF IN-CIRCUIT ARCING WITH BYPASS DIODES. Bypass diodes thus appear to be a practical method by which the hazards otherwise associated with in-circuit arcing can be handled. The bypass diodes would be inserted in the circuit in such a manner so as to limit the arc energy to less than those values which are likely to cause ignition of materials.

Thus, it is proposed that where open-circuit voltages and corresponding short-circuit currents are below the levels described (Figure 38.1 of the Proposed UL Standard), the circuits be considered incapable of causing ignition of materials in photovoltaic circuits, and therefore, the risk of fire hazard from arcing in such circuits is considered eliminated.

2.4.2.2.2 Terminating Arc

If an unwanted arc can be detected, it may be possible to terminate it. In the case of in-circuit arcing, all the current of the arc is generally in the normal current path (see footnote to 2.4.2), and not above any normal current level. Thus, detection of the arc is difficult. However, if the arc is detected, it appears possible to terminate it by removing the load.

Because electric arcs involve rapid changes in circuit current, they create high frequency current components. These high frequency currents if detectable, could be used to effect circuit shut-down, thereby extinguishing the arc. A simple circuit to do such detection might be as shown in Figure 2.4.2.2.2, with coil L_1 and capacitor C_1 creating a pole pair at a prominent frequency in the spectrum of the arc current. A detector, and an integrating circuit would complete the "arc detector", the integrating circuit giving a brief time delay before reaction. The response would be an opening of the affected circuits; and without a load on the circuit, the in-circuit arc would be extinguished.

In an effort to advance such an idea an arc detection device was built and field tested. The precursor to this work involved searching for the frequencies at which the arc energy is most prevalent. For this, arcing was deliberately introduced in the circuit of a photovoltaic array at MIT/Lincoln Laboratory. An array of approximately 220 volts open-circuit was used.

Using one source circuit of the array, an interconnect within one module was severed. This was accomplished by cutting through the module superstrate to gain access to the interconnect. The arc was then created (1) by bringing the severed interconnect segments together and then separating them, and (2) by connecting a conductor to one side of the break in the circuit and bringing it into contact with the face of a cell of the module on the other side of the break.

The loads on the array were both nominal short-circuit and 'maximum power' into conical lampshell base heating elements. A spectrum analyzer was used to observe energy levels as a function of frequency in the current wave. See Figure 2.4.2.2.2A.

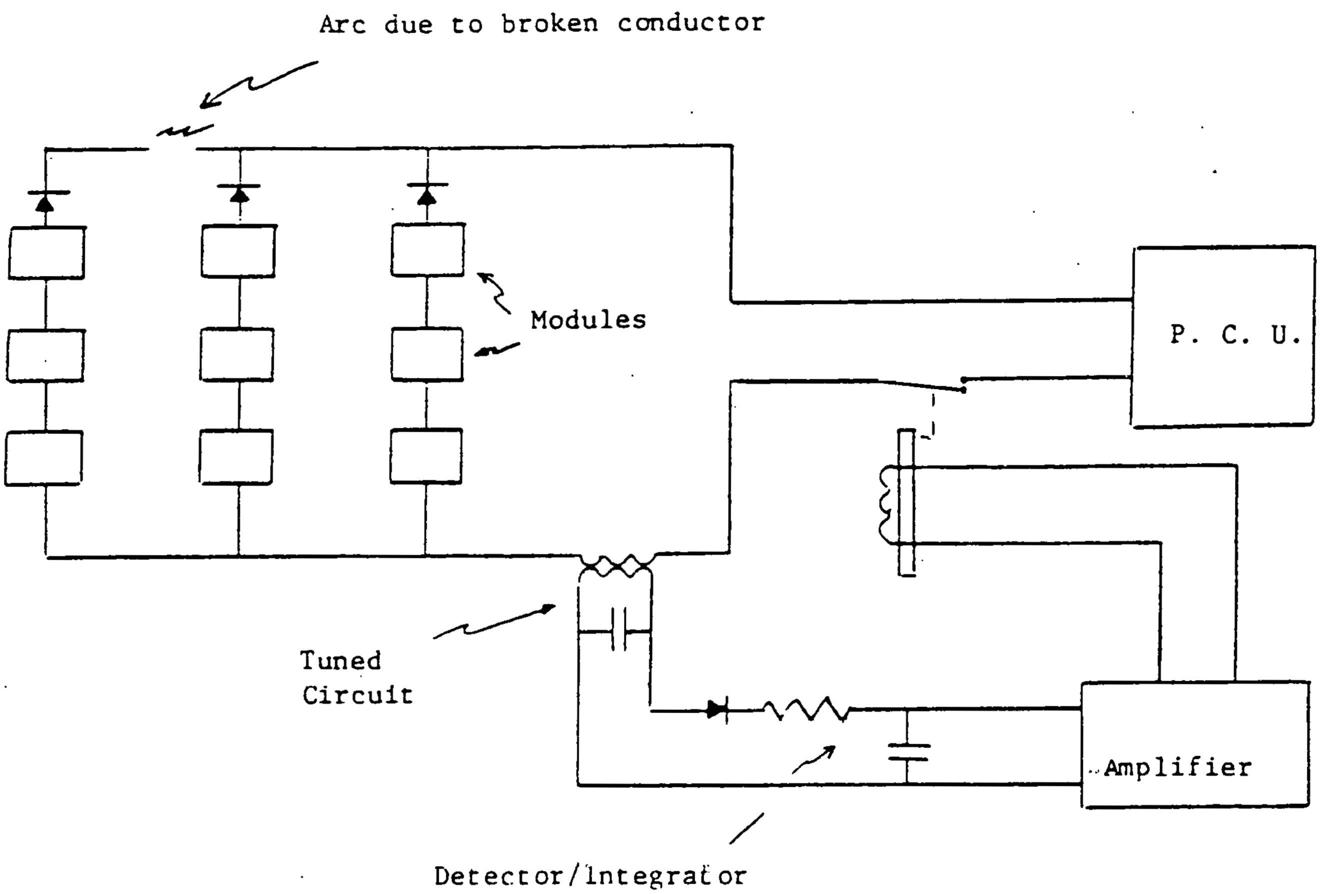


Figure 2.4.2.2.2

Application of Arc Detector

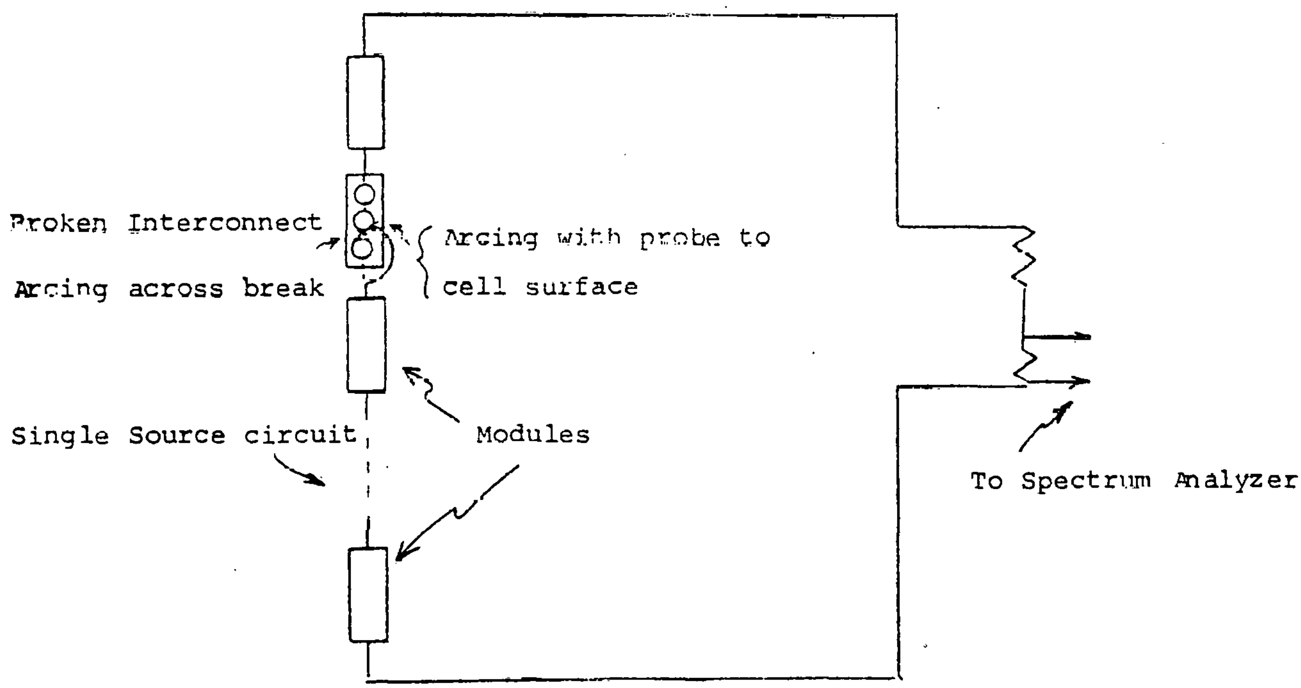


Figure 2.4.2.2.2A

In-Circuit Arcing

Attempt at Identifying Frequencies

The results of this work showed no distinct energy distribution as a function of frequency; rather, the arc energy was distributed widely over the frequency spectrum. Thus, the detector, built to sense arcing, would not be tuned to any particular frequency.

Construction of the arc detector is described in Appendix I, DEVELOPMENT OF AN ARC DETECTOR. The work resulted in a device that met with limited success. Because of (1) the problems encountered in establishing sensitivity levels, (2) the attenuation of the high frequency components by the photovoltaic power system wiring, and (3) expected false responses to other sources of radio frequencies, arc detection sensing high frequency current may not be a workable safety system for photovoltaic arrays because the problems appear to require considerable research toward solution, and because an equivalent level of protection is believed achievable using bypass diodes. Thus, no further work in this area was conducted.

2.4.2.2.3 Flammable Materials Isolated From Arcs

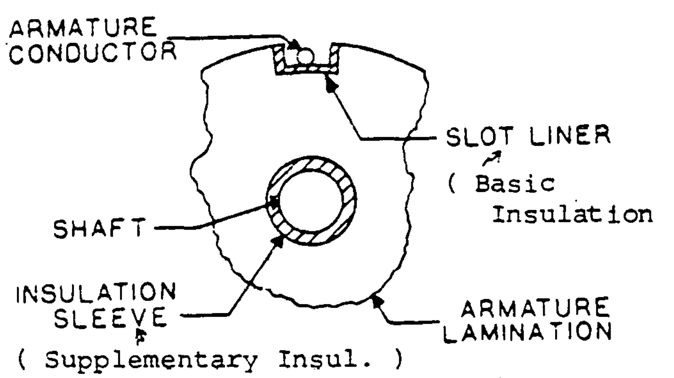
If arcs can be contained within the module sandwich, and can be confined by arc resistant superstrates and substrates, this approach appears to be viable.

2.4.2.2.4 Prevent Arc

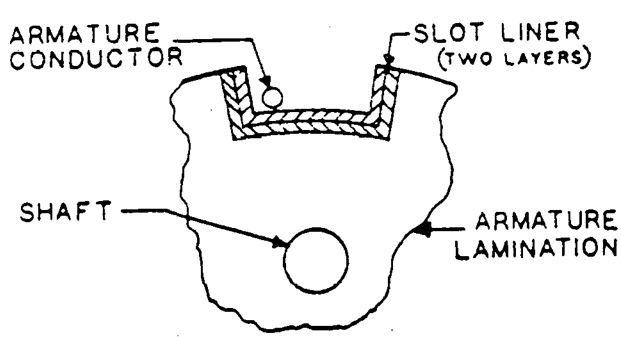
Redundant current paths appear to provide a method by which the possibility for in-circuit arcs can be eliminated.

2.4.3 Double Insulation Systems

A double insulation system is an insulation system comprised of basic insulation and supplementary insulation, with the two insulations physically separated and so arranged so that they are not simultaneously subjected to the same deteriorating influences to the same degree. See Figure 2.4.3 for examples as applied to motors.



A – Considered to constitute double insulation



B-Not considered to constitute double insulation

Figure 2.4.3
Double Insulation in Motors

Double insulation systems, like any other enhanced insulation may be employed in any electrical product. In some instances, credit is given in the NEC for the extra degree of safety these systems impart to the product, the credit being in the form of relaxed grounding requirements. Reinforced insulation, a variant of double insulation, is an improved basic insulation with such mechanical and electrical qualities, that it, in itself, provides the same degree of protection against electric shock as does double insulation. Specific rules describing acceptable constructions of reinforced insulation systems have been developed, generally for cord-connected, motor-operated products, and now appear in the Standard for Double Insulation Systems for Use in Electrical Equipment, UL1097-1978.

The NEC, in Section 250-45, identifies specific instances for which double insulation is accepted in lieu of equipment grounding. This section covers only plug and cord-connected, factory-built products (e. g., electric drills, typewriters, vacuum cleaners), and not in any instances systems assembled in the field. Thus, accepting double insulation in lieu of grounding as a feature in a field assembly of photovoltaic modules or for permanently wired products would seem to require revision of, or an exception to, the equipment-grounding requirements of NEC Section 250-42.

While the present acceptances of double insulation are for cord-connected, powered apparatus, Underwriters Laboratories does not foresee any hindrance toward the acceptance of double insulation in photovoltaic systems if the NEC were revised accordingly. It appears that the present restriction is applied only because that is where double insulation is used. If acceptance by UL of double or reinforced insulation is sought for photovoltaic modules and systems, specific rules for these reinforced insulation systems would have to be developed. These rules would normally be formulated based upon a product submittal, and not on conjecture as to what would be most appropriate. If submitted to Underwriters Laboratories Inc., Proposals for Listings of Double-Insulated Systems and Modules would likely be subject to review by the Electrical Council of Underwriters Laboratories Inc. (by a Council Report). Any photovoltaic system Listing involving credit to double insulation would necessarily be by 'Listing by Report'¶ unless the National Electrical Code would provide guidance as to how a double-insulated photovoltaic system should be installed.

¶ - Listing by Report - A procedure in which the UL Listing Report describes the information essential for the proper installation and use of the system. This assumes that this information cannot be adequately described otherwise, for example, by a marking on the product. A "Listing by Report" is not permitted to be used to circumvent on established installation code.

The restriction of the acceptance of double insulation to cord and plug-in connected equipment seems to be based on the presumption that permanently-connected equipment will be reliably grounded, and that this grounding will obviate the need for any double insulation. In keeping with this logic, plug-connected (as against permanently-wired) modules or entire photovoltaic arrays could be accepted with double insulation. However, there appears to be little logic in such a distinction when the prime problem may be grounding versus double insulation of separately applied hold-down pieces, the grounding of which might not be effected through a plug, in any case.

Provisions in the present UL Standard for Double Insulation that might be considered applicable to "double insulated" photovoltaic modules and systems are presented in Appendix E, PROVISIONS OF THE STANDARD FOR DOUBLE INSULATION SYSTEMS FOR USE IN ELECTRICAL EQUIPMENT, UL1097-1978, THAT MAY BE CONSIDERED APPLICABLE TO PHOTOVOLTAIC MODULES AND SYSTEMS.

Some particular items of interest, and their references in Appendix E, relate to the exclusion of grounding conductors from any multiple conductor cords also containing current-carrying conductors, paragraph 6.1, dielectric voltage withstand tests between accessible and shock hazard parts at voltage levels above those used for single insulation products, Section 14, and tying of leads so that breakage of a lead at its termination will not allow the bared lead end to become free to contact random parts, paragraph 12.1. Each of these provisions and the others described in Appendix E are designed to provide the double level of protection.

2.4.4 Ground Sensor

An electrical system can be electrically isolated from ground, and when so isolated will not cause ground-fault currents upon the occurrence of any single fault (conductive path) between the system and ground. In this context, isolated systems includes systems where deliberate connection to ground is by way of only high impedance paths that would limit current to values not constituting a shock hazard condition. Thus, in isolated systems, the likelihood of fires from circuit-ground arcs and shock from circuit-ground body currents is lessened.

However, any accidental, generally unknown low impedance connection between the system and ground may be the start of a hazard situation. Thus, maintenance of the isolated condition is important, for should initial grounding occur, followed by a second ground, either involving an arc, or by way of a body, a fire hazard or a shock hazard situation is possible. To prevent this, isolated systems can be provided with detectors to sense the presence of the initial ground and lead to corrective action. The device described below can determine whether this isolated condition has been breached.

2.4.4.1 Device Specifics

The basic version of the ground sensing device is a three terminal device connected to (a) earth ground, and (b) each side of the photovoltaic source circuit. The device consists of two high-resistance resistors, and a sensitive (responsive to low currents) detector such as a neon lamp. See Figures 2.4.4.1 and 2.4.4.1A for device and connection specifics. Resistors R_1 and R_2 are of high enough resistance to keep the circuit effectively "isolated" from ground, and are not considered grounds in any of the following.

With the device connected in the circuit, a ground such as A will result in fault current, I_f through the neon lamp NE_1. Illumination of the lamp or energization of any other detector in its place is the response to the current I_f, which can be used to signal an alarm or take other corrective action.

The direction of current through the sensor is indicative of the side of the array grounded, and can be utilized in array diagnosis.

Should the array circuit become grounded near or in its electrical center, the detector of Figure 2.4.4.1 will not be activated. Thus, when using this detector in isolated circuits the electrical center of the array should be rigorously isolated from ground by being in the electrical center of a minimum voltage module. An alternative solution is to provide the detector with an oscillator rapidly switching the lamp from resistor to resistor, as shown in Figure 2.4.4.1A.

2.4.4.2 Response

Because the presence of the first ground does not constitute an immediate hazard, the circuit might be permitted to operate for a short time until shutdown or a corrective fix is undertaken. Thus, an acceptable detection and response scenario might be only the sounding of an alarm upon the occurrence of the fault, with the assumption that the array operator would take appropriate action to correct the situation.

If the array operator cannot be relied upon, automatic response to terminate operation of the circuit, such as by short-circuiting of the array or segmenting it, would be necessary. It is recognized that segmenting may be economically unworkable and a short-circuit placed across the array may be detrimental to it. However, no other means of correcting the problem appears viable.

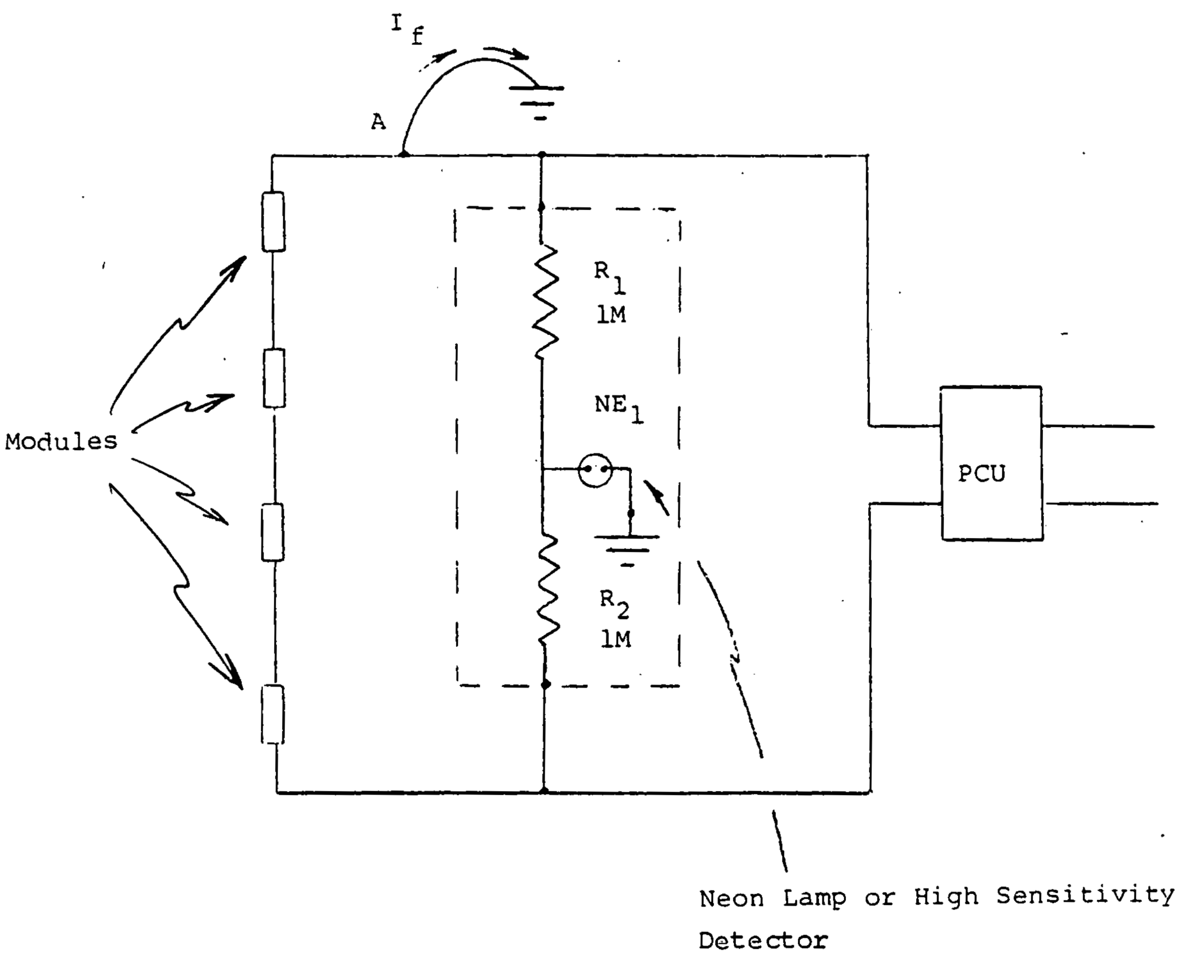


Figure 2.4.4.1

Ground Sensor

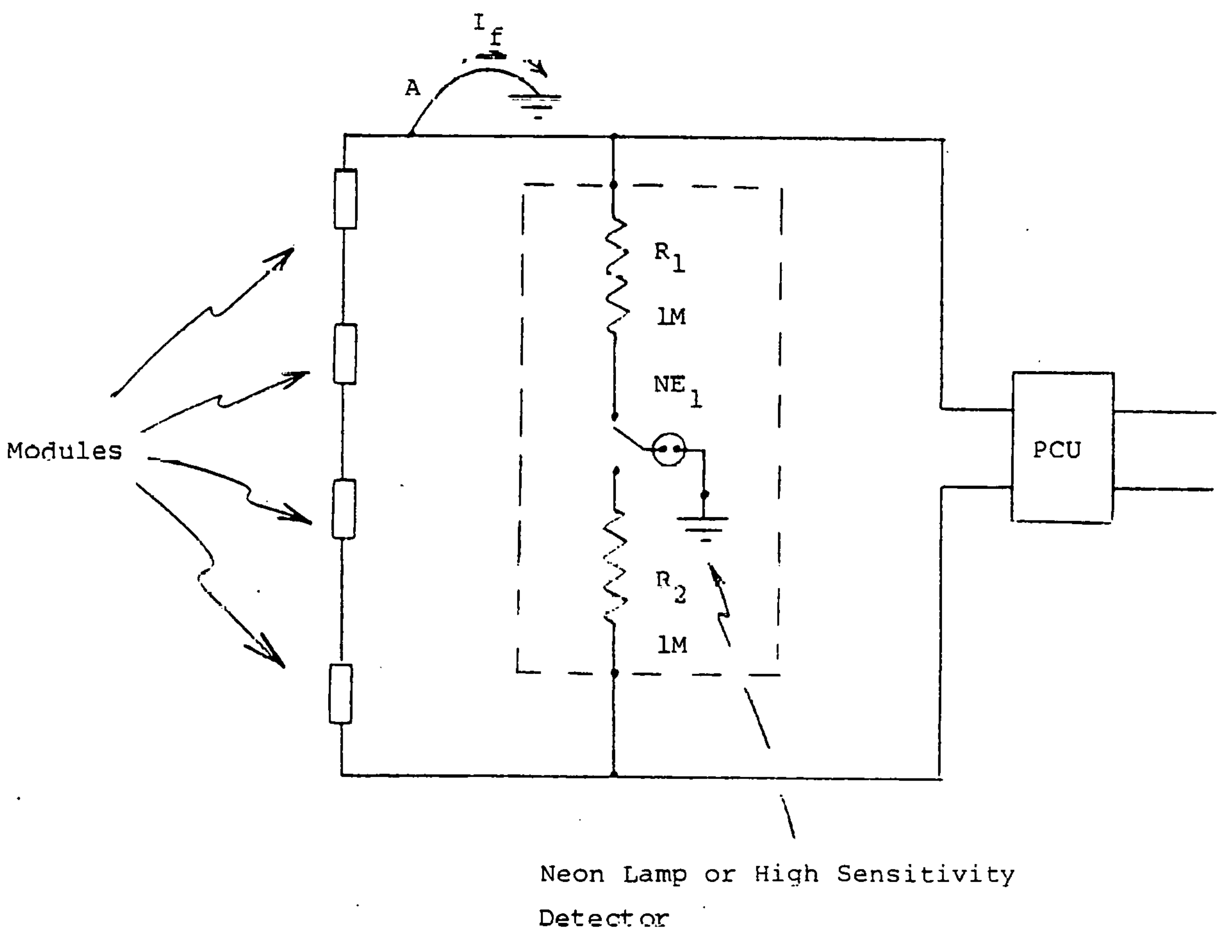


Figure 2.4.4.1A

Ground Sensor Responsive to Fault

At Any Location

2.4.5 Bypass Diodes

2.4.5.1 Background

While bypass diodes may be included in a photovoltaic array for performance purposes, a safety function is also served by limiting the voltage across the bypassed cells. Thus, the voltage across a break in between-cell interconnects will be limited to the voltage of the cells bypassed by the single bypass diode. The limited voltage reduces (1) fire hazard possibilities from arcing, see Appendix G CURRENT AND VOLTAGE LEVELS ASSOCIATED WITH IN-CIRCUIT ARCING, and Appendix H, SUPPRESSION OF IN-CIRCUIT ARCING WITH BYPASS DIODES, and (2) cell reverse voltage heating levels that accompany reverse-biased cells. Bypass diodes also allow removal of modules from an array (e. g. - for servicing), with the voltage across the gap of the removed module limited to the forward voltage drop across the bypass diode. Thus, assuming that the array circuit is not grounded through a low impedance path which would not constrain array circuit to ground shock hazard currents, that other array electrical parts are not accessible to contact, and that the open-circuit voltage of the module being removed is 30 volts or less, exposure of only the two terminals of a module during its replacement would not create a shock hazard situation. Similarly, bypass diodes allow assembly of an array of modules where the terminals of the modules are accessible during the assembly process, without the exposure of any voltage greater than the module voltage.

The Proposed UL Standard for Flat-Plate Photovoltaic Modules and Panels (Appendix A) gives credit to the reduced (from full source circuit) voltages that occur across modules when used in conjunction with bypass diodes as concerns the Hot-Spot Endurance Test (Section 37) and the Arcing Test (Section 38).

2.4.5.2 Location

For module removal to not compromise the protection afforded by the diodes, the diodes must be external to the modules and remain with the array. Their connection must be independent of the module's connection. For a section of the array, a typical scheme might look like that of pictorial Figure 2.4.5.2.

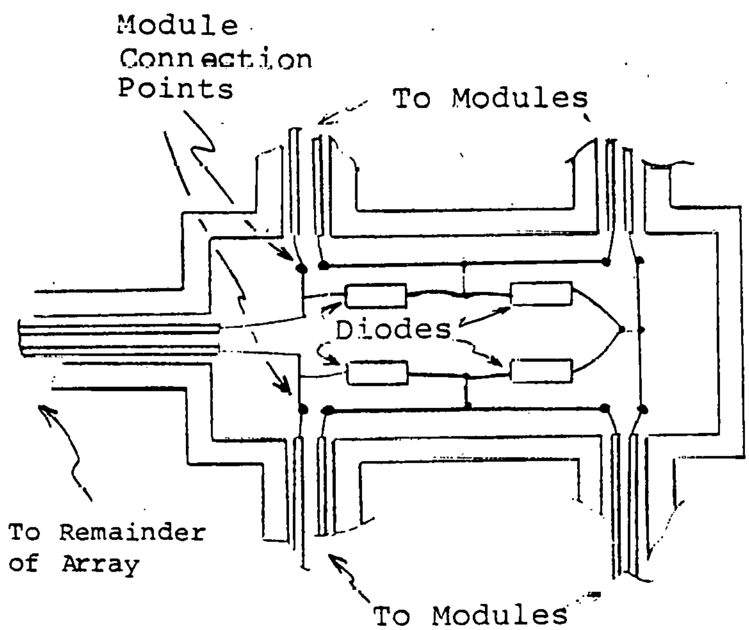


Figure 2.4.5.2

Physical Mounting of Bypass Diodes

Unless intermediate circuit points within a module are accessible, external-to-module bypass diodes cannot be applied in any greater concentration than one per module, and thus may not be capable of affording the degree of protection against cell reverse voltage conditions that is desired. Thus, under conditions of reduced output from a single cell of a series string (e. g. - by cell shadowing), and with the source circuit current kept above that of the short-circuit current of that cell, the reduced output cell will be driven into reverse voltage, and the reverse voltage present across the cell will be almost equal to the module voltage, even with the best case condition of one bypass diode for each module. To afford any additional degree of protection against (a) reverse voltage heating and (b) arcing, but <u>not</u> to cover conditions related to module replacement and array assembly, the module may include internal bypass diodes, bypassing segments of the module. (Redundant diodes bypassing the entire module may also be in place internal to the module.) See Figure 2.4.5.2A for the hierarchy of bypass diodes thus created.

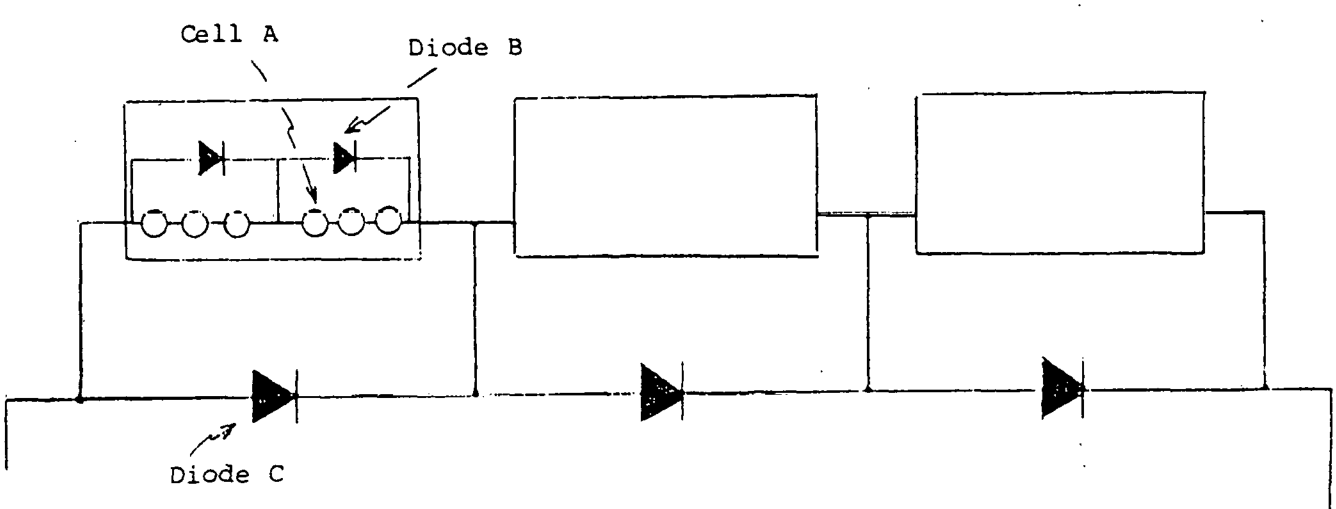


Figure 2.4.5.2A

Hierarchy of Bypass Diodes

Shading of cell A should preferably cause conduction of diode B rather than diode C to keep the reverse voltage across cell A to the lower value of only the cells bypassed by diode B. Therefore, diode C should be chosen to go into conduction after diode B, or, in other words, diode C should have a higher forward voltage drop than that of diode B.

2.4.5.3 Ratings

Typically, diodes in parallel cannot be relied upon to "equally share" currents, and each must be capable of carrying the total current. Thus, in situations involving parallel combinations of modules, generally the bypass diode must have a forward current rating equal to the sum of the currents of the bypassed modules. As an alternative, the diodes must have an additional series resistance that forces equal current sharing.

The peak reverse voltage ratings of the bypass diode need be equal to only the bypassed voltage V_m, see Figure 2.4.5.3. Where a module is removed, such as module A in Figure 2.4.5.3, diodes A and B, and any other diode in the source circuit around which the module is removed, function as a blocking diode in series with the dedicated source circuit blocking diode. Blocking diodes must ordinarily be rated for the peak voltage of the source circuit, but in this case, where diode A functions as an ersatz blocking diode in series with a true blocking diode, it need not be rated as a blocking diode, because its failure in a reverse breakdown mode would not result in any current back feed, the basic diode dedicated as a blocking diode would still be present functioning as such (B in Figure 2.4.5.3) and breakdown of diode A would likely be a short-circuit condition, in which case the only consequence would be a reduced output from the array.

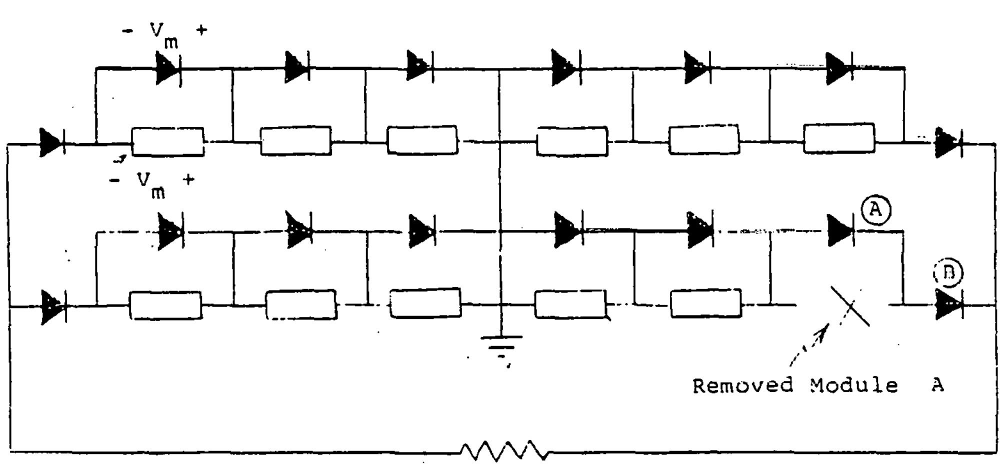


Figure 2.4.5.3

Application of Bypass Diodes

2.4.6 Blocking Diodes and Source Circuit Fuses

Where photovoltaic source circuits are connected in parallel, or where the photovoltaic system is interactive with a utility supply, back feed from one source into a source circuit may occur if that source circuit is of lower than normal voltage. Back feed, if of sufficient magnitude, may overload the particular source circuit with resultant fire hazard possibilities. To guard against such, either blocking diodes and/or source circuit fuses are incorporated in each source circuit, see Figure 2.4.6. Blocking diodes, if utilized, are to have forward current ratings equal to the source circuit forward current and peak inverse voltage ratings equal to the greater of the source circuit voltage or the voltage which can be impressed on the array as backfed through any power conditioning unit. Fuses, if utilized, are to have a continuous current rating equal to or less than the series fuse marking as indicated on the module. Each module complying with the UL Proposed Standard for Photovoltaic Modules and Panels will be so marked, and the marking will correspond to a reverse current level which the module can tolerate without a fire hazard problem.

(Note: The 1984 National Electrical Code, Article 690 stipulates that source circuit overcurrent protective devices are to be used. The fuses referred to above are one such overcurrent protective device.)

2.4.7 Redundant Connections

Arcing which can otherwise occur in the photovoltaic circuit path due to broken connections can be made less likely by the incorporation of redundant current paths. Where so incorporated, the redundant paths should preferably be located with respect to each other so that they will not be affected to the same degree by the same occurrence, and each should have the capability of carrying the full circuit current.

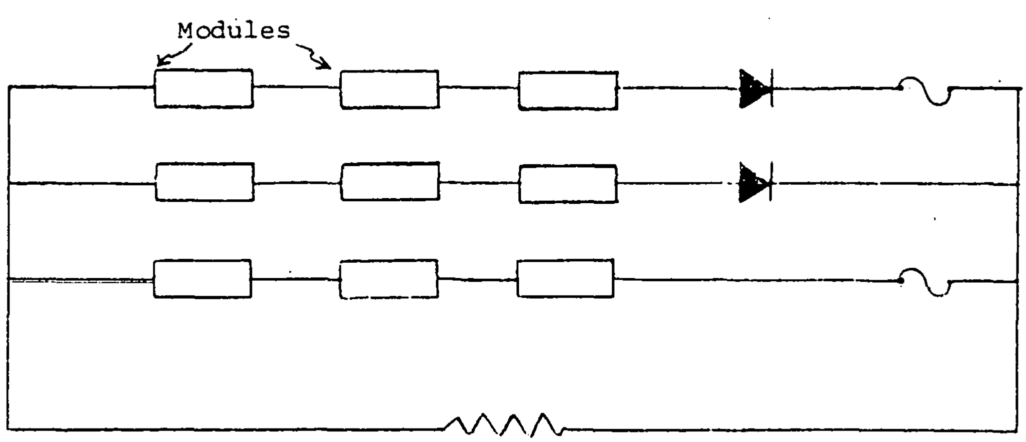


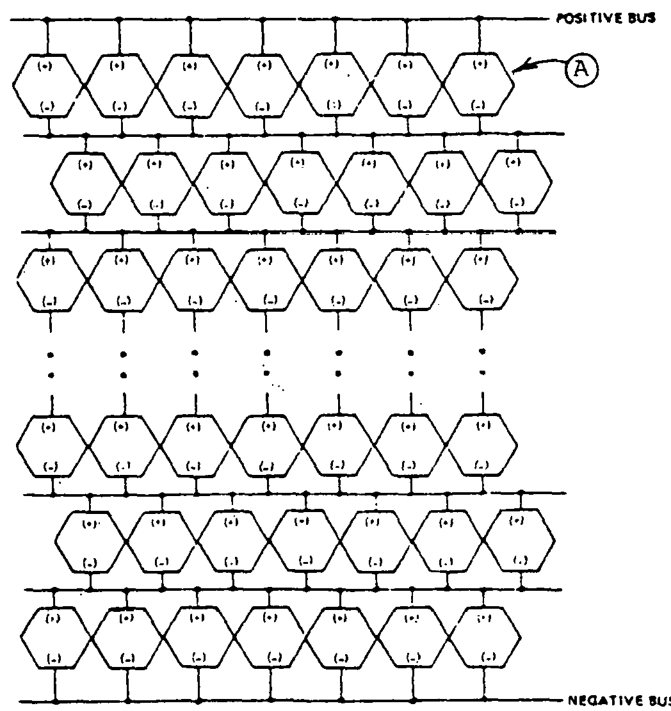
Figure 2.4.6

Application of Blocking Diodes and Source Circuit Fuses

2.4.8 Multiple Parallel Strings With Cross-Ties and Maximum Power Tracking Loads

When modules are connected in series-parallel combination, without bypass diodes, as in the circuit shown in Figure 2.4.8, and used in conjunction with a maximum-power-tracking load, loss or reduction of output from any one module, e. g. - A, will redefine the array operating characteristic, see Figure 2.4.8A, and relocate the operating point. With this relocation, hot-spot heating is avoided even though bypass diodes are not incorporated. The cross-ties are provided to effectively render each parallel combination of modules a "single module", and these "single modules" are connected in series. For this system to function properly, the array load is to be maintained at the higher voltage local maximum power point or at a point of higher voltage than the voltage of this maximum power point (that is the load current is to be restricted). Thus, the maximum-power-tracking must start at maximum (open-circuit) voltage and track down toward increased current levels, to find the local maximum at the higher voltage. This avoids operation at local maximum power points, e. g. B in Figure 2.4.8A, where the current may be excessive. The ultimate operating point would be at no current, where there is then power transfer between cells.

The control circuit utilized for maximum load power tracking must not involve a reference cell electrically isolated from the array cells, otherwise the maximum load power tracking circuit (typically in a power conditioning unit) will adjust the load basically according to the insolation level and a predetermined algorithm relating fully operative array output as a function of insolation, and not as a function of array condition (including local shadowing). In this reference cell scenario, cell failures or shadowing, which might alter the array characteristics, are not detected by the reference cell, and do not modify the impedance of the load seen by the array. Thus, in the reference cell scenario, cell shadowing, cracking, or the like are likely to cause operation of the array at a point of lower voltage than a maximum power voltage, and, depending upon individual cell characteristics and cross-tie arrangements, result in reverse voltage heating or damage to the modules.



ELECTRICAL INTERCONNECTION

Figure 2.4.8

Cross-Tied Array

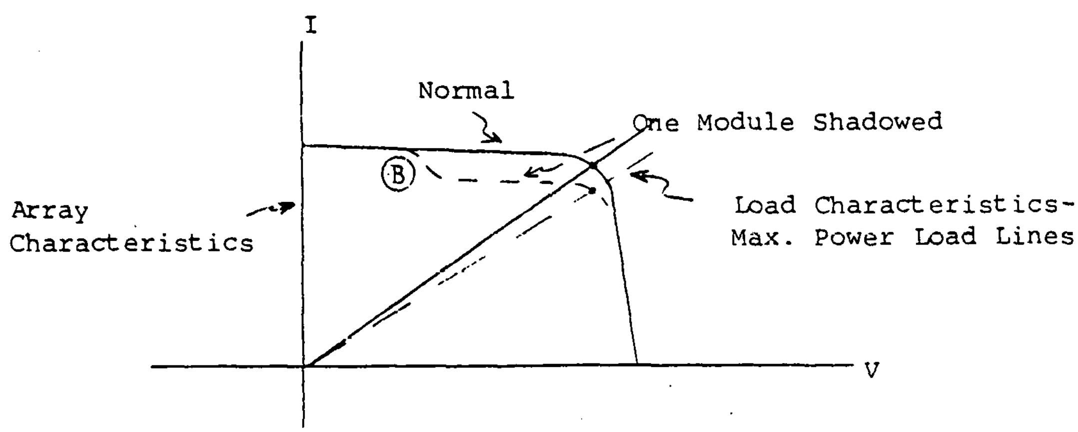


Figure 2.4.8A

Cross-Tied Array

Modification in Output Characteristic with Partial Shadowing

The operating point of a load, typically a maximum-power-tracking power conditioning unit, can be adjusted to a voltage and current point that on the array output characteristics has a high enough voltage and low enough current to prevent damaging module reverse voltage heating. The power conditioning unit must be properly mated to the array for this safety feature to be operative, and how a local electrical inspector could satisfy himself as to the mating is in question. One solution that might satisfy local electrical inspectors (who are concerned over the safety of the installation) involves evaluation of the complete photovoltaic system by an independent testing laboratory, recognizing that the maximum-power-tracking feature of the power conditioning unit is a safety feature. In such a case, it would be necessary to assure proper and reliable functioning of the maximum power tracking circuit. This would require evaluation of the power conditioning unit beyond the procedure described in the Draft Standard for Power Conditioning Units for Use in Residential Photovoltaic Power Systems, Appendix B (prepared for MIT/Lincoln Laboratory under Contract DE-AC02-76ET20279).

For the present, the parameters to be used for the Hot-Spot Endurance Test, Section 37 of the Proposed UL Standard for Flat-Plate Photovoltaic Modules and Panels, would be as stated therein and applied to the case of modules shown in Figure 2.4.8. Thus, the reverse voltage for the Hot-Spot Endurance Test, V_L, would be equal to the system direct voltage rating. As described in the Proposed UL Standard, this test simulates conditions associated with deliberate or uncontrolled faults such as array short-circuit. While deliberate faults might be precluded in a particular installation, uncontrolled ones can't be. An uncontrolled fault might create the short-circuit condition which the array without bypass diodes might not be capable of tolerating, unless cells, encapsulant, superstrate, and substrate of the module could survive conditions involving reverse voltages equal to the array voltage.

A system voltage rating may typically be 200-400 volts, but it is doubtful whether the present modules could comply with the Hot-Spot Endurance Test with V_L set equal to a value in this range. Thus, arrays configured as shown in Figure 2.4.8, without bypass diodes, are likely to be unacceptable under the provisions of the Proposed UL Standard.

2.4.9 Connectors

Separable connectors may be used to allow for array assembly and module replacement, without exposing the assembler or maintainer to a shock hazard situation. Connectors should comply with the specifications described in Section 4, INVESTIGATIONS OF COMPONENTS FOR PHOTOVOLTAIC SYSTEMS, and companion report DOE/JPL 955392-3; SAFETY REQUIREMENTS FOR WIRING SYSTEMS AND CONNECTORS FOR PHOTOVOLTAIC SYSTEMS. Specifics on acceptable constructions, including requirements relating to accessibility of shock hazard parts are described in that material.

2.4.10 Restrictions on Voltages and Currents, Guarding of Live Parts

An array may be considered inherently free from a risk of electric shock if it complies with the provisions applicable to Class 2 circuits, Article 725 of the 1984 National Electrical Code. Because useful array currents are typically in excess of 5 mA (0.005 A), system voltage limits would be the major item of concern.

A shock hazard situation is present when currents through a body exceed values related to let-go, ventricular fibrillation, cardiac arrest, or burn. In the case of Underwriters Laboratories Inc. requirements, the current related to the lowest of any of these four items is used, and generally the value is related to the let-go current when considering currents at and about power line frequencies (including dc). A detailed discussion of the effects of current through body parts, considering skin resistance, frequency, waveshape, body weights, and duration of current is contained in Underwriters Laboratories Inc. Report "Development of Test Equipment and Methods For Measuring Potentially Lethal and Otherwise Damaging Current Levels, May 1981 (Revised October 1982)". +

One conclusion is that, except for burns, the body can tolerate greater dc currents than 60 Hz ac currents before the same physiological disturbance is encountered. In particular, a 5 mA ac level (the maximum permitted in the NEC and in some UL standards) translates to 30 mA dc. However, this does not translate into greatly increased allowed voltage levels, because body impedance is nonlinear, with decreasing impedance as the applied voltage and current increases. Thus, the maximum allowed accessible voltage, while higher for dc than for ac, is only two times the ac value, or 30 V for the presumed wet location of the dc photovoltaic array. This is the value described in Article 725 of the National Electrical Code. Circuit parts energized with voltages or currents exceeding the above (30 volts, 5 milliamperes) are thus to be guarded so that they are not accessible to contact by persons. See Section 15 of the Proposed UL Standard for Flat-Plate Photovoltaic Modules and Panels.

+ - Available for purchase from Underwriters Laboratories Inc., $25.00.

2.4.11 Standard for Safety

Compliance of system components, particularly the module, with the provisions of a nationally-recognized safety standard, such as the Proposed UL Standard for Flat-Plate Photovoltaic Modules and Panels also constitutes an essential safety subsystem. The first draft of the Proposed UL Standard for Safety - Flat-Plate Photovoltaic Modules and Panels was disseminated as part of the June, 1982 Final Report@. This draft of the standard was used as the basis of discussions at the June 29th and 30th, 1982 Underwriters Laboratories Inc. Photovoltaic Module and Panel Industry Advisory Group Meeting. A report of this meeting, including a partially revised draft of the Standard incorporating certain of the ideas presented and accepted at the meeting, was issued on August 9, 1982, under Underwriters Laboratories Inc. File Subject 1703.

2.4.11.2 Industry Advisory Group Meeting Report Distribution

The August 9, 1982 report was distributed to the Electrical Council of Underwriters Laboratories Inc. and to others known to have an interest in the topic. Others known to have an interest included most organizations on the Jet Propulsion Laboratory Distribution List No. 649 - Engineering Task; Flat-Plate Solar Array Project. Additional copies of the meeting report are maintained at Underwriters Laboratories Inc. for a limited time and are available from:

Underwriters Laboratories Inc.
Publication Stock
333 Pfingsten Road
Northbrook, Illinois 60062

2.4.11.2 Further Revisions to Proposed Standard

Although the August, 1982 draft included certain changes, much remained to be completed. A new version of the Proposed Standard, incorporating all of the changes agreed to at the June 29th and 30th, 1982 Industry Advisory Group Meeting is included as Appendix A of this report.

@ - "Development of Photovoltaic Array and Module Safety Requirements", DOE/JPL 955392-1, Underwriters Laboratories Inc. (June 1982).

Some of the most significant content changes beyond the August, 1982 draft relate to (a) Polymeric Materials Section 6, a completely new text referencing Underwriters Laboratories Inc. Standard UL746C, Polymeric Materials - Use in Electrical Equipment Evaluations; (b) Accessibility, Section 15, a new probe is introduced; (c) module maximum output power measured, new paragraph 20.3; (d) Roof Fire Rating for stand-off or direct modules "... shall be coincident with or at a lower level than the basic roof covering rating.", paragraph 16.1; and (e) a Mechanical Loading Test is added, Section 39.

Some basic points in any UL product standard include primary insulation systems and enclosures. In this regard, two additional points, not yet addressed in the Proposed UL Standard, are noteworthy.

2.4.11.3 Accessibility

For assessing shock hazard possibilities, whether a part is accessible or inaccessible is judged with the module in the fully assembled state, except that (1) covers that may be removed without the use of a tool are removed, and (2) covers that may be removed (with or without tools) for routine maintenance such as cleaning, or to gain access to tools, are also removed. There is no stipulation that the means that secures the cover and for which a tool is required for removal be an essential part of the cover securing means. Thus the cover could be properly held in place yet be removable without the use of a tool after the cover has been once removed and replaced, should the securing means which requires a tool for removal not have been replaced along with the cover. This may be an undesirable condition; and UL is considering a revision to the Proposed Standard to address it.

2.4.11.4 Grounding

In certain use configurations, the grounding member of a module or panel may be called upon to carry ground-fault currents as determined by the number of parallel connected modules. Thus, if sufficient modules are connected in parallel, the module grounding member would be overloaded and possibly fail to perform its function. See Section 2.2.6.3.

To alleviate this problem, UL is considering adding a provision to the standard calling for a marking on the module or panel indicating the maximum number of modules that are to be connected in parallel.

2.4.11.5 Flame Containment

From the standpoint of safety, arcing within a module (either in-circuit or to ground) could be tolerated in a photovoltaic system if the arcing were contained within enclosures, e. g. - between the superstrate and substrate, which were not penetrable by the flame, and which would not track or otherwise deteriorate under the influence of the continuing arc. Besides those materials considered inherently capable of containing arcing (e. g. - ceramics, steel), polymeric materials might be considered acceptable in this regard if their performances under electrical disturbances exceeded certain values.

2.5 Detailed Candidate Safety System Concepts

"Safety System" design involves addressing the various hazard situations which may be expected to occur in a photovoltaic installation. The possible occurrences and their safety consequences are itemized and detailed, and a safety subsystem that can remove or lessen the hazard is recommended. This material is summarized in Table 2.5.

Subsystems for responses to each of the hazard situations are then combined to devise safety systems that address all reasonably foreseeable hazards, Table 2.5A. The material of Table 2.5A is not intended to represent every safety system, but rather some that may be in a typical photovoltaic installation. This would include installations employing combinations of safety subsystem components such as bypass diodes and ground-fault sensing and reaction devices. The system designer is expected to select those combinations of subsystems most appropriate for the installation.

Table 2.5

OCCURRENCE	SAFETY CONSEQUENCE	RESOLVING SAFETY SYSTEM	REACTION AND HOW HAZARD SITUATION IS ALLEVIATED
I Fractured Cells	(a) Arcing Across Cell Break (b) Reverse Voltage Heating from Reduced Output Cell	(1) Bypass Diodes I (a) & (b) II (a)	(1) Voltage across gap is inherently limited to voltage across smallest bypassed segment. No active reaction involved. Low output cell circuitry bypassed.
II Broken Interconnects	(a) Arcing Across Interconnect Break	(2) Arc Detection and Reaction Device I (a) II (a)	(2) Load is removed, terminating arcing current
	I & II - In-Circuit Arcing - Possibility of Ignition of Material by Arcing; Possibility of Destruction of Insulation by Arcs or Flames	(3) Paralleled Modules with Cross-Ties and Controlled Load I (a) & (b) II (a)	(3) Voltage across gap is limited by cross-tied modules and reverse voltage is prevented by limited load.
	I - Localized Heating Leading to Destruction of Insulation	(4) Encapsulants, Superstrates, Substrates Resistant to Arcing and Heating Levels Involved I (a) & (b) II (a)	(4) Heating and arcing is contained within and does not ignite module or material around module
		(5) Reduntant Interconnects II (a)	(5) Parallel Path - thus no arc occurs in the one broken path
I Deteriorated 'Primary' Insulation - Circuit Parts Shorted to Dead Metal (a) "Bolted Fault" (b) "Arcing Fault" [Also see "System Insulation Failure"]	To ungrounded dead metal #(circuit grounded) (a) & (b) -Shock hazard from personal contact with exposed 'dead metal' parts.	(1) Supplementary or Reinforced Insulation (Double Insulation System)	(1) Additional insulation level to provide separation between dead metal (and thus person) and hazardous part in the event of primary insulation failure
		(2) Ground-Fault Detection and Reaction Circuit (Personnel Protection Type)	(2) Current and energization of hazardous parts terminated by any one of several switching reactions shortly after any ground-fault currents above a predetermined current/time threshold
		(3) Low-Voltage Array (<30 volts)	(3) Low voltage inherently reduces shock hazard possibility
	To Grounded Dead Metal (circuit grounded) (a) No Hazard (b) Arcing from Cell String to Ground - Possibility of Ignition of Material by Arcing; Possibility of Destruction of Insulation by Arcs or Flames	(1) Supplementary or Reinforced Insulation (Double Insulation System)	(1) Additional insulation level to provide separation between grounded dead metal and hazardous part in the event of primary insulation failure
		(2) Ground-Fault Detection and Reaction Circuit (Equipment Protection Type)	(2) Arcing due to ground-fault current will be terminated by any one of several switching reactions shortly after initiated if above a predetermined current/time threshold.
		(3) Low Voltage, Low Current Array	(3) Low voltage, low current combinations (defined elsewhere) inherently reduce arcing possibilities
I Deteriorated 'Primary' Insulation-Circuit Parts Through Insulation (and Exposed) (Example: Broken Super or Substrate) [Also see "System Insulation Failure"]	Shock Hazard from Personal Contact with Exposed Circuit Parts (Circuit Grounded)	(1) Ground-Fault Detection and Reaction Circuit (Personnel Protection Type)	(1) Current from exposed hazardous part will be terminated by any one of several switching reactions shortly after any ground-fault currents above a predetermined current/time threshhold occur
		(2) Supplementary or Reinforced Insulation (Double Insulation System)	(2) Additional insulation level prevents personal contact with hazardous parts upon failure of primary insulation.
		(3) Low Voltage Array (<30 volts)	(3) Low voltage inherently reduces shock hazard possibility
	Arcing Between Exposed Circuit Parts and Grounded Metal, Possibility of Ignition of Materials (Circuit Grounded)	(1) Ground-Fault Detection and Reaction Circuit (Equipment Protection Type)	(1) Arc from ground-fault current will be terminated by any one of several switching reactions
		(2) Supplementary or Reinforced Insulation (Double Insulation System)	(2) Additional insulation level prevents breakdown and establishment of arc
		(3) Low-Voltage, Low Current Array	(3) Low voltage, low current combinations (defined elsewhere) inherently reduce arcing possibilities.

Table 2.5 (cont'd)

OCCURRENCE	SAFETY CONSEQUENCE	(2) RESOLVING SAFETY SYSTEM	REACTION AND/OR HOW HAZARD SITUATION IS ALLEVIATED
Short-Circuited Blocking Diode	Possible Excessive Reverse Current Through Module, Module, Connector and Conductor Overheating	(1) Fuse in Photovoltaic Source Circuit (2) Redundant Series Diode	(1) If excessive reverse current is encountered, fuse will clear (2) Redundant diode will prevent reverse current
Open-Circuited Blocking Diode	None		
Open-Circuited Bypass Diode	Arcing - Possibility of ignition of materials if in combination with another circuit break	(1) Hierarchy of diodes (2) Redundant parallel diodes	(1) & (2) Extra diodes, either redundant or in a hierarchy arrangement will suppress in-circuit arcing in the event of one diode failure by keeping open-circuit voltages to relatively low levels.
Short-Circuited Bypass Diode	None		
Ice Damming (Direct-Mounted Modules)	Flooding of terminals, shock hazard via accumulated water	(1) Restrict areas of placement of modules (2) Environmentally sealed terminals and other circuit parts	(1) & (2) Water is prevented from contacting hazardous "live" parts
Module Failure Necessitating Module Replacement	Shock hazard from terminals or leads exposed in and during the module replacement process	(1) Connectors with inaccessible contacts, both parts of connector (2) Bypass diodes and array shorting switch to restrict voltage across gap created by removal of module to the module voltage, together with low voltage (<30 volts) modules	(1) Shock hazard parts are rendered inaccessible (3) With diodes forward-biased on short circuiting of array, no more than the module voltage will be encountered upon the removal of any module.
Utility Outage	Energization of Presumed "dead" utility line	"Drop-Out" system in power conditioning unit (PCU)	Terminate parallel PCU operation - No energization of power line
Utility Off Voltage or Frequency	Harmonic or disturbed currents, overheating of connected appliances, overheating of power conditioning unit	"Drop-out" system in power conditioning unit (PCU)	Terminate parallel PCU operation - No harmonic or distrubed currents
System Insulation Failure	Energization of Accessible Parts, Circuit-Ground Arcing	(Not Exclusive) System ground or reference to ground to stabilize system voltage Frame grounding (2) Surge-Devices (e.g. Varistors)	Potential for overstressing of insulation is diminished or removed, thus insulation systems are less likely to fail Effectively tying the frame to the surrounding earth keeps the voltage between the two to zero (nominal) thus no shock hazard voltage can exist between frame and earth upon the occurrence of insulation failures (2) Absorb impulses of energy, thus preventing breakdown.

Ungrounded dead metal proscribed by the provisions of the National Electrical Code - 1984, Article 690

TABLE 2.5A SAFETY SYSTEMS

System	Gnding Ckt	Gnding Frame	Gnd Fault* Shock	Gnd Fault* Fire	Gnd Sensor	Bypass Diode@	Multiple Strings with Cross-ties, and Max PWR Tracking Load	Blocking Diode#	Arc Detector	Low Voltage Array	Limited Voltage ModulesØ	Redundant Connections	Double Insulation	Module Plug Connectors+
I	X	X	X					X	X					X
II	X	X	X			X		X			X			
III	X	X				X		X			X		X	
IV	X	X		X				X		X				
V	X	X	X					X				X		X
VI	X	X	X				X	X			X			
VII	X	X	X				X	X	X					
VIII		X			X	X		X			X			
IX		X						X		X				
X		X			X		X	X			X			
XI		X			X			X	X		X			X
XII		X			X	X								X

* - Ground fault detection and reaction subsystem (Section 5.2.1).

@ - Shock hazard ground fault system also protects against fire from ground fault arcs. External to module.

\# - Optional alternative - module series fuse, module is evaluated to determine that it can withstand reverse current allowed by fuse.

Ø - A prescribed voltage module denotes a module (or panel), the output voltage of which is less than the threshold for shock hazard purposes; that is, 30 volts. This voltage limit also serves to reduce or eliminate in-circuit arcing conditions.

\+ - The electrical contacts of both parts of the connector are inaccessible to contact.

FF8 E1/pbe

Commentary for Table 2.5A

Grounding of conductive frames is recommended in all instances and stipulated in NEC Article 690. Unlike circumstances of some product use locations where ground points may be minimal, photovoltaic arrays are likely to be installed where other earth ground points are available, either directly (contact with earth) or by way of other grounded parts (vent pipes, gutters, electrical conduit). Grounding of the frame, and all other accessible dead-metal assists in preventing a shock hazard situation upon the occurrence of a fault between a circuit part and the dead-metal, and in preventing insulation failure due to accumulated charges.

"Low Voltage Array" and "Limited Voltage Modules" are not synonymous. A Low Voltage Array is one in which the total array voltage is under the limit for shock hazard, 30 volts dc for wet locations. Limited Voltage Modules refer to the individual module voltages, without any particular constraint (other than what may be expressed elsewhere) on the total array voltage.

All systems incorporate blocking diodes and/or fuses (the use of overcurrent protective devices is stipulated in NEC Article 690) to prevent or limit reverse currents.

Systems I-VII

Circuit grounding is provided, thus the possibility exists for circuit-ground arcs and circuit ground shock hazard situations. The circuit-grounding means should include an interrupt device to allow for termination of ground-fault currents, and to allow for array servicing, e. g. - replacement of modules with exposed terminals, provided these terminals are of a single module of limited voltage. The circuit ground can be of a "virtual" nature, thus these systems are compatible with a transformerless power conditioning unit interactive with a grounded utility line.

System I - Both fire and shock hazard situations from ground-fault currents are mitigated by a shock hazard sensitivity ground-fault system. In-circuit arcing is mitigated by an arc detection and reaction system. Module replacement without shock hazard is made possible by plug connectors. It is noted that this system would require development of a workable Arc Detector, which, as far as it is known, is not now available.

Note: This system may not protect satisfactorily against hot-spot heating unless the modules or panels incorporate integral bypass diodes.

System II - Both fire and shock hazard situations from ground-fault currents are mitigated by a shock hazard sensitive ground-fault system. In-circuit arcing and cell hot-spot heating are prevented by limited-voltage modules and bypass diodes. Module replacement without shock hazard is possible by the use of limited-voltage modules, and external to module bypass diodes.

System III - Both fire and shock hazard situations from ground-fault currents are inhibited by system and component "double insulation". System double insulation and double insulation of other than cord connected products is a new concept and its probability of acceptance has not yet been determined. In this system both the factory-finished product (the module or panel) and the assembly would need to comply with the rules governing double insulation. Thus, for example, wiring would have to be arranged so that a broken wiring connection would not result in contact between the loose wire end and any accessible part, and the single insulation provided over a conductor would not be acceptable as the sole barrier between the conductor and personal contact.

In-circuit arcing and cell hot-spot heating are prevented by limited-voltage modules and bypass diodes. Module replacement without shock hazard is possible by limited-voltage modules and external to module bypass diodes.

System IV -

Fire hazard situations from ground-fault current are mitigated by a "fire level sensitive" ground-fault system. Shock hazard situations from ground-fault currents are mitigated by "low-voltage" arrays (less than 30 V).

Both the likelihood of no in-circuit arcing and module replacement without a shock hazard are made possible by the low-voltage array.

A low-voltage array is inherently free from hazards due to cell hot-spot heating.

System V -

Both fire and shock hazard situations from ground-fault currents are mitigated by a shock hazard sensitive ground-fault system. In-circuit arcing is mitigated by redundant connections. Module replacement without shock hazard is possible by the use of plug connectors.

Note: This system may not protect satisfactorily against hot-spot heating unless the modules or panels incorporate integral bypass diodes.

System VI -

Both fire and shock hazard situations from ground-fault currents are mitigated by a shock hazard sensitive ground-fault system. In-circuit arcing and hot-spot heating are mitigated by multiple cell strings with cross-ties with a maximum power tracking load (power conditioning unit). Module replacement without shock hazard is made possible by limited voltage modules together with cross-ties.

System VII -

Both fire and shock hazard situations from ground-fault currents are mitigated by a shock hazard sensitive ground-fault system. In-circuit arcing and hot-spot heating are mitigated by multiple cell strings with cross-ties with a maximum power tracking load (power conditioning unit). Module replacement without a shock hazard situation is made possible by plug connectors.

Systems VIII Through XII -

The circuit is isolated from earth ground to prevent circuit-ground shock hazard currents and arcing ground faults. Because an inadvertent circuit connection to ground, either solid or intermittent, would negate the benefit of the isolation, a sensor must be provided to sense any connection between the circuit and ground and sound an alarm or take other appropriate action upon such an occurrence. Because the circuit is not grounded under normal conditions, other means must be provided to stabilize system voltage with respect to earth and absorb energy from line surges. The system voltage can be stabilized by high resistance resistors connected between the circuit and earth, energy absorption facilities can be provided by varistors.

System VIII -

Module replacement without a shock hazard and suppression of in-circuit arcing are effected by limited-voltage modules and external to module bypass diodes.

System IX -

Both the likelihood of no in-circuit arcing and module replacement without a shock hazard are made possible by the low-voltage array.

A low-voltage array is inherently free from hazards due to hot-spot heating.

System X -

In-circuit arcing and hot-spot heating are mitigated by multiple cell strings with cross-ties with a maximum-power-tracking load (power conditioning unit). Module replacement without shock hazard is made possible by limited-voltage modules together with cross-ties.

System XI -

In-circuit arcing is mitigated by an arc detection and reaction circuit. Module replacement without a hazard is made possible by plug connectors.

System XII -

For modules (1) whose cells can withstand reverse voltages greater than 30 volts, or (2) modules with internal bypass diodes bypassing portions of the module circuit, module replacement without a shock hazard is made possible by plug connectors.

2.5.1 System Selection

Of the twelve systems described, Systems II and VIII appear to be the most desirable and immediately implementable in terms of tried technology and accepted ideas. Their use is suggested if Safety Systems, beyond those specified in the NEC are sought.

System XII is the next choice followed by the two low-voltage systems, Systems IV and IX, if such systems are useable in the installation. The "double insulation" system, System III is rated next, followed by System V, redundant connections.

Systems VI and X with cross-ties and a maximum-power-tracking load, are rated next but are rated low because maximum-power-tracking systems without pilot cells have not been workable to date. Systems with arc detectors, Systems I, VII, and XI follow, the arc detector built to date has not been shown to be a practical method of detecting in-circuit arcing.

2.6 Mechanical Aspects That Affect Safety

The preceding has dealt with the electrical design of an array. However, the physical placement and characteristics of the array and its components also affect system safety. Three such items of concern are (1) the ability of a roof-mounted array to tolerate persons walking on it, (2) ice-damming in a roof-mounted array that could result in the flooding of areas with electrical connections, and (3) placement of modules to allow safe access to a roof by fire-fighting personnel.

The Proposed UL Standard for Flat-Plate Photovoltaic Modules and Panels does not address either the damage that might occur to modules should they be walked upon, and the friction between the module's superstrate and the soles of shoes of persons walking on the array.

When an entire roof is covered with modules and the pitch of the roof is less than a certain angle, it is likely that at some time the owner or maintenance personnel may walk on the roof. In these cases, the module superstrate should be such that it will not be penetrated by the shoes of the person walking on the modules, and the modules and their backing should be capable of bearing the walker's weight without the creation of a shock or fire hazard. For example electrical connections within the module and the cells should not be broken during this activity.

Additionally, the superstrate should either (1) have sufficient static friction in conjunction with soles so that at the angle of inclination the walker will not slide off the array after making a partially successful ascent, or the static friction should be so low that a walking ascent of the roof cannot be started.

Ice-damming on roofs occurs when water, from snow, melted by the heat rising through a building's roof, runs down the roof to the point of roof overhang. With no heat passing through the roof at this overhang point, no snow melts here, and the running water is trapped behind it and refreezes to ice. The ice backs up water behind it, and may cause this water to seep under the roof shingles. See Figure 2.6. The modules of an array should not be placed where water accumulation due to the damming action is possible, that is they should not be placed at or near the edge of the roof, if integral with the roof.

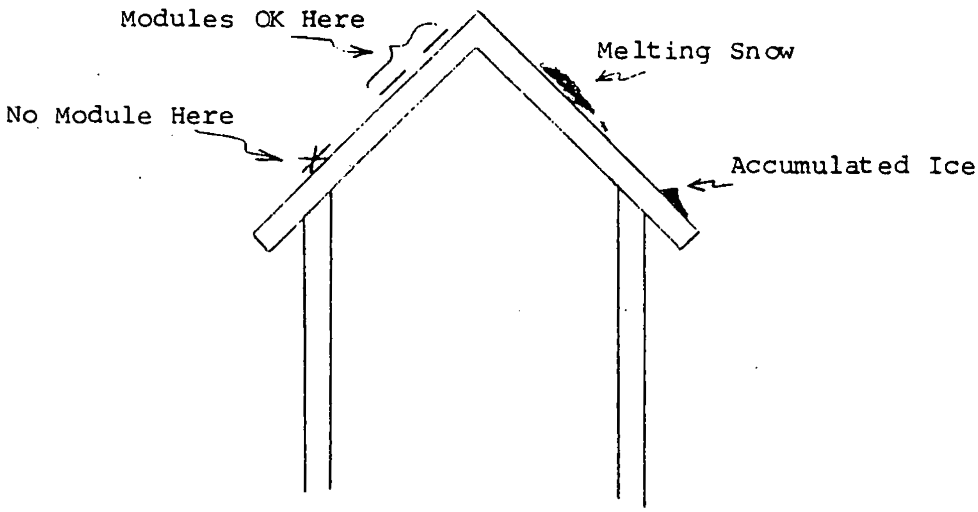


Figure 2.6

Module Mounting on Roof

In an emergency situation, fire-fighting personnel may alight on a roof from ladders placed against the building. To provide a clear zone so that these personnel do not immediately encounter electrically hazardous parts, buildings of three stories and more where the array is considered not evident from the ground area immediately adjacent to the building, and in heights up to the limit of aerial ladders, should be provided with a clear area at the roof edge (i.e. - free from array parts) to allow for the alighting of such personnel.

2.7 Flammability From Externally Applied Sources That Affects Safety

One basic provision of the Proposed UL Standard for Photovoltaic Modules and Panels, UL 1703, Sections 16 and 30, concerns fire response performance of the module or panel when under the influence of applied external flames. Although the application of this aspect of the module or panel provision is optional on the part of the entity for whom the product is being evaluated, compliance with the provision will afford enchanced safety. Three levels of fire performance are attainable, from A, the best; B, a middle rating; to C, the lowest of the three.

In any installation, the degree of fire resistance required of a roof-mounted array, whether it be stand-off, rack, direct, or integral, is determined by the local building codes, and not by any UL or other product standard. Thus, the wording of Section 16 of the Proposed UL Standard for Photovoltaic Modules and Panels; "A module or panel intended for ... mounting in combination with a specified roof ... shall comply with the requirements for Class A, B, or C roof covering in terms of fire resistance ..." is intended to mean only that if the module or panel is marked, and thus so intended, it shall comply.

Because a module or panels roof fire performance is dependent upon its mounting configuration and, in many cases, the underlying roof, a module or panel may have several ratings for an equal number of mounting styles.

3. FURTHER DEVELOPMENT OF THE UL STANDARD THROUGH MODULE SUBMITTALS

3.1 Background

The development of any product standard cannot be completed without an evaluation of a sample of the product to the provisions of the Standard. In this regard, Underwriters Laboratories Inc. has investigated under the provisions of its Proposed Photovoltaic Module and Panel Standard, and Listed for ARCO Solar, Inc. of Woodland Hills, California, their M51 photovoltaic module. The work was funded by ARCO Solar, Inc. and the mention of any of the details of the investigation is with their permission. The following is a discussion of the generic points of the investigation that led to the Listing and how the investigation resulted in the further development of the Proposed UL Standard for Flat-Plate Photovoltaic Modules and Panels so as to improve it. All paragraph and section references in this report section are to this Proposed Standard, UL1703, March, 1984, Appendix A.

The M51 module is comprised of 35 solar cells in a polymeric encapsulant between a tempered glass superstrate and a polymeric/aluminum substrate. Electrical connections are made in a polymeric wiring compartment.

The investigation was conducted over a period of slightly more than a year, during which time the Proposed Standard went through many changes. It is expected that subsequent investigations of photovoltaic products would take approximately three months time. Several revisions to the Standard involved eliminating tests, such as the maximum power aspect of the temperature test, the ac plus dc aspect of the dielectric voltage withstand test, the voltage surge test, the twist test, and the hail test.

3.2 Test Facilities and Samples

A great deal of the investigation was conducted at the ARCO Solar facilities under the direction of Underwriters Laboratories Inc. personnel. This procedure was followed because Underwriters Laboratories Inc. does not possess much of the specialized equipment needed for the tests, such as the Large Area Pulsed Solar Simulator (LAPSS). When utilizing any manufacturers facilities, Underwriters Laboratories Inc. personnel verify that instrumentation calibration is current, within the allowed bounds for uncertainty, and traceable to a national standard. Computer programs performing data reduction and extrapolation are checked to determine their correctness and applicability.

Certain other tests, including those relating to a Roof Covering Fire Rating were conducted at Underwriters Laboratories Inc. facilities. (The roof fire rating aspect of the test program is optional, ARCO Solar elected to have a rating assigned to their product.)

Ten samples of the module were made available for the basic aspect of the investigation, that is all those parts exclusive of the roof fire rating testing. All samples submitted were used so as to avoid subjecting pieces to multiple tests. Where samples are not damaged during tests, and if the submittor so elects, a single piece may be used for a number of tests. Table 18.1 of the Proposed UL Standard can be used as a guide for sample requirements. If samples can be subjected to any number of tests, the test program exclusive of roof fire tests could be completed with as few as three complete samples, plus necessary parts. Additional samples, many of which were electrically imperfect, were made available and used for the roof fire rating tests.

3.3 Test Program

3.3.1 Voltage and Current Measurements (Output Characteristics)

At the outset, current-voltage (I-V) characteristic curves were obtained for each of the modules, using a LAPSS. The curves for three of these modules were used to satisfy the test. Besides the characteristic curves developed at room temperature, the data was translated to generate curves describing characteristics at 20°C, 0°C, and -20°C by the relationships described in the JPL "Block V Solar Cell Module Design and Test Specification for Residential Applications-1981"; 5101-162

$$I_{NOC} = I_{OTC} + C_I \, (T_N - T_O)$$

$$V_{NOC} = V_{OTC} + C_V \, (T_N - T_O)$$

where

V_{OTC}, I_{OTC}	are coordinates of a selected point on the curve obtained at OTC. (Optional Test Conditions)
V_{NOC}, I_{NOC}	are coordinates of the corresponding point on the NOC (Normal Operating Condition) (corrected) curve.
T_N	is the cell temperature at which the current-voltage characteristic is desired.
T_O	is actual cell temperature during the OTC curve measurement.
C_I	is the current-temperature coefficient, expressed as A/°C.
C_V	is the voltage-temperature coefficient, expressed as V/°C (usually a negative value).

Following the June, 1982 UL Flat-Plate Photovoltaic Module and Panel Industry Advisory Group Meeting, the "Voltage and Current Measurement" scheme, Section 20 of the Proposed Standard was modified to utilize measurements at NOCT[c]. Because of this, additional I-V curves were later obtained translated to NOCT.

[c] - NOCT - (Nominal Operating Cell Temperature) -- The equilibrium cell junction temperature corresponding to nominal module service operating conditions in a reference environment of 80 mW/cm^2 irradiance 20°C ambient air temperature, 1 m/s wind, and electrically open circuit.

The curves were utilized to establish product ratings to be reflected in the product marking. As these ratings varied somewhat from the ratings originally assigned by ARCO Solar, the product rating information had to be modified somewhat.

Because of the availability of the LAPSS and the linked computer facilities available at ARCO Solar to do the curve drawing and translating, the output characteristics were obtained without difficulty and in a relatively short time (minutes). Had such facilities not been available, it is expected that this work would have been more time consuming and possibly at the mercy of the weather, depending upon the light source chosen.

3.3.2 Temperature Test

Because of (a) lack of ready access to a continuous large area solar simulator, (b) expense, and (c) availability of facilities, including computers and computer programs to effect least square fit curve fitting, the temperature test was conducted under natural sunlight. The method used was that basically described in the JPL Block V Module Specification, 5101-162, for the Determination of Nominal Operation Cell Temperature, except that the temperatures were measured at and on the superstrate, substrate, and within the wiring compartment, rather than on the cells. The module was mounted outdoors on a steel rack adjacent to one other module on a wood platform above a roof covered with gray asphalt sheet roofing. At the time of the tests, three electrical operating conditions were specified, open-circuit, short-circuit, and maximum power output from the module, and the test so conducted. Because of the several operating conditions, the ability to monitor only one-half the number of test points at any one time, and the vagaries of the weather, this test was accomplished over several weeks. In spite of the relatively long time required for the conduct of the test, it ran relatively unattended for data collection after set-up for each operating condition and set of points for measurement. Procedures and computer programs were already established, and instrumentation, such as a pyranometer, were already in place for this method of temperature measurement. Previously, they were used only for the NOCT determination. The procedures and instrumentation were easily adapted to measuring the temperatures of all the other points in question.

It is recognized that this procedure may not reflect module temperatures for a module mounted in the center of the array. However, based on built-in safety factors, UL believes this test method will be adequate, and unless later experience negates this assumption, will be retained.

The module temperatures at maximum power output from the module were later deleted from the Proposed Standard. The theory was that module temperatures at maximum output power would be less than those at open circuit because of power removed from the module under maximum output power conditions, and this was confirmed, for this module at least, by the tests conducted under this investigation. Because of the deletion of one-third of the temperature test program, the test time for the temperature test aspect of the investigation for any new submittals would be reduced considerably over what was experienced in this investigation.

A main point to be considered is the physical placement of the thermocouples. If the thermocouples must be placed within a module with a tempered glass superstrate and a tempered glass substrate, it would be necessary that they be imbedded before the module is assembled. However, where both the superstrate and substrate are of tempered glass and where there is no circumstance under which failure of any insulation within the module sandwich would result in a shock hazard situation, it would likely not be necessary to measure temperatures within the module sandwich.

In the case of the product in question, the thermocouples could be and were placed within the module sandwich by cutting through the substrate.

As a result of these tests, the limit on surface temperatures under the condition of short-circuit operation was established as 40°C (72°F) above temperature achieved during open-circuit conditions for nonmetallic surfaces, and 20°C (36°F) above temperature achieved during open-circuit conditions for metallic surfaces.

3.3.3 Leakage Current Test

For the leakage current test, the module circuit to frame insulation was placed in series with an ammeter and both a dc and ac supply (separately). The supplies were set equal to the maximum system voltages. The measurement procedure was straightforward with no pecularities that might be related to photovoltaic products. Although the tests were done with both ac and dc, the ac part of the test (along with the ac system voltage rating) has since been eliminated. Elimination of the ac test was based on the consideration that power conditioning units, or power conditioning units and their ancillary inductors are expected to keep the ac voltages impressed on arrays low, i. e. values below 3-4 volts. The maximum current backfed through a power conditioning unit complying with the Draft UL Standard for Power Conditioning Units for Use in Residential Photovoltaic Power Systems would be as described in paragraph 45.6 of said document.

Minimal time and only standard laboratory power supplies and meters were required for this test.

3.3.4 Push and Cut Tests

Standard laboratory spring scale push testers were utilized for the push test, which was conducted in a short time (minutes). No problems are foreseen in the conduct of this test.

The right angle corner of a cut 0.025 in. thick hacksaw blade mounted on a wheeled cart was used for the cut test. This apparatus was constructed at minimal expense, from material on hand. This test was conducted in minimal time and with no difficulty.

3.3.5 Bonding Path Resistance (Integrity) Test

The bonding path integrity test was conducted with standard laboratory meters and power supplies. The test method and interpretation of results were straightforward with no peculiarities that could be related to photovoltaic products. Minimal time was involved.

3.3.6 Dielectric Voltage Withstand Test

The dielectric voltage withstand tests were conducted with standard dielectric test fixtures. For the dc only aspect of the test no special precautions were necessary. For the ac + dc portion of the test the compatability of the two supplies had to be insured, so that one would not do damage to the other. This ac + dc portion has been deleted from the test program, and thus the potential problem of incompatability of supplies has been eliminated. The rationale for the elimination of the composite test was the limited ac voltage on the array, see commentary under 3.3.3, Leakage Current Test.

3.3.7 Inverse Current Overload Test

No problems were encountered in the conduct of this test which was continued for five (5) hours, rather than the required two (2) hours. The module was resting face down on the tissue paper covered board. Both tissue paper and cheesecloth are readily available items.

3.3.8 Installation and Maintenance Tests

Only a torque screwdriver was needed for the conduct of this test. The ten cycles of loosening and tightening was accomplished rapidly and without any problem. No parts that are detachable, hinged, or the like for routine maintenance, which would have been subjected to 300 cycles of operation, are present on the product.

This 300 cycle portion of the test program has since been deleted, thus eliminating any potential time consuming hand operation, or alternately, a need to devise special test jigs for each mode of servicing operation peculiar to each product.

3.3.9 Exposure to Water Spray Test

This test was conducted without any problem. Because the module can be oriented in many ways, the test was conducted with the module in various attitudes.

3.3.10 Accelerated Aging of Gaskets and Seals

These tests, conducted on samples of the wiring compartment gasket, were completed without problems or unusual circumstances.

3.3.11 Temperature Cycling and Humidity (With Temperature Cycling) Tests

Both of these tests, the basic test procedures of which were taken from the JPL Block V Module Specification, 5101-162, were conducted without special problem. Some points do relate to (a) cost, they are perhaps the second most costly tests to be conducted, the fire tests being the most expensive, and (b) time, inherently, they are the longest of the UL Listing program, the temperature cycling test taking 50 days to complete. In conducting these tests, continuously operating chart recorders were used to determine whether any circuit openings or continuity between circuit and frame occurred.

In the particular instance of this test program, the temperature cycling test was first conducted for only 100 cycles. Later, as a result of discussions at the June, 1982 Industry Advisory Group Meeting, the test procedure was modified from 100 to 200 cycles, and the tests on the M51 module had to be redone.

The UL test procedure differs from that generally employed by JPL, in that, while with JPL some modules are removed after 50 cycles of temperature cycling for placement in the humidity environment, and then returned to the temperature cycling, the UL procedure allows separate samples for each test.

3.3.12 Solar Radiation Weathering Tests

The procedure for this test, formerly described in the Proposed UL Standard for Photovoltaic Modules and Panels has been deleted. This test is now described by reference to the UL Standard for Polymeric Materials, Use in Electrical Equipment Evaluations, UL746C, in Section 6, paragraph 6.1 of the Proposed Module Standard.

The single problem relating to this test was the incapability of the test equipment to accommodate the product. This was solved by using for the test, a substitute physically smaller module, identical in every respect except for size, to the candidate module.

3.3.13 Hot Spot Endurance Test

This test, patterned after procedures described in the JPL Block V Module Specification, 5101-162, was conducted without special problems. In some circumstances with other modules, difficulties may arise if cells cannot be individually accessed, as could happen with a module incorporating a tempered glass superstrate and a tempered glass substrate. In such cases specially built modules will be needed.

In the case at hand, the intrusive method of cell selection was used. After the cells to be tested were selected, automatic apparatus was assembled to energize the cells for the one hour period, and then deenergize the cells until their temperatures had cooled to within 10°C of the ambient temperature. Thermocouples were affixed to the module to record temperatures about the cells. In one instance, cell characteristics changed during the conduct of the test, and the test procedure had to be modified to accommodate this change.

3.3.14 Impact Test

Only a standard size steel ball, a string, and a ruler were necessary for the conduct of this test, which was conducted without any problems.

3.3.15 Exposure to Hail Test

Although the test procedure outlined is relatively simple, the test involved considerable expense because of (a) the time involved in calibrating the hail gun to propel the ice balls at the specified speed, (b) the precision necessary in the ice ball dimensions and weight, and (c) the limited time allowed between removal of the ice balls from the freezer and when they were fired at the target. The ice balls were prepared in advance in rubber balloons, which were cut apart to retrieve them. They were then placed in a pneumatically operated hail gun, which fired them, horizontally, at the target.

It quickly became apparent that the Steel Ball Impact Test (5 ft lbs from a rigid sphere) was a much more severe evaluation tool than the Hail Impact Test (1.7 ft lbs from a readily deformable sphere), and thus, as a result of discussions at the IAG meeting, the Exposure To Hail Test was deleted from the proposed UL standard.

3.3.16 Roof Fire Tests (Spread of Flame Test) (Burning Brands Test)

These tests are optional on the part of the product submitter. A casual view of the modules, with their glass superstrates, which are intended for standoff mounting above an asphalt sheet roofing covered roof, would make it appear that the products would comply with the requirements applicable to the most fire resistant of roof covering materials, that is, Class A.

It was discovered that the most severe of the burning brands and applied flame (Class A) may penetrate and ignite the leading modules and then ignite the underlying roof covering. Once the underlying roof covering is ignited, it no longer behaves as its rating would imply. Rather, the flame tunnel created by the intact segments of the overlying modules and the underlying roofing causes spread of flaming. This flaming, including flaming of back surface components of the module, such as polymeric wiring compartments, can create flaming pieces which remain burning after they land on the floor.

Less severe test conditions (both burning brand and applied flame) may result in test performances in accordance with the applicable acceptance criteria. Based on an acceptable performance, Class B burning brand, and the equivalent of an acceptable performance, Class C spread-of-flame, the module was assigned a Class C roof fire rating.

The test is optional as (a) not all modules need be qualified for roof mounting on buildings i. e. some might be used only in open fields where roof fire ratings are inapplicable and (b) even when roof mounted, different rating requirements are applied, from community to community, from Class A to nothing. To emphasize this point, the guide information for the UL product classification "Photovoltaic Modules and Panels" preceding the Listing of these products includes the following statement:

> Installation of direct or rack mounted modules or panels on roofs may adversely affect the resistance to external fire exposure of the building's roof covering materials. Direct or rack mounted modules or panels may be marked to identify them as Class A, Class B, or Class C to denote that when installed above or upon roof covering materials with the same Class rating or better, the resistance to external fire of the material will not be less than the Classification rating for the roof module. When modules are installed above roof covering materials with lesser Classification ratings then the Classification rating of the module, the Classification rating of the roof covering material will not be adversely affected. Integral roof mounted modules or panels, which serve as the primary barrier to external fire exposure may be identified as Class A, Class B, or Class C to denote that they have resistance to external fire exposure equivalent to similarly identified roof covering materials. Modules or panels which have not been identified with respect to resistance to external fire exposure are marked "Not Fire Rated". For the significance of Class A, Class B, and Class C external fire exposures, see Roof Covering Materials, Guide TEVT in the Building Materials Directory.

No special problems were associated with the conduct of these tests.

3.3.17 Static Loading Test

Bags of rock salt, which happened to be on hand, were used as the load for this test. No special problems were noted.

3.3.18 Water Absorption Test

The dimensional stability of the substrate laminate under conditions of immersion in water was determined by measuring the dimensions and weight of the laminate dry, and then following immersion in water for 24 hours. No problems were encountered.

3.3.19 Water Exposure

The substrate laminate, and a portion of this laminate were conditioned by immersion in water prior to their being subjected to the High Current Arc Ignition, Comparative Track Index and Flammability Classification Tests. No problems were encountered in this water exposure procedure which involves only simple water immersion of the material.

3.3.20 High Current Arc Ignition and Comparative Track Index Tests

Both of these tests were attempted on the complete substrate laminate. However the aluminum portion of the laminate interfered with the conduct of the tests, making it necessary to evaluate the polymeric material alone.

3.3.21 Flammability Classification Tests

No problems were experienced in evaluating the substrate laminate material to determine its flammability classification.

3.4 Construction Features

3.4.1 Wiring Terminals

The provision expressed in Paragraph 9.7, Subparagraph A of the Proposed Standard, states that a wire binding screw terminal -- such as used on the subject product, shall have provision to retain an accommodated wire in position even with the binding screw slightly loose. The original construction of the subject product, the wiring terminals of which are intended by its manufacturer to properly accommodate a specific dedicated necked-down spade lug through the gap in the interrupted thread screw, did not provide a facility to retain an ordinary wire without a special termination should the screw become slightly loose. While a provision to properly retain a special dedicated device is acceptable, every terminal intended for the connection of field wiring is assumed to be field wired with ordinary copper wire without special terminations, and must be capable of properly accommodating that wire. This does not preclude any provisions which the manufacturer may elect to provide with regard to securement of special connectors.

To correct this condition, ARCO Solar elected to incorporate a cup washer under the head of the terminal screw. This allows use of the special connector, (spade lug), and will serve to retain a wire in position should the screw become slightly loose.

3.4.2 Wiring Compartment

At one stage in the Standard development, the provisions described in Paragraph 12.2 would have required a minimum wiring compartment dimension of 2 inches in the space providing the minimum required compartment volume.

Experience with the M51 module disclosed that this 2 inch dimension requirement was excessive, in fact it is not provided for in the M51 product. A 3/4 inch dimension was shown as adequate by examination of the M51, and this figure is used for the Standard.

3.4.3 Accessibility

The provisions of Section 15, particularly Paragraph 15.4, describe when a part of a photovoltaic module or panel is considered accessible for purposes of determining shock hazard possibility. In the M51 module, the twist-on and twist-off cover of the wiring compartment was originally removable without the use of a tool, and per Exception No. 1 of Paragraph 15.4, the cover would then be removed when judging accessibility to live parts. When the cover is so removed, the product's wiring terminals, which may be operating at up to 600 volts from earth (the module system voltage rating) are then accessible, an unacceptable condition. To correct this feature, ARCO Solar, Inc. added tabs to the wiring compartment cover and body, and provided a screw to secure these tabs together, thereby preventing twisting and subsequent removal of the wiring compartment cover unless the screw between the tabs is first removed with the use of the tool.

Some thought is being given to changing the Proposed Standard, so that when a cover is provided for compliance with accessibility requirements, that part of the cover's securing means which requires a tool for its removal constitute an essential part of the securing means. The M51 module would not comply with such a revised requirement. See Section 2.4.11.3.

3.4.4 Marking

The module, as originally submitted was lacking most of the marking called for in Section 41. This material was subsequently provided.

4. UL INVESTIGATIONS OF COMPONENTS FOR PHOTOVOLTAIC SYSTEMS

4.1 Background

A basic provision of the National Electrical Code, Section 110-2, is that "The conductors and equipment required or permitted by this code shall be acceptable only if approved". Approved equipment is defined as equipment examined for safety under standard conditions by an organization properly equipped and qualified for experimental testing and inspections of runs of good at the factory. The indication of compliance of the equipment with the standard as determined by that organization is a listing or labeling of the product under the permission of the testing organization.

Further, equipment shall be suitable for the installation (intended use), and where there may be a question, the suitability may be identified by a description marked on or provided with the product to identify the specific purpose, use environment, etc.

Other than the modules and panels themselves, the components of a photovoltaic power system are thus candidates for such investigation and listing or labeling. Some of these may be investigated to presently established requirements. These include items such as wire, raceways, outlet and junction boxes, and grounding and bonding equipment. If UL Standards are used as the basis for investigation, those described in Table 4.1 are germane. This table indicates whether the standard contains generic safety requirements; requirements applicable to components of a system, such as UF cables; or requirements which may be applied to the photovoltaic module or panel itself, such as fire resistance as a roof covering. Certain UL standards, identified by an "X" in more than one column, may be applicable to items which may be a part of the module, such as wiring (but tested separately), and also included separately as a part of the photovoltaic array. Additionally, a Proposed UL Standard for Transient Voltage Surge Suppressors, UL1449, November, 1982 would cover varistors.

Additional system components are eligible for listing or labeling by a nationally-recognized testing laboratory even though they might not yet be covered by specific UL or other organization standards. Some such components would be covered by requirements in the Proposed UL Standard for Flat-Plate Photovoltaic Modules and Panels, UL 1703, for as specifically stated in Paragraph 1.3 of this standard, "These requirements also cover components intended to provide electrical connection to and mounting facilities for flat-plate photovoltaic modules and panels." Connectors and mounting frames are the items specifically intended to be covered, whether they are provided as a part of the module or panel, or provided separately to either a module or panel manufacturer or consumer.

Other than the Draft Standard for Safety - Power Conditioning Units for Use in Residential Photovoltaic Power Systems, April, 1982, Appendix B of this report, there are no other proposed or adopted standards known to UL which may be considered appropriate under which photovoltaic power system products might be judged per the National Electrical Code.

TABLE 4.1
APPLICABILITY OF UL STANDARDS TO PHOTOVOLTAIC SUBSYSTEM/COMPONENTS

Standard		Generic Safety Requirements	Applied to Components of System	Applied to Module or Panel
Number	Title			
1	Flexible Metal Electrical Conduit		X	
3	Flexible Nonmetallic Tubing for Electric Wiring		X	
4	Armored Cable		X	
6	Rigid Metal Electrical Conduit		X	
44	Rubber-Insulated Wires and Cables		X	X
50	Electrical Cabinets and Boxes		X	X
83	Thermoplastic-Insulated Wires		X	X
94	Test for Flammability of Plastic Materials for Parts in Devices and Appliances	X		
96	Lightning Protection Components		X	
310	Quick-Connect Terminals		X	X
360	Liquid-Tight Flexible Steel Conduit, Electrical		X	
467	Electrical Grounding and Bonding Equipment		X	
486A	Wire Connectors and Soldering Lugs for Use with Copper Conductors		X	X
486B	Wire Connectors for Use with Aluminum Conductors		X	X
493	Thermoplastic-Insulated Underground Feeder and Branch-Circuit Cables		X	
514	Electrical Outlet Boxes and Fittings		X	X
580	Tests for Wind-Uplife Resistance of Roof Assemblies			X
651	Rigid Nonmetallic Electrical Conduit		X	

TABLE 4.1 (CONT'D.)

Standard Number	Standard Title	Generic Safety Requirements	Applied to Components of System	Applied to Module or Panel
719	Nonmetallic-Sheathed Cables		X	
723	Tests for Surface Burning Characteristics of Building Materials			X
746A	Polymeric Materials - Short Term Property Evaluations	X		
746B	Polymeric Materials - Long Term Property Evaluations	X		
746C	Polymeric Materials - Use in Electrical Equipment Evaluations	X		
790	Tests for Fire Resistance of Roof Covering Materials			X
797	Electrical Metallic Tubing		X	
854	Service Entrance Cables		X	
943	Ground Fault Circuit Interrupters		X	
969	Marking and Labeling Systems		X	X
997	Wind Resistance of Prepared Roof Covering Materials			X
1059	Electrical Terminal Blocks		X	X
1097	Double Insulation Systems for Use in Electrical Equipment	X		
1439	Determination of Sharpness of Edges on Equipment	X		
1446	Systems of Insulation Material - General	X		

4.2 Specific Requirements

4.2.1 Connectors

For photovoltaic installations where compliance with the National Electrical Code (NEC) is necessary, any separable connectors would be required to comply with the provisions of Section 690-33. Specifically, connectors: (1) shall be polarized, (2) shall have a configuration that is non-interchangeable with receptacles in other electricity systems on the premises, (3) shall be constructed so as to guard against inadvertent contact with live parts by persons, (4) shall be of the latching or locking type, and (5) if equipped with a grounding member, shall have that member arranged so that it makes first and breaks last with the mating connector.

To assure module, panel, and connector compliance with these NEC provisions, similar stipulations, except the one related to non-interchangeability with other electricity systems on the premises, have been included in the Proposed UL Standard for Flat-Plate Photovoltaic Modules and Panels. Additionally, per this Proposed UL Standard but not the NEC, if two or more separable connectors are provided on a module or panel they are to be configured or arranged so that the mating connector for one will not be accepted by the other, and vice-versa, if such is an improper connection.

The Proposed UL Photovoltaic Module Standard includes these provisions in Paragraphs 9.9, 9.10, and 15.1. Additionally, paragraph 22.2 describes a strain relief test to be conducted on separable connectors. For compliance with the requirements of Paragraph 15.1, the stipulation that no accessible part involve a risk of electric shock (related to the NEC provision - guarding against inadvertant contact with live parts), the connectors are to be judged while operating at voltages up to their system voltage rating, and both unengaged and engaged with their mating pieces.

The NEC and Proposed UL Photovoltaic Module Standard stipulations are that the connectors be of the locking or latching type.

A locking type connector is one in which, following insertion in its mating piece must itself be manipulated relative to its mating piece or have one of its parts manipulated to prevent disengagement of the connectors by a direct pull. Disengagement is possible after the mating pieces have been returned to their original orientation. (There is no general provision that electrical connection not be effective unless the connectors are in the locked position.)

A latching type connector is one that, following insertion in its mating piece and without any further action, cannot be disengaged from its mating piece by a simple direct pull. Disengagement is possible after a tab or the like is depressed to release the latching mechanism.

In either the locking or latching types, the locking or latching means may be in either the contact assembly or the body.

The NEC provision that a connector of a photovoltaic system have a configuration that is non-interchangeable with receptacles in other electricity systems on the premises is, strictly speaking, unenforceable in a product Standard. This is based on the consideration that the types of receptacles installed in the building accommodating the array (the premises) are beyond the control or knowledge of the module manufacturer. It might be assumed that receptacles such as the general-purpose parallel blade type 2-pole, 2-wire, rated 15 amperes, 125 volts, would be provided in any premises, so that connectors configured in this manner would not be acceptable in any photovoltaic system. However, where a low-voltage photovoltaic system is installed at a remote cabin, parallel blade receptacles might not be present in the premises, in which case, per the NEC, they would not be rejected in the photovoltaic system on this grounds. (Whether or not this remote low-voltage system would be evaluated to the provision of the NEC, at all, is in question.) (The use of general purpose, e. g. - parallel blade receptacles in photovoltaic source and output circuits is not believed to be in conflict with Section 210-7 of the NEC, which governs the acceptability of receptacles in branch circuits.) But because such plugs and receptacles are generally not locking or latching types, they are likely to be rejected for this reason, although parallel blade latching type plugs and receptacles (connectors) could be built to overcome this point. Further, because the blades of the male portion of a parallel blade plug and receptacle combination are accessible, there might be no feature that guards against inadvertent contact with live parts by persons, and in certain applications in photovoltaic installations the contacts on both portions of the connector may be energized and hazardous when the portions are separated.

As an expansion of the NEC provision, UL suggests that (1) because of their use in standard electrical installations, and (2) because of their accepted nonlocking nature, connectors with contacts configured as described in Section 81, General Purpose Nonlocking Plugs and Receptacles, Figures 81.1 through 81.38, of the Attachment Plugs and Receptacles Standard, UL 498-1981#, not be used in photovoltaic power systems. In accordance with this, UL, in evaluating a module, panel, or connector to the provisions of the proposed UL photovoltaic module standard would assume that any of the receptacles of Section 81 would be in the premises of the array installation. UL would thus reject any such connectors on the module or separately, unless the submitter presented adequate evidence indicating that a particular connector submitted was not likely to be found in a particular installation, a latching feature was provided, and live parts were guarded so that contact by persons with such parts with the connectors engaged and separated was not possible.

It is UL's interpretation that devices with any of the configurations described in Section 82, Specific Purpose Locking Plugs and Receptacles, of the Receptacle Standard are acceptable as photovoltaic system connectors, if they are "... constructed and installed so as to guard against inadvertent contact with live parts by persons." The caveat is that in some locations any particular connector configuration described in Section 82 may be unacceptable, if in that location the same configuration connector is also used in other (than photovoltaic) circuits.

Other items to be considered in any UL investigation of connectors would be assembly of parts, compatibility of metals, polymeric materials including the dielectric strength of such, ampacity and mounting of current-carrying parts, sharp edges, spacings, bonding, mechanical strength, sealing of internal parts against the weather, resistance to damage from environmental extremes, appropriateness of grounding members, performance in interrupting overload currents, temperature rise, and resistance of insulating materials to degradation from arcing on contact separation. Details on such are provided in report DOE/JPL 955392-3; SAFETY REQUIREMENTS FOR WIRING SYSTEMS AND CONNECTORS FOR PHOTOVOLTAIC SYSTEMS, Underwriters Laboratories Inc.

#Available for purchase from Underwriters Laboratories Inc., price $10.50.

Compliance with the appropriate requirements for connectors would qualify the product for UL Listing or a Component Recognition not encumbered by avoidable "Conditions of Acceptability" Other testing laboratories may offer equivalent listing or labeling services and their policies concerning the foregoing should be received directly from them.

Alternately, if desired by the product submitter, UL Component Recognition could be extended without the connector demonstrating compliance to each of the test requirements, e. g. - the Thermal Cycling Test, Paragraphs 33.1 through 33.5, with tho understanding (described in a statement in the Component Recognition Report) that such tests must be conducted on the connector as installed in the end product. In this case the Recognition is encumbered by "Conditions of Acceptability".

Notwithstanding the foregoing, UL suggests that any connector with a general listing or labeling (not a photovoltaic system listing or labeling) could be acceptable for use in the applicable environment (e. g. - dry location), if used within its rating and other limitations as described in the NEC.

4.2.2 Mounting Frames

Mounting frames are not covered by any of the requirements described for the NEC. For their Listing, however, their construction would be influenced by many of the provisions of the Proposed UL Photovoltaic Module Standard. Examples of items of UL concern are assembly provisions, compatibility of metals, polymeric materials, sharp edges, continuity for bonding purposes, corrosion resistance, mounting (for fire consideration), and structural strength. Accordingly, particular parts of the proposed photovoltaic module standard considered applicable to mounting frames are contained in paragraphs 5.1, 5.3 through 5.8, 6.1 through 6.4, 8.1, 10.3 through 10.8, 13.1 through 13.8, 14.1, 25.1, 25.2, 30.1 through 30.8, 35.1 through 35.19, 36.1 through 36.9, and 39.1 through 39.3.

Again, if these items are to be submitted to other test laboratories for consideration for listing or labeling their policies would dictate their action. They should be contacted directly in this regard.

4.2.3 Diode and Varistor Housings

Requirements for housings for bypass and blocking diodes, presumably of polymeric materials, would again not be covered by any of the provisions in the NEC. Such requirements would be covered in product standards. If intended to be Listed by UL, the product would need to comply with the provisions of the proposed UL standard for photovoltaic modules related to assembly, polymeric materials including their dielectric strength, ampacity and mounting of current-carrying parts, sharpness of edges, leads for connections, spacings between and access to electrical parts, mechanical strength, sealing of internal parts against the weather, and resistance to damage due to environmental extremes. Particular paragraphs in the proposed UL photovoltaic module standard are 5.5, 5.6, 5.8, 6.1 through 6.6, 7.1, 7.5 through 7.7, 8.1, 9.5, 9.6, 11.1, 11.3, 11.4, 14.1, 15.1, 22.1, 26.1 through 26.7, 29.1, 29.2, 31.1 through 31.8, 32.1, 33.1 through 33.5, and 34.1 through 34.6.

4.2.4 Diodes

Provisions describing UL requirements for bypass and blocking diodes are not contained in the proposed UL standard for photovoltaic modules. However, diodes would be eligible for investigation and UL Listing or Component Recognition. Any investigation would involve confirming the peak inverse voltage and forward current ratings of the diode, considering the use environment (mounting, ambient temperature, irradiance level), and how their use would be coordinated with the photovoltaic modules and panels.

4.2.5 Multiple Function Components

Where a component for a photovoltaic system provides multiple functions, such as a diode housing that is also a connector, the combined requirements from both groups are applicable.

4.2.6 Overview

The requirements contained in the paragraphs enumerated in the foregoing are typical, but may be supplemented or replaced by others, depending upon the components particular construction. Thus, while the foregoing presentation would relate to a typical component and investigation, it is not to be inferred that this presents the nature of the complete investigation for <u>any</u> connector, mounting frame, or diode housing.

5. NATIONAL ELECTRICAL CODE STATUS

5.1 Background

Between December, 1980 and August, 1981, an Ad-Hoc Subcommittee (AHSC) appointed by the National Electrical Code Correlating Committee met to formulate installation guidelines for residential, commercial, and industrial photovoltaic installations. The outcome of that committee's work, with National Electrical Code Panel commentary, was published in the National Electrical Code Technical Committee Report - Preprint of the Proposed Amendments for the 1984 National Electrical Code; as Proposed National Electrical Code Article 690. This material, which included Panel commentary on the Technical Committee Report was considered at the National Fire Protection Association Annual Meeting, May 16-20th, 1983. With some modification, the material was then included as first a part of the Advanced Printing of the Proposed 1984 National Electrical Code and then as Article 690 of the 1984 National Electrical Code. A copy of Article 690 is presented as Appendix C of this report.

While most of Article 690 appears straightforward, two items are likely to be open to considerable interpretation. A discussion of these items is presented following. In considering these interpretations, it is to be noted that the opinions herein are those of the authors of this report, and are not those of the National Fire Protection Association's National Electrical Code Panel 3, which has been assigned the responsibility of keeping Article 690 current, and responding to inquiries and suggestions concerning it.

5.2 Specific Quotations

The two points of the Proposed Article which deserves special attention are:

> 690-18. Disablement of An Array. Means shall be provided to disable an array or portions of an array.
>
> Fine Print Note: Photovoltaic modules are energized while exposed to light. Installation, replacement, or servicing of array components while a module(s) is irradiated may expose persons to electric shock.

- and -

690-52. Photovoltaic Power Source. A marking, specifying the photovoltaic power source rated (1) operating current, (2) operating voltage, (3) open-circuit voltage and (4) short-circuit current, shall be provided at an accessible location at the disconnecting means for the photovoltaic power source.

Fine Print Note: Reflecting systems used for irradiance enhancement may result in increased levels of output current and power.

5.3 Disablement

5.3.1 Definitions

Since the NEC provides no special definition of disablement, standard dictionary definitions are applicable. Among various dictionary definitions, the most appropriate would appear to be "to incapacitate" or "to deprive of capacity." Section 690-18, along with the following fine print note, would seem to indicate that the intent is to deprive the array of the capacity to expose persons to electric shock during installation, replacement, or servicing. Further, since the NEC is an installation code, the concern is for installation, replacement, and servicing of the array or parts of the array at the installation site, as opposed to at a shop or repair facility where individual parts from an array might be handled.

5.3.2 Background

Certain questions might be raised concerning the intent of Section 690-18 with respect to mechanism for providing disablement (i.e., manual or automatic) and the speed at which disabling is to occur. Because the requirement for disablement is placed under the general heading Disconnecting Means, the AHSC apparently sought to provide for means of de-energizing the array, or mitigating hazardous voltage and current levels, in a manner that is distinct from the use of ordinary disconnect devices (e. g., switches or circuit breakers) for the reasons and purposes stated in the fine print note. It is believed that the intent of the AHSC was to provide manual means to disable the array in order to facilitate maintenance and module replacement by professional service personnel, rather than to provide rapid, automatic disablement to remedy a hazardous situation.

Thus, in conclusion, the means for disablement can be of a type that is manually and slowly implemented and to address circumstances such as handling of the modules and servicing the array.

5.3.3 Methods

By couching the requirement for disablement in very general terms, the AHSC allowed the electrical inspector considerable latitude in judging the acceptability of any specific method. It is conceivable, therefore, that either mechanical or electrical means may be found acceptable.

Available mechanical means of disablement involve shielding the array from irradiation using an opaque cover of some type. Although a permanently attached mechanical shutter would accomplish the intended purpose, it would probably be too expensive and perhaps unworkable under some climatic conditions, and it is not further considered here. Another mechanical means that could be used for photovoltaic applications would be an opaque blanket.

There is reason to question whether or not such means would satisfy the intent of the NEC, which generally deals with features that are permanent parts of the electrical installation. Should the inspector conclude that a portable blanket does satisfy the Code requirement, the electrical inspector would obviously have to consider a number of other factors in determining the adequacy of an opaque blanket, over and above its ability to "turn off" an array or sections of an array. Among factors to be considered are:

1. How would the blanket be stored and made readily available?
2. How would the blanket be secured in place?
3. Would a blanket need to be identified with a specific array?
4. What provisions are necessary for installing the blanket?

Numerous electrical methods are available which the electrical inspector might find to be acceptable for disabling an array. Portable equipment, such as clip leads, which could be used to short-circuit modules, groups of modules, or an entire array might be considered adequate, especially if special single-purpose terminals, marked for use with short circuiting leads, were provided. A refinement of this approach would be plug-in connectors on permanently attached leads, provided that the plug removal operations could be accomplished without rendering hazardous parts accessible, and provided that the connectors would be able to withstand the arcs generated.

Among electric means for disablement that are permanent parts of the array, the following are noted: short-circuit switches in conjunction with bypass diodes, disconnect switches in the solid ground path, and segmenting switches to divide the array into nonhazardous parts.

It is noted that certain manipulations made in the process of array servicing could render any disablement scheme ineffective. This would include removal for replacement of bypass diodes and the shorting switches themselves.

Although array short-circuiting is described as a disabling means, such an action is not without its problems. For example, under array short-circuit, cells are likely to be subjected to reverse voltage conditions, and full array voltage may be present across a circuit gap. The other known method of electrically disabling an array, by segmenting it into nonhazardous segments, probably requires too much hardware to be of practical value.

Other approaches to disabling should also allow the necessary actions without exposing the operator to a shock or fire hazard situation. Thus, fully enclosed switches with guarded terminals are possible. See also Section 2.4.10 under "SAFETY SYSTEMS" in this report.

5.3.4 Conclusion

In view of the general nature of the wording of Section 690-18, it appears that any means by which an array can be mechanically or electrically modified to make it safe for handling would be in compliance, subject to acceptance by the electrical inspector. Although both portable and permanently corrected means would seem to be acceptable, the NEC generally deals with features that are permanent parts of the electrical installation. For obvious reasons, provision of a definite means, integral with the array, to deprive the array of the capacity to introduce a risk of shock would appear to be the more reliable method.

5.4 Ratings

5.4.1 Background

Section 690-52 of the NEC might not be clear to some readers as to how system current and voltage ratings are to be determined. Additionally, the fine print note indicates the effect of radiation enhancement, but no position is taken in that respect.

The Proposed UL Standard for Photovoltaic Modules and Panels states that modules are to be provided with instructions stating that deliberately increasing the level of the irradiance by reflectors or the like is to be avoided. Nevertheless, enchanced radiation, defined broadly as irradiation in excess of 100 mW/cm^2, the standard level for output measurements, is possible due to natural reflections, such as certain cloud covers, snow, white sand, white pebbles. In addition, higher direct levels are noted in the Southwest.

5.4.2 Conclusion

Because of the complications that would arise in attempting to influence system wire size, fusing, etc. based on array location, weather factors, terrain, etc., and because natural enhancement appears limited, the output of a module is always to be taken as the marked rating (referred to measurements at 100 mW/cm^2, 0 degrees C or NOCT, see Proposed UL Standard for Photovoltaic Modules and Panels for detail on temperature), as long as no "deliberate" enhancement is provided. Further, no deliberate enhancement is to be provided; paragraph 42.2 of the Proposed UL Standard for Photovoltaic Modules and Panels.

Thus, the photovoltaic system marking should be interpreted as; (1) and (4) currents, from the sum of the currents of the parallel-connected modules, and (2) and (3) voltages, from the sum of the voltages of the series-connected modules. The numbers (1), (2), (3), and (4) relate to the item entries in <u>NEC</u> Section 690-52.

6. SUMMATION AND RECOMMENDATIONS

6.1 Summation

1. The Second Draft of the Proposed UL Standard for Safety - Flat-Plate Photovoltaic Modules and Panels, Subject 1703, March, 1984, has been prepared. Proposals for the National Electrical Code (NEC) provisions for Photovoltaic Systems, Article 690, have been accepted. Photovoltaic system components and the systems themselves built and assembled to the provisions described in these documents are expected to provide appropriate levels of safety consistent with other electrical systems. Some aspects of the NEC Article 690 contain ideas not found elsewhere in the NEC, and application of these ideas requires that inspectors enforcing the provisions of the NEC (as they appear in local electrical codes) be versed in the meaning of new terminology.

2. The Proposed Standard was prepared in conjunction with photovoltaic module manufacturers and others interested in this topic, who serve on the UL Photovoltaic Module and Panel Industry Advisory Group.

3. A photovoltaic module was evaluated to the provisions of the Proposed Standard, to determine and develop the reasonableness, appropriateness, and workability of the document.

4. Applicable requirements in the Proposed Photovoltaic Module Standard may be used as a guide to evaluate other photovoltaic system components, such as mounting frames, diodes, and connectors.

5. Components may be added to the photovoltaic system to enhance the safety of such system. These components (subsystems) can be combined in specific combinations to form systems to resolve all major potential hazards associated with operation and existence of an array.

6. The circuit of a photovoltaic array may be either grounded or deliberately isolated, and so controlled, so as to achieve certain safety conditions.

6.2 Recommendations

The Proposed Standard should be further evaluated by additional module evaluations. The envisioned safety systems should be installed in photovoltaic installations so as to judge their adequacy and effectiveness. Safety-related performances of other photovoltaic systems, both those installed in accordance with provisions of Article 690 of the 1984 NEC, and other systems whose installation methods are not in accord with the NEC, should be evaluated.

The additional evaluations of photovoltaic system products (including the modules themselves) will allow a further refinement of the requirements for such, and a transformation of the Proposed UL Standard for Photovoltaic Modules and Panels into an adopted Standard.

APPENDIX A

PROPOSED FIRST EDITION OF THE STANDARD FOR FLAT-PLATE PHOTOVOLTAIC MODULES AND PANELS, UL 1703

MARCH, 1984

PROPOSED FIRST EDITION OF THE STANDARD FOR
FLAT-PLATE PHOTOVOLTAIC MODULES
AND PANELS, UL 1703

MARCH, 1984

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FOREWORD

A. This Standard contains basic requirements for products covered by Underwriters Laboratories Inc. (UL) under its Follow-Up Service for this category within the limitations given below and in the Scope section of this Standard. These requirements are based upon sound engineering principles, research, records of tests and field experience, and an appreciation of the problems of manufacture, installation, and use derived from consultation with and information obtained from manufacturers, users, inspection authorities, and others having specialized experience. They are subject to revision as further experience and investigation may show is necessary or desirable.

B. The observance of the requirements of this Standard by a manufacturer is one of the conditions of the continued coverage of the manufacturer's product.

C. A product which complies with the text of this Standard will not necessarily be judged to comply with the Standard if, when examined and tested, it is found to have other features which impair the level of safety contemplated by these requirements.

D. A product employing materials or having forms of construction differing from those detailed in the requirements of this Standard may be examined and tested according to the intent of the requirements and, if found to be substantially equivalent, may be judged to comply with the Standard.

E. UL, in performing its functions in accordance with its objectives, does not assume or undertake to discharge any responsibility of the manufacturer or any other party. The opinions and findings of UL represent its professional judgment given with due consideration to the necessary limitations of practical operation and state of the art at the time the Standard is processed. UL shall not be responsible to anyone for the use of or reliance upon this Standard by anyone. UL shall not incur any obligation or liability for damages, including consequential damages, arising out of or in connection with the use, interpretation of, or reliance upon this Standard.

F. Many tests required by the Standards of UL are inherently hazardous and adequate safeguards for personnel and property shall be employed in conducting such tests.

GENERAL

1. Scope

1.1 These requirements cover flat-plate photovoltaic modules and panels intended for installation on or integral with buildings, or to be free-standing (i.e. not attached to buildings), in accordance with the National Electrical Code and Model Building Codes.

1.2 These requirements cover modules and panels intended for use in systems with a maximum system voltage of 1000 volts or less.

1.3 These requirements also cover components intended to provide electrical connection to and mounting facilities for flat-plate photovoltaic modules and panels.

1.4 These requirements do not cover equipment intended to accept the electrical output from the array, such as power conditioning units (inverters) and batteries, nor do they cover any tracking mechanism.

1.5 These requirements do not cover cell assemblies intended to operate under concentrated sunlight nor do they cover optical concentrators.

1.6 These requirements do not cover combination photovoltaic-thermal modules or panels.

2. Glossary

2.1 For the purpose of this standard, the following definitions apply.

2.2 Air Mass (AM) -- A dimensionless quantity, the ratio of the actual path length of radiation through the atmosphere, to the vertical path length of radiation through the atmosphere to sea level. For all but very high zenith angles (θ_z) (the angle subtended by the zenith and the line of sight to the sun),

$$AM = \sec \theta_z, \text{ at sea level.}$$

2.3 Array -- A mechanically-integrated assembly of modules and panels, together with support structure and foundation, tracking, thermal control, and other components, if used, to form a dc power-producing unit.

2.4 Blocking Diode -- A diode connected in series with module(s) or panel(s) to prevent reverse current in such module(s) or panel(s).

2.5 Bypass Diode -- A diode connected across one or more cells, modules, or panels in the forward current direction, to allow current to bypass such cells, modules, or panels.

2.6 Cell -- The basic photovoltaic device that generates electricity when exposed to sunlight.

2.7 Electric Shock -- A risk of electric shock is considered to be present at a part if the potential between the part and earth ground or any other accessible part is more than 30 V dc and the leakage current exceeds the allowable values specified in Table 21.1.

2.8 Encapsulant -- Insulating material enclosing the cells and cell interconnects.

2.9 Interconnect -- A conductor within a module that provides a mechanism for conducting electricity between cells.

2.10 Maximum System Voltage -- The sum of the maximum open circuit voltages of the maximum number of modules or panels to be connected in series in a system. See paragraph 20.2.

2.11 Metallization -- Electrically conductive metal coating on the surface of a cell.

2.12 Module (Flat-plate) -- The smallest environmentally protected, essentially planar assembly of solar cells and ancillary parts such as interconnects and terminals, intended to generate dc power under unconcentrated sunlight.

2.13 Nominal Operating Cell Temperature (NOCT) -- The equilibrium cell junction temperature corresponding to nominal module service operating conditions in a reference environment of 80 mW/cm² irradiance, 20°C ambient air temperature, 1 m/s wind, and electrically open circuit.

2.14 Panel (Flat-plate) -- A collection of modules fastened together, assembled and wired, intended to provide a field-installable unit.

2.15 Rated Operating Voltage -- The voltage, at NOCT, ±10%, at which maximum power is available from the module or panel.

2.16 Substrate -- The material forming the outer surface for the back of the cells.

2.17 Superstrate -- The transparent material forming the top (light facing) outer surface of the module.

3. Units Of Measurement

3.1 If a value for measurement is followed by a value in other units in parentheses, the second value may be only approximate. The first stated value is the requirement.

CONSTRUCTION

4. Components

4.1 A component of a product covered by this standard shall comply with the requirements for that component and shall be used in accordance with its recognized rating and other limitations of use. A component need not comply with a specific requirement that:

A. Involves a feature or characteristic not needed in the application of the component in the product covered by this standard, or

B. Is superseded by a requirement in this standard.

5. General

5.1 A module shall be completely assembled when shipped from the factory. A panel may be completely assembled when shipped from the factory, or may be provided in subassemblies, providing assembly of the panel does not involve any act that is likely to affect compliance with the requirements of this standard.

Exception: An assembly part need not be affixed to the module at the factory.

5.2 A module or panel assembly bolt, screw, or other part shall not be intended for securing the complete device to the supporting surface or frame.

5.3 Incorporation of a module or panel into the final assembly shall not require any alteration of the module or panel unless specific details describing necessary modification(s) for alternate installation(s) are provided in the installation instructions. If a module or panel must bear a definite relationship to another for the intended installation and operation of the array (e.g. - to allow connectors to mate), it shall be constructed to permit it to be incorporated into the array in correct relationship without the need for alteration.

5.4 The construction of a product shall be such that during installation it will not be necessary to alter or remove any cover, baffle, insulation, or shield that is required to: (1) prevent excessive temperatures, or (2) guard against unintentional contact with parts that may involve a risk of electric shock.

Exception: A cover of a wiring compartment providing access to a connection means that may involve a risk of electric shock may be removable to allow for the making of electrical connections.

5.5 Parts shall be prevented from loosening or turning if such loosening or turning can create a risk of electric shock, fire, or injury to persons.

5.6 Friction between surfaces is not acceptable as the sole means to inhibit the turning or loosening of a part, but a lock washer properly applied is acceptable for this purpose.

5.7 An adjustable or movable structural part shall be provided with a locking device to reduce the likelihood of unintentional shifting, if any such shifting may result in a risk of electric shock, fire, or injury to persons.

5.8 Metals used in locations that may be wet or moist shall not be employed in combinations that could result in deterioration of either metal such that the product would not comply with the requirements in this standard.

6. Polymeric Materials

6.1 A polymeric material system serving as the enclosure of a part involving a risk of electric shock or fire shall comply with the requirements concerning: 1) flammability, 2) ultraviolet radiation resistance, 3) water immersion and exposure, and 4) resistance to hot wire ignition in the Standard for Polymeric Materials - Use in Electrical Equipment Evaluations, UL 746C as applicable to such.

Exception: The flammability provision does not apply to the superstrate, encapsulation, and substrate materials.

6.2 A polymeric material system serving as the support or insulation of a part involving a risk of electric shock or fire shall:

A. Have a minimum High-Current Arc Ignition in accordance with the following:

Flammability Classification of Material	High-Current Arc Ignition
94HB	60
94V-2	30
94V-1	30
94V-0	15

B. Have a Comparative Track Index of 250 volts minimum, if the system voltage rating is 600 volts or less, as determined in accordance with the Standard for Polymeric Materials - Short Term Property Evaluations, UL 746A.

C. Have an Inclined Plane Tracking (ASTM D2303) rating of one hour using the time to track method at 2.5 kV if the system voltage rating is in the range 601-1000 volts, and

D. Comply with the requirements for exposure to ultraviolet light as determined in accordance with the Standard for Polymeric Materials - Use in Electrical Equipment Evaluations, UL 746C if exposed to light during normal operation of the product. Polymeric materials that are exposed to sunlight but are protected by glass, or other transparent medium, may be tested with an equivalent layer of that medium attenuating the ultraviolet light exposure during the test.

E. Have a flammability classification of 94HB, 94V-2, 94V-1, or 94V-0.

6.3 All polymeric encapsulant, substrate, and superstrate materials shall have a thermal index (electrical and mechanical) as determined in accordance with the Standard for Polymeric Materials - Long Term Property Evaluations, UL 746B, of at least; 90°C (194°F). In addition, the thermal index shall be at least 20°C (36°F) above the measured operating temperature of the material. All other polymeric materials shall have a thermal index (electrical and mechanical) at least 20°C above the measured operating temperature. The measured operating temperature is that which is measured during the open-circuit mode Temperature Test, or the operating temperature of the material as measured during the short-circuit mode Temperature Test, whichever is greatest.

6.4 Polymeric materials which serve as the outer enclosure for the module or panel shall have a maximum flame spread index of 100 as determined under the Standard Method of Test for Surface Flammability of Materials Using a Radiant Heat Energy Source, ASTM E162-1981A.

Exception: Small covers or boxes provided for electrical connection need not comply.

6.5 A barrier or liner of electrical grade fiber providing the sole insulation between a live part and an accessible metal part or between uninsulated live parts not of the same potential shall not be less than 0.028 inch (0.71 mm) thick. The barrier or liner shall be held in place and shall not be adversely affected to the extent that its necessary properties may fall below the minimum values required for the application.

6.6 A barrier or liner of polymeric insulating material providing the sole insulation between a live part and an accessible metal part or between uninsulated live parts not of the same potential shall be of adequate thickness and of a material appropriate for the application. The barrier or liner shall be held in place and shall not be adversely affected to the extent that its necessary properties may fall below the minimum values required for the application.

7. Current-Carrying Parts and Internal Wiring

7.1 A current-carrying part and wiring shall have the mechanical strength and ampacity necessary for the service.

7.2 A current-carrying part shall be of nonferrous metal or other material appropriate for the application.

7.3 Wiring used in a module or panel shall be insulated and acceptable for the purpose, when considered with respect to temperature, voltage, and the conditions of service to which the wiring is likely to be subjected within the equipment.

7.4 A splice shall be provided with insulation equivalent to that required for the wires involved.

7.5 A joint or connection shall be mechanically secure and shall provide electrical contact without strain on connections and terminals. Soldered connections between interconnects and metallizations are considered mechanically secure when held in encapsulation systems.

7.6 An uninsulated live part, including a terminal, shall be secured to its supporting surface by a method other than friction between surfaces so that it will be prevented from turning or shifting in position if such motion may result in reduction of spacings to less than required in Tables 11.1 and 11.2.

7.7 Strain relief shall be provided so that stress on a lead intended for field connection, or otherwise likely to be handled in the field, including a flexible cord, is not transmitted to the connection inside the module or panel.

7.8 The wiring of a module or panel shall be located so that after installation of the product in the intended manner it will not be exposed to the degrading effects of direct sunlight.

Exception: Wiring rated sunlight resistant.

8. Wireways

8.1 An enclosure for wire shall be smooth and free from sharp edges, burrs, or the like that may damage insulation or conductors.

9. Connection Means

9.1 In paragraphs 9.2-9.10, connection means are considered to be those to which field-installed wiring is connected when the product is installed. Connection means may be within a wiring compartment, may be connectors outside of a wiring compartment, or may be another means acceptable for the application.

9.2 A module or panel shall be capable of accommodating at least one of the acceptable wiring systems described in the National Electrical Code (NEC).

9.3 A module or panel shall be provided with wiring terminals, connectors, or leads to accommodate current-carrying conductors of the load circuit.

9.4 The connection means for a module or panel shall be so located that after installation of the product in the intended manner they will not be exposed to the degrading effects of direct sunlight.

Exception: Connection means rated for use in direct sunlight.

9.5 A lead that is intended to be spliced in the field to a circuit conductor shall not be smaller than No. 18 AWG (0.82 mm^2) and the insulation shall not be less than 1/32 inch (0.8 mm) thick.

9.6 The free length of a lead for field connection shall be at least 6 inches (152 mm).

9.7 A wire binding screw or stud and nut-type terminal may be used to terminate conductors not larger than No. 10 AWG and shall comply with the following:

A. A threaded screw or stud shall be of nonferrous metal, stainless steel or plated steel appropriate for the application, shall not have more than 32 threads per inch, and shall not be smaller than No. 8 for accommodating No. 10 or 12 AWG (5.3 and 3.3 mm^2 respectively) wire and not smaller than No. 6 for accommodating No. 14 AWG (2.1 mm^2) and smaller wire. A wire-binding screw or stud-and- nut terminal shall be provided with upturned lugs, a cupped washer, a barrier, or other equivalent means to retain the wire in position even though the screw or nut becomes slightly loose. The head of a wire-binding screw for accommodating No. 12 AWG or smaller wire shall have a minimum diameter of 0.275 inch (7.0 mm) and that of a screw for accommodating No. 10 AWG wire shall have a minimum diameter of 0.327 inch (8.3 mm).

B. A tapped terminal plate shall be of nonferrous metal, shall not have less than two full screw threads, and shall be of metal not less than 0.050 inch (1.27 mm) thick for accommodating No. 10 or No. 12 AWG (5.3 and 3.3 mm^2 respectively) wire and not less than 0.030 inch (0.76 mm) thick for accommodating a No. 14 AWG (2.1 mm^2) or smaller wire. Screw threads provided by extruding a hole are acceptable if the thickness of the unextruded metal is not less than the pitch of the screw thread.

9.8 A wire connector intended to accommodate copper conductors only shall comply with the requirements for wire connectors and soldering lugs for use with copper conductors, UL 486A. A wire connector intended to accommodate aluminum and copper conductors shall comply with the requirements for wire connectors for use with aluminum conductors, UL 486B.

9.9 A separable connector shall be of a locking or latching type. A separable multipole connector shall be polarized. Where two or more separable connectors are provided, they shall be configured or arranged so that the mating connector for one will not be accepted by the other, and vice-versa, if such is an improper connection.

9.10 For a connector incorporating a grounding member, the grounding member shall be the first to make and the last to break contact with the mating connector.

10. Bonding For Grounding

10.1 A module or panel shall have a provision for grounding all accessible conductive parts. The grounding means shall comply with the provisions of Section 9. The grounding means shall be bonded to each such conductive part of the module or panel that is accessible during normal use.

Exception No. 1: Where the grounding means is a module or panel mounting member intended to contact an array structural member, the module or panel grounding means need not comply with the provisions of Section 9.

Exception No. 2: For modules or panels having a system voltage rating of 30 volts or less, a grounding means is not required.

10.2 Any act of routine maintenance of a module or panel shall not involve breaking or disturbing the bonding path. A bolt, screw, or other part used for bonding purposes within a module or panel shall not be intended for securing the complete device to the supporting surface or frame.

10.3 Bonding shall be by a positive means, such as clamping, riveting, bolted or screwed connections, or welding, soldering (see paragraph 10.5) or brazing. The bonding connection shall penetrate nonconductive coatings, such as paint or vitreous enamel.

10.4 A bolted or screwed connection that incorporates a star washer under the screwhead or a serrated screwhead may be acceptable for penetrating nonconductive coatings. If the bonding means depends upon screw threads, two or more screws or two full threads of a single screw shall engage the metal.

10.5 All joints in the bonding path shall be mechanically secure independent of any soldering.

10.6 A separate bonding conductor or strap shall be of copper, copper alloy, or other material acceptable for use as an electrical conductor. A separate bonding conductor or strap shall: (1) be protected from mechanical damage, and (2) not be secured by a removable fastener used for any purpose other than bonding unless the bonding conductor is unlikely to be omitted after removal and replacement of the fastener.

10.7 A ferrous metal part in the grounding path shall be protected against corrosion by metallic or nonmetallic coatings, such as painting, galvanizing or plating. Stainless steel is acceptable without additional coating.

10.8 A metal-to-metal multiple-bearing pin-type hinge is considered to be an acceptable means for bonding.

11. Spacings

11.1 The spacings between uninsulated live parts not of the same potential and between a live part and an accessible metal part, shall not be less than the values specified in Tables 11.1 and 11.2.

Exception: These spacing requirements do not apply to the inherent spacings of a component, such spacings shall comply with the requirements for the component in question.

11.2 The spacings at a field-wiring terminal are to be measured with and without wire connected to the terminal. The wire is to be connected as it would be in actual use. If the terminal will properly accommodate it, and if the product is not marked to restrict its use, the wire is to be one size larger than that required; otherwise, the wire is to be the size required.

11.3 Surfaces separated by a gap of 0.013 inch (0.33 mm) or less are considered to be in contact with each other for the purpose of judging over-surface spacings.

11.4 In Tables 11.1 and 11.2, the potential involved is the maximum voltage that may exist between parts during any anticipated use of the module or panel.

TABLE 11.1
MINIMUM ACCEPTABLE SPACINGS AT WIRING TERMINALS

Potential Involved Volts	Through Air and Over Surface Inch	(mm)
0-50	1/4	(6.4)
51-300	3/8	(9.5)
301-600	1/2	(12.7)
601-1000	5/8	(15.9)

TABLE 11.2
MINIMUM ACCEPTABLE SPACINGS ELSEWHERE THAN AT WIRING TERMINALS

Potential Involved	Through Air		Over Surface	
Volts	Inch	(mm)	Inch	(mm)
0-50	1/16	(1.6)	1/16	(1.6)
51-300	1/8	(3.2)	1/4	(6.4)
301-600	1/4	(6.4)	3/8	(9.5)
601-1000	3/8	(9.5)	1/2	(12.7)

12. Wiring Compartments

General

12.1 A wiring compartment, if provided, shall comply with the requirements specified in paragraphs 12.1 through 12.19.

12.2 At least 2 cubic inches (32.8 cm^3) for each intended No. 14 AWG (2.1 mm^2) or smaller conductor and at least 2.25 cubic inches (36.9 cm^3) for each intended No. 12 AWG (3.3 mm^2) conductor including integral conductors of the module or panel shall be provided in a wiring compartment. In the space comprising the minimum required volume, no enclosure dimension shall be less than 3/4 inch (19.1 mm).

12.3 A wiring compartment shall have provision for accommodating a wiring system employing a raceway or cable.

12.4 A wiring compartment shall have no more than one opening when the module or panel is shipped from the factory. Tapped holes with screwed-in plugs are not considered openings.

12.5 Gaskets and seals shall not deteriorate beyond limits during accelerated aging, and shall not be used where they may be subject to flexing during normal operation. See Section 32.

Metallic Wiring Compartments

12.6 A wiring compartment of sheet steel shall have a wall thickness of not less than 0.053 inch (1.35 mm) if measured uncoated, or 0.056 inch (1.42 mm) if measured with a zinc coating.

12.7 A wiring compartment of sheet aluminum shall have a wall thickness of not less than 0.0625 inch (1.59 mm).

12.8 A wiring compartment of cast iron, aluminum, brass, or bronze shall have a wall thickness of not less than 3/32 inch (2.4 mm).

12.9 A hole intended for the connection of rigid metal conduit in the enclosure of a metal wiring compartment shall be threaded, unless it is located entirely below the lowest live part in the compartment other than insulated wires.

12.10 A threaded hole in a metal wiring compartment intended for the connection of rigid metal conduit shall be reinforced to provide metal not less than 1/4 inch (6.4 mm) thick, and shall be tapered unless a conduit end stop is provided.

12.11 If threads for the connection of conduit are tapped all the way through a hole in a compartment wall, or if an equivalent construction is employed, there shall not be less than 3-1/2 nor more than 5 threads in the metal and the construction shall be such that a conduit bushing can be attached as intended.

12.12 If threads for the connection of conduit are not tapped all the way through a hole in a compartment wall, there shall not be less than five full threads in the metal and there shall be a smooth, rounded inlet hole for the conductors which shall afford protection to the conductors equivalent to that provided by a standard conduit bushing. The throat diameter of an inlet hole shall be within the limits specified in the Standard for Outlet Boxes and Fittings, UL 514.

12.13 For a non-threaded opening (where permitted) in a metal wiring compartment intended to accommodate rigid metallic conduit, a flat surface of sufficient area as described in the Standard for Outlet Boxes and Fittings, UL 514 shall be provided around the opening to accept the bearing surfaces of the bushing and lockwasher.

Nonmetallic Wiring Compartments

12.14 A wiring compartment of a nonmetallic (polymeric) material shall have a wall thickness of not less than 0.125 inch (3.18 mm).

12.15 A nonmetallic wiring compartment intended to accommodate nonmetallic conduit shall either (1) have one or more unthreaded conduit-connection sockets that comply with the requirements in paragraphs 12.17-12.19, integral with the compartment, (2) have one threaded or unthreaded opening for a conduit-connection socket, or (3) be blank for use with a conduit connection socket.

12.16 If a conduit connection socket may be used, the accommodating wall of a nonmetallic compartment shall have a sufficient flat surface to accommodate the bearing surfaces of the locknut and male adapter.

12.17 In a nonmetallic compartment, a socket for the connection of nonmetallic conduit shall provide a positive end stop for the conduit; and the socket diameters, the throat diameter at the entrance to the box, and the wall thickness of the socket shall be within the limits specified in Table 12.1.

12.18 The socket depth shall be within the limits specified in Table 12.1.

12.19 The wall thickness of the socket shall not be less than specified in Table 12.1.

TABLE 12.1
DIMENSIONS OF CONDUIT CONNECTION SOCKETS, NONMETALLIC WIRING COMPARTMENTS

Trade Size of Conduit, Inches	Socket Wall Minimum Thickness in. (mm)	Socket Diameter, Inches (mm) At Entrance Maximum	Socket Diameter, Inches (mm) At Entrance Minimum	Socket Diameter, Inches (mm) At Bottom Maximum	Socket Diameter, Inches (mm) At Bottom Minimum	Socket Depth, Inches (mm) Maximum	Socket Depth, Inches (mm) Minimum	Minimum Throat Diameter, Inches (mm) For Use With Heavy-Wall Conduit	Minimum Throat Diameter, Inches (mm) For Use With Thin-Wall Conduit
1/2	0.095	0.860	0.844	0.844	0.828	1.500	0.652	0.630	0.728
	(2.41)	(21.84)	(21.44)	(21.44)	(21.03)	(38.10)	(16.56)	(16.00)	(18.49)
3/4	0.095	1.074	1.054	1.056	1.036	1.500	0.719	0.834	0.840
	(2.41)	(27.28)	(26.77)	(26.82)	(26.31)	(38.10)	(18.26)	(21.18)	(21.34)
1	0.100	1.340	1.320	1.320	1.300	1.875	0.875	1.059	1.205
	(2.54)	(34.04)	(33.53)	(33.53)	(33.02)	(47.63)	(22.23)	(26.90)	(30.61)
1-1/4	0.120	1.689	1.665	1.667	1.643	2.000	0.938	1.392	1.532
	(3.05)	(42.90)	(42.29)	(42.34)	(41.73)	(50.80)	(23.83)	(35.36)	(38.91)
1-1/2	0.120	1.930	1.906	1.906	1.882	2.000	1.062	1.622	1.752
	(3.05)	(49.02)	(48.41)	(48.41)	(47.80)	(50.80)	(26.97)	(41.20)	(44.50)
2	0.130	2.405	2.381	2.381	2.357	2.000	1.125	2.097	2.187
	(3.30)	(61.09)	(60.48)	(60.48)	(59.87)	(50.80)	(28.58)	(52.81)	(55.55)
2-1/2	0.165	2.905	2.875	2.883	2.853	3.000	1.469	2.484	2.670
	(4.19)	(73.79)	(73.03)	(73.23)	(72.47)	(76.20)	(37.31)	(63.09)	(67.82)
3	0.216	3.530	3.500	3.507	3.477	3.125	1.594	3.083	3.365
	(5.49)	(89.66)	(88.90)	(89.08)	(88.32)	(79.38)	(40.49)	(78.31)	(85.47)
3-1/2	0.226	4.065	3.965	4.007	3.977	3.250	1.687	3.598	3.760
	(5.74)	(103.25)	(100.71)	(101.78)	(101.02)	(82.55)	(42.85)	(91.39)	(95.50)
4	0.237	4.565	4.465	4.506	4.476	3.375	1.750	4.076	4.250
	(6.02)	(115.95)	(113.41)	(114.45)	(113.69)	(85.73)	(44.45)	(103.53)	(107.95)
5	0.258	5.643	5.543	5.583	5.523	3.625	1.937	5.097	-
	(6.55)	(143.33)	(140.79)	(141.81)	(140.28)	(92.80)	(49.20)	(129.46)	-
6	0.280	6.708	6.608	6.644	6.584	3.750	2.125	6.115	-
	(7.11)	(170.38)	(167.84)	(168.76)	(167.23)	(95.25)	(53.98)	(155.32)	-

13. Corrosion Resistance

13.1 Sheet steel having a thickness of 0.120 inch (3.05 mm) or more that may be exposed to the weather shall be made corrosion-resistant by one of the following coatings:

A. Hot-dipped mill-galvanized sheet steel conforming with the coating designation G60 in Table I of ASTM A525-76, with not less than 40% of the zinc on any side, based on the minimum single spot-test requirement in this ASTM specification. The weight of zinc coating may be determined by any method; however, in case of question, the weight of coating shall be established in accordance with the test method of ASTM A90-69.

B. A zinc coating, other than that provided on hot-dipped mill-galvanized sheet steel, uniformly applied to an average thickness of not less than 0.00041 inch (0.010 mm) on each surface with a minimum thickness of 0.00034 inch (0.009 mm). The thickness of the coating shall be established by the Metallic Coating Thickness Test in Section 36.

C. An organic or inorganic protective coating system on both surfaces, applied after forming. The results of an evaluation of the coating system shall demonstrate that it provides protection at least equivalent to that afforded by the zinc coating described in item A. See Sections 6 and 35.

D. Any one of the means specified in paragraph 13.2.

13.2 Sheet steel having a thickness of less than 0.120 inch (3.05 mm) which may be exposed to the weather shall be made corrosion resistant by one of the following coatings:

A. Hot-dipped mill-galvanized sheet steel conforming with the coating designation G90 in Table I of ASTM A525-76, with not less than 40% of the zinc on any side, based on the minimum single spot-test requirement in this ASTM Specification. The weight of zinc coating may be determined by any method; however, in case of question, the weight of coating shall be established in accordance with the test method of ASTM A90-69.

B. A zinc coating, other than that provided on hot-dipped mill-galvanized sheet steel, uniformly applied to an average thickness of not less than 0.00061 inch (0.015 mm) on each surface with a minimum thickness of 0.00054 inch (0.014 mm). The thickness of the coating shall be established by the Metallic Coating Thickness Test in Section 36. An annealed coating shall also comply with paragraphs 13.4 and 13.5.

C. A cadmium coating not less than 0.0010 inch (0.025 mm) thick on both surfaces. The thickness of the coating shall be established by the Metallic Coating Thickness Test in Section 36.

D. A zinc coating conforming with Item A or B of Paragraph 13.1 with one coat of outdoor paint. The coating system shall comply with Paragraph 13.2, Part F.

E. A cadmium coating not less than 0.00075 inch (0.019 mm) thick on both surfaces with one coat of outdoor paint on both surfaces, or not less than 0.00051 inch (0.013 mm) thick on both surfaces with two coats of outdoor paint on both surfaces. The thickness of the cadmium coating shall be established by the Metallic Coating Thickness Test in Section 36 and the coating system shall comply with Item F.

F. With reference to Parts D and E, the results of an evaluation of the coating system shall demonstrate that it provides protection at least equivalent to that afforded by the zinc coating as described in Part A (G90). See Sections 6 and 35.

13.3 With reference to paragraphs 13.1 and 13.2, other finishes, including paints, special metallic finishes and combinations of the two may be accepted when comparative tests with galvanized sheet steel (without annealing, wiping, or other surface treatment) conforming with Item A of paragraph 13.1 or 13.2 as applicable, indicate they provide equivalent protection. See Section 35.

13.4 An annealed coating on sheet steel that is bent or similarly formed or extruded or rolled at edge of holes after annealing shall additionally be painted in the bent or formed area if the bending or forming process damages the zinc coating. If flaking or cracking of a zinc coating at the outside radius of a bent or formed section is visible at 25 power magnification, the zinc coating is considered damaged.

13.5 Simple sheared or cut edges and punched holes are not required to be additionally protected.

13.6 Iron or steel serving as a necessary part of the product but not exposed to the weather shall be plated, painted, or enameled for protection against corrosion.

13.7 Aluminum, stainless steel and polymeric materials may be used without special corrosion resistance coatings or platings.

13.8 Materials not specifically mentioned in Section 13 shall be evaluated on an individual basis. The tests described in Sections 6 and 35 may be used in this evaluation.

14. Edges

14.1 Edges, projections, and corners of photovoltaic modules and panels shall be such as to reduce the risk of cuts to personnel. Compliance is to be determined as described in the Standard, Determination of Sharpness of Edges on Equipment, UL 1439.

15. Accessibility

15.1 No accessible part of a module or panel shall involve a risk of electric shock.

Exception: A part that is not energized when it is accessible.

15.2 In determining whether a part is energized, the module or panel is to be both (a) not connected, and (b) connected in any implied or described acceptable manner; in both cases with the module or panel in the state described in paragraph 15.4 and in the environment described in paragraph 20.4.

15.3 For voltages and currents between parts of the individual unconnected product, voltage is to be determined in accordance with paragraph 20.4. For voltages and currents between parts of the assembly of products, voltage is to be the maximum system voltage, current is to be the available current.

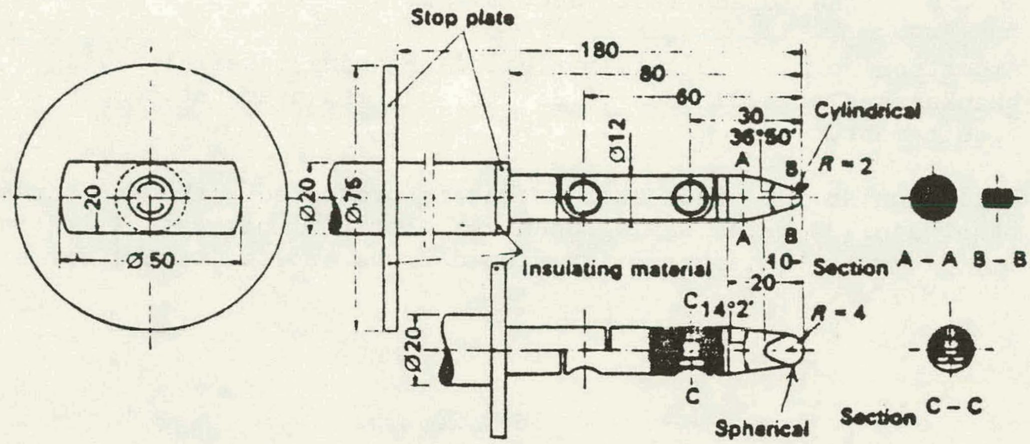
15.4 A part is considered accessible if, in a fully assembled module or panel (that is, with all covers in place) the part may be touched by the probe illustrated in Figure 15.1.

Exception No. 1: A cover that may be removed without the use of a tool is to be removed for purposes of this requirement.

Exception No. 2: A cover that may be removed (with or without a tool) for routine maintenance such as cleaning, or to gain access to tools, is to be removed for purposes of this requirement.

15.5 The probe illustrated in Figure 15.1 shall be applied to any depth that the opening will permit; and shall be rotated or angled before, during, and after insertion through the opening to any position that is necessary to examine the product. The probe shall be applied in any possible configuration; and, if necessary, the configuration shall be changed after insertion through the opening. The probe shall be used as a measuring instrument to judge the accessibility provided by an opening, and not as an instrument to judge the strength of a material; it shall be applied with the minimum force necessary to accurately determine accessibility.

FIGURE 15.1
PROBE FOR DETERMINING ACCESSIBILITY OF LIVE PARTS



Dimensions in millimetres

Tolerances:
on angles ± 5'
on linear dimensions:
less than 25 mm: + 0 / 0.05
over 25 mm: ± 0.2

16. Fire Resistance

16.1 A module or panel intended for stand-off, rack, or direct mounting in combination with a specified roof, and a module or panel intended for integral mounting shall comply with the requirements for a Class A, B, or C roof covering in terms of fire resistance if it is indicated or implied as being fire rated. For the combination situation, this rating shall be coincident with or at a lower level than the basic roof covering material rating. The fire resistance shall be determined by the procedure of tests for fire resistance of roof covering materials, UL 790, as modified by Section 30.

17. Superstrate

17.1 A module or panel superstrate shall comply with one of the following:

A. The requirements in Performance Specifications and Methods of Test for Safety Glazing Material Used in Buildings, ANSI Z97.1-1975, or

B. The requirements in the Safety Standard for Architectural Glazing Materials, CPSC, Standard Part 1201, or

C. The Impact Test, Section 29.

Exception No. 1: Thin-film flexible glazing material having a thicknesses of 0.01 inch (0.254 mm) or less need not comply with this requirement.

Exception No. 2: Encapsulant that is protected with wire screen or other similar means having openings that will not pass a 1/2 inch (12.7 mm) diameter hemispherically tipped probe applied with a force of 1 lb (4.4 N).

PERFORMANCE

18. General

18.1 The irradiance shall be essentially uniform over the surface of the module or panel during the temperature and voltage and current measurements tests, Sections 19 and 20.

18.2 The angle of incidence of the radiation at any point on the module or panel during the temperature and voltage and current measurements tests, Sections 19 and 20, is not to be more than 30 degrees.

18.3 Samples of the module or panel, or partial or representative samples are to be subjected to the tests enumerated in Table 18.1. The order of presentation of the tests is for convenience only, and is not intended to imply that any one sample need be subjected to the complete sequence or a partial sequence of tests unless specifically stated. Except where a sample is to be subjected to a sequence of tests, separate samples may be used; for example, one for each test, if desired.

TABLE 18.1
MODULE AND PANEL PERFORMANCE

Section	Test	Number of Samples
19	Temperature	1
20	Voltage and Current Measurements	1
21	Leakage Current	3
22	Strain Relief	1
23	Push	1
24	Cut	1
25	Bonding Path Resistance	3
26	Dielectric Voltage Withstand	3
27	Inverse Current Overload	1
28	Terminal Torque	1
29	Impact	1
30	Fire	+
31	Exposure to Water Spray	1
32	Accelerated Aging of Gaskets and Seals	@
33	Temperature Cycling	3
34	Humidity	3
35	Corrosive Atmosphere	1
36	Metallic Coating Thickness	1
37	Hot-Spot Endurance	1
38	Arcing	&
39	Mechanical Loading	1

+ A function of the physical size of the module.

@ A function of the physical size of the gasket and seal material.

& One or more, depending upon test procedure elected.

19. Temperature

19.1 When a module or panel is at thermal equilibrium in its intended application mounting at electrical open circuit and also reverse voltage hot-spot heating associated with operation at short-circuit; no part shall attain a temperature that would:

A. Ignite materials or components.

B. Cause the temperature limits of surfaces, materials, or components, as described in Table 19.1, to be exceeded.

C. Cause creeping, distortion, sagging, charring or similar damage to any part of the product, if such damage or deterioration may impair the performance of the product under the requirements of this Standard.

TABLE 19.1. MAXIMUM TEMPERATURE

Part, Material, or Component	Temperature °C	(°F)
1. Insulating materials: (d)		
Polymerics	(a)	(a)
Varnished cloth	85	185
Fiber	90	194
Laminated phenolic composition	125	257
Molded phenolic composition	150	302
2. Sealing compound (d)	(b)	(b)
3. Field wiring terminals (c)	60	140
4. Field wiring compartment that wires may contact (c)	60	140
5. Wood and wood products	90	194
6. Insulated conductors	(e)	(e)
7. Surfaces accessible to contact	(f)	(f)
8. Mounting surface and adjacent structural members (d)	90	194

Notes for Table 19.1:

(a) For the open-circuit mode, the relative thermal index, less 20°C (36°F). For the short-circuit "hot spot" mode, the relative thermal index.

(b) The maximum sealing compound temperature, when corrected to a 40°C (104°F) ambient temperature, is to be 15°C (27°F) less than the softening point of the compound as determined by the Standard Test Method for Softening Point by Ring and Ball Apparatus, ASTM E28-1967 (1977).

(c) If a marking is provided in accordance with paragraph 41.4, the temperatures observed on the terminals and at points within a wiring compartment may exceed the value specified but shall not attain a temperature higher than 90°C (194°F).

(d) Higher temperatures than specified are acceptable if it can be determined that the higher temperatures will not cause a risk of shock or fire or conditions not in compliance with Items A or C of paragraph 19.1.

(e) The temperature rating.

(f) Only for hot-spot heating under short-circuit conditions; for nonmetallic surfaces 40°C (72°F) above temperature achieved during open-circuit conditions; for metallic surfaces, 20°C (36°F) above temperature achieved during open-circuit conditions.

19.2 Material and component temperatures are to be determined for an ambient temperature of 40°C; AM1.5, 100 mW/cm^2 irradiance as measured in the plane of the module or panel; and 1 meter/sec (2.237 mph) average wind speed. The ambient temperature may be in the range of 10°C to 55°C, in which case each observed temperature shall be corrected by the addition (if the ambient temperature is below 40°C) or subtraction (if the ambient temperature is above 40°C) of the difference between 40°C and the observed ambient temperature. If the irradiance is other than 100 mW/cm^2, temperature rises for numerous irradiance levels are to be determined, and a linear extrapolation conducted to determine temperature rise under 100 mW/cm^2 irradiance.

19.3 Should an unacceptable performance be encountered during the temperature test, and the performance be attributed to a test condition that, although within the limits specified, may be considered more severe than necessary; for example an ambient temperature near the bounds allowed (10°C or 55°C), the test may be reconducted under conditions closer to the norm.

19.4 For the determination of temperatures, a module or panel is to be operated under both open and short-circuit conditions.

19.5 To cover the heating effect caused by reverse voltage operation of a cell, a cell is to be shadowed during the short-circuit condition of the temperature test by covering one-half of one of the cells of the module or panel with black vinyl tape, 0.007 in. (0.18 mm) thick in direct contact with the superstrate so that this cell is not fully irradiated. During this test, the modules or panels shall be connected in series without bypass diodes to the extent that is permitted by the marking specified in paragraph 41.7. The temperatures of the shaded cell and adjacent area are to be measured.

19.6 A module or panel is to be installed according to the instructions provided with it. If the instructions do not describe the accommodating structure, spacings, and the like, the module or panel is to be mounted as described in paragraphs 19.8-19.10.

19.7 With reference to paragraphs 19.8 and 19.9, the type of mounting intended, (for example, stand-off, direct, and the like) is to be determined from the construction of the module or panel. If more than one type of mounting is possible, the module or panel is to be tested in each such mounting, unless one mounting can be shown to represent all.

19.8 A module or panel intended for direct mounting on a roof or wall surface is to be mounted on a platform constructed of wood, pressed wood, or plywood, 3/4 inch (19 mm) thick (see Figure 19.1). The platform is to be painted flat black at the side facing the test sample. The platform is to extend at least 2 feet (0.6 m) beyond the module or panel on all sides.

19.9 A module or panel intended for stand-off or rack mounting on a roof, wall, or the ground is to be mounted on a frame constructed from 2 by 4-inch (trade size) lumber. Two frame members are to be located at the outside edges of the underside of the module or panel, and are to be oriented longitudinally along the long axis of the module or panel. Additional frame members are to be located at the outside edges of the underside of the module or panel along its short axis. If the distance between the two outer short axis members exceeds 2 feet (0.6 m), an additional frame member is to be located at the center line of the module or panel assembly. The frame is to be secured to a platform as described in paragraph 19.8 with a 4-foot (1.22 m) spacing between the back of the module or panel and the platform (see Figure 19.2). The frame is to be painted flat black on the side facing the test sample.

19.10 A module or panel intended for integral mounting within a roof or wall is to be tested while mounted on a platform constructed as described in paragraph 19.8 with the module or panel boxed in on all sides by 1-inch thick (trade size) wood boards that are wide enough to cover the entire outer edge. The boards are to be painted flat black on the side facing the sample.

19.11 Temperatures are to be measured by means of thermocouples. Thermocouples exposed to irradiation are to be shielded from the direct effect of such irradiation. A thermocouple junction is to be securely held in positive thermal contact with the surface of the material the temperature of which is being measured. Thermal contact may be achieved by securely cementing the thermocouple in place. For a metal surface, brazing, welding, or soldering the thermocouple to the metal may be used. A thermocouple junction may be secured to wire insulation or wood surfaces by taping.

19.12 Commonly, thermocouples consisting of iron and constantan wires No. 30 AWG (0.05 mm^2) are employed. If it is not practical to use iron and constantan thermocouples some other type described Temperature Measurement Thermocouples, ANSI MC96.1-1975, may be used.

FIGURE 19.1
FIXTURE FOR TEST
PRODUCTS FOR DIRECT MOUNTING

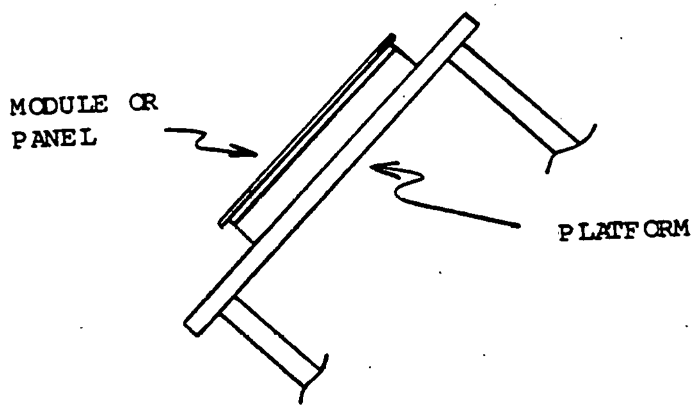


FIGURE 19.2
FIXTURE FOR TEST
PRODUCTS FOR STAND-OFF OR RACK MOUNTING

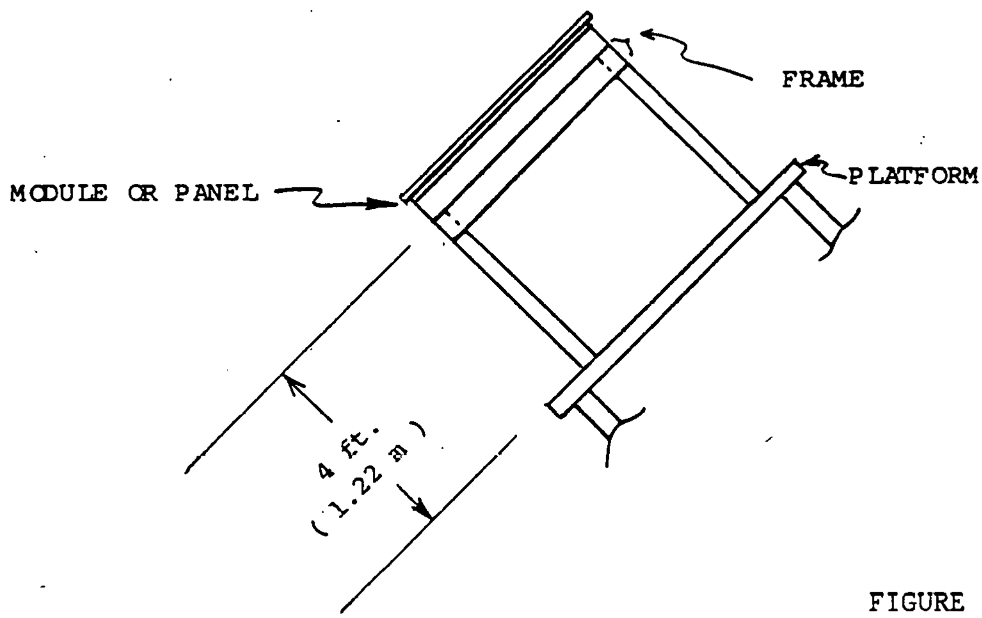
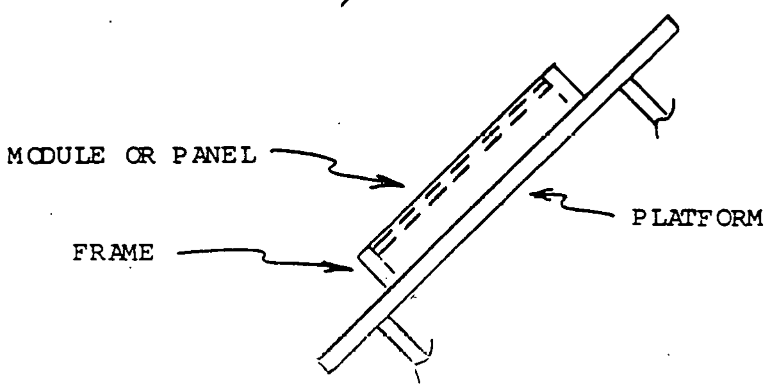


FIGURE 19.3
FIXTURE FOR TESTS
PRODUCTS FOR
INTEGRAL MOUNTING



20. Voltage and Current Measurements

20.1 The output currents of a module or panel shall not be less than 80 percent nor more than the rated current values under conditions of:

A. Short circuit, and

B. Rated operating voltage

both at an irradiance of 100 mW/cm^2, AM1.5 and at NOCT.

20.2 The maximum open circuit voltage of a module or panel shall be within ±10 percent of the rated value under the condition of an irradiance of 100 mW/cm^2, AM1.5 and a cell temperature of 0°C.

20.3 The maximum output power of a module or panel shall be within ±10 percent of the rated value under the condition of an irradiance of 100 mW/cm^2, AM1.5 and at NOCT.

20.4 For purposes of accessibility to individual module or panel live parts, paragraph 15.3, voltage shall be determined under conditions of open circuit, an irradiance of 100 mW/cm^2, AM1.5 and a cell temperature of -20°C.

20.5 Voltage, current, and power values may be measured at temperatures other than those specified in paragraphs 20.1-20.4, and values at the specified temperatures calculated by way of temperature correction coefficients.

21. Leakage Current

21.1 The leakage current of a module having a marked maximum system voltage of more than 30 volts shall not be greater than the values specified in Table 21.1 when tested as described in paragraphs 21.3-21.7.

21.2 The test is to be conducted on three unconditioned modules, and the module that has been subjected to the Exposure to Water Spray Test, Section 31. The leakage current of the unconditioned modules is to be measured with the module cell temperature at 25±3°C, and then with the cells at NOCT ±2°C. Where panels are used for the Exposure to Water Spray Test, a module of a panel is to be used for the Leakage Current Test.

21.3 Leakage current refers to all currents that may be conveyed between accessible parts of a module when the module is connected to the source described in paragraphs 21.4 and 21.5.

21.4 The dc test voltage is to be at a level equal to the rated Maximum System Voltage.

TABLE 21.1
ALLOWABLE LEAKAGE CURRENT

Surface or Part from Which Measurement Is Made	Maximum Current (dc)
Accessible conductive frame, pan, or the like.	10 μA
Accessible circuit parts	1 mA
Conductive foil over accessible insulating surfaces	1 mA

21.5 All accessible parts and surfaces are to be tested for leakage current. The positive and negative terminals of an unilluminated module are to be connected together and to one terminal of a dc power supply. Both polarities of the source connection are to be used, unless it can be shown that one polarity will represent both. Leakage currents are to be measured between the part or surface and the other terminal of the power supply. Leakage current is to be measured with the meter described in paragraphs 21.7.

21.6 When leakage current is measured at an insulating surface, a 40 by 20 cm conductive foil is to be in contact with the surface, and the measurement is to be made from the foil. If the surface is less than 40 by 20 centimeters, the foil is to be the same size as the surface.

21.7 The meter for the measurement is to be responsive to dc only, and is to have an input impedance of 500 ohms.

22. Strain Relief

22.1 A lead or cable for connection to external wiring, or a lead or cable terminated at both ends on the product but which may be subject to handling during installation or routine servicing of a module or panel shall withstand for one minute a force of 20 pounds (89 newtons) applied in any direction permitted by the construction, without damage to the lead or cable, its connecting means, and the module or panel.

22.2 A separable connector not enclosed by a wiring compartment, and such connector's joining to its mating connector, shall withstand for one minute a force of 20 pounds (89 newtons) applied in any direction permitted by the construction, either directly or through any wire or cable attached to the mating connector, without damage to the connector, the module or panel, or the mounting of the connector to the module or panel, or separation of the two mating connectors.

23. Push

23.1 A module or panel shall be capable of withstanding for one minute the application of a 20 pound (89 newton) force applied by a 1/2 inch (12.7 mm) diameter steel rod, the end of which is rounded to a 1/2 inch (12.7 mm) diameter hemisphere, and the application of a 4 pound (17.8 newton) force applied by a 1/16 inch (1.6 mm) diameter steel rod, the end of which is rounded to a 1/16 inch (1.6 mm) diameter hemisphere to any point, without the creation of a shock, fire, or casualty hazard condition.

23.2 A fire hazard situation is considered to exist, if, as a result of the application of either probe, parts of the module are displaced to the extent that arcing between parts of available current and voltage in the "ARC TEST" zone, Figure 38.1 is likely.

23.3 A shock hazard situation is considered to exist if either, either applied probe contacts a part involving shock hazard, or if a shock hazardous part is rendered accessible (transitory or permanent) as a result of the application of either probe.

23.4 A casualty hazard situation is considered to exist, if, as a result of the application of either probe, parts are displaced or broken so as to expose edges which would not comply with Section 14, Sharp Edges.

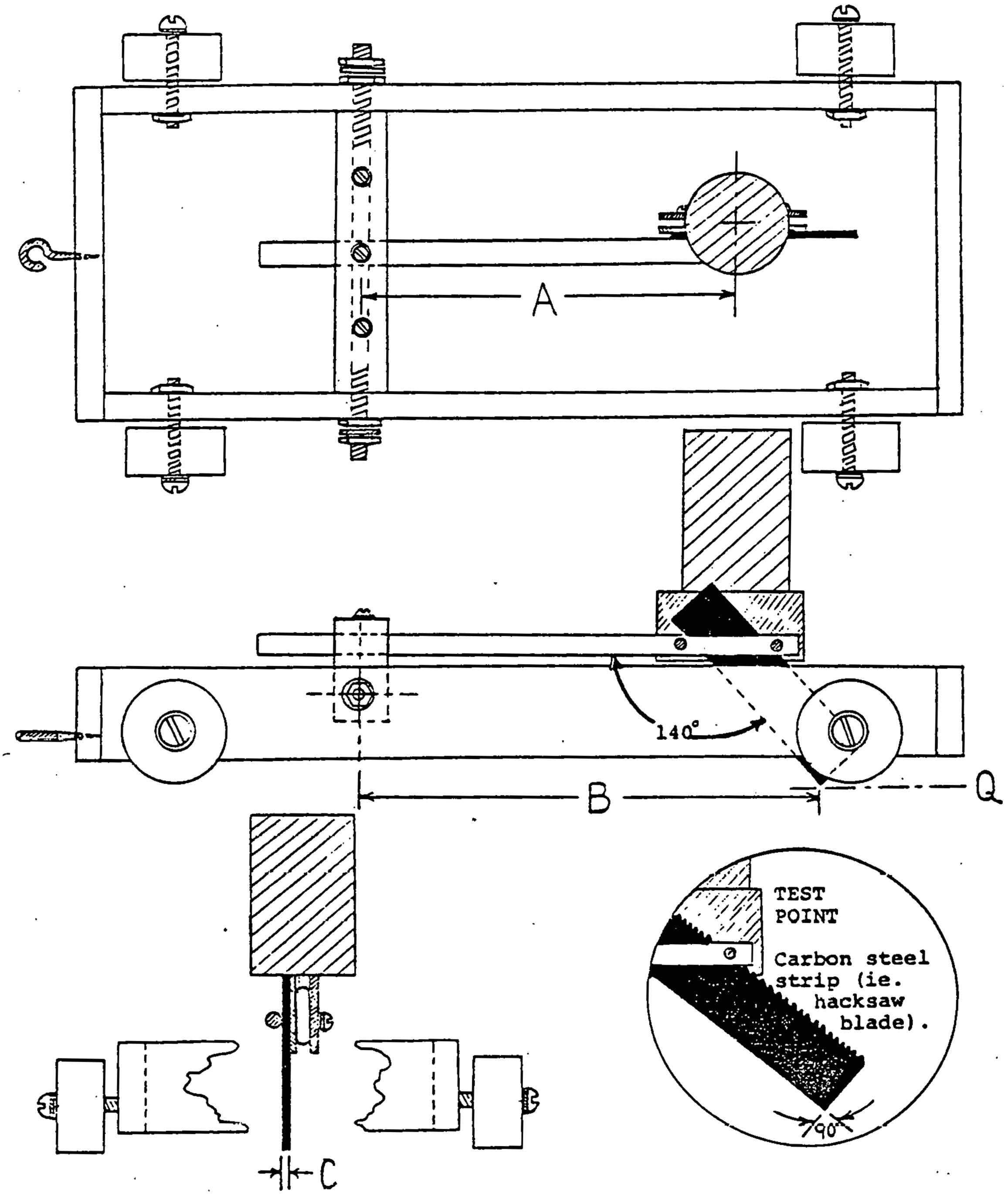
24. Cut

24.1 A module or panel shall be capable of withstanding the application of a sharp object drawn across its superstrate and substrate surfaces without the creation of a shock hazard.

24.2 The module or panel is to be positioned in a horizontal plane with the surface under test facing upward. The tool described in Figure 24.1 is to be placed on the surface for one minute, and then drawn across both the front and rear surfaces of the module or panel at a speed of 6 ± 1.2 inches/sec (152.4 ± 30.5 mm/sec).

24.3 A shock hazard situation is considered to exist if either the blade of the tool contacts a part involving shock hazard, or if a shock hazardous part is rendered accessible (transitory or permanent) as a result of the placement of the blade on or the drawing of the blade across the surface.

FIGURE 24.1
CUT TEST TOOL



A - 5-7/8 in. (14.9 cm) from axis to center of weight.
B - 6-5/8 in. (16.8 cm) from axis to test point.
C - Test point - 0.025 in. (0.64 mm) thick carbon steel strip.
Q - Total force exerted at test point Q; 2 lbs. (907 gm).

25. Bonding Path Resistance

25.1 The resistance between the grounding terminal or lead and any accessible conductive part shall not be more than 0.1 ohm when measured in accordance with paragraph 25.2.

25.2 Compliance with the requirement specified in paragraph 25.1 is to be determined as follows: A current of twice the back feed series fuse size rating (see paragraph 41.8) is to be passed between the grounding terminal or lead and the conductive part in question. The resistance is then calculated based on the voltage drop measured between the grounding terminal or lead and a point to within 1/2 in. (12.7 mm) from the point of current injection.

25.3 The current shall be increased from zero to the specified level in approximately 5 seconds. The specified current shall be maintained for 2 minutes.

25.4 At no time during the test shall the resistance between the points of application of current exceed 0.1 ohm.

25.5 If more than one test is deemed necessary to evaluate all the paths of conduction between accessible metal parts, a cooling time of at least 15 minutes between tests shall be observed.

25.6 The test is to be conducted on three unconditioned specimens.

26. Dielectric Voltage Withstand

26.1 The insulation and spacings between live parts and accessible conductive parts and between live parts and exposed nonconductive surfaces shall withstand the application of a direct test voltage equal to 2 x system voltage + 1000 volts without the leakage current between these two points exceeding 50 A, dc. The voltage is to be applied in both polarities.

Exception: For a module with a system voltage rating of 30 volts or less the applied voltage shall be 500 volts.

26.2 The test voltage is to be applied between all current carrying parts and all accessible parts.

26.3 The voltage is to be increased from zero at a substantially uniform rate so as to arrive at the specified test potential in approximately 5 seconds, and then held at the required test voltage until the leakage current stabilizes for at least 1 minute. The module or panel is to be observed during the test and there are to be no signs of arcing or flash-over.

26.4 The test voltage is to be gradually and smoothly increased to the specified value so that (a) there are no transients that might cause the instantaneous voltage to exceed the peak value specified, and (b) the flow of capacitive current, as due to charging, does not cause the test device to indicate breakdown.

26.5 The test is to be conducted on three unconditioned specimens, and the specimens that have been subjected to Exposure to Water Spray, Section 31; Temperature Cycling, Section 33; Humidity, Section 34; and Corrosive Atmosphere, Section 35. The unconditioned samples are to be at both room temperature and also as heated from the short-circuit operation portion of the temperature test in Section 19.

26.6 For tests on exposed surfaces of insulating parts, the part is to be covered with conductive foil or the equivalent.

26.7 The equipment for conducting the dielectric voltage-withstand test is to have the following features and characteristics:

A. A means for indicating the test voltage that is being applied to the product under test.

B. A sensitivity such that a current in excess of 50 microamperes across the output indicates unacceptable performance.

C. A capacity of at least 500 VA.

Exception: The capacity may be lower if the means for indicating the test voltage is located in the output circuit - to maintain the potential indicated in paragraph 26.1 except in the case of breakdown. The voltage of the source is to be continuously adjustable.

27. Inverse Current Overload

27.1 There shall be no flaming of the cheesecloth or tissue paper in contact with a module or panel, or flaming of the module or panel itself for 15 seconds or more, when a current equal to 135 percent of the module or panel series fuse rating current (see paragraph 41.8) is caused to flow in a reverse direction through a module or panel (4th quadrant operation).

27.2 A module or panel is to be placed on a single layer of white tissue paper over a 3/4 inch (19.1 mm) thick pine board and covered with a single layer of cheesecloth. The cheesecloth is to be untreated cotton cloth running 14-15 square yards per pound (26-28 square meters per kilogram) and having what is known to the trade as a count of 32 by 28.

27.3 Any blocking diode provided as a part of the module or panel is to be defeated (short-circuited).

27.4 The test is to be conducted in an area free of drafts, and the irradiance on the module or panel is to be less than 5 mW/cm^2.

27.5 The test is to be continued for two hours or until ultimate results are known, whichever occurs first.

28. Terminal Torque

28.1 A wire-binding screw or nut on a wiring terminal shall be capable of withstanding 10 cycles of tightening to and releasing from the values specified in Table 28.1 without damage to the terminal supporting member, without loss of continuity and without short circuiting of the electrical circuit to accessible metal.

TABLE 28.1

TORQUE REQUIREMENTS

Screw Size	Torque lb-in.	(N-m)
No. 6	12	(1.4)
No. 8	16	(1.8)
No. 10	20	(2.3)

29. Impact

29.1 A polymeric material serving as the enclosure of a part involving a risk of electric shock or fire hazard and a superstrate material evaluated in accordance with item C of paragraph 17.1 are to be subjected to the tests described in paragraphs 29.2 and 29.3.

29.2 When a module or panel is impacted as described in paragraph 29.3, there shall be no accessible live parts as defined in Section 15. Breakage of the superstrate material may occur providing that there are no particles larger than 1 sq. in. released from their normal mounting position.

29.3 A module or panel is to be mounted in a manner representative of its intended use, and is to be subjected to a 5 ft lb (6.78 joules) impact normal to the surface from a 2 inch (51 mm) diameter smooth steel sphere weighing 1.18 pounds (535 grams) falling through a distance of 51 inches (1.295 m). The module or panel is to be struck at any point considered most vulnerable. If the construction of a module or panel does not permit it to be struck freely from above by the freely falling sphere, the sphere is to be suspended by a cord and allowed to fall as a pendulum through the vertical distance 51 inches (1.295 m) with the direction of impact normal to the surface.

30. Fire

30.1 A module or panel intended for roof mounting and designated as being intended for installation above, upon, or integral with a building roof structure surfaced with Class A, Class B, or Class C type material shall be subjected to a spread-of-flame test as described in the tests for fire resistance of roof covering materials, UL 790 modified as described herein, or as may otherwise be appropriate for the particular module or panel being tested. At no time during or after the tests shall:

A. Any portion of the module or panel or the roof covering material be blown or fall off the test deck in the form of flaming or glowing brands,

B. The roof deck, (including any part under a module or panel) be exposed by breaking, sliding, cracking, or warping of the roof covering, or

C. Portions of the roof deck or portions of a module or panel intended for installation integral with or forming a part of the building structure, fall away in the form of glowing particles.

30.2 At the conclusion of the spread-of-flame tests, the flaming shall not have spread beyond 6 feet (1.82 m) for Class A, 8 feet (2.4 m) for Class B, and 13 feet (3.9 m) for Class C rating; measured from the leading edge of the sample. There shall have been no significant lateral spread-of-flame from the path directly exposed to the test flame. Spread-of-flame includes flaming on both the top surface (the surface to which the external flame is applied) and in any intermediate channel, such as the space between stand-off or direct mounted modules and a shingle roof.

30.3 For a module or panel intended for installation above a building roof structure, the spread-of-flame test is to be conducted with the module or panel oriented with respect to the test flame such that the flame impinges only on the top surface of the module or panel.

30.4 A module or panel intended for roof mounting and designated as being intended for installation above, upon, or integral with a building roof structure surfaced with Class A, Class B, or Class C type roof covering material shall be subjected to a burning-brand test as described in the tests for fire resistance of roof covering materials, UL 790, modified as described herein or as may otherwise be appropriate for the particular module or panel being tested. At no time during or after the test shall:

A. Any portion of the module or panel or the roof covering material be blown or fall off the test deck in the form of flaming or glowing brands,

B. The roof deck be exposed by breaking, sliding, cracking, or warping of the roof covering (including any part of the module or panel),

C. Portions of the roof deck, or portions of a module or panel intended for installation integral with or forming a part of the building roof structure fall away in the form of glowing particles, or

D. There be sustained flaming of the underside of the roof deck or the underside of the module or panel.

30.5 For both the spread-of-flame and burning-brands tests, the test severity (Class A, B, or C) shall be commensurate with the intended designated class of roof covering material.

30.6 For these tests the module or panel is to be installed in accordance with the instructions provided with it. Any mounting hardware furnished with the module or panel is to be used to mount the module or panel for test. The slope of the module or panel with respect to the horizontal is to be the minimum slope specified in the installation instructions. The slope of the simulated roof deck is not to exceed 5 inches per foot (416 mm/m).

30.7 A module or panel is not required to be useable after any of the tests of this section.

30.8 For each mode of test only one test need be conducted.

31. Exposure to Water Spray

31.1 A module or panel shall be subjected to a water spray test as described in paragraphs 31.2-31.6, and

A. The test shall not result in:

(1) Water on uninsulated live parts or the collection of water in a compartment containing live parts, and

B. Immediately following the test, the module or panel shall comply with

(1) The dielectric voltage withstand test in Section 26, and

(2) The leakage current test in Section 21.

Both tests are to be conducted without any drying of the samples.

31.2 A module or panel is to be mounted and oriented in a manner representative of its intended use in the focal area of the apparatus described in paragraph 31.5. If the mounting or orientation of the module or panel under the water spray may affect the results, the test is to be conducted with the module or panel in those mountings and orientations deemed necessary to represent any application of the product, considering also that the mounting may be on a tracking frame which alters the module orientation.

31.3 If a module or panel is intended to be mounted as an integral part of the roof with an adjacent module or panel in an array using factory-designed joining sections, the test is to be conducted using the joining hardware in accordance with the installation instructions.

31.4 Field wiring connections are to be made in accordance with the wiring method specified for the product. If more than one method is specified, the method least likely to restrict the entrance of water is to be used. A threaded opening intended to terminate in conduit is to be sealed, unless a possible use of the threaded opening is with a wiring method likely to allow the entrance of water.

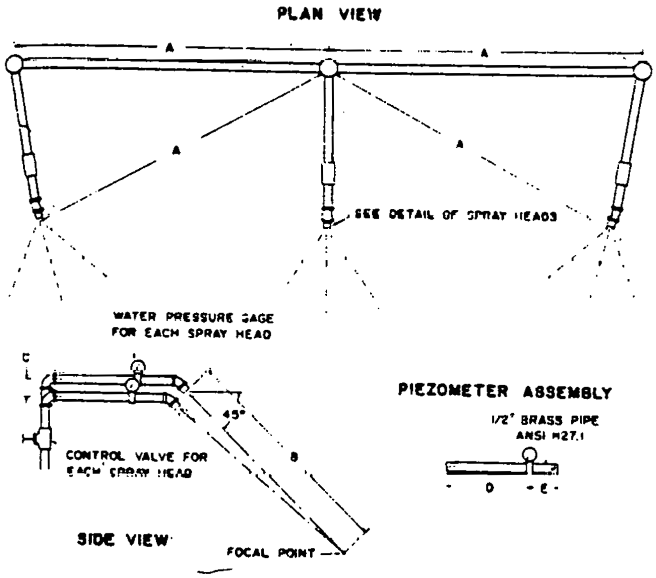
31.5 The rain test apparatus is to consist of three spray heads mounted in a water supply rack as illustrated in Figure 31.1. Spray heads are to be constructed in accordance with Figure 31.2. The water pressure for all tests is to be maintained at 5 psig (34.5 kPa) at each head. The distance between the center nozzle and the product is to be approximately 3 feet (0.9 m). The product is to be brought into the focal area of the three spray heads in such position and under such conditions so as to present the greatest quantity of water to entrances to the product. The spray is to be directed toward the module or panel at an angle of 45 degrees to the vertical.

31.6 The water for the test is to have a resistivity before the test, of 3500±175 ohm-centimeters at 25°C (77°F). At the conclusion of the test, the resistivity of the water is not to be less than 3200 ohm-centimeters nor more than 3800 ohm-centimeters at 25°C (77°F).

31.7 The exposure time is to be 1 hour.

31.8 After exposure, the module or panel shall be examined for evidence of water penetration to and above uninsulated live parts and for evidence of the collection of water in any compartment containing live parts. If drain holes are provided, consideration is to be given to their preventing the water level from reaching uninsulated live parts.

FIGURE 31.1
EXPOSURE TO WATER SPRAY-TEST SPRAY-HEAD PIPING



Item	inch	mm
A	28	710
B	55	1400
C	2-1/4	55
D	9	230
E	3	75

FIGURE 31.2
EXPOSURE TO WATER SPRAY-TEST SPRAY HEAD

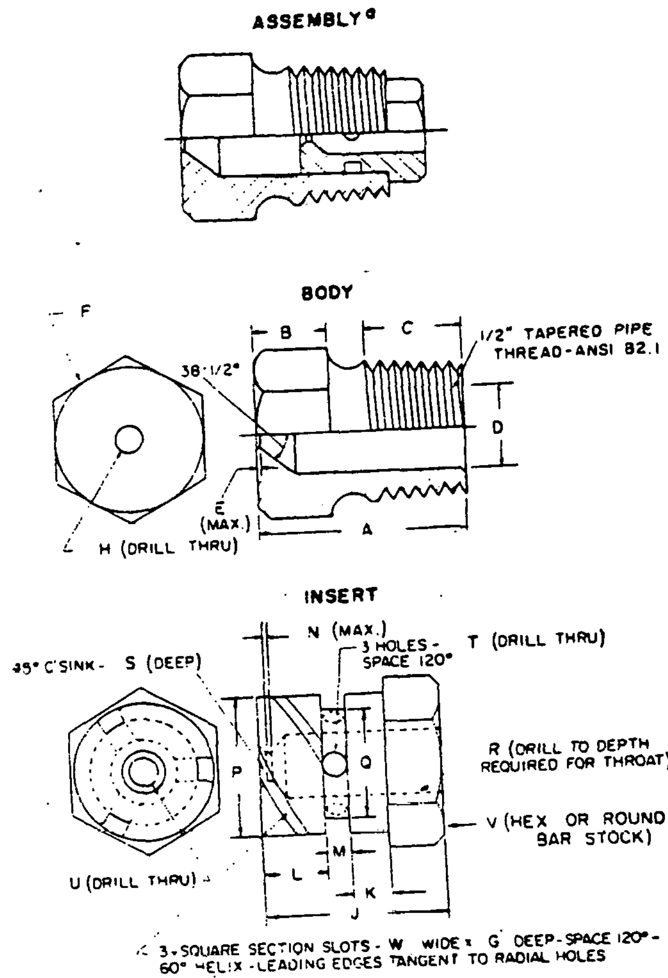
Item	inch	mm	Item	inch	mm
A	1-7/32	31.0	N	1/32	0.80
B	7/16	11.0	P	.575	14.61
C	9/16	14.0		.576	14.63
D	.578	14.68	Q	.453	11.51
	.580	14.73		.454	11.53
E	1/64	0.40	R	1/4	6.35
F	c	c	S	1/32	0.80
G	.06	1.52	T	(No. 35)[b]	2.79
H	(No.9)[b]	5.0	U	(No. 40)[b]	2.49
J	23/32	18.3	V	5/8	16.0
K	5/32	3.97	W	0.06	1.52
L	1/4	6.35			
M	3/32	2.38			

a - Molded nylon Spray Heads are available from Underwriters Laboratories Inc.

b - ANSI B94.11 Drill Size.

c - Optional - To serve as wrench grip.

SA 0820A



32. Accelerated Aging of Gaskets and Seals

32.1 Materials used for gaskets, seals, and the like (except for cork, fiberous material and similar products) shall have the physical properties as specified in Table 32.1, and shall comply with the physical property requirements of Table 32.2. The material shall not deform, melt, or harden to a degree which would affect its sealing properties.

TABLE 32.1
Physical Property Requirements

Min. Tensile Strength[a]	Min. Ultimate Elongation[a]	Compressive Set[c], Maximum Set
A. For Silicone Rubber:		
500 psi (3.45 MPa)	100%	15%
B. For Other Elastomers:		
1500 psi[b] (10.3 MPa)	300%[b]	15%
C. For Nonelastomers (excluding cork, fiber and similar materials):		
1500 psi (10.3 MPa)	200%	15%

a Tensile strength and ultimate elongation are to be determined using Die C specimens described in the Standard Test Methods for Rubber Properties in Tension, ASTM D 412-1975 or Type I specimens described in the Standard Test Method for Tensile Properties of Plastics ASTM D 638-1977.

b As an alternate, an ultimate elongation of 200% is acceptable providing that the tensile strength is at least 2,200 psi (15.1 MPa).

c Compressive set is to be determined 30 minutes after specimen release using the Standard Test for Rubber Property-Compression Set ASTM, D 395, Method B.

TABLE 32.2

PHYSICAL REQUIREMENTS AFTER CONDITIONING

Temperature on Material During Temperature Test	Conditioning Procedure	Minimum Percent of the Result with Unaged Specimens		Maximum Change (Duro) from Unconditioned Value[a]
		Tensile Strength	Ultimate Elongation	
60°C (140°F) or less	Oxygen bomb, 96 hrs. at 70°C (158°F) and 300 PSI (2.07 MPa) gauge	60	60	5
61-75°C (142-167°F)	Oxygen bomb, 168 hrs. at 80°C (176°F) and 300 PSI (2.07 MPa) gauge; and air bomb, 20 hrs. at 127°C (260°F) and 80 PSI (551 KPa) gauge	50	50	5
76-90°C (169-194°F)	Air circulating convection oven, 168 hrs. at 121°C (250°F)	50	50	10
91-105°C (196-221°F)	Air circulating convection oven, 168 hrs. at 136°C (277°F)	50	50	10
Above 105°C (221°F)	20 degrees C, (36 degrees F), greater than use temperature in circulating convection oven, 168 hrs. exposure	50	50	10

[a] Determined by the Standard Method for Rubber Property Durometer Hardness, ASTM D-2240.

33. Temperature Cycling

33.1 A module or panel shall be subjected to 200 cycles of temperature change as described in paragraphs 33.2-33.5; and

A. The test shall not result in:

1. Loss of circuit continuity.

2. Accessibility of parts that may involve a risk of electric shock, such as might be caused by delamination or separation of materials.

3. A reduction in the resistance between parts involving a risk of electric shock and an accessible part such that the module or panel would not comply with the Leakage Current Requirements, Section 21.

4. Reduction in thickness of a nonmetallic wiring compartment wall below acceptable values.

5. Reduction in volume of a nonmetallic wiring compartment below acceptable values, or

6. Creation of a gap greater than 1/16 inch (1.6 mm) or an increase of 1/16 inch (1.6 mm) or more in an existing opening between nonmetallic wiring compartment walls and the cover, and

B. The module or panel shall comply with:

1. The dielectric voltage withstand test in Section 26, immediately following the last excursion to 90°C and also at room temperature.

33.2 Three samples of a module or panel are to be placed in a circulating air chamber, the temperature of which can be varied and controlled. Leads are to be connected to the terminals, and frame where necessary, of the samples, to allow for a continuous individual detection of loss of circuit continuity; and loss of resistance between the electrical circuit and accessible metal.

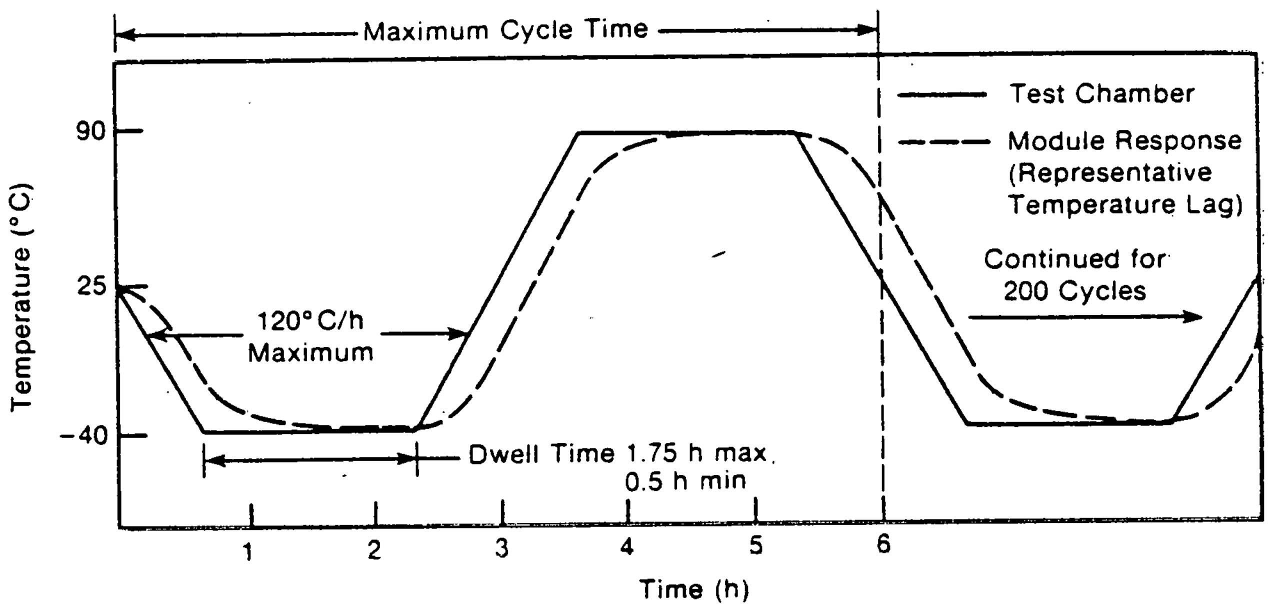
33.3 The samples are to be mounted in a test frame that simulates the support rigidity and differential thermal expansion likely to occur in service between the product and its support structure.

33.4 Each test is to consist of a transition in test chamber temperature from 25°C to -40°C, a dwell at -40°C for 30 minutes or until the module or panel attains a temperature within 2°C of the chamber temperature, whichever is longer, but in no case longer than 1 hour, 45 minutes, a transition in test chamber temperature from -40°C to 90°C, a dwell at 90°C for 30 minutes or until the module or panel attains a temperature within 2°C of the chamber temperature, whichever is longer, but in no case longer than 1 hour, 45 minutes, and a transition in test chamber temperature from 90°C to 25°C. The total cycle time is not to exceed 6 hours. Where the 25°C temperature is the start or end of the 200 cycles, any nominal room temperature in the range of 15-35°C may be used. For all transitions, the instantaneous rate of temperature change of the test chamber with respect to time shall be no greater than 120°C/hour. See Figure 33.1.

33.5 The dew point of the chamber air is to be between 9 and 15°C, except that when the chamber air temperature is below this value the dew point is to be the chamber temperature.

FIGURE 33.1

THERMAL CYCLE TEST



34. Humidity

34.1 A module or panel shall be subjected to 10 cycles of humidity-freezing as described in paragraphs 34.2-34.6; and

A. The test shall not result in:

1. Loss of circuit continuity.

2. Accessibility of parts that may involve a risk of electric shock, such as might be caused by delamination or separation of materials.

3. A reduction in the resistance between a part involving a risk of electric shock and an accessible part such that the module or panel would not comply with the Leakage Current Requirements, Section 21.

4. Corrosion of metal parts.

5. Reduction in thickness of a nonmetallic wiring compartment wall below acceptable values.

6. Reduction in volume of a nonmetallic wiring compartment below acceptable values, or

7. Creation of a gap greater than 1/16 inch (1.6 mm) or an increase of 1/16 inch (1.6 mm) or more in an existing opening between nonmetallic wiring compartment walls and the cover, and

B. The module or panel shall comply with:

1. The dielectric voltage withstand test in Section 26.

34.2 Three samples of a module or panel are to be placed in a chamber, the humidity and temperature of which can be varied and controlled. Leads are to be connected to the terminals, and frame where necessary, of the samples, to allow for a continuous individual detection of loss of circuit continuity; and loss of resistance between the electrical circuit and accessible metal.

34.3 The samples are to be mounted in a test frame that simulates the support rigidity and differential thermal expansion likely to occur in service between the product and its support structure.

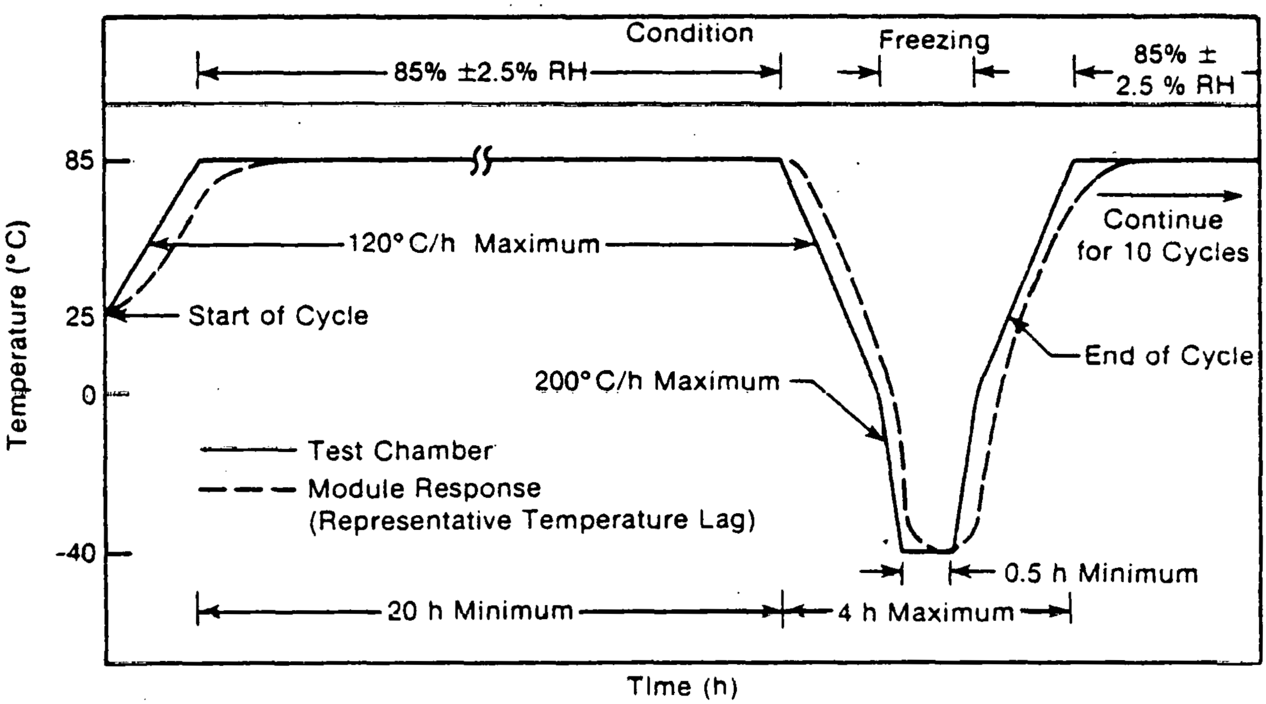
34.4 The test apparatus and arrangement of samples is to be such that dripping of condensate on a sample is prevented. Terminations are to be afforded the least degree of protection against condensation of water as they would be in any intended installation of the product.

34.5 Each cycle is to consist of a transition in test chamber temperature from 25°C to 85°C, a dwell at 85°C for 20 hours minimum, a transition from 85°C to -40°C, a dwell at -40°C for 30 minutes minimum, and a transition from -40°C to 25°C. When the temperature is 0°C or above, the temperature transitions of the test chamber with respect to time are not to be greater than 120°C/hour. When the temperature is less than 0°C, the temperature transitions of the test chamber with respect to time are not to be greater than 200°C/hour. The total time for the transitions and the -40°C dwell together shall not exceed 4 hours. Where the 25°C temperature is the start or end of the 10 cycles, any nominal room temperature in the range 15-30°C may be used. Total cycle time is not to exceed 24 hours. See Figure 34.1.

34.6 The humidity of the chamber air when the chamber air temperature is 85°C is to be 85% R.H. During all temperature transitions the chamber air is to be isolated from the outside air (no make-up air) to allow condensing water vapor to freeze in the module or panel.

FIGURE 34.1

HUMIDITY-FREEZING CYCLE TEST



35. Corrosive Atmosphere

Salt Spray Test

35.1 One complete sample of the module or specimen samples of materials representative of that used in the module are to be subjected to this test.

Exception: Modules constructed of materials such as polymerics, stainless steel, or aluminum which are inherently resistant to atmospheric corrosion need not be tested.

35.2 The apparatus for salt spray testing consists of a chamber with inside measurements of 48 by 30 by 36 inches (1.22 by 0.76 by 0.91 meter) or larger if required; a salt solution reservoir; a supply of conditioned compressed air; one dispersion tower constructed in accordance with ASTM designation B117-1973, for producing a salt fog; specimen supports; provision for heating the chamber; and necessary means of control.

35.3 The dispersion tower for producing the salt spray is to be located in the center of the chamber and is to be supplied with humidified air at a gauge pressure of 17 to 19 pounds per square inch (117 to 131 kilopascals) so that the solution is aspirated as a fine mist or fog into the interior of the chamber.

35.4 The salt solution is to consist of 5 percent by weight of common salt (sodium chloride) in distilled water. The pH value of the collected solution is to be between 6.5 and 7.2 and have a specific gravity between 1.026 and 1.040 at 95 F (35 C). The temperature of the chamber is to be maintained within the range of 92 to 97 F (33 C to 36 C)throughout the test.

35.5 The test sample is to be supported on plastic racks at an angle of 15 degrees from the vertical.

35.6 Drops of solution which accumulate on the ceiling or cover of the chamber are to be diverted from dropping on the specimen and drops of solution which fall from the specimens are not to be recirculated, but are to be removed by a drain located in the bottom of the apparatus.

35.7 Reference specimens, 4 by 12 inches (102 by 305 mm) of commercial zinc coated sheet steel are used for comparison. The specimens are selected to be representative of the minimum acceptable amount of zinc coating under requirements for G90 or G60 coating designation (as applicable, see Section 13) as determined by test using ASTM Method A90-73, "Test for the Weight of Coating on Zinc Coated Iron or Steel Articles". Such zinc coatings are considered as providing acceptable corrosion protection.

35.8 The zinc coated reference specimens are cleaned with soap and water, rinsed with ethyl alcohol and ethyl ether, dried and the cut edges protected with paint, wax or other effective medium before being placed in the salt spray chamber.

35.9 Both the reference specimen and the samples under test are to be scribed with a single groove, approximately 6 inches (152 mm) long to expose the underlying steel.

35.10 The test is to continue until the coating on the test samples or reference samples are broken down and corrosion products are formed on the underlying steel.

35.11 The corrosion products formed on the test sample shall be no more than that formed on the reference sample as determined by visual observation. Corrosion in the scribed line area is judged by the spread of corrosion from the scribed line.

Moist Carbon Dioxide/Sulphur Dioxide:

35.12 One complete sample of the module or specimen samples of materials representative of that used in the module are to be subjected to this test.

Exception: Modules constructed of materials such as polymerics, stainless steel or aluminum which are inherently resistant to atmospheric corrosion need not be tested.

35.13 A chamber measuring 48 by 30 by 36 inches (1.22 by 0.76 by 0.91 meter) or larger if required, having a water jacket and thermostatically controlled heater in order to maintain a temperature of 95 ± 3 F (35 ± 1.7 C) is to be used.

35.14 Sulphur dioxide and carbon dioxide are to be supplied to the test chamber from commercial cylinders containing these gases under pressure. An amount of sulphur dioxide equivalent to 1 percent of the volume of the test chamber and an equal volume of carbon dioxide are to be introduced into the chamber each day. Prior to introducing the new charge of gas each day, the remaining gas from the previous day is to be purged from the chamber. A small amount of water is maintained at the bottom of the chamber for humidity. The samples are to be supported on plastic racks at an angle of 15 degrees from the vertical.

35.15 Reference specimens 4 by 12 inches (102 by 305 mm) of commercial zinc coated sheet steel are used for comparison. The specimens are selected to be representative of the minimum acceptable amount of zinc coating under requirements for G90 or G60 coating designation (as applicable, see Section 13) as determined by tests using ASTM Method A90-73. Such zinc coatings are considered as providing acceptable corrosion protection.

35.16 The zinc coated specimens are cleaned with soap and water, rinsed with ethyl alcohol and ethyl ether, dried, and the cut edges protected with paint, wax or other effective media before being placed in the chamber.

35.17 Both the reference specimen and sections of the module being tested are to be scribed with a single groove, approximately 6 inches (152 mm) long to expose the underlying steel.

35.18 The test is to continue until the coating on the module or reference specimen is broken down and corrosion products are formed on the underlying steel.

35.19 The corrosion products formed on the test sample shall be no more than that formed on the reference sample as determined by visual observation. Corrosion in the scribed line area is to be judged by the spread of corrosion from the scribed lines.

36. Metallic Coating Thickness

36.1 The method of determining the thickness of a zinc or cadmium coating mentioned in paragraphs 13.1 and 13.2 is described in paragraphs 36.2-36.9.

36.2 The solution to be used for the metallic coating thickness test is to be made from distilled water and is to contain 200 grams per liter of reagent (or better) grade chromium trioxide (CrO_3) and 50 grams per liter of reagent (or better) grade concentrated sulphuric acid (H_2SO_4). (The latter is equivalent to 27 milliliters per liter of reagent grade concentrated sulphuric acid, specific gravity 1.84, containing 96 percent of H_2SO_4.)

36.3 The test solution is to be contained in a glass vessel such as a separatory funnel with the outlet equipped with a stopcock and a capillary tube of approximately 0.025 inch (0.64 mm) inside bore and 5.5 inches (150 mm) long. The lower end of the capillary tube is to be tapered to form a tip, the drops from which are about 0.05 milliliter each. To preserve an effectively constant level, a small glass tube is inserted in the top of the funnel through a rubber stopper and its position is to be adjusted so that, when the stopcock is open, the rate of dropping is 100±5 drops per minute. If desired, an additional stopcock may be used in place of the glass tube to control the rate of dropping.

36.4 The sample and the test solution are to be kept in the test room long enough to acquire the temperature of the room, which should be noted and recorded. The test is to be conducted at a room temperature of 70.0-90.0°F (21.2-32.0°C).

36.5 Each sample is to be thoroughly cleaned before testing. All grease, lacquer, paint, or other nonmetallic coatings, including skin oils, are to be removed completely by means of solvents. Samples are then to be thoroughly rinsed in water and dried with clean cheesecloth.

36.6 The sample to be tested is to be supported from 0.7 to 1 inch (17 to 25 mm) below the orifice. The surface to be tested shall be inclined at approximately 45 degrees from the horizontal so that the drops of solution strike the point to be tested and run off quickly.

36.7 The stopcock is to be opened and the time in seconds is to be measured until the dropping solution dissolves the protective metal coating, exposing the base metal. The end point is the first appearance of the base metal recognizable by the change in color at that point.

36.8 Each sample of a test lot is to be subjected to the test at three or more points, excluding cut, stenciled, and threaded surfaces, on the inside surface and at an equal number of points on the outside surface, at places where the metal coating may be expected to be the thinnest. (On enclosures made from precoated sheets, the external corners that are subjected to the greatest deformation are likely to have thin coatings.)

36.9 To calculate the thickness of the coating being tested, select from Table 36.1 the thickness factor appropriate for the temperature at which the test was conducted and multiply by the time in seconds required to expose base metal as noted in paragraph 36.7.

TABLE 36.1
COATING THICKNESS FACTORS

Temperature, °F	°C	Thickness Factors 0.00001 Inches (0.00025 mm) per second: Cadmium Platings	Zinc Platings
70	21.1	1.331	0.980
71	21.7	1.340	0.990
72	22.2	1.352	1.000
73	22.8	1.362	1.010
74	23.3	1.372	1.015
75	23.9	1.383	1.025
76	24.4	1.395	1.033
77	25.0	1.405	1.042
78	25.6	1.416	1.050
79	26.1	1.427	1.060
80	26.7	1.438	1.070
81	27.2	1.450	1.080
82	27.8	1.460	1.085
83	28.3	1.470	1.095
84	28.9	1.480	1.100
85	29.4	1.490	1.110
86	30.0	1.501	1.120
87	30.6	1.513	1.130
88	31.1	1.524	1.141
89	31.7	1.534	1.150
90	32.2	1.546	1.160

37. Hot-Spot Endurance

General

37.1 Representative cells of a module or panel shall be subjected to simulated reverse voltage hot-spot heating conditions for a total of 100 hours, intermittently, as described in paragraphs 37.2-37.29. The test shall not result in:

A. the accessibility of parts involving a risk of electric shock.

B. melting of solder, or

C. any other indication of a risk of fire or electric shock.

37.2 The reverse voltage hot-spot heating condition specified in paragraph 37.1 occurs when a module is operating at current levels that exceed the reduced short-circuit current capability of an individual cell or group of cells in an array circuit. This reduced short-circuit current capability can be the result of a variety of causes including non-uniform illumination of the module (local shadowing), individual cell degradation due to cracking, or loss of a portion of a series-parallel circuit due to individual interconnect open circuits. A module can operate at current levels exceeding its reduced short-circuit current capability during uncontrolled or deliberate fault conditions such as a short circuit deliberately placed on the module for servicing or to otherwise disable the array. During a reverse voltage hot-spot heating condition power is dissipated in the over-current cell(s) at a level equal to the product of the current and the reverse voltage that develops across the cell(s). This can heat the cell(s) to elevated temperatures.

37.3 The procedure for conducting this test includes a series of steps: 1) select and connect power sources and instruments to appropriate cells for testing, 2) determine the hot-spot test levels, and 3) conduct the hot-spot endurance test.

Cell Selection and Instrumentation

37.4 The degree of hot-spot heating within an affected cell is dependent upon, in part, the reverse-voltage current-voltage (I-V) characteristics of the affected cell(s). The reverse-voltage I-V characteristics may vary considerably from cell-to-cell within a given module. Accordingly, the range of the dark reverse-voltage I-V curves for a representative sample of cells (at least 10) within the test module are to be determined in accordance with paragraphs 37.5-37.12. This can be done by either directly accessing individual cells (intrusive method), or by a shadowing technique (non-intrusive method) if the module is a simple series string of cells. The intrusive-nonintrusive option relates to cell selection only. All cells subjected to hot-spot endurance shall be individually accessed.

37.5 The dark reverse voltage current-voltage (I-V) curves for at least 10 cells within the module(s) or panel are to be determined for reverse voltages from 0 to V_L or currents from 0 to I_L, whichever limit is reached first, where:

$I_L = I_{SC}$ (short circuit current) of an average cell at 100 mW/cm², NOCT.

$V_L = N \times V_{mp}$ of an average cell at 100 mW/cm², NOCT. (V_{mp} is the average maximum power voltage.)

N = Number of series cells per bypass diode as either (1) an integral part of the module or panel, or (2) as is described for use with the module or panel in marking affixed to the module or panel; whichever is less. (See paragraph 41.7.)

Exception: Where no bypass diode information is provided, V_L shall be equal to the system direct voltage rating.

INTRUSIVE METHOD

37.6 For the determination of cell I-V characteristics, paragraph 37.5, by the intrusive method, each cell tested is to be provided with individual positive and negative electrical leads, to allow it to be accessed independently of other cells.

37.7 The reverse voltage I-V curves from the tested cells are to be plotted. The cells are to be identified as Type A (voltage limited) or Type B (current limited). (A graph similar to Figure 37.1 should be obtained.)

NONINTRUSIVE METHOD

37.8 The nonintrusive method may be used to determine cell I-V characteristics only if the module consists of a single series string of cells without bypass diodes. This method consists of uniformly illuminating all but one of the cells, while passing a known current (less than the illuminated short circuit current) through the module. This results in reverse biasing the shadowed cell, while the remaining illuminated cells are in their normal forward biased condition.

37.9 For example at the particular known current level example, A in Figure 37.2, the output voltage at the module terminals (V_o) under the condition of one cell shadowed will be the normal output voltage of the module with all cells illuminated (V_{am}), less the voltage of one cell (V_c), less the reverse voltage of the shadowed cell (V_r), that is:

$$V_o = V_{am} - V_c - V_r$$

The module normal output voltage and voltage of one cell, both at a particular current level are fixed. The reverse voltage of a cell at a particular current level is variable, cell-to-cell, being higher for higher shunt resistances. Thus, shadowing of the highest shunt resistance cell will result in lowest module output voltage, and shadowing of the lowest shunt resistance cell will result in the highest module voltage.

37.10 To determine the relative cell I-V characteristics by the non-intrusive method, the module is to be connected to a variable resistor so that the output current may be maintained at a fixed level under conditions of shadowing any one cell (same current regardless of which cell is shadowed). The module is to be illuminated under a source which can illuminate all cells at a repeatable and uniform intensity. The module temperature is to be monitored and is to remain constant. Normally these conditions can be achieved by outdoor testing under sunlight.

37.11 With the module so connected and illuminated, each cell in turn is to be shadowed, the resistor is to be adjusted to maintain the current at the preselected fixed value, and the output voltage of the module measured. That cell that is shadowed when the output voltage is maximum is the cell with minimum shunt resistance, and that cell shadowed when the output voltage is minimum is the cell with maximum shunt resistance. Intermediate shunt resistance cells will have intermediate module voltage outputs.

37.12 This method is relative only, and in the manner presented does not provide a numerical value of any of the resistances. The cells of a module may be all voltage limited (high shunt resistance, Type A), all current limited (low shunt resistance, Type B), or a combination of both. In general, the cells associated with the highest hot-spot heating levels are those with the highest shunt resistance, although low shunt resistance may be associated with highly localized heating.

37.13 Three non-adjacent individual cells within the test module or panel are to be selected: one representative of the highest shunt resistance obtained, one representative of the average, and one representative of the lowest. Each cell to be tested is to be provided with individual positive and negative electrical leads to allow the cells to be connected individually and directly to separate power supplies. Parallel current paths around the cells to be tested are to be eliminated by disrupting cell-to-cell connections as necessary. The lead attachment should minimize disruption of the heat transfer characteristics of the cell or the hot-spot endurance of the encapsulant system.

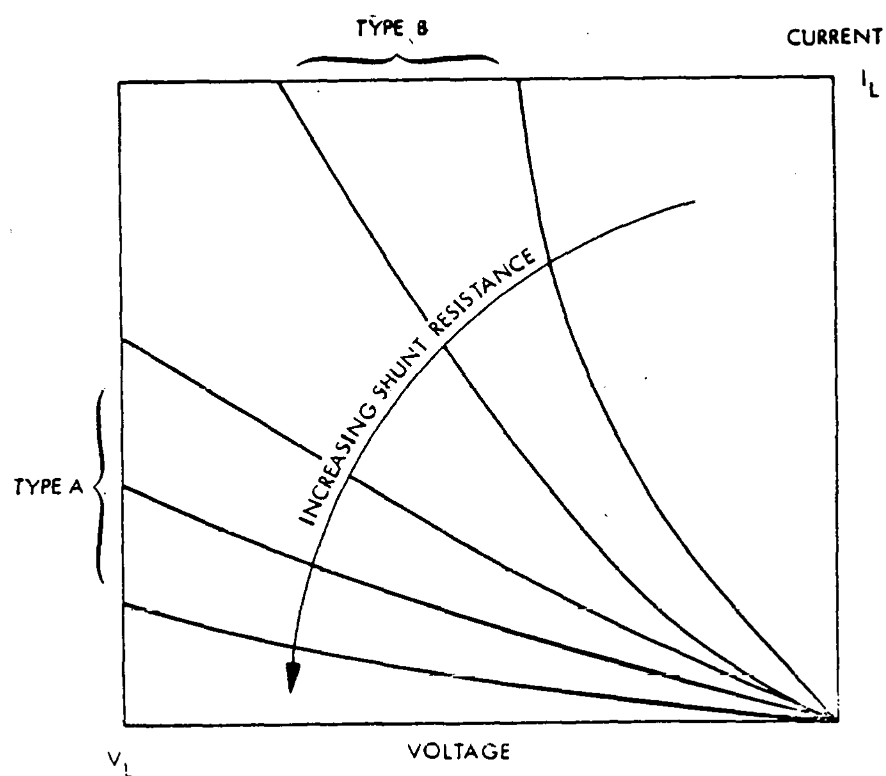
Selection of Hot-Spot Test Level

37.14 The objective of this portion of the test procedure is to select the level of heating and the corresponding test condition that will stress the module or panel in a manner similar to a severe hot-spot field condition. The severity of the field condition will depend on the array circuit configuration, the array I-V operating point, the ambient thermal conditions, the overall irradiance level, and the previously described characteristics of the affected cells. When a module is incorporated into a photovoltaic source circuit, the maximum reverse voltage imposed on an individual cell can approach the system voltage unless bypass diodes are properly used. V_L is set to yield the maximum reverse voltage that can be applied across a single cell when the module is applied in a circuit with the minimum number of bypass diodes as specified by its marking.

37.15 Thermocouples are to be affixed to the cell insulation system. See paragraphs 19.11 and 19.12.

37.16 In the paragraphs below the detailed levels are separately specified for Type A and Type B cells.

FIGURE 37.1
TYPICAL REVERSE-VOLTAGE I-V PLOT FOR SAMPLE OF CELLS



Type A Cells (High Shunt Resistance)

37.17 The governing parameters concerning reverse voltage heating are (1) the maximum cell reverse voltage (V_L), (2) the cell irradiance level, and (3) the ambient thermal environment.

37.18 V_L is to be set equal to N times the V_{mp} of an individual cell, where N is the number of series cells per specified or integral bypass diode.

37.19 The irradiance level directly controls the hot-spot current level, and therefore the power level. As illustrated in Figure 37.3, there is a unique irradiance level that corresponds to worst-case power dissipation for any particular Type A photovoltaic cell. The irradiance level on the test cell is to be adjusted to achieve this worst case power dissipation with a current I_{TEST} equal to the maximum power current of the cell at 100 mW/cm², NOCT.

37.20 The test is to be conducted in an ambient air temperature of 20±5°C and with a radiant heating source that will result in a uniform background module cell temperature equal to NOCT ±2°C.

Type B Cells (Low Shunt Resistance)

37.21 The cell shunt resistance of a Type B cell is so low that the maximum reverse voltage is set by the I-R drop across the cell. Worst-case heating occurs when the test cell is totally shadowed, and the current level is at a maximum. Accordingly, the irradiance is to be not more than 5 mW/cm², this level allows for room lighting and an IR heating source, and the current (I_L) is to be equal to the short-circuit current of an average cell at 100 mW/cm², NOCT.

37.22 The test is to be conducted in an ambient air temperature of 20±5°C with a radiant heating source that will result in a uniform background module cell temperature equal to NOCT ±2°C.

Test Execution

37.23 The three selected test cells are to be subjected to cyclic hot-spot heating at the levels determined above for a period of 100 hours total on-time as specified in paragraphs 37.24-37.28.

37.24 A constant voltage power supply (for Type A cells) and a constant current power supply (for Type B cells) is to be connected to the cell under test, with polarity arranged to drive the cells with reverse voltage. The voltage is to be adjusted to V_L and then the current is to be adjusted to I_{TEST} (for Type A cells) or I_L (for Type B cells). See paragraphs 37.18, 37.19, and 37.21.

37.25 An infra-red radiant heating source with a visible light contribution below 5 mW/cm^2 is to be applied to the module or panel and adjusted to result in a uniform module cell temperature equal to NOCT ±2°C. The ambient air is to be still and at a temperature of 20±5°C.

37.26 For Type A cells only, an additional light source is to be used to illuminate each test cell to the level determined in paragraph 37.19 (Figure 37.3). This is most easily accomplished after the power supply and IR source are turned on by adjusting the irradiance level to achieve the I_{TEST} current after equilibrium test conditions stabilize.

37.27 The power supply, IR source, and irradiance source are to be energized for one hour followed by an off-period sufficient to allow the cells under test to cool to within 10°C of the ambient temperature.

37.28 The operation is to be repeated until a total of 100 hours of on-time have been accumulated.

FIGURE 37.2
MODULE AND CELL CHARACTERISTICS - SHADOWED CELLS

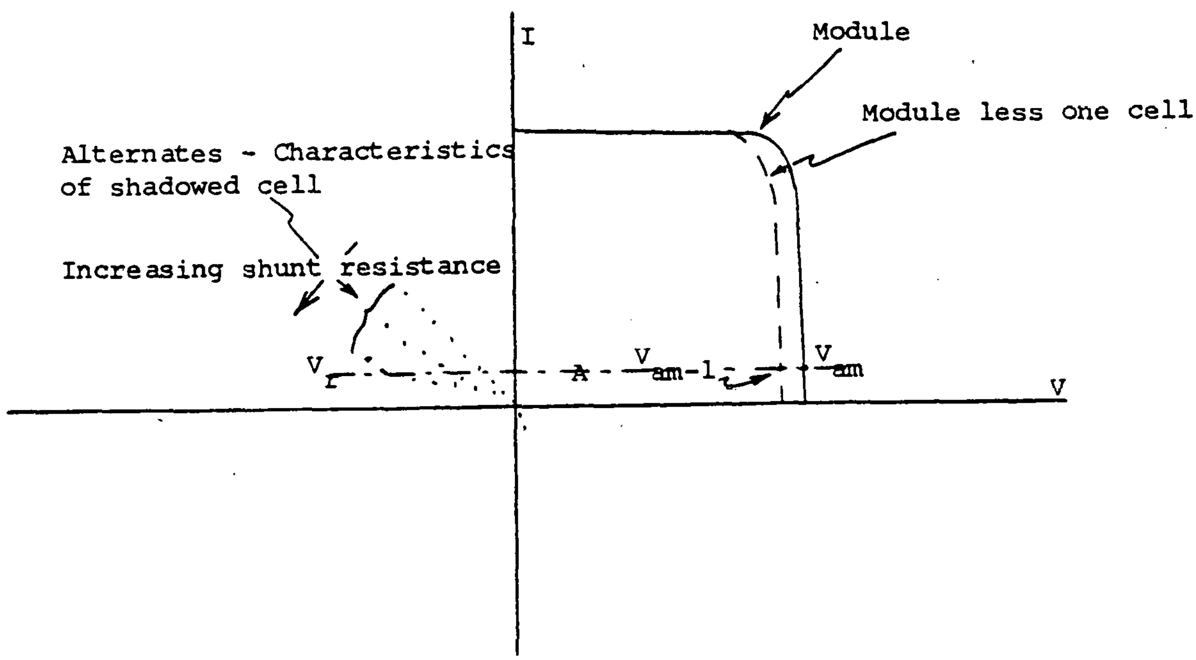
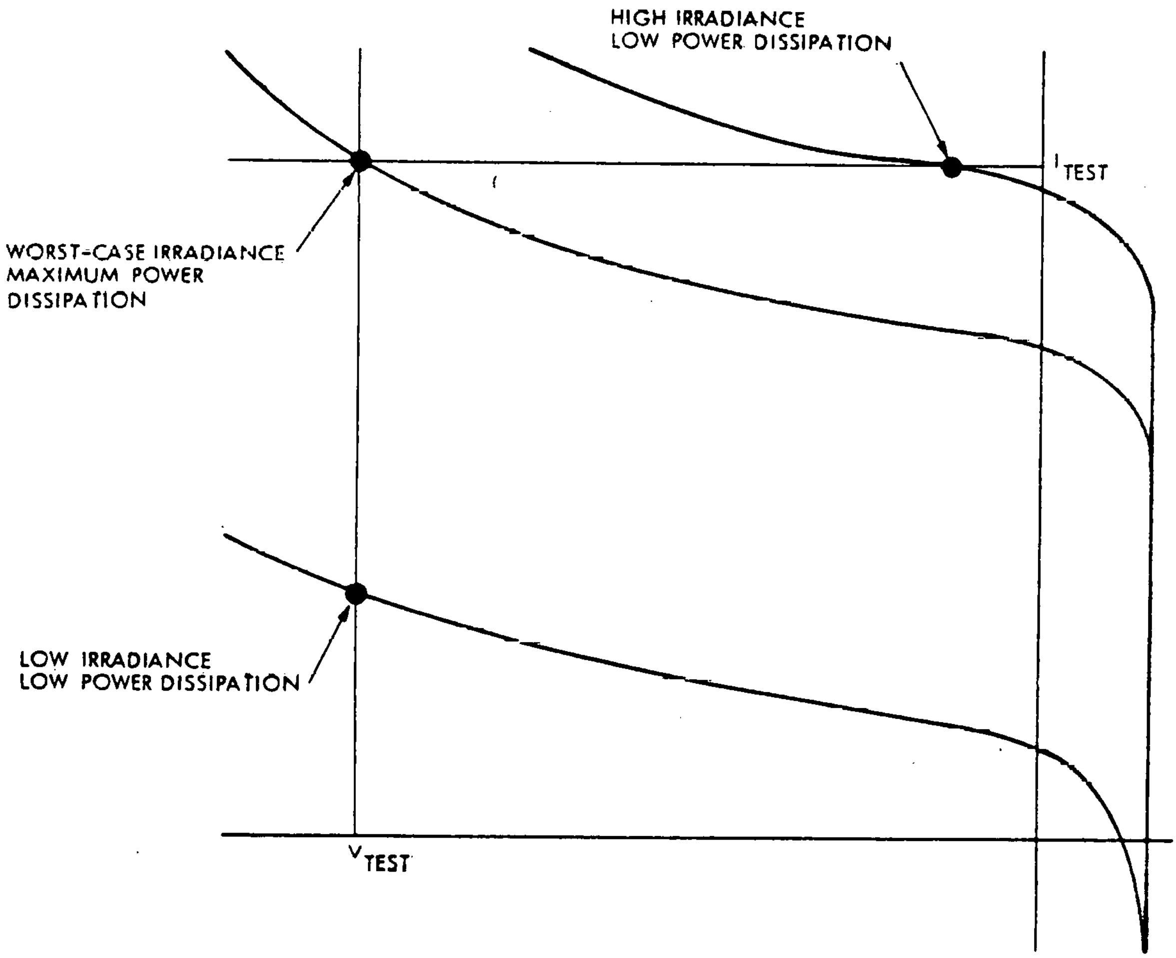


FIGURE 37.3
EFFECT OF TEST-CELL ILLUMINATION LEVEL ON HOT-SPOT
POWER DISSIPATION



37.29 The test cells and the adjacent areas of the encapsulation system are to be visually inspected at 24 hour intervals during the test while the cells are under impressed voltage conditions and also upon completion of the 100-hour sequence.

38. Arcing

38.1 If the point of current (at rated operating voltage) and voltage that can appear across a cell or interconnect fracture is in the 'ARC TEST' zone in Figure 38.1, the module or panel shall comply with the provisions of paragraphs 38.2-38.10. In determining the voltage, the value is to be the maximum that can be achieved considering the specified use of bypass diodes, i.e. - V_L as defined in paragraph 37.5. Also see paragraph 41.7.

38.2 Under conditions of simulated cell or interconnect fracture, there shall be no ignition of the module or panel.

Method A

38.3 Similar modules or panels under test are to be connected in series to achieve an open-circuit voltage across the fracture equal to that which is present in the normal use of the modules or panels with the specified bypass diodes. All the modules and panels are to be irradiated at 80 mW/cm^2 minimum at 20°-30°C.

Method B

38.4 A single module or panel is to be used with a separate power supply as described in paragraph 38.6 connected in series to provide the remainder of the source. The module or panel under test is to be irradiated at 80 mW/cm^2 minimum at 20°-30°C.

Method C

38.5 A single module or panel is to be used to provide the material for the ignition attempt. However, all power in the arc is to be provided by an external power supply as described in paragraph 38.6 connected in series with only passive portions of the module's circuit. Cells are to be jumpered if necessary to involve specific portions of the module or panel's insulation system.

38.6 In reference to paragraphs 38.4 and 38.5, the power supply is to be a constant voltage supply with a series connected current limiting resistor. The parameters of the total system are as follows:

Open-Circuit Voltage - Adjusted to that which is present across the fracture in the normal use of the modules or panels with the specified bypass diodes.

Short Circuit Current - Not less than 80 percent nor more than the rated module or panel short-circuit current, when the current limiting resistor is adjusted so that the voltage across the module or panel under test is zero.

Methods A and B

38.7 All bypass diodes, either included with the module or panel or described in the markings shall be included in the test circuit.

All Methods

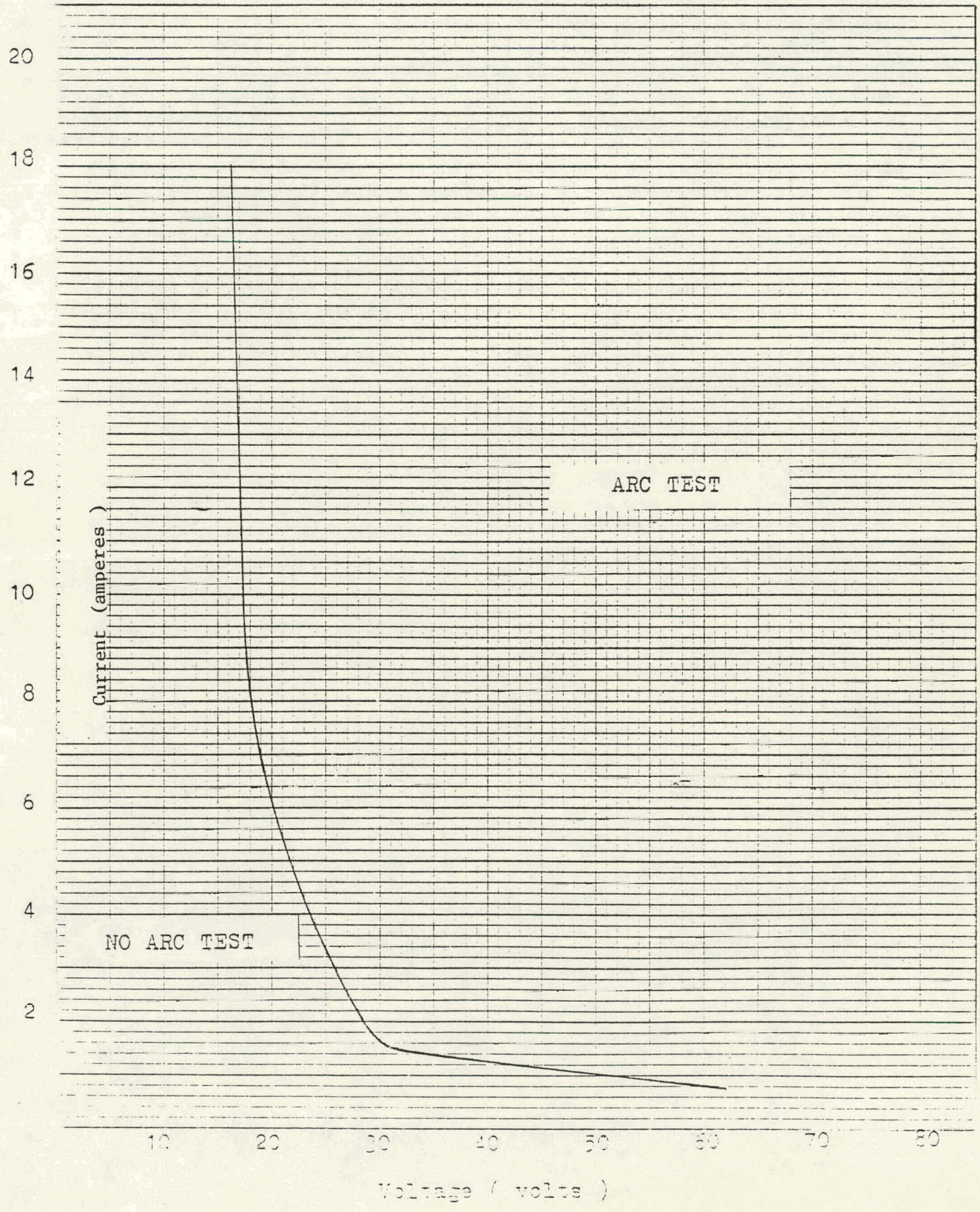
38.8 The system load is to be a short circuit.

38.9 Any connection(s) within the module or panel may be broken (fractured). The breaks are to be chosen to achieve a worst case condition of maximum open circuit voltage and/or maximum short circuit current at one of the chosen break points.

Exception: Any electrical connection made with wire of circular cross section or flexible braided construction that is mechanically secured to its connection points is not to be broken. Braided or stranded wire shall not have any process performed on it which reduces its flexibility. Solder coating of a portion of the wire at the connection points is acceptable.

38.10 An arc is to be drawn across the breaks, the arc is to be across that material of the module or panel with which it might contact in the use of the module or panel. The arcing shall be continued for 15 minutes at each location tested.

FIGURE 38.1 CURRENTS AND VOLTAGES FOR ARC TEST



39. Mechanical Loading

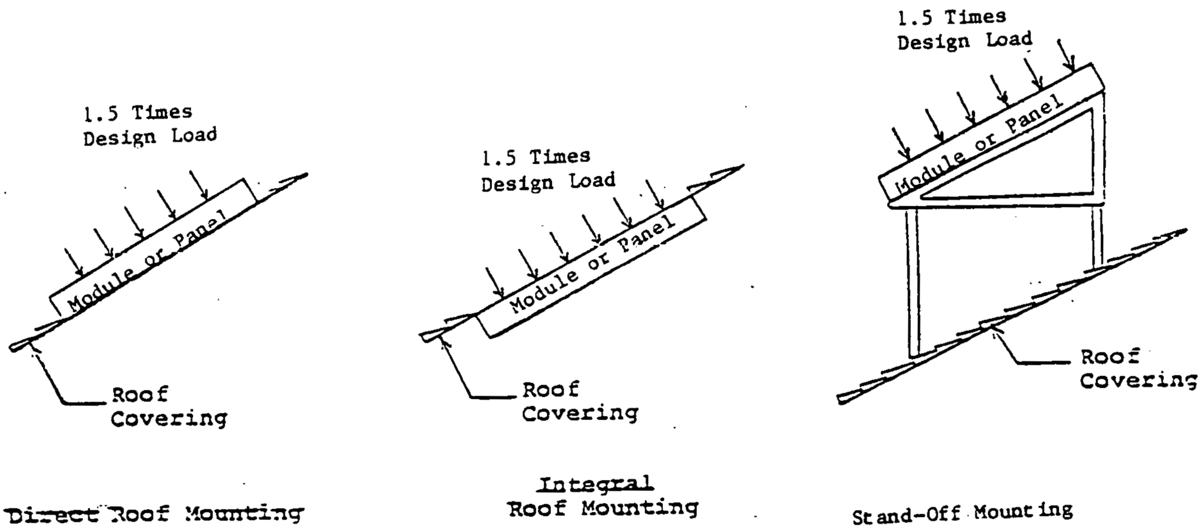
39.1 Modules and panels and any mounting hardware furnished therewith shall withstand, without evidence of structural or mechanical failure, the loading specified in Figure 39.1. Where loads are to be applied to the front and rear surfaces, they are to be applied simultaneously. The design load shall be 30 psf (146.5 Kgs/m^2) downward (positive) or upward (negative); or at the option of the organization responsible for the product a specified greater load. Modules which are intended to be installed such that they form a part of a building wall of roof structure and serve as primary members of that structure, shall have a maximum deflection of L/240 when subjected to 1.5 times the design load. (L = the clear span length of the deflected member.)

39.2 For determination of compliance with paragraph 39.1 by test, the test loads shall be applied as shown in Figure 39.1 for a period of 30 minutes. Alternatively, compliance with paragraph 39.1 may be determined by engineering analysis. Downward and upward loads shall not be applied simultaneously.

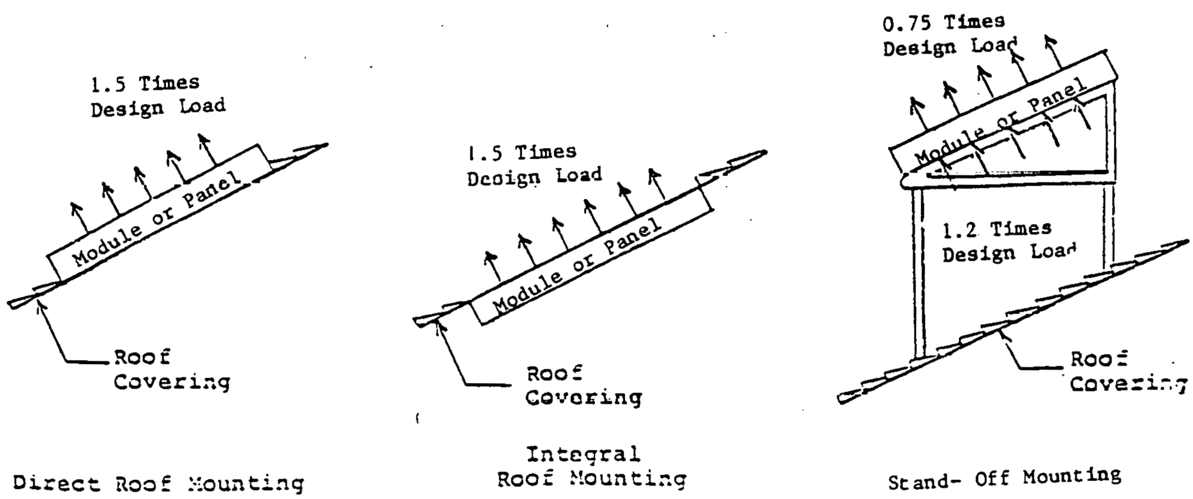
39.3 All glazing materials shall be of such strength as to withstand the loads specified in paragraph 39.1.

FIGURE 39.1
LOAD APPLICATION

Positive (Downward) Load Distribution



Negative (Upward) Load Distribution



RATING

40. Details

40.1 The electrical rating of a module or panel shall include the voltage, current, and power ratings specified in Table 40.1.

TABLE 40.1

ELECTRICAL RATINGS

Voltage	Current	Power
Open circuit voltage	Short circuit current	Maximum power at NOCT
Operating voltage	Current at rated operating voltage	
Maximum system voltage		

MARKING

41. Details

41.1 A module or panel shall have a plain, legible, permanent marking that includes: (1) the manufacturer's name, trademark, or other descriptive marking by which the organization responsible for the product can be identified; (2) the model number or the equivalent; (3) the electrical rating; and (4) the date or other dating period of manufacture not exceeding any three consecutive months. Items (1) and (2) of the marking shall be located so that they will be readily visible after the module or panel has been installed as intended.

Exception No. 1: The manufacturer's identification may be in a traceable code if the product is identified by the brand or trademark owned by a private labeler.

Exception No. 2: The date of manufacture may be abbreviated; or may be in a nationally accepted conventional code or in a code affirmed by the manufacturer, provided that the code:

A. Does not repeat in less than 10 years.

B. Does not require reference to the production records of the manufacturer to determine when the product was manufactured.

41.2 If a module or panel is manufactured at more than one factory, it shall have a marking indicating its point of manufacture.

41.3 The output power wiring terminals, leads, connectors, or other connection means of a module or panel shall be identified by a permanent marking:

"+" or "POS" or "POSITIVE"	and	"-" or "NEG" or "NEGATIVE"

41.4 If, during the temperature test, the temperature on a field-installed lead or on any part of the wiring compartment that the lead might contact is more than 60°C (140°F), the module or panel shall be marked with one of the statements indicated in items (a) or (b) below or the equivalent. The marking shall be located at or near the points where field connections will be made, and located so that it will be readily visible during installation.

(a) "For field connections, use No. _____ AWG wires insulated for a minimum of 75°C",

(b) "For field connections, use No. _____ AWG wires insulated for a minimum of 90°C".

41.5 If the pressure wire connectors of a module or panel are not acceptable for use with aluminum wire, or if the module or panel manufacturer intends the use of only copper wire, the module or panel shall be marked, at or adjacent to the terminals, with the statement "Use copper wire only", "CU only" or the equivalent. This marking may be combined with that required by paragraph 41.4.

41.6 If the pressure wire connectors of a module or panel are acceptable for accommodating both copper and aluminum wire and if the manufacturer intends such use, the module or panel shall be marked (independent of any marking of the terminal) with the statement "Use aluminum or copper wire", "AL-CU", or the equivalent. This marking may be combined with that required by paragraph 41.4.

41.7 A module or panel shall be marked (a) relative to the minimum acceptable diode bypassing, or (b) to make reference to manufacturer's literature where information on diode bypassing can be found. If option (b) is chosen, the manufacturer shall provide this literature with the modules or panels.

Exception: Marking and/or literature need not be provided if the system direct voltage rating is equal to the limit voltage (V_L) used for the Hot Spot Endurance Test and the voltage used for the Arcing Test. See paragraphs 37.5 and 38.1 respectively.

41.8 A module or panel shall be marked relative to the maximum electrical rating of an acceptable series fuse (for protection against backfeed).

41.9 A module or panel shall be marked relative to its fire resistance rating as a roof covering. A module or panel shall be marked "Not Fire Rated", unless it complies with the requirements for fire rating. If a module or panel is fire rated and if its use is so intended by the manufacturer, it shall be marked accordingly, for example - "Modules mounted free standing 6 inches above a Class B roof constitute a Class C roof".

41.10 A module provided as a part of a panel shall be provided with all of the markings which would be required for its existence as a separate entity.

41.11 A terminal of a module or panel (for example, a wire-binding screw, a pressure wire connector, or a nut-on-stud) intended to accommodate an equipment grounding conductor shall be identified by being marked "G", "GR", "GROUND", "GROUNDING", or the like, or shall have a green-colored part. No other terminal shall be so identified.

41.12 If a marking is used to identify an equipment grounding terminal, it shall be located on or adjacent to the terminal, or on a wiring diagram affixed to the module or panel near the terminal.

41.13 If a green-colored part is used to identify the equipment grounding terminal, it shall be readily visible during and after installation of the equipment grounding conductor and the portion of the terminal that is green shall not be readily removable from the remainder of the terminal.

41.14 The surface of a lead of a module or panel intended for the connection of an equipment grounding conductor shall be identified by insulation colored green, or green with yellow stripe(s). No other lead shall be so identified.

41.15 A module or panel found acceptable for structural loads greater than the minimum, see paragraph 39.1, may be marked with the design load.

42. Installation and Assembly Instructions

42.1 Installation instructions shall be provided describing the method of electrical and mechanical installation and the electrical ratings of the module or panel. Detail on the acceptable mounting structure, spacings, etc. shall be included for any module or panel provided with a fire rating if the fire rating is a function of these parameters.

42.2 The installation instructions shall include a statement advising that artificially concentrated sunlight shall not be directed on the module or panel.

42.3 Assembly instructions shall be provided with a product shipped in subassemblies, and shall be detailed and adequate to the degree required to facilitate total assembly of the product.

PRODUCTION LINE TESTS

43. Factory Dielectric Voltage Withstand Test

43.1 Each module or panel shall withstand for one minute without electrical breakdown as a routine production line test, the application of a test potential between parts involving a risk of electric shock and accessible metal parts. The test period may be reduced to one second if the potential shown below is increased to 120 percent of the value described.

43.2 The test potential is to be 2 V + 1,000 v dc. "V" is the rated maximum acceptable system direct voltage.

Exception: If the module or panel system voltage rating is 30 volts or less, the test potential is to be 500 volts.

43.3 The test equipment is to include a means of indicating the test voltage that is being applied to the product under test. This may be accomplished by sensing the voltage at the test leads or by an equivalent means. The test equipment is also to include a means of effectively indicating unacceptable performance. The indication is to be (1) audible if it can be readily heard above the background noise level; (2) visual, if it commands the attention of the operator; or (3) a device that automatically rejects an unacceptable product. If the indication of unacceptable performance is audible or visual, the indication is to remain active and conspicuous until the test equipment is manually reset.

43.4 The test potential mentioned in paragraph 43.2 may be obtained from any convenient source having a capacity of at least 500 VA.

Exception: The capacity may be lower if the means of indicating the voltage is located in the output circuit - to maintain the potential indicated in paragraph 43.2 except in case of breakdown. The voltage of the source is to be continuously adjustable.

43.5 The test equipment is to indicate unacceptable performance within 0.5 second if the leakage current at the test voltage exceeds 50 microamperes.

43.6 The test is to be conducted when the module is complete and ready for packing, or when it is complete except for covers or other parts that may interfere with the performance of the test.

44. Continuity of Grounding Connection

44.1 Each module or panel provided with a connection for grounding accessible conductive parts shall be subjected to a routine production line test to demonstrate electrical continuity between the grounding connection and all accessible conductive parts.

44.2 Any appropriate indicating device, ohmmeter, low voltage battery and buzzer combination or the like may be employed for the test described in paragraph 44.1.

APPENDIX B

DRAFT STANDARD FOR POWER CONDITIONING UNITS FOR USE IN RESIDENTIAL PHOTOVOLTAIC POWER SYSTEMS

SEPTEMBER, 1982

DRAFT STANDARD FOR
POWER CONDITIONING UNITS
FOR USE IN
RESIDENTIAL PHOTOVOLTAIC
POWER SYSTEMS

Contract No. BX-707

September, 1982

Prepared For

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY

Submitted By

UNDERWRITERS LABORATORIES INC.

TABLE OF CONTENTS

GENERAL

1. Scope

1.1 These requirements cover permanently connected power conditioning units which change dc electric power from residential photovoltaic arrays to ac electric power intended for use in parallel with a single phase electric utility (utility interactive). The power conditioning units covered by this standard are rated up to 600 volt dc, input; 10 kilowatt, 600 volt, ac or less, single phase output and are intended to be installed in accordance with the National Electrical Code. Additional requirements may be needed for: (1) power conditioning units which are intended to be used with energy storage systems and (2) power conditioning systems not intended to be connected to the electric utility.

2. Glossary

2.1 For the purposes of this standard, the following definitions apply.

2.2 ELECTRIC SHOCK - A part that involves a risk of electric shock is a part at which:

A. The potential between the part and ground, or any other simultaneously accessible part, exceeds

1. 30 volt rms (42.4 volt peak), or

2. 60 volt dc, or

3. 24.8 volt dc interrupted at a rate of 10-200 hertz, and,

the current through a 1500 ohm noninductive resistance exceeds 5 milliamperes, or at which

B. the potential between the part and ground, or any other simultaneously accessible part, exceeds:

1. 42.4 volt peak but is not more than 450 volt peak, and the capacitance between the parts exceeds 0.1μF; or

2. 450 volt peak but is not more than 15 kilovolt peak, and the product of capactance in microfarads times the potential in volts exceeds 45μC.

2.3 ENCLOSURE - That portion of a power conditioning unit that (1) renders all or any part that may otherwise present a risk of electric shock or injury to persons inaccessible, or (2) prevents propogation of flame, sparks and molten metal initiated by electrical disturbances occurring within.

2.4 FIELD-WIRING TERMINAL - Any terminal to which a supply, load, or other wire is intended to be connected by an installer.

2.5 LIVE PARTS - Denotes metal or other conductive parts within the unit that, in normal use, have a potential difference with respect to earth ground or any other conductive part.

2.6 LOW-VOLTAGE, LIMITED-ENERGY CIRCUIT - A circuit involving a potential of not more than 30 volts rms -- 42.4 volt peak for nonsinusoidal waveforms -- and supplied by a (1) primary battery, (2) standard Class 2 transformer, or (3) combination of a transformer and a fixed impedance that as a unit, complies with all the performance requirements for a Class 2 transformer.

2.7 SAFETY CIRCUIT - Any primary or secondary circuit that is relied upon to reduce risk of fire, electric shock, or injury to persons. An interlock circuit, for example, is to be considered a safety circuit.

2.8 SECONDARY CIRCUIT - A secondary circuit is a circuit supplied from a secondary winding of an isolating transformer.

3. Components

3.1 A component used as a part of a power conditioning unit covered by this standard shall comply with the standard or other requirements for that component and shall be used in accordance with its recognized rating and other limitations of use. A component need not comply with a specific requirement that:

A. Involves a feature or characteristic not needed in the application of the component in the product covered by this standard, or

B. Is superseded by a requirement in this standard.

4. Units of Measurement

4.1 If a value for measurement is followed by a value in other units in parentheses, the second value may be only approximate. The first stated value is the requirement. SI units are in accordance with the American National Standard for Metric Practice, ANSI/ASTM E380.

CONSTRUCTION

5. General

5.1 A power conditioning unit shall employ materials found by investigation to be acceptable for the use, and shall be made and finished with the degree of uniformity and grade of workmanship practicable in a well-equipped factory.

6. Frame and Enclosure

General

6.1 A power conditioning unit shall be provided with an enclosure that shall house all live or current-carrying parts. The enclosure shall protect the various parts of the power conditioning unit against mechanical damage from forces external to the overall power conditioning unit. The parts of the enclosure that are required to be in place to comply with the requirements for risk of fire, electric shock, injury to persons shall comply with the applicable enclosure requirements specified in this standard.

6.2 The frame or chassis of a power conditioning unit shall not be relied upon to carry current during normal operation.

Exception: As provided in the exception to paragraph 14.11.

6.3 A part, such as a dial or nameplate that is, in effect, a part of the enclosure shall comply with the enclosure requirements.

Access Covers

6.4 An enclosure cover shall be hinged if it gives access to a fuse or other overload-protective device, the functioning of which requires renewal, or if it is necessary to open the cover in connection with normal operation of the power conditioning unit. The cover shall not depend solely upon screws or other similar means requiring the use of a tool to hold it closed, but shall be provided with a spring latch or catch, or a hand operable captive fastener.

Exception No. 1: A cover is not required to be provided with a hinge if the only overload-protective devices enclosed are: (1) supplementary types in control circuits, provided the protective device and the circuit loads are within the same enclosure, (2) supplementary types rated 2 amperes or less for loads not exceeding 100 volt-amperes, (3) extractor fuses having an integral enclosure, or (4) protective devices connected in a low-voltage, limited-energy circuit.

Exception No. 2: A cover is not required to be provided with a hinge for an enclosure that contain no user-serviceable or -operable parts and which is provided with a marking in accordance with paragraph 50.5.

6.5 A door or cover giving access to a fuse or thermal cutout shall (1) shut closely against a 1/4-inch (6.4-mm) rabbet or the equivalent, (2) have turned flanges for the full length of four edges, or (3) have angle strips fastened to it. Flanges or angle strips shall fit closely with the outside of the walls of the box proper and shall overlap the edges of the box not less than 1/2 inch (12.7 mm). A strip used to provide a rabbet and an angle strip fastened to the edges of a door shall be secured at not less than two points, not more than 1-1/2 inches (38.1 mm) from each end of each strip and at points between these end fastenings not more than 6 inches (152 mm) apart. A construction that affords equivalent protection or a combination of flange and rabbet is acceptable. See Figures 6.1 and 6.2.

Exception: See Exception No. 1 to paragraph 6.4.

FIGURE 6.1
RABBET

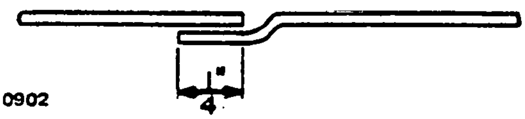


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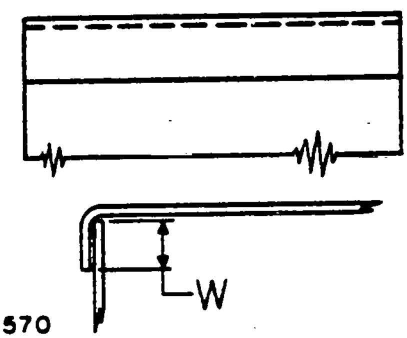
FIGURE 6.2
MEASUREMENT OF OVERLAP



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Cast Metal

6.6 The thickness of cast metal for an enclosure shall be as indicated in Table 6.1.

Exception: Cast metal of lesser thickness may be employed if, upon investigation (consideration being given to the shape, size, and function of the enclosure), it is found to have adequate mechanical strength.

TABLE 6.1
THICKNESS OF CAST METAL ENCLOSURES

Use, or Dimension of Area Involved	Minimum Thickness			
	Die-Cast Metal[a]		Cast Metal Other Than Die-Cast Type	
	Inches	(mm)	Inches	(mm)
Area of 24 square inches (154.8 cm^2) or less having no dimension greater than 6 inches (152 mm)	1/16[b]	(1.6)	1/8	(3.2)
Area greater than 24 square inches (154.8 cm^2) or having any dimension greater than 6 inches (152 mm)	3/32	(2.4)	1/8	(3.2)
At a threaded conduit hole	1/4	(6.4)	1/4	(6.4)
At an unthreaded conduit hole	1/8	(3.2)	1/8	(3.2)

[a] Die-cast metal may be employed if, upon investigation, it is found to have adequate mechanical strength and to be otherwise suitable for the particular application.

[b] The area limitations for metal 1/16 inch (1.6 mm) thick may be obtained by the provision of suitable reinforcing ribs subdividing a larger area.

Sheet Metal

6.7 Unless investigated and found acceptable for the application, the thickness of a sheet-metal enclosure shall not be less than that specified in Tables 6.2 and 6.3, except that uncoated steel shall not be less than 0.032 inch (0.81 mm) thick, zinc-coated steel shall not be less than 0.034 inch (0.86 mm) thick, and nonferrous metal shall not be less than 0.045 inch (1.14 mm) thick at points at which a wiring system is to be connected.

6.8 Tables 6.2 and 6.3 are based on a uniform deflection of the enclosure surface for any given load concentrated at the center of the surface regardless of metal thickness.

6.9 With reference to Tables 6.2 and 6.3, a supporting frame is a structure of angle or channel or a folded rigid section of sheet metal that is rigidly attached to and has essentially the same outside dimensions as the enclosure surface and that has the torsional rigidity to resist the bending moments that may be applied via the enclosure surface when it is deflected. Construction that is considered to have equivalent reinforcing may be accomplished by designs that will produce a structure that is as rigid as one built with a frame of angles or channels.

TABLE 6.2
THICKNESS OF SHEET METAL FOR ENCLOSURES, CARBON STEEL OR STAINLESS STEEL

Without Supporting Frame[a]				With Supporting Frame or Equivalent Reinforcing[a]				Minimum Thickness, Inch (mm)			
Maximum Width,[b] Inches	(cm)	Maximum Length,[c] Inches	(cm)	Maximum Width,[b] Inches	(cm)	Maximum Length Inches	(cm)	Uncoated	(mm)	Metal Coated	(mm)
4.0	(10.2)	Not limited		6.25	(15.9)	Not limited		0.020[d]	(0.51)	0.023[d]	(0.58)
4.75	(12.1)	5.75	(14.6)	6.75	(17.1)	8.25	(21.0)				
6.0	(15.2)	Not limited		9.5	(24.1)	Not limited		0.026[d]	(0.66)	0.029[d]	(0.74)
7.0	(17.8)	8.75	(22.2)	10.0	(25.4)	12.5	(31.8)				
8.0	(20.3)	Not limited		12.0	(30.5)	Not limited		0.032	(0.81)	0.034	(0.86)
9.0	(22.9)	11.5	(29.2)	13.0	(33.0)	16.0	(40.6)				
12.5	(31.8)	Not limited		19.5	(49.5)	Not limited		0.042	(1.07)	0.045	(1.14)
14.0	(35.6)	18.0	(45.7)	21.0	(53.3)	25.0	(63.5)				
18.0	(45.7)	Not limited		27.0	(68.6)	Not limited		0.053	(1.35)	0.056	(1.42)
20.0	(50.8)	25.0	(63.5)	29.0	(73.7)	36.0	(91.4)				
22.0	(55.9)	Not limited		33.0	(83.8)	Not limited		0.060	(1.52)	0.063	(1.60)
25.0	(63.5)	31.0	(78.7)	35.0	(88.9)	43.0	(109.2)				
25.0	(63.5)	Not limited		39.0	(99.1)	Not limited		0.067	(1.70)	0.070	(1.78)
29.0	(73.7)	36.0	(91.4)	41.0	(104.1)	51.0	(129.5)				
33.0	(83.8)	Not limited		51.0	(129.5)	Not limited		0.080	(2.03)	0.084	(2.13)
38.0	(103.4)	47.0	(119.4)	54.0	(137.2)	66.0	(167.6)				
42.0	(106.7)	Not limited		64.0	(162.6)	Not limited		0.093	(2.36)	0.097	(2.46)
47.0	(119.4)	59.0	(149.9)	68.0	(172.7)	84.0	(213.4)				
52.0	(132.1)	Not limited		80.0	(203.2)	Not limited		0.108	(2.74)	0.111	(2.82)
60.0	(152.4)	74.0	(188.0)	84.0	(213.4)	103.0	(261.6)				
63.0	(160.0)	Not limited		97.0	(246.4)	Not limited		0.123	(3.12)	0.126	(3.20)
73.0	(185.4)	90.0	(228.6)	103.0	(261.6)	127.0	(322.6)				

[a] See paragraphs 6.7 and 6.8

[b] The width is the smaller dimension of a rectangular sheet metal piece that is part of an enclosure. Adjacent surfaces of an enclosure may have supports in common and be made of a single sheet.

[c] For panels that are not supported along one side; for example, side panels of boxes, the length of the unsupported side shall be limited to the dimensions specified.

[d] Sheet steel for an enclosure intended for outdoor use shall not be less than 0.034 inch (0.86 mm) thick if metal coated and not less than 0.032 inch (0.81 mm) thick if uncoated.

TABLE 6.3
THICKNESS OF SHEET METAL FOR
ENCLOSURES, ALUMINUM, COPPER, OR BRASS

Without Supporting Frame[a]				With Supporting Frame or Equivalent Reinforcing[a]				Minimum Thickness Inch (mm)
Maximum Width,[b] Inches	(cm)	Maximum Length,[c] Inches	(cm)	Maximum Width,[b] Inches	(cm)	Maximum Length, Inches	(cm)	
3.0	(7.6)	Not limited		7.0	(17.8)	Not limited		0.023[d]
3.5	(8.9)	4.0	(10.2)	8.5	(21.6)	9.5	(24.1)	(0.58)
4.0	(10.2)	Not limited		10.0	(25.4)	Not limited		0.029
5.0	(12.7)	6.0	(15.2)	10.5	(26.7)	13.5	(34.3)	(0.74)
6.0	(15.2)	Not limited		14.0	(35.6)	Not limited		0.036
6.5	(16.5)	8.0	(20.3)	15.0	(38.1)	18.0	(45.7)	(0.91)
8.0	(20.3)	Not limited		19.0	(48.3)	Not limited		0.045
9.5	(24.1)	11.5	(29.2)	21.0	(53.3)	25.0	(63.5)	(1.14)
12.0	(30.5)	Not limited		28.0	(71.1)	Not limited		0.058
14.0	(35.6)	16.0	(40.6)	30.0	(76.2)	37.0	(94.0)	(1.47)
18.0	(45.7)	Not limited		42.0	(106.7)	Not limited		0.075
20.0	(50.8)	25.0	(63.5)	45.0	(114.3)	55.0	(139.7)	(1.91)
25.0	(63.5)	Not limited		60.0	(152.4)	Not limited		0.095
29.0	(73.7)	36.0	(91.4)	64.0	(162.6)	78.0	(198.1)	(2.41)
37.0	(94.0)	Not limited		87.0	(221.0)	Not limited		0.122
42.0	(106.7)	53.0	(134.6)	93.0	(236.2)	114.0	(289.6)	(3.10)
52.0	(132.1)	Not limited		123.0	(312.4)	Not limited		0.153
60.0	(152.4)	74.0	(188.0)	130.0	(330.2)	160.0	(406.4)	(3.89)

[a] See paragraphs 6.7 and 6.8

[b] The width is the smaller dimension of a rectangular sheet metal piece that is part of an enclosure. Adjacent surfaces of an enclosure may have supports in common and be made of a single sheet.

[c] For panels that are not supported along one side; for example, side panels of boxes, the length of the unsupported side shall be limited to the dimensions specified.

[d] Sheet copper, brass, or aluminum for an enclosure intended for outdoor use shall not be less than 0.029 inch (0.74 mm) thick.

6.10 With reference to paragraph 6.9 and Tables 6.2 and 6.3, a construction is not considered to have a supporting frame if it is:

A. A single sheet with single formed flanges -- formed edges;

B. A single sheet that is corrugated or ribbed;

C. An enclosure formed or fabricated from sheet metal; or

D. An enclosure surface loosely attached to a frame; for example, by spring clips.

Nonmetallic

6.11 A polymeric enclosure or polymeric part of an enclosure shall comply with the requirements in the Standard for Polymeric Materials -- Use in Electrical Equipment Evaluations, UL 746C.

6.12 A nonmetallic part, such as a reset knob, lever, or button protruding through a hole in the enclosure shall be made of a material classified as 94V-0, 94V-1, or 94V-2 in the Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94, if the hole is not larger than 0.6 square inch (3.9 cm^2). Nonmetallic parts protruding through a hole larger than 0.6 square inch shall be made of materials that comply with the requirement in paragraph 6.11.

6.13 If an electrical instrument, such as a meter, forms part of the enclosure, the face or the back of the instrument housing, or both together, shall comply with the requirements for an enclosure.

Exception: A meter complying with the requirements in the Standard for Electrical Analog Instruments -- Panelboard Type, UL 1437.

Glass Covered Openings

6.14 Glass covering an opening shall be secured in place so that it cannot be readily displaced in service, and shall provide mechanical protection for the enclosed parts. Glass for an opening not more than 4 inches (102 mm) in any dimensions shall not be less than 1/16 inch (1.6 mm) thick, and glass for a larger opening, but not more than 144 square inches (929 cm^2) in area and having no dimension greater than 12 inches (305 mm), shall not be less than 1/8 inch (3.2 mm) thick. Glass used to cover a larger area shall not be less than 1/8 inch thick and:

A. Shall be of a nonshattering or tempered type that, when broken, complies with the Performance Specifications and Methods of Test for Safety Glazing Material Used in Buildings, ANSI Z97.1-1975; or

B. Shall withstand a 2-1/2 foot-pound (3.38 joules) impact from a 2 inch (50.8 mm) diameter, 1.18 pound (535 grams) steel sphere without cracking or breaking to the extent that a piece is released or dropped from its normal position.

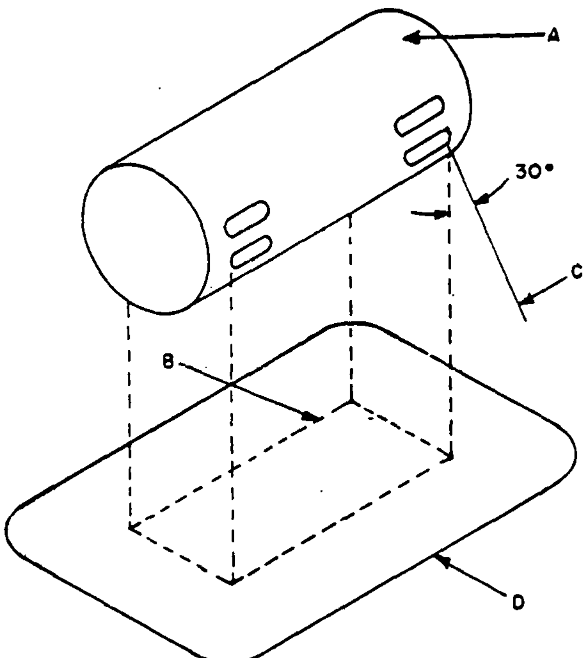
Wiring Openings

6.15 If threads for the connection of conduit are tapped all the way through a hole in an enclosure wall, or if an equivalent construction is employed, there shall not be less than three nor more than five threads in the metal, and the construction of the enclosure shall be such that a conduit bushing can be properly attached. If threads for the connection of conduit are not tapped all the way through a hole in an enclosure wall, conduit hub, or the like, there shall not be less than 3-1/2 threads in the metal and there shall be a smooth, rounded inlet hole for the conductors equivalent to that provided by a standard conduit bushing and that shall have an internal diameter approximately the same as that of the corresponding trade size of rigid conduit.

6.16 Clamps and fasteners for the attachment of conduit, electrical metallic tubing, armored cable, nonmetallic flexible tubing, nonmetallic-sheathed cable, service cable, or the like, that are supplied as a part of an enclosure shall comply with the Standard for Outlet Boxes and Fittings, UL 514.

6.17 A knockout in a sheet-metal enclosure shall be reliably secured but shall be capable of being removed without undue deformation of the enclosure.

FIGURE 6.3
PROTECTIVE PAN



SB0852

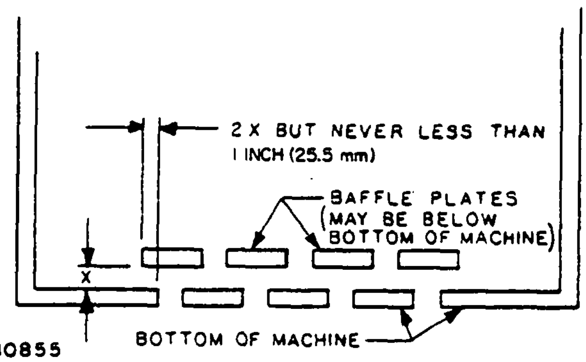
A. The entire component under which a barrier (flat or dished with or without a lip or other raised edge) of noncombustible material is to be provided. The sketch (Figure 6.3) is of an acceptably enclosed component with ventilating openings showing that the protective barrier is required only for those openings through which flaming parts might be emitted. If the component or assembly does not have its own noncombustible enclosure, the area to be protected is the entire area occupied by the component or assembly.

B. Projection of the outline of the area of A that needs a bottom barrier vertically downward onto the horizontal plane of the lowest point on the outer edge D of the barrier.

C. Inclined line that traces out an area D on the horizontal plane of the barrier. Moving around the perimeter of the area B that needs a bottom barrier, this line projects at a 30-degree angle from the line extending vertically at every point around the perimeter of A and is oriented to trace out the largest area, except that the angle may be less than 30 degrees if the barrier or portion of the bottom cover contacts a vertical barrier or side panel of noncombustible material, or if the horizontal extension of the barrier B to D exceeds 6 inches or 152 mm.

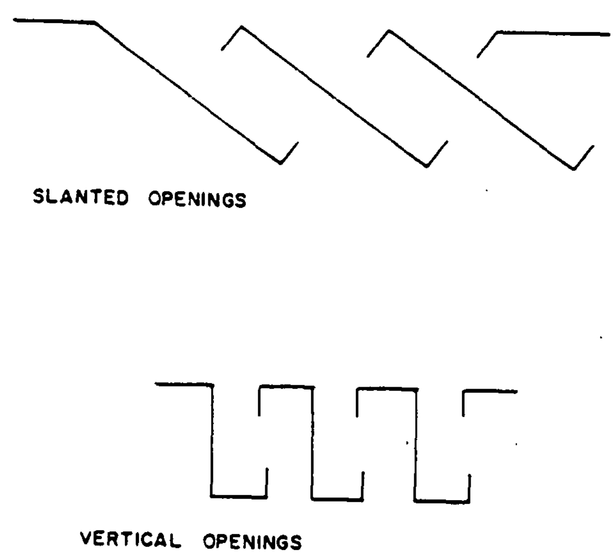
D. Minimum outline of the barrier, except that the extension B to D need not exceed 6 inches or 152 mm (flat or dished with or without a lip or other raised edge). The bottom of the barrier may be flat or formed in any manner provided that every point of area D is at or below the lowest point on the outer edge of the barrier.

FIGURE 6.4
EXAMPLE OF ACCEPTABLE BAFFLE



SB0855

FIGURE 6.5
CROSS SECTIONS OF TOP-COVER DESIGNS



SB0853

6.18 A knockout shall be provided with a flat surrounding surface adequate for proper seating of a conduit bushing and shall be located so that installation of a bushing at any knockout likely to be used during installation will not result in spacing between uninsulated live parts and the bushing of less than the requirements in this standard.

6.19 In measuring a spacing between an uninsulated live part and a bushing installed in a knockout as mentioned in paragraph 6.18 it is to be assumed that a bushing having the dimensions specified in Table 6.4 is in place, in conjunction with a single locknut installed on the outside of the enclosure.

TABLE 6.4
KNOCKOUT OR HOLE SIZES AND DIMENSIONS OF BUSHINGS

Trade Size of Conduit	Knockout or Hole Diameter		Bushing Dimensions: Overall Diameter		Bushing Dimensions: Height	
Inches	Inches	mm	Inches	mm	Inches	mm
1/2	7/8	22.2	1	25.4	3/8	9.5
3/4	1-3/32	27.8	1-15/64	31.4	27/64	10.7
1	1-23/64	34.5	1-19/32	40.5	33/64	13.1
1-1/4	1-23/32	43.7	1-15/16	49.2	9/16	14.3
1-1/2	1-31/32	50.0	2-13/64	56.0	19/32	15.1
2	2-15/32	62.7	2-45/64	68.7	5/8	15.9
2-1/2	3	76.2	3-7/32	81.8	3/4	19.1
3	3-5/8	92.1	3-7/8	98.4	13/16	20.6
3-1/2	4-1/8	104.8	4-7/16	112.7	15/16	23.8
4	4-5/8	117.5	4-31/32	126.2	1	25.4
4-1/2	5-1/8	130.2	5-35/64	140.9	1-1/16	27.0
5	5-5/8	142.9	6-7/32	158.0	1-3/16	30.2
6	6-3/4	171.5	7-7/32	183.4	1-1/4	31.8

6.20 For an enclosure not provided with conduit openings or knockouts, spacings not less than the minimum required in this standard shall be provided between uninsulated live parts and a conduit bushing installed at any location likely to be used during installation. Permanent marking on the enclosure, a template, or a full-scale drawing furnished with the power conditioning unit may be used to limit such a location.

6.21 A plate or plug for an unused conduit opening or other hole in the enclosure shall have a thickness not less than (1) 0.014 inch (0.36 mm) for steel or 0.019 inch (0.48 mm) for nonferrous metal for a hole having a 1/4-inch (6.4-mm) maximum dimension and (2) 0.027-inch (0.69-mm) steel or 0.032-inch (8.1-mm) nonferrous metal for a hole having a 1-3/8-inch (34.9-mm) maximum dimension. A closure for a larger hole shall have a thickness equal to that required for the enclosure of the power conditioning unit or a standard knockout seal shall be used. Such plates or plugs shall be securely mounted.

Ventilating Openings

6.22 The enclosure of a power conditioning unit shall be designed and constructed to minimize the possibility of emission of flame, molten metal, flaming or glowing particles, or flaming drops.

6.23 The requirement in paragraph 6.22 necessitates a complete noncombustible bottom or a construction employing individual noncombustible pans under components, groups of components, or assemblies, as specified in Figure 6.3.

Exception: Ventilation openings may be provided in the bottom panel or protective pans if baffle plates are provided to prevent materials from falling directly from the interior of the unit onto the supporting surface or any other location under the unit. The drawing in Figure 6.4 illustrates a type of baffle that meets this requirement.

6.24 Openings in the top of the enclosure shall be so located and of such size that entry of foreign objects is prevented. Openings directly over uninsulated live parts shall not exceed 0.187 inch (4.7 mm) in any dimension unless the configuration is such that direct entry to uninsulated live parts is prevented. See Figure 6.5 for examples of top surface openings that prevent direct entry.

6.25 The thickness of perforated sheet steel and sheet steel employed for expanded-metal used to cover an opening in the enclosure mesh shall comply with the requirements of Table 6.5.

Exception: Thicknesses less than specified in Table 6.5, but not less than specified in Table 6.6 may be used, if (1) the indentation of the material will not affect performance or reduce spacings to live parts below the minimum values given in Section 19, and (2) provided that either (3) the protected opening has an area of not more than 72 square inches (464.5 cm^2) and no dimension greater than 12 inches (304.8 mm), or (4) the width of the protected opening is not greater than 3-1/2 inches (88.9 mm).

TABLE 6.5
MINIMUM THICKNESS OF EXPANDED METAL MESH[a]

Openings	Uncoated Inch	(mm)	Zinc Coated Inch	(mm)
Max. 1/2 square inch ($3.23 cm^2$)	0.042	(1.07)	0.045	(1.14)
More than 1/2 square inch ($3.23 cm^2$)	0.080	(2.03)	0.084	(2.13)

In accordance with paragraph 6.23

TABLE 6.6
MINIMUM THICKNESS OF EXPANDED METAL MESH[a]

Uncoated Inch	(mm)	Zinc Coated Inch	(mm)
0.020	(0.51)	0.024	(0.61)

[a] In accordance with conditions given in exception to paragraph 6.23

7. Accessibility of Live Parts

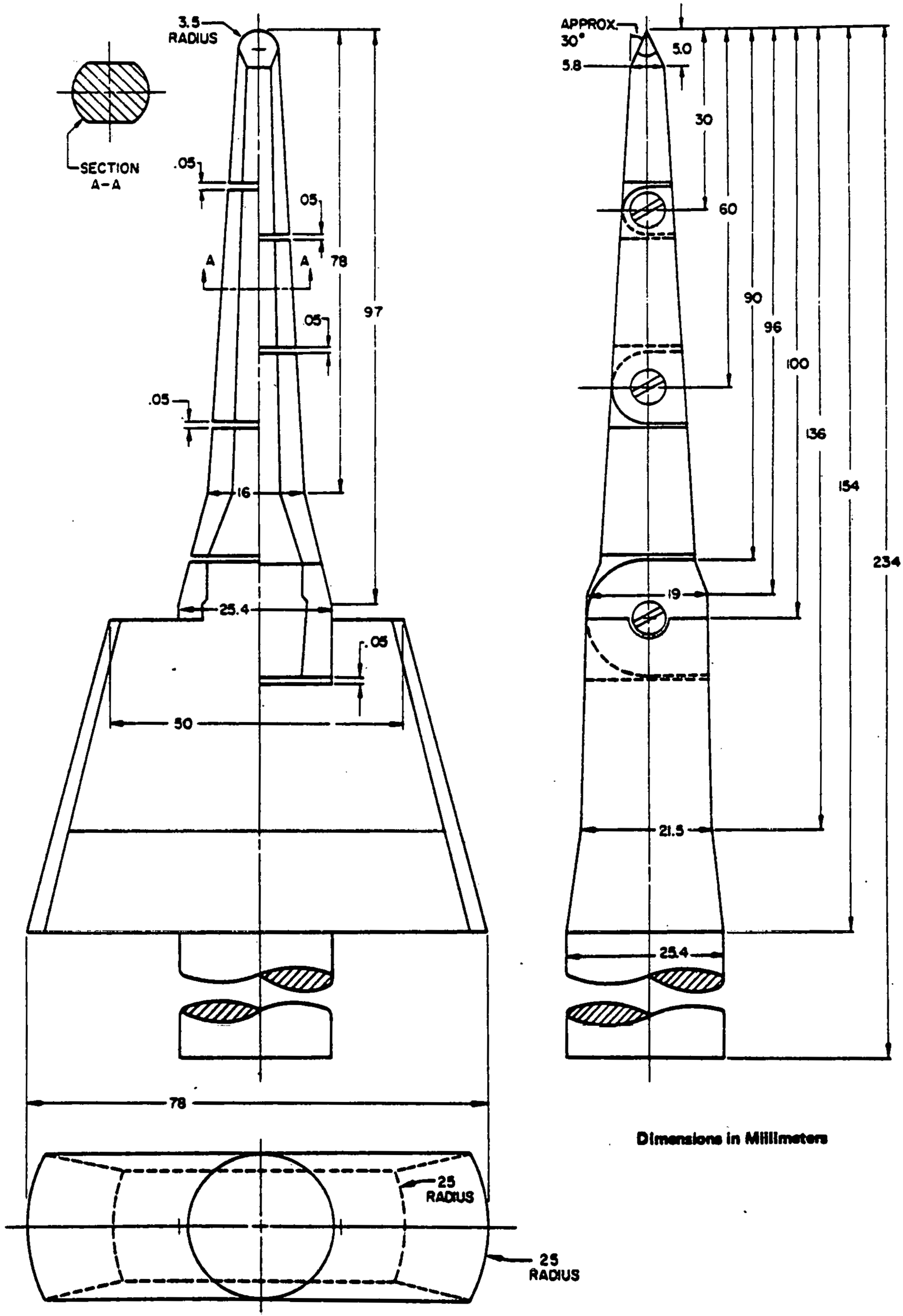
7.1 An opening in the enclosure or guard shall have a minor dimension less than 1 inch (25.4 mm), and shall not permit the probe illustrated in Figure 7.1 to contact an uninsulated live part involving a risk of electric shock when the probe is inserted through the opening to its maximum depth in a straight or articulated position.

7.2 A door or cover that provides access to a live part involving a risk of electric shock shall be securely held in place so that it can be opened or removed only by using a tool.

Exception: A door or cover that provides access to a live part that does not involve a risk of electric shock shall be securely held in place, but need not be secured so that it is necessary to use a tool to open or remove it.

7.3 Sheet-metal screws threading directly into metal shall not be used to attach a cover, a door, or other part that is removed to install field wiring or for operation of the power conditioning unit. Sheet metal screws may thread into sheet-metal nuts that are permanently mounted and protected against corrosion, and machine screws and self-tapping machine screws may thread directly into sheet-metal walls. See paragraph 16.8.

FIGURE 7.1
ACCESSIBILITY PROBE



Dimensions in Millimeters

7.4 A handle, knob, or other part intended to be user-operable or -accessed shall be arranged so that it can be operated from outside the enclosure.

7.5 A guard or baffle that can be removed without using a tool shall be removed when determining if a part is exposed to contact by persons. A part that can be contacted by the probe illustrated in Figure 7.1 when inserted through an opening in a permanently-attached guard or baffle is considered to be exposed to contact by persons.

8. Protection of Service Personnel

General

8.1 These requirements apply to live parts used in circuits other than low-voltage, limited-energy circuits.

8.2 Live parts shall be so arranged and covers so located as to reduce the risk of electric shock while covers are being removed and replaced.

8.3 An uninsulated live part involving a risk of electric shock and a moving part that involves a risk of injury to persons shall be located, guarded, or enclosed so as to prevent unintentional contact by service personnel adjusting or resetting controls, or the like, or performing mechanical service functions that may be performed with the equipment energized, such as lubricating a motor, adjusting the setting of a control with or without marked dial settings, resetting a trip mechanism, or operating a manual switch.

8.4 A component that may require examination, resetting adjustment, servicing, or maintenance while energized shall be so located and mounted with respect to other components and with respect to grounded metal parts that it is accessible for electrical service functions without subjecting the serviceperson to the risk of electric shock or injury to persons. Access to such components is not to be impeded by other components or by wiring in the direction of access.

8.5 Protection against the risk of electric shock and injury to persons may be obtained by mounting control components so that unimpeded access to each component is provided by an access cover or panel in the outer cabinet.

8.6 A live heat sink for a solid-state component, a live relay frame, and the like, which may be mistaken for dead metal shall be guarded to prevent contact by the serviceperson or be marked in accordance with paragraph 50.3.

9. Mounting

9.1 Provision shall be made for securely mounting a power conditioning unit in position. Bolts, screws, or other parts used for mounting a power conditioning unit shall be independent of those used for securing components to the frame, base, or panel.

Exception: Mounting holes may not be required for a floor supported or freestanding type power conditioning unit. See Stability, Section 33.

9.2 Keyhole slots for mounting screws may be provided if there is at least one round hole for accommodation of a permanent mounting screw. Keyhole slots shall be arranged to prevent wall-mounting screws from projecting into a compartment containing electrical parts and reducing spacings to less than than those specified in Section 19.

10. Corrosion Protection

10.1 Iron and steel parts shall be protected against corrosion by enameling, galvanizing, sherardizing, plating, or other equivalent means. This requirement applies to all enclosing cases whether of sheet steel or cast iron, and to all springs and other parts upon which proper mechanical operation may depend. Bearing surfaces should be of such materials and design as to inhibit binding due to corrosion.

Exception: The following need not be protected against corrosion: (1) bearings, or the like, where such protection is impracticable, (2) minor parts, such as washers, screws, bolts, and the like, if the failure of such unprotected parts would not be likely to result in a risk of fire, electric shock, or injury to persons, or the operation of the equipment being affected adversely, (3) a decorative grille that is not required to form a part of the enclosure, and (4) parts made of stainless steel (properly polished or treated, if necessary).

11. Mechanical Assembly

11.1 A power conditioning unit shall be assembled so that it will not be adversely affected by the vibration of normal operation.

11.2 A switch, a fuseholder, a lampholder, or other component shall be mounted or assembled securely, and shall be prevented from turning or shifting in its mounting panel.

Exception: The requirement that a switch be prevented from turning or shifting may be waived provided all four of the following conditions are met:

A. The switch is a plunger, slide, or other type that does not tend to rotate when operated. A toggle switch is considered to be subject to forces that tend to turn the switch during normal operation of the switch.

B. Means for mounting the switch make it unlikely that operation of the switch will loosen the switch.

C. Spacings are not reduced below the minimum acceptable values if the switch rotates.

D. Normal operation of the switch is by mechanical means rather than by direct contact by persons.

11.3 With reference to the requirements in paragraph 11.2, friction between surfaces is not acceptable as the sole means to prevent shifting or turning of live parts or a device having a single-hole mounting means but a properly applied lock washer is acceptable.

12. Switches and Controls

12.1 A switch or other control device shall have current, voltage and frequency ratings appropriate for the load when the power conditioning unit is operated normally or shall be investigated for the application.

Exception: A switch rated not less than twice the full-load current rating of the load is acceptable for controlling an alternating current inductive load having a power factor less than 75 percent, or the switch shall be investigated for the application.

13. Field Wiring Connections

General

13.1 A power conditioning unit shall have provision for permanent connection of a wiring system that is in accordance with the National Electrical Code, ANSI/NFPA No. 70-1981 is acceptable for the equipment.

13.2 The provision for making field-wiring connections are to be made shall be located so that the connections may be readily inspected after the power conditioning unit is installed as intended.

13.3 A field-wiring compartment intended for connection of a wiring shall have sufficient space for the wires intended to be used.

13.4 An outlet box, terminal box, wiring compartment, or the like, in which connections to the power conditioning unit circuit will be made in the field shall be free from any sharp edge, including screw threads, a burr, a fin, a moving part, or the like, that may abrade the insulation on conductors or otherwise damage the wiring.

13.5 An opening for the entry of a conductor or conductors of a low-voltage, limited-energy circuit shall be provided with an insulating bushing. The bushing may be mounted in place in the opening or may be within the enclosure so that it may be properly mounted when the equipment is installed.

13.6 The opening mentioned in paragraph 13.5 may be acceptable for permanent connection of a wiring system. See paragraph 13.1.

13.7 A bushing or rubber or rubber-like material provided in accordance with paragraph 13.5 shall be 1/8 inch (3.2 mm) or more thick, except that it may be not less than 3/64 inch (1.2 mm) thick if the metal around the hole is eyeletted or similarly treated to provide smooth edges. A hole in which such a bushing is mounted shall be free from sharp edges, burrs, projections, or the like, that might damage the bushing.

Wiring Terminals

13.8 Wiring terminals shall be provided for the connection of field-wiring conductors.

13.9 Field-wiring terminals shall be suitable for the connection of conductors having an ampacity not less than 125 percent of the rating of the power conditioning unit.

13.10 A wiring terminal shall be provided with a pressure terminal connector securely fastened in place -- for example, firmly bolted or held by a screw.

Exception: A wire-binding screw may be employed at a wiring terminal intended for connection of a No. 10 AWG or smaller conductor if upturned lugs or the equivalent are provided to hold the wire in position.

13.11 A wiring terminal shall be prevented from turning or shifting in position by a means other than friction between surfaces. This may be accomplished by two screws or rivets; by square shoulders or mortises; by a dowel pin, lug or offset; by a connecting strap or clip fitted into an adjacent part; or by an equivalent method.

13.12 A wire-binding screw at a field-wiring terminal shall not be smaller than No. 10.

Exception No. 1: A No. 8 screw may be used at a terminal intended only for the connection of a No. 14 AWG or smaller conductor.

Exception No. 2: A No. 6 screw may be used for the connection of a No. 16 AWG or smaller control-circuit conductor.

13.13 A wire-binding screw shall thread into metal.

13.14 A terminal plate tapped for a wire-binding screw shall be of metal not less than 0.050 inch (1.27 mm) thick.

Exception No. 1: A plate not less than 0.030 inch (0.76 mm) thick is acceptable if the tapped threads have adequate mechanical strength as determined by the Terminal Torque Test, Section 47.

Exception No. 2: A plate less than 0.030 inch thick is acceptable in a low-voltage, limited-energy circuit if the tapped threads have adequate mechanical strength as determined by the Terminal Torque Test, Section 46.

13.15 There shall be two or more full threads in the metal of a terminal plate. The metal may be extruded at the tapped hole to provide at least two full threads.

Exception: Two full threads are not required for a terminal in a low-voltage, limited-energy circuit, if a lesser number of threads has adequate mechanical strength as determined by the Terminal Torque Test, Section 46.

13.16 Upturned lugs, a cupped washer, or the equivalent shall be capable of retaining a solid or stranded conductor of the size specified in Table 13.1 under the head of the screw or washer.

TABLE 13.1

CONDUCTOR AND WIRE BINDING SCREW SIZE

Size of Terminal Screw, No.	Wire Size, AWG
6	16
8	14
10	10

Identification

13.17 A power conditioning unit with (1) a provision for grounding the input circuit or (2) a rated output of 125 volts; or 125/250 volts, three-wire, or less; and employing an Edison-base lampholder, or a single-pole switch or overcurrent-protective device other than an automatic control without a marked off position in the grounded circuit, shall have one terminal or lead identified for the connection of the grounded conductor of the grounded circuit. The terminal intended to be grounded shall be the one that is electrically connected to the screw shell of a lampholder and to which no switch or overcurrent protective device of the single-pole type other than an automatic control without a marked off position is connected.

13.18 A terminal intended for connection of a grounded conductor of a power conditioning unit input or output circuit shall be made of or plated with metal substantially white in color and shall be readily distinguishable from other terminals; or proper identification of that terminal shall be clearly shown in some other manner, such as on an attached wiring diagram.

Equipment Grounding Connection

13.19 A power conditioning unit shall be provided with a properly identified, separate, equipment grounding terminal. The grounding terminal shall be reliably connected to all exposed dead metal parts as described in paragraph 14.1.

13.20 The equipment grounding terminal shall be capable of securing a conductor size equal to the largest of the input or output field wiring conductors which are to be used to connect the power conditioning unit.

13.21 A terminal screw intended for the connection of an equipment grounding conductor shall have a green colored head that is hexagonal, slotted, or both. A pressure wire connector intended for connection of such a conductor shall be plainly identified, such as being marked "G," "GR," "Ground," "Grounding," or the equivalent, or by a marking on a wiring diagram provided on the power conditioning unit. The grounding terminal shall be so located that it is unlikely to be removed during normal servicing of the power conditioning unit.

14. Bonding for Grounding

14.1 If accessible to the user or serviceperson, noncurrent carrying metal part, such as the enclosure, component mounting bracket, capacitor body, transformer core, or the like, which is liable to become energized by an electrical fault shall be realiably bonded to the field-equipment grounding terminal.

14.2 Metal parts as described below need not comply with the requirement of paragraph 14.1.

A. Adhesive attached metal foil markings, screws, handles, and the like, which are located on the outside of the enclosure and isolated from electrical components or wiring by grounded metal parts so that they are not liable to become energized.

B. Isolated metal parts, such as small assembly screws, and the like, which are positively separated from wiring and uninsulated live parts.

C. Panels and covers which do not enclose uninsulated live parts if wiring is positively separated from the panel or cover so that it is not liable to become energized.

D. Panels and covers which are insulated from electrical components and wiring by an insulating barrier of vulcanized fiber, varnished cloth, phenolic composition, or similar material not less than 1/32 inch (0.8 mm) thick and reliably secured in place.

14.3 A component bonding conductor shall be of copper, a copper alloy, or other material acceptable for use as an electrical conductor. Ferrous metal parts in the grounding path shall be protected against corrosion by enameling, galvanizing, plating, or other equivalent means. A separate bonding conductor or strap shall (1) be protected from mechanical damage or be located within the outer enclosure or frame, and (2) not be secured by a removable fastener used for any purpose other than bonding for grounding unless the bonding conductor is unlikely to be omitted after removal and replacement of the fastener.

14.4 The size of a conductor or a strap employed to bond an electrical enclosure or component shall not be smaller than the conductors supplying power to the electrical enclosure or component.

14.5 The bonding shall be by a positive means, such as by clamping, riveting, bolted or screwed connection, or by welding, soldering, or brazing with materials having a softening or melting point greater than 850°F (455°C). The bonding connection shall penetrate nonconductive coatings, such as paint or vitreous enamel. Bonding around a resilient mount shall not depend on the clamping action of rubber or similar material, other than as indicated in paragraph 14.10.

14.6 A bolted or screwed connection that incorporates a star washer under the screwhead, is considered acceptable if it penetrates nonconductive coatings.

14.7 Where the bonding means depends upon screw threads, two or more screws or two full threads of a single screw engaging two full threads in the metal may be used.

14.8 Metal-to-metal hinge-bearing members for doors or covers may be considered as a means for bonding the door or cover for grounding providing a multiple-bearing, pin type hinge is employed.

14.9 Splices shall not be employed in conductors used to bond electrical enclosures or components.

14.10 If the continuity of the grounding system relies on the dimensional integrity of a nonmetallic material, the material shall be acceptable for the purpose when investigated for dimensional stability.

14.11 The equipment grounding connection, the enclosure, the frame, and a component mounting panel shall not carry current except during an electrical fault.

Exception: An enclosure, frame, chassis or panel, including bolted joints may carry the current of a low-voltage, limited-energy circuit. Current shall not normally be carried through the field-equipment grounding means, the metallic raceway or other power conditioning unit grounding means, or the earth ground.

15. Input Circuit Grounding

General

15.1 If a means for grounding the photovoltaic array circuit is provided within a power conditioning unit, one of the methods outlined below in items A-C shall be employed. The operating and installation instructions shall specify which method of protection is provided and shall describe what connections, if any, are to be made for proper installation. See paragraph 51.4.

A. Solid grounding of the input circuit as specified in paragraphs 15.2-15.4.

B. Grounding of the input circuit through a bleeder resistor as specified in paragraph 15.5.

C. Other means of protection which has been evaluated and found to provide the equivalent protection as item A or B.

Solid Circuit Grounding

15.2 A power conditioning unit employing a means for solidly grounding the photovoltaic array circuit in accordance with item A of paragraph 15.1, shall be provided with a terminal for the connection of the grounding electrode conductor to input circuit conductor intended to be grounded. The terminal shall comply with paragraphs 13.9-13.16 and shall be capable of securing a conductor of the same size as required for the input conductors. A soldering lug or other connection means that depends upon solder is not acceptable. The terminal shall be identified "Grounding Electrode Terminal."

15.3 The terminal for connection of the grounding electrode conductor shall be integral with the terminal assembly intended for connection of the input circuit conductor intended to be grounded.

Exception: The terminal may be integral with the equipment-grounding-terminal if a bonding jumper consisting of a bus bar or conductor is connected directly from the input circuit grounding terminal to the equipment-grounding-terminal assembly.

15.4 If the input circuit grounding terminal is insulated from the power conditioning unit enclosure, a jumper consisting of a separate screw, strap, or other means shall be provided to bond the power conditioning unit enclosure to the insulated terminal assembly. Except for steel or brass screws as noted in the note to Table 15.1, the bonding means shall be copper or aluminum and shall have a cross section area as specified in Table 15.1. When an insulated terminal assembly is provided, the construction shall be such that when the bonding means is not used, at least the minimum acceptable spacings will be maintained. Instructions for bonding the insulated terminal assembly to the power conditioner enclosure shall be provided in the operating and installation instructions. See paragraph 51.4.

TABLE 15.1

SIZE OF BONDING JUMPER

Ampere Rating Not Exceeding	Size of Bonding Jumper (Minimum)		Cross Section of Main Bonding Jumper in Square Inches (mm^2) Minimum[a]	
	Copper, AWG or MCM (mm^2)	Aluminum, AWG or MCM (mm^2)	Copper	Aluminum
90	8 (8.4)	6 (13.3)	0.013 (8.4)[a]	0.021 (13.6)[a]
100	6 (13.3)	4 (21.2)	0.021 (13.6)[a]	0.033 (21.3)[a]

[a]A No. 8 or larger brass or No. 10 or larger steel screw may be used.

Resistive Circuit Grounding

15.5 A power conditioning unit employing a means for grounding the photovoltaic array circuit through a bleeder resistor in accordance with item B of paragraph 15.1 shall have a parallel combination of a resistor and a surge protector having a suitable dc voltage rating for the application connected to the grounding electrode conductor terminal. Based on the maximum open circuit dc voltage rating of the power conditioning unit, the resistor, during a fault condition, shall: (1) limit the leakage current to ground to 5 milliampere or less and (2) have a power dissapation not greater than 50 percent of its rating. The other end of the parallel resistor and surge combination shall be connected to: (3) one side of the input circuit for a power conditioning unit intended to be connected to a two-wire photovoltaic power source or (4) the neutral conductor for a power conditioning unit intended to be connected to a three-wire photovoltaic power source.

16. Internal Wiring

General

16.1 The internal wiring of a power conditioning unit shall consist of general-use wire or appliance wiring material acceptable for the application, when considered with respect to the temperature, voltage, and conditions of service to which the wiring is likely to be subjected.

16.2 Appliance wiring material of one or more of the types specified in Table 16.1 may be used for internal wiring when considered with respect to the requirement in paragraph 16.1.

TABLE 16.1
APPLIANCE-WIRING MATERIAL

Type of Insulation	Nominal Thickness of Insulation, Inch[a]	
	600-Volt Applications	300-Volt Applications
Thermoplastic	1/32	1/32 [b,c]
Rubber	1/32 plus an impregnated-braid cover	1/64 plus impregnated-braid cover 1/32 without a braid cover
Neoprene	3/64	1/64 plus an impregnated-braid cover 1/32 without a braid cover
Silicone Rubber	1/32 plus an impregnated-braid cover 1/32 without a braid cover[d]	1/64 plus an impregnated-braid cover 1/32 without a braid cover[d]
Cross-linked synthetic polymer	1/64	1/64

[a]The minimum acceptable thickness is 0.028 inch (0.71 mm) for 1/32-inch-thick insulation; the minimum thickness is 0.013 inch (0.33 mm) for 1/64-inch-thick insulation.

[b]May be not less than 0.013 inch (0.33 mm) only for short, moving pigtails or coil leads in a small device, provided such leads make no more than casual contact with parts of opposite polarity and with ungrounded parts.

[c]May be not less than 0.007 inch (0.18 mm) only if routed away from live parts of opposite polarity and protected from mechanical damage both during installation of field wiring and while the equipment is in operation.

[d]Only if routed away from live parts of opposite polarity and protected from mechanical damage both during installation of field wiring and while the equipment is in operation.

16.3 Appliance wiring material having an insulation thickness other than those specified in Table 16.1 may be used provided the insulation, when considered with respect to temperature, voltage, and conditions of service, is equivalent to one of those specified in that table.

16.4 Insulating tubing or sleeving may be used for a short length of insulated conductor, e.g., a short coil lead, or the like, if:

A. Not subjected to compression, repeated flexure, or sharp bends;

B. The conductor covered with the tubing or sleeving is well rounded and free from sharp edges;

C. A shrinkable tubing used in accordance with the manufacturer's instructions; and

D. Not subjected to a temperature or voltage higher than that for which the tubing or sleeving is rated.

16.5 Where wiring extends from the cabinet to a hinged door or other parts that are subject to movement in use, stranded conductors shall be employed, and the arrangement shall preclude twisting or stressing of conductors as a result of the movement. The wiring shall be routed or protected to reduce the likelihood of damage to the insulation. The conductors shall be secured so that stress will not be transmitted to terminals or splices.

Protection of Wiring

16.6 Internal wiring shall not be accessible from outside the enclosure as accordance with paragraph 7.1.

16.7 Wires within an enclosure, compartment, raceway, or the like, shall be located or protected to prevent contact with any sharp edge, burr, fin, moving part, or the like, that can damage the conductor insulation.

16.8 Mounting screws and nuts shall be designed or located so that sharp edges will not damage wiring. A screw shall have a flat or blunt end. The end of the screw shall have no burrs, fins, or sharp edges that may abrade wire insulation, and shall not project more than 3/16 inch (4.8 mm) into a wireway.

16.9 A hole through which insulated wires pass in a sheet metal wall within the overall enclosure of a power conditioning unit shall be provided with smooth, rounded surfaces upon which the wires may bear, to prevent abrasion of the insulation.

Electrical Connections

16.10 A splice or connection shall be mechanically secure and shall make reliable electrical contact.

16.11 A soldered connection is considered to be mechanically secure when the lead is:

A. Wrapped one full turn around a terminal,

B. Bent at a right-angle after being passed through an eyelet or opening, except on printed-wiring boards where components are properly inserted and wave- or lap-soldered, or

C. Twisted with other conductors.

16.12 A stranded internal wiring connection shall be such that loose strands of wire will be prevented from contacting dead metal parts or other live parts not always of the same potential. This may be accomplished by the use of a pressure terminal connector, a soldering lug, a crimped eyelet, soldering of all strands together, or other reliable means.

16.13 An open-end spade lug secured by a screw or nut shall be secured by additional means, such as upturned ends on the lug, or bosses or shoulders on the terminal, to hold the lug in place if the screw or nut loosens.

16.14 Aluminum conductors, insulated or uninsulated, used as internal wiring, such as for interconnection between current-carrying parts or in a component winding, shall be terminated at each end by a method suitable for the combination of metals involved at the connection points.

16.15 With reference to paragraph 16.14, a wire-binding screw or a pressure wire connector used as a terminating device shall be acceptable for use with aluminum under the conditions involved -- for example, temperature, heat cycling, vibration, and the like.

16.16 A splice shall be provided with insulation equivalent to that of the wires involved unless permanent spacings will be maintained between the splice and other metal parts.

A. Splicing devices such as pressure wire connectors may be employed if insulated acceptably for the voltage and temperature to which they are subjected.

B. Insulating tubing or sleeving used to cover a splice shall be used in accordance with paragraph 16.4.

C. Two layers of thermoplastic tape, of two layers of friction tape, or one layer of friction tape and one layer of rubber tape, may be used on a splice if the voltage involved is less than 250 volts. Thermoplastic tape wrapped over a sharp edge is not acceptable.

Exception: Splices within coil windings.

17. Live Parts

17.1 A current-carrying part shall be of silver, copper, copper alloy, aluminum or other metal investigated and found to be acceptable for the application.

Exception: Iron or steel provided with an acceptable corrosion-resistant coating, or stainless steel may be used for a current-carrying part if acceptable in accordance with paragraph 3.1.

17.2 Uninsulated live parts and components that have uninsulated live parts shall be secured to prevent turning or shifting in position if such displacement results in a reduction of spacings below the minimum values specified in Section 19.

18. Separation of Circuits

18.1 Unless provided with insulation rated for the highest voltage involved, insulated internal wiring conductors of different circuits shall be separated by barriers or shall be segregated from each other. Internal wiring conductors shall be separated from uninsulated live parts connected to different circuits.

18.2 Segregation of insulated conductors may be accomplished by clamping, routing, or equivalent means that will maintain permanent separation.

18.3 Field-installed conductors of the input circuit, output circuit and control circuits shall be separated by barriers from each other and internal wiring or uninsulated live parts not of the same circuit.

Exception: Control circuit conductors may be routed together with related input or output conductors provided that all conductors are or will be insulated for the maximum voltage of either circuit.

18.4 A barrier used to provide separation between the wiring of different circuits, shall be metal or of a rigid insulating material secured in place. A barrier of insulating material shall not be less than 0.028 inch (0.71 mm) thick.

19. Spacings

General

19.1 Uninsulated parts of different circuits shall be spaced from each other as if they were parts of different potential, in accordance with the requirement in paragraph 19.7. The spacings shall be the largest of those required for the individual circuits, using the opposite polarity potential of each circuit to determine its spacings requirement.

19.2 Enameled or film-coated wire is considered to be an uninsulated live part in judging spacings.

19.3 The spacings specified in Table 19.3 do not apply to the inherent spacings of a solid state component or a component where specific requirements exist for that component. Examples of such components are snap switches, lampholders, motors, or clock motors, or the like. Spacings from such a component to another component and to the enclosure, and spacings at component terminals used for field-wiring shall comply with the requirements in Tables 19.1-19.3.

Exception: A component connected in a circuit which is used in lieu of direct grounding the input circuit.

TABLE 19.1

SPACINGS AT FIELD-WIRING TERMINALS

Potential Involved, Volts Peak	Minimum Spacings, Inch (mm)[a] Between Field-Wiring Terminals, Through Air or Over Surface	Between Field-Wiring Terminals and Other Uninsulated Parts Not Always of the Same Potential: Over Surface	Between Field-Wiring Terminals and Other Uninsulated Parts Not Always of the Same Potential: Through Air
71 or less	1/8 (3.2)	1/8 (3.2)	1/8 (3.2)
72-353	1/4 (6.4)	1/4 (6.4)	1/4 (6.4)
354-848	1/2 (12.7)	1/2 (12.7)	3/8 (9.5)

[a]These spacings apply to the sum of the spacings involved wherever an isolated dead metal part is interposed.

TABLE 19.2

SPACINGS BETWEEN AN UNINSULATED LIVE PART AND A METAL ENCLOSURE OR OTHER ACCESSIBLE DEAD METAL PART INCLUDING A FITTING FOR CONDUIT OR ARMORED CABLE

Potential Difference Volts Peak	Minimum Spacings Through Air and Over Surface, Inch (mm)
71 or less	1/16 (1.6)
72-212	1/4 (6.4)
213-848	1/2 (12.7)

TABLE 19.3

SPACINGS IN AC AND DC POWER CIRCUITS

Potential Difference in Volts Peak	Minimum Spacings, Inch (mm)[a]	
	Over Surface	Through Air
71 or less	3/64 (1.2)	3/64 (1.2)
72-177	1/16 (1.6)	1/16 (1.6)
178-353	3/32 (2.4)	3/32 (2.4)
354-848	1/2 (12.7)	3/8 (9.5)

[a] On printed-wiring boards, their connectors, and board-mounted electrical components, wired on the load side of line filters or similar voltage peak reduction networks and components, a minimum spacing of 0.0230 inch (0.580 mm) plus 0.0002 inch (0.005 mm) per volt peak shall be maintained over surface and through air between an uninsulated part and any other uninsulated part not of the same potential.

19.4 Opposite polarity spacings are not specified for a circuit beyond an impedance that limits the product of the current through and the voltage across this impedance to a (1) value not exceeding the wattage rating of the impedance, and (2) level not exceeding 15 watts, when a direct short is applied across the remainder of the circuit.

Field Wiring Terminals

19.5 The spacings between field-wiring terminals of opposite polarity and the spacings between a field-wiring terminal and any other uninsulated metal part not of the same potential shall not be less than indicated in Tables 19.1 and 19.2.

19.6 A spacing at a field-wiring terminal is to be measured with the appropriate fittings or bushing installed and wires connected as in actual service. See paragraph 6.19.

AC and DC Power Circuits

19.7 In ac and dc power units these spacings between uninsulated live parts of different potential, and between an uninsulated live part and a dead metal part shall not be less than indicated in Tables 19.2 and 19.3. If an uninsulated live part is not rigidly fixed in position (by means other than friction between surfaces) or if a movable dead metal part is in proximity to an uninsulated live part, the construction shall be such that at least the minimum acceptable spacing will be maintained with the movable part in any position.

Secondary Circuits

19.8 The minimum spacings specified in Tables 19.2 and 19.3 apply in all secondary circuits supplied by a transformer winding of 200 volt-amperes or a higher capacity (maximum available power) at a potential higher than 100 volts. The spacings in all other secondary circuits are judged on the basis of the dielectric voltage-withstand test mentioned in paragraph 40.1.

19.9 Spacings are not specified for in an isolated internal secondary circuit after:

A. A reliable impedance that limits the available power to less than 200 volt-amperes under all conditions; or

B. A fuse or nonautomatic-reset overcurrent-protective device having a current rating in amperes not exceeding

$$\frac{200\ VA}{2.0\ V_{max}}$$

where:

V_{max} is the open-circuit voltage of the secondary in question in volts rms with the primary connected to maximum rated voltage.

Maximum available power is measured using a variable resistor connected in place of the circuit in question. For a transformer having multiple secondary windings, all measurements on a secondary-winding circuit are to be made with all other windings unloaded.

Safety Spacings

19.10 If short circuiting a spacing defeats the intended function of a safety circuit, that spacing shall comply with Tables 19.4 and 19.5.

TABLE 19.4

MINIMUM SPACINGS IN LOW-VOLTAGE LIMITED-ENERGY SAFETY AND ISOLATED LIMITED ENERGY SAFETY CIRCUITS

Spacings Between Uninsulated Live Parts		Low-Voltage Class 2 Inch	Low-Voltage Class 2 mm	Isolated Limited Energy Circuit[a] Inch	Isolated Limited Energy Circuit[a] mm
A. and Exposed Isolated (Insulated) Dead Metal Part	Through Air	1/8	3.2	1/8	3.2
	Over Surface	1/8	3.2	1/4	6.4
B. and Grounded Dead Metal Part Other Than the Enclosure	Through Air	1/32	0.8	1/16	1.6
	Over Surface	1/32	0.8	1/16	1.6
C. and Wall of Metallic Enclosure[b]	Through Air	1/8	3.2	1/4	6.4
	Over Surface	1/8	3.2	1/4	6.4
D. and Uninsulated Live Part of Opposite Polarity	Through Air	1/32	0.8	1/16	1.6
	Over Surface	1/32	0.8	1/16	1.6
E. and Uninsulated Live Part of Same Polarity	Through Air	1/32	0.8	1/32	0.8
	Over Surface	1/32	0.8	1/16	1.6
F. of Field-Wiring Terminals Regardless of Polarity and Also Between Field Wiring Terminal and Dead Metal Part Including the Enclosure[b]	Through Air	1/4	6.4	1/4	6.4
	Over Surface	1/4	6.4	1/4	6.4

[a]A circuit derived from an isolated secondary winding of a transformer having a capacity of not more than 200 volt-amperes or a potential not exceeding 100 volts, rms.

[b]Including fittings for connection of conduit or armored cable.

TABLE 19.5

MINIMUM SPACINGS IN SAFETY CIRCUIT FOR OTHER THAN LOW-VOLTAGE CLASS 2 AND ISOLATED LIMITED ENERGY CIRCUITS

		Potential Involved, Volts rms (Peak)					
		212 or Less		213-424		425-848	
		Inch	mm	Inch	mm	Inch	mm
Between any uninsulated live part and an uninsulated live part of opposite polarity, an uninsulated grounded dead metal part other than the enclosure, or an exposed dead metal part which is isolated (insulated).[a]	Through air	1/8[b]	3.2[b]	1/4	6.4	3/8	9.5
	Over Surface	1/4	6.4	3/8	9.5	1/2	12.7
Between any uninsulated live part and the walls of a metal enclosure, including fittings for conduit or armored cable.[c]	Shortest Distance	1/2	12.7	1/2	12.7	1/2	12.7

[a]The spacing between uninsulated live parts of the same polarity shall not be less than 1/32 inch (0.8 mm) through air and 1/16 inch (1.6 mm) over the surface.

[b]The spacing between wiring terminals regardless of polarity and between a wiring terminal and a grounded or an exposed dead metal part shall not be less than 1/4 inch (6.4 mm) if short-circuiting or grounding of such terminals may result from projecting strands of wire.

[c]For the purpose of this requirement, a metal piece attached to the enclosure is considered to be a part of the enclosure if deformation of the enclosure is liable to reduce the spacing between the metal piece and uninsulated live parts.

20. Insulating Materials

General

20.1 Uninsulated live parts shall be mounted on a material that has been investigated and found to be acceptable for the application and shall be classed 94V-0 or 94V-1 in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94. The use of a material classed 94V-2 requires the use of an enclosure without ventilating openings.

Exception: This requirement does not apply to a material supporting only live parts connected in low-voltage, limited-energy circuits where deterioration of the material does not result in a risk of fire or electric shock.

20.2 Electrical insulation grade vulcanized fiber may be used for an insulating bushing, a washer, a separator, or a barrier, but not as the sole support of an uninsulated live part if shrinkage, current leakage, or warpage may introduce a risk of fire or electric shock.

20.3 Polymeric materials used to support uninsulated live parts, shall have adequate mechanical strength and rigidity, resistance to heat, resistance to flame propagation, dielectric strength, and other properties acceptable for the application in accordance with the Standard for Polymeric Materials — Short Term Property Evaluations, UL 746A; Standard for Polymeric Materials -- Long Term Property Evaluations, UL 746B; and the Standard for Polymeric Materials -- Use in Electrical Equipment Evaluations, UL 746C.

Barriers

20.4 An insulating barrier of vulcanized fiber, thermoplastic or other material employed in lieu of required spacings shall not be less than 0.028 inch (0.71 mm) thick and shall be so located or of such material that it will not be adversely affected by arcing.

Exception No. 1: Vulcanized fiber not less than 0.013 inch (0.33 mm) thick may be used (1) in conjunction with an air spacing of not less than 50 percent of the minimum acceptable through-air spacing, (2) between a heat sink and a metal mounting surface, including the enclosure, or an isolated secondary circuit rated 50 volts rms or less.

Exception No. 2: An insulating material having a thickness less than that specified in paragraph 20.4 or Exception No. 1 may be used if, upon investigation, it is found to be acceptable for the application and is equivalent in all respects.

Coil Insulation

20.5 Insulation required in place of spacings between a magnet-coil winding and other uninsulated live parts or grounded dead metal parts, shall comply with paragraph 20.4.

Exception: The type and thickness of crossover-lead insulation and insulation under coil terminals secured to the coil winding may be less than that specified in paragraph 20.4 if:

A. The insulation is at least 0.013 inch (0.33 mm) thick; or

B. The coil withstands the dielectric voltage-withstand test specified in either item 1 or 2:

1. Application of the test potential in accordance with paragraphs 40.1 and 40.2 between coil-end leads after breaking the inner coil lead where it enters the layer, or an equivalent opposite polarity test.

2. Application of the induced potential test described in paragraph 40.3.

20.6 A slot in a molded bobbin for guiding the crossover- or start-lead -- unspliced at the windings -- of a magnet-coil is to be filled with an insulating material unless (1) the slot provides a graduated spacing to the winding, increasing to the end turns, and (2) the magnet-coil winding withstands the induced potential test in paragraph 40.3.

21. Capacitors

21.1 A capacitor used for EMI elimination or power-factor correction shall be housed within an enclosure of metal providing strength and protection not less than that of uncoated steel having a thickness of 0.020 inch (0.51 mm) to protect the plates against mechanical damage to reduce the risk of the emission of flame or molten material resulting from breakdown of a capacitor.

Exception: The container may be of thinner sheet metal or may be of material other than metal, if mounted inside a power conditioning unit having an enclosure that complies with the requirements in paragraphs 6.1-6.11.

21.2 A container of an electrolytic capacitor having a thickness less than that required by paragraph 21.1 shall employ an adequate means for venting.

21.3 A means, such as a bleeder resistor, shall be provided to drain the charge stored in a capacitor to the extent that the potential, V, measured between the terminals of the capacitor 1 minute after the capacitor has been disconnected from its source of energy is less than 50 volts and the energy stored, J, is less than 20 joules as determined by the following relation, in which C is in microfarads:

$$J = 5 \times 10^{-7} CV^2$$

Exception: The requirement does not apply if the power conditioning unit is marked as specified in paragraph 50.7.

21.4 A capacitor employing a dielectric medium more combustible than askarel shall not cause or increase a risk of fire or electric shock and shall not vent or rupture and expel dielectric medium either under conditions of normal or abnormal use.

22. Fuses and Fuseholders

21.1 A fuse having only an ac rating may be used in a dc circuit provided that it is investigated and found to be acceptable for the application.

22.2 Plug-type and extractor type fuseholders shall not be used in circuits which may be energized from both directions, such as the alternating current output of the power conditioning unit.

22.3 The screw shell of a plug-type fuseholder and the outermost terminal of an extractor-type fuseholder shall be connected toward the load.

23. DC Isolation From the Utility

23.1 A power conditioning unit shall be designed to protect against direct current flowing from the PV array into the utility supply during (1) normal operation and, (2) a component malfunction or failure within the power conditioning unit. Devices, such as an isolation transformer having separate primary and secondary windings, a blocking capacitor or a direct current sensor with a high-speed disconnect switch may be used.

Exception: A power conditioning unit marked in accordance with paragraph 50.4.

24. Motors

24.1 Each motor shall be protected from overheating due to any condition of load up to and including stalled rotor.

Exception No. 1: A motor used for air-handling only, such as a direct-drive blower motor or a ventilating fan need be protected only against locked-rotor conditions.

Exception No. 2: A shaded-pole motor having a difference of 1 ampere or less between no-load and locked-rotor currents and having a 2 to 1 or smaller ratio between locked-rotor and no-load currents if it is protected against locked rotor only.

24.2 The protection required by paragraph 24.1 may be accomplished by one of the following:

A. Thermal protection complying with requirements in the Standard for Thermal Protectors for Motors, UL 547.

B. Impedance protection complying with appropriate requirements in the Standard for Motor-Operated Appliances, UL 73.

C. Other protection that tests show is equivalent to the protection mention in item A.

25. Printed-Wiring Boards

General

25.1 A printed-wiring board in a power conditioning unit shall comply with the Standard for Printed-Wiring Boards, UL 796. For a power conditioning unit with openings in the enclosure, the board shall be classed 94V-0 or 94V-1, in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94. The use of a material classed 94V-2 requires the use of an enclosure without ventilating openings.

Exception: This requirement does not apply to a printed wiring board connected only in low-voltage, limited-energy circuits and where deterioration or breakage of the bond between the conductor and the base material does not result in a risk of fire or electric shock.

25.2 A resistor, capacitor, inductor, or other part that is mounted on a printed-circuit board to form a printed-circuit assembly shall be secured so that it cannot be displaced to cause a risk of fire or electric shock by a force likely to be exerted on it during assembly or normal operation as determined during the impact test, specified in paragraph 32.2.

Conformal Coating

25.3 A conformal coating employed on the surface of a printed-wiring board and intended to be used for the acceptance of reduced spacings shall be acceptable for the application by being investigated on the printed-wiring board material in accordance with the Standard for Polymeric Materials — Use in Electrical Equipment Evaluations, UL 746C.

26. Component Evaluation

General

26.1 A component reliability evaluation shall be conducted on a circuit which is used in lieu of direct grounding of the input circuit when a single-mode component fault results in loss in protection which the circuit is intended to provide.

Evaluation Program

General

26.2 There are two phases required to evaluate the reliability of electronic components or circuits.

Phase A

26.3 A fault analysis and failure-mode table of all components shall be established which identifies the critical components; that is, those components the malfunction of which may result in loss in protection which the circuit is intended to provide. If the fault in a component or circuit results in an acceptable shutdown, or in no appreciable effect on performance as confirmed by test, Phase B may be omitted.

26.4 The failure-mode information may be made up as shown in Table 26.1.

Phase B

26.5 The maximum stress applied to critical components shall not exceed 50 percent of the maximum rated values, such as temperature, voltage, and power. This applies to resistors, capacitors, solid state components, relays, and the like.

TABLE 26.1
FAILURE-MODE INFORMATION

Part[a] Name	Manufacturer's Name, Cat. No., and Ratings[b]	Thermal & Electrical	Schematic Reference[c]	Function[d]	Failure Mode[e]	Failure Effect[f]	Stress Levels, Percent Rated (Thermal & Electrical)[g]

[a]Part Name - Include each electronic component in the circuit to be investigated.

[b]Manufacturer's Name, Cat. No., and Ratings - To be provided for each component.

[c]Schematic Reference - Each component is to be identified as R1, C1, and the like.

[d]Function - Describe the function of each component.

[e]Failure Mode - Include open- and short-circuit catastrophic faults for each component. All terminals are to be included on multiple-terminal devices.

[f]Failure Effect - The system effect caused by the fault is to be stated.

[g]The thermal and electrical stress levels are to be expressed as a percentage of their nominal rated values as specified by the manufacturer. Node voltage for all normal modes of operation are to be indicated on the schematic diagram. This assists in verification of the invividual component stress levels.

Phase C

26.6 To further demonstrate reliability, the Environmental tests specified in Section 43 and the Voltage Transient and Static Discharge tests specified in Section 44 shall be conducted.

26.7 To verify that the circuit is not adversely affected by voltage transients and static discharge, the tests specified in Section 45 shall be conducted.

PROTECTION AGAINST INJURY TO PERSONS

27. General

27.1 If operation, maintenance, or reasonably foreseeable misuse of a power conditioning unit involves a risk of injury to persons, protection shall be provided to reduce the risk.

27.2 Among the factors to be considered in judging the acceptability of an exposed moving part are (1) degree of exposure necessary to perform its intended function, (2) sharpness of the moving part, (3) likelihood of unintentional contact, (4) speed of the moving part, and (5) likelihood that a part of the body would be endangered or that clothing would be entangled by the moving part. These factors are to be considered with respect to both intended operation of the power conditioning unit and reasonably foreseeable misuse.

27.3 The adequacy of a guard, a release, an interlock, or the like, and whether such a device is required are to be determined from a study of the complete power conditioning unit, its operating characteristics, and the likelihood of a risk of injury to persons resulting from a cause other than gross negligence. The investigation is to include consideration of the results of a breakdown or malfunction of any one component; but not more than one component at a time, unless one event contributes to another. If the study shows tht malfunction of a component can result in a risk of injury to persons, that component is to be investigated for reliability.

28. Enclosures and Guards

28.1 A part capable of causing a risk of injury to persons shall be enclosed.

28.2 An opening in a guard or enclosure around a moving part that may involve a risk of injury to persons shall have a minor dimension less than 1 inch (25.4 mm), and shall not permit the probe illustrated in Figure 7.1 to contact the part when the probe is inserted through the opening to its maximum depth in a straight or articulated position.

28.3 An enclosure, an opening, a frame, a guard, a knob, a handle, or the like, shall not be sufficiently sharp to cause a risk of injury to persons in normal maintenance or use.

28.4 A guard or portion of an enclosure acting as a guard for a part that may involve a risk of injury to persons shall be either (1) mounted to the assembly so that the part cannot be operated with the guard or portion of the enclosure removed, (2) secured to the assembly using fasteners requiring a tool for removal, or (3) provided with an interlock to reduce the risk of contacting the part.

29. Enclosure Mounting

29.1 If mounting instructions furnished with a power conditioning unit specify mounting hardware that is not readily available commercially, the manufacturer shall provide the hardware with the power conditioning unit.

30. Materials

30.1 If the breakage or damage of a part, such as an enclosure, a frame, a guard, or the like, may result in a risk of injury to persons, the material shall have such properties as to meet the demand of expected loading conditions.

31. Moving Parts

31.1 A rotating member, such as a fan blade, breakage of which may result in a risk of injury to persons, shall be enclosed or guarded to reduce the risk of injury to persons.

31.2 A rotating or moving part that may involve a risk of injury to persons if it should become disengaged shall be provided with a positive means to retain it in place under conditions of use.

32. Impact

32.1 A power conditioning unit employing a part as mentioned in paragraph 30.1 shall be tested as described in paragraph 32.2; and, following the test, shall:

A. Not permit a probe, as illustrated in Figure 7.1 and applied in accordance with paragraph 28.2, to contact an uninsulated live part or a moving part that may involve a risk of injury to persons; and

B. Comply with the dielectric voltage-withstand requirements in Section 40 with the potential applied between live parts and accessible dead metal parts.

32.2 The power conditioning unit is to be subjected to three impacts using a smooth steel sphere 2 inches (50.8 mm) in diameter and weighing 1.18 pounds (0.5 kg). The sphere is to be allowed to fall vertically from rest through a distance of 51 inches (1295 mm) to strike the part being tested. For a part not able to be struck from above by the free-falling sphere, the sphere is to be suspended by a cord and allowed to fall as a pendulum through the required vertical distance.

33. Stability

33.1 A power conditioning unit shall not tip over but shall return to its normal at-rest position when:

A. Tipped through an angle of 10 degrees in the direction of least stability from an at-rest position on a horizontal surface,

B. Placed on a plane inclined at an angle of 10 degrees from the horizontal, or

C. Positioned in accordance with the manufacturer's instructions, if any, under the normal operating condition most likely to cause tip over and subjected to an externally-applied horizontal force of 20 percent of the weight of the power conditioning unit or 50 pounds (22.7 kg), whichever is less. See paragraph 33.3.

Exception: A power conditioning unit provided with instructions indicating that it is to be fastened to the floor or wall need not be subjected to this test.

33.2 If a part or surface of the power conditioning unit not normally in contact with the horizontal supporting surface touches the supporting surface before the unit has been tipped to an angle of 10 degrees, the tipping is to be continued until the surface or plane of the surface of the power conditioning unit originally in contact with the horizontal supporting surface is at an angle of 10 degrees from the horizontal supporting surface.

33.3 The force specified in item C in paragraph 33.1 is to be applied in a horizontal direction at that point on the power conditioning unit most likely to overturn the power conditioning unit, but not applied more than 5 feet (1.5 m) above floor level. The legs or points of support may be blocked to prevent the power conditioning unit from sliding during the application of the force.

34. Switches and Controls

34.1 If unintentional operation of a switch may involve a risk of injury to persons, the actuator of the switch shall be located or guarded so that such operation is unlikely.

34.2 If required, the actuator of a switch may be guarded by recessing ribs, barriers, or the like.

35. Utility Fluctuation

35.1 A power conditioning unit shall be provided with a means to automatically disconnect its output from all ungrounded conductors to the utility supply under the conditions of utility fluctuations and shall not reconnect until the utility is restored. See Section 42.

35.2 The disconnection control shall be a control employing contacts that provide physical separation between the output of the power conditioning unit and the utility supply when opened.

36. Static Load

36.1 When mounted as recommended by the manufacturer, a power conditioning unit intended to be fastened to a supporting structure shall be loaded as described in paragraph 36.2 for 1 minute with a force equal to three times the weight of the power conditioning unit but not less than 20 pounds (89 N). As a result of this loading, there shall be no permanent deformation, breakage, dislocation, cracking, or other damage to the unit or its mounting hardware.

Exception: A power conditioning unit intended for floor mounting.

36.2 The force is to be applied through the approximate center of gravity of the power conditioning unit, is to be increased gradually so as to reach the required value in 5 to 10 seconds, and is to be maintained at that value for 1 minute.

37. Surface Temperatures

37.1 During the temperature test described in Section 39, the temperature of a surface that may be contacted shall not be more than the value specified in Table 37.1. The results of a test that is conducted at a room temperature of other than 25°C (77°F) are to be corrected to 25°C.

TABLE 37.1

MAXIMUM ACCEPTABLE SURFACE TEMPERATURES

Location or Type of Surface	Composition of Surface[a]			
	Metallic, Degrees		Nonmetallic, Degrees	
	C	F	C	F
Handle or knob and other surfaces that are intended to be contacted during operation	60	140	85	185
A surface which may be subjected to casual contact	70	158	95	203

[a]A material other than metal that is plated or clad with metal having a thickness of 0.005 inch (0.13 mm) or less is to be judged as a nonmetallic part.

PERFORMANCE

38. General

38.1 A representative sample of a power conditioning unit shall be subjected to the tests described in Sections 39-42. Unless otherwise specified, the power conditioning unit is to be energized from a supply that simulates the current-voltage characteristics and time response of a photovoltaic array simulator, and the tests are to be conducted at the maximum and minimum rated input voltages. The output of the power conditioning unit is to be connected to a utility supply voltage as defined in Table 38.1.

TABLE 38.1

VALUES OF OUTPUT VOLTAGES

Rated Output Voltage, AC	Test Voltage, AC
110-120	120
121-219	Rated voltage
220-240	240
241-253	Rated voltage
254-277	277
278-439	Rated voltage
440-480	480
481-525	Rated voltage
550-600	600

38.2 The supply that simulates the photovoltaic array simulator described in paragraph 38.1 shall have ratings in accordance with the power conditioning unit input rating.

39. Temperature

39.1 Under the following conditions, the unit shall not reach a temperature at any point high enough (1) to cause a risk of fire, (2) to damage any material used, (3) shall not cause a protective device to operate, and (4) to exceed the temperature rises specified in Table 39.1.

A. The power conditioning unit delivering maximum rated output power,

B. Simulated utility fluctuations specified in Section 42, and

C. Ambient temperature as specified in paragraph 39.7.

39.2 During the normal temperature test, the power conditioning unit shall be connected as specified in paragraph 38.1 and mounted as in normal service to allow normal convective cooling.

39.3 A power conditioning unit designed for mounting or support in more than one position or in a confined location shall be tested in a manner representing the most severe conditions. An adjacent mounting or supporting surface shall consist of 1-inch thick soft-pine boards.

TABLE 39.1
MAXIMUM TEMPERATURE RISES

Materials and Components	Degrees C	Degrees F
1. A surface upon which the power conditioning unit may be mounted in service, and surfaces that may be adjacent to the power conditioning unit when so mounted	65	117
2. Any point on or within a terminal box or compartment of a power conditioning unit where field-installed conductors may rest	35	63
3. Field wiring terminals	50	90
4. Class 105 coil insulation systems of a relay, solenoid, etc.,		
Thermocouple method	65[a]	117[a]
Resistance method	85	153
5. Class 130 coil insulation systems of a relay, a solenoid, etc.,		
Thermocouple method	85[a]	153[a]
Resistance method	95	171
6. Class 105 transformer insulation systems:		
Thermocouple method	65[a]	117[a]
Resistance method	70	126
7. Class 130 transformer insulation systems:		
Thermocouple method	85[a]	153[a]
Resistance method	95	171
8. Class 155 transformer insulation systems;		
Thermocouple method	105	198
Resistance method	115	216
9. Class 180 transformer insulation systems:		
Thermocouple method	125	225
Resistance method	135	243
10. Class 200 transformer insulation systems:		
Thermocouple method	140	252
Resistance method	150	270
11. Class 220 transformer insulation systems:		
Thermocouple method	155	279
Resistance method	165	297

TABLE 39.1
MAXIMUM TEMPERATURE RISES (CONT'D)

Materials and Components	Degrees C	Degrees F
12. Class A motor coil insulation systems:		
A. In an open motor:		
Thermocouple method	65	117
Resistance method	75	135
B. In a totally-enclosed motor:		
Thermocouple method	70	126
Resistance method	80	144
13. Class B motor coil insulation systems:		
A. In an open motor:		
Thermocouple method	85	153
Resistance method	95	171
B. In a totally-enclosed motor:		
Thermocouple method	95	171
Resistance method	100	180
14. Varnished-cloth insulation	60	108
15. Fiber employed as electric insulation	65	117
16. Polymeric materials	25[b]	90[b]
17. Wood and other combustible material	65	117
18. Rubber- or thermoplastic-insulated wire and cord	35[b,c]	63[b,c]
19. Other types of insulated wire	d	d
20. Fuses	65	117
21. Fuse Clips	30	54
22. Capacitor:		
Electrolytic	40[e]	72[e]
Other than electrolytic	65[e]	117[e]
23. Sealing compound	f	f
24. Semiconductor devices	75[g]	135[g]
25. Buses and connecting straps	65	117

(NOTES FOR TABLE 39.1)

[a]At a point on the surface of a coil where the temperature is affected by an external source of heat, the temperature rise measured by means of a thermocouple may be 5°C (9°F) higher than that specified, if the temperature rise of the coil as measured by the resistance method is not more than that specified.

[b]The temperature limitations on polymeric and on rubber and thermoplastic for wire and cord insulation do not apply to a material that has been investigated and found to be acceptable for a higher temperature.

[c]A short length of rubber- or thermoplastic-insulated flexible cord inside the power conditioning unit may be exposed to a temperature of more than 60°C (140°F) if supplementary insulation acceptable for the measured temperature and of adequate dielectric properties is employed on each individual conductor.

[d]For insulated conductors, reference is to be made to the National Electrical Code NFPA No. 70-1981. The maximum allowable temperature rise is not to exceed 25°C (45°F) less than the temperature limit of the wire except as noted in footnote[c].

[e]A capacitor that operates at a temperature rise of more than 40°C (72°F) for electrolytic and more than 65°C (117°F) for other types may be judged on the basis of its marked temperature limit. In any case, the measured temperature shall not exceed the temperature rating of the capacitor based on a 25°C ambient temperature.

[f]Unless a thermosetting compound, the maximum sealing compound temperature, when corrected to a 25°C (77°F) ambient temperature, is 15°C (27°F) less than the softening point of the compound as determined in accordance with the Test for Softening Point by the Ball and Ring Apparatus ASTM, E28-1972.

[g]The limitation does not apply to a material that has been investigated and found acceptable for a higher temperature limit.

39.4 A thermocouple junction and the adjacent thermocouple lead wires are to be held securely in good thermal contact with the surface of which the temperature is being measured. Usually adequate thermal contact will result from securely taping or cementing the thermocouple in place, but if a metal surface is involved, brazing or soldering the thermocouple to the metal may be necessary.

39.5 Coil and winding temperatures are to be measured by thermocouples located on exposed surfaces, except that the resistance method may be used for a coil that is inaccessible for mounting thermocouples, such as a coil (1) immersed in sealing compound, (2) wrapped with thermal insulation, such as asbestos, or (3) wrapped with more than two layers of material, such as cotton, paper, or rayon, more than 1/32 inch (0.8 mm) thick. In an alternating-current motor, the thermocouple is to be mounted on the integrally-applied insulation of the coil wire.

39.6 The temperature rise of a winding by the resistance method is determined by comparing the resistance of the winding at a temperature to be determined with the resistance at a known temperature according to the formula:

$$\Delta t = \frac{R}{r}(k + t_1) - (k + t_2)$$

in which:

Δt is the temperature rise of the winding in degrees C;
R is the resistance of the coil at the end of the test in ohms;
r is the resistance of the coil at a known temperature in ohms;
t_1 is the room temperature in degrees C at the beginning of the test;
t_2 is the room temperature in degrees C at the end of the test; and
k is 234.5 for copper, 225.0 for electrical conductor grade (EC) aluminum; values of the constant for other conductors are to be determined.

39.7 All values for temperature rises in Table 39.1 are based on an assumed ambient temperature of 25°C (77°F). However, tests may be conducted at any ambient temperature within the range of 10-40°C (50-104°F).

39.8 Thermocouples are to consist of wires not larger than No. 24 AWG and not smaller than No. 30 AWG. When thermocouples are used in determining temperatures in electrical equipment, it is common practice to employ thermocouples consisting of No. 30 AWG iron and constantan wire and a potentiometer type instrument. Such equipment is to be used whenever referee temperature measurements by thermocouples are necessary. The thermocouples and related instruments are to be accurate and calibrated in accordance with good laboratory practice. The thermocouple wire is to conform with the requirements for special thermocouples as listed in the table of limits of error of thermocouples in Temperature Measurement Thermocouples, ANSI MC96.1-1975.

39.9 A temperature is considered to be constant when three successive readings taken at intervals of 10 percent of the previously elapsed duration of the test, but not less than 15 minutes, indicate no further increase.

40. Dielectric Voltage Withstand

General

40.1 While still in a heated condition, a power conditioning unit shall withstand for 1 minute without breakdown the application of a potential of:

A. One thousand volts plus twice the maximum rated voltage between (1) the input circuit and dead metal parts, (2) the output circuit and dead metal parts, and (3) the input and output circuits.

Exception: Item (3) is not applicable to power conditioning units not provided with a transformer or capacitor network isolating the input from the output circuit.

B. One thousand volts between live and dead metal parts of a motor.

C. Five hundred volts between a secondary circuit operating at 50 volts or less and dead metal parts; 1000 volts plus twice the maximum rated secondary circuit voltage between a secondary circuit operating at more than 50 volts and dead metal parts.

D. One thousand volts plus twice the rated voltage between the terminals of a capacitor used across the ac or dc power circuit for EMI elimination or power factor correction; and between the terminals of a capacitor connected between the ac or dc power circuit and the enclosure.

40.2 To determine whether a power conditioning unit complies with the requirements in paragraph 40.1, the power conditioning unit is to be tested using a 500 volt-ampere or larger capacity transformer, the output voltage of which can be varied. A direct-current source is to be used for a direct-current circuit. A 60-hertz essentially sinusoidal voltage is to be used for testing alternating-current circuits and for testing between the input and output circuits. The applied potential is to be increased from zero until the required test level is reached, and is to be held at that level for 1 minute. The increase in applied potential is to be at a substantially uniform rate as rapid as is consistent with correct indication of its value by a voltmeter.

Exception: If a voltmeter is connected across the output circuit to directly indicate the test potential, the transformer may be rated less than 500 volt-amperes.

Induced Potential (Crossover Lead)

40.3 Each of three separate magnet-coil-winding samples shall withstand without breakdown the test mentioned in paragraphs 20.5 and 20.6 after constant temperatures have been reached as the result of operation under the conditions specified in the Temperature Test. While still heated, the coil winding shall be subjected to an alternating potential of twice the rated voltage at any acceptable frequency -- typically twice rated or higher for 60 seconds. The required test voltage is to be obtained by starting at one-quarter or less of the full value and increasing to the full value in not more than 15 seconds.

41. Harmonic Distortion

41.1 The total rms of the harmonic voltages excluding the fundamental delivered by a power conditioning unit connected to a utility line shall not exceed 5 percent of the fundamental rms output voltage rating. Also, the rms voltage in any single harmonic shall not exceed 3 percent of the nominal fundamental rms output voltage rating. These measurements are to be made with the power conditioning unit delivering 100 percent of its rating into a simulated utility with an impedance of 0.32 ohms resistance and 0.14 ohms inductive reactance.

42. Utility Fluctuations

42.1 The power conditioning unit shall disconnect from the simulated utility source within 1.0 minute after the output voltage and frequency of the simulated utility source are adjusted to each condition specified in paragraph 42.2 and Table 42.1.

TABLE 42.1

UTILITY FLUCTUATIONS

Condition	Simulated Utility Source Voltage	Simulated Utility Source Frequency
A	80 percent of nominal output rating	Rating
B	106 percent of nominal output rating	Rating
C	Nominal output rating	96.7 percent of nominal output rating
D	Nominal output rating	103.3 percent of nominal output rating
E	0[a]	0[a]

[a]Utility abrubtly disconnected with a switch to simulate utility interruption.

42.2 The output of a power conditioning unit shall be connected to an adjustable resistive load in parallel with a simulated utility source having an output rating of at least 10 kilowatts and an adjustable output voltage and frequency. During this test, the input to the power conditioning unit may be adjusted so that the power conditioning unit may deliver from 0 to 100 percent of its output rating. The resistive load may be adjusted to dissapate from 0 to 125 percent of the power conditioning unit power rating. For each combination of power output-loading selected, the frequency and voltage of the simulated utility source are to be initially adjusted to the nominal output ratings of the power conditioning unit and then varied as specified in conditions A-E of Table 42.1.

42.3 Following disconnection, the simulated utility source voltage and frequency are to be restored to the rated output values of the power conditioning unit, and:

A. A power conditioning unit provided with a manual reset control shall remain disconnected from the simulated utility source.

B. A power conditioning unit with an automatic reset control shall not reconnect to the simulated utility source until the utility voltage and frequency are restored to values between those specified in items A-D of Table 42.1.

43. Environmental

43.1 In accordance with paragraph 26.6, a circuit utilized in lieu of direct grounding shall be subjected to the environmental tests specified below.

A. Three samples of the circuit assembly shall be conditioned for 48 hours to 85-100 percent relative humidity at $32.0 \pm 2.0^{\circ}C$ ($89.6 \pm 3.6^{\circ}F$).

B. Three samples of the circuit assembly shall be conditioned for 3 hours to a $40.0 \pm 2.0^{\circ}C$ ($104.3 \pm 3.6^{\circ}F$) ambient air plus operational ambient.

C. Three samples of the circuit assembly shall be subjected to 5 cycles of thermal shock consisting of 4 hours at a temperature of $40.0 \pm 2.0^{\circ}C$ ($104.0 \pm 3.6^{\circ}F$) ambient plus operational ambient followed by 4 hours at minus $35.0 \pm 2.0^{\circ}C$ (minus $31.0 \pm 3.6^{\circ}F$).

43.2 Following the above tests, the circuit assembly is to be installed in the power conditioning unit and the power conditioning unit is to be operated under the appropriate conditions necessary to determine that the circuit continues to provide its intended protection.

44. Voltage Transient and Static Discharge

General

44.1 A power conditioning unit containing a circuit utilized in lieu of direct grounding the input circuit in accordance with paragraph 26.1 shall be subjected to the tests specified in paragraphs 44.2-44.7. During these tests the power conditioning unit is to be connected as specified in paragraph 38.1 and a resistive load is to be connected to the output terminals. The load is to be adjusted to allow the power conditioning unit to deliver maximum rated power. Following the application of the externally induced transients and the static discharges specified in paragraphs 44.2-44.6, the power conditioning unit is to be operated under the appropriate conditions necessary to determine that the circuit continues to provide its intended protection. During the application of the extraneous transients specified in paragraph 44.7, the power conditioning unit is to be operated under the appropriate conditions necessary to verify that the circuit provides its intended protection.

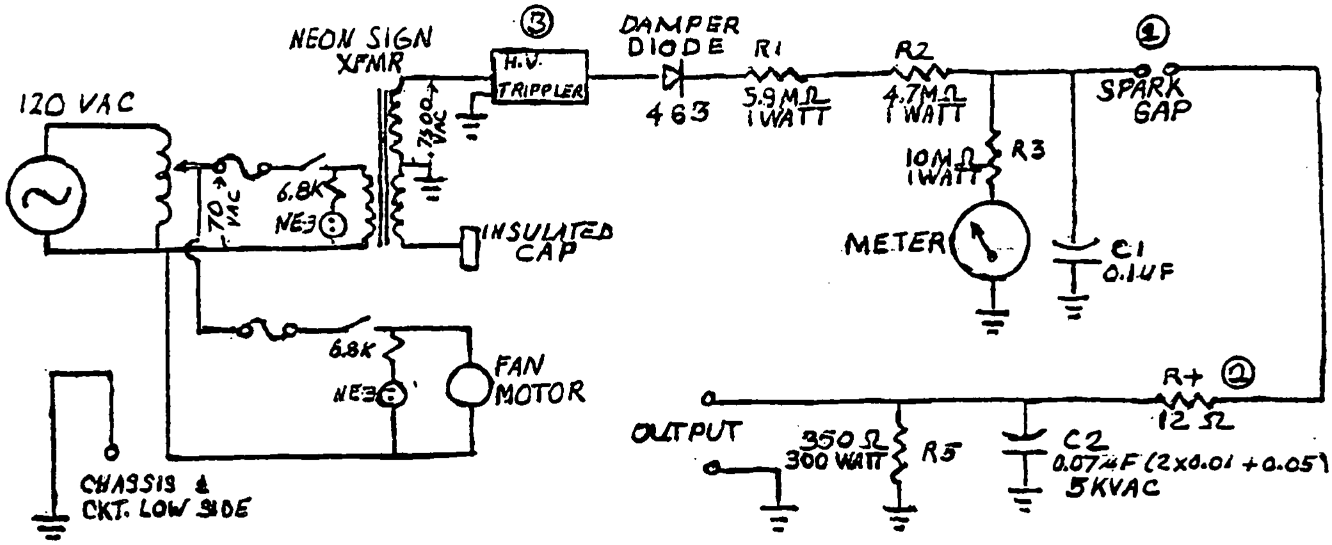
Externally Induced Transients

44.2 Ten random applications or three controlled applications of surge impulses at 60 second intervals is to be applied to the output circuit of one sample of the power conditioning unit. Each of the ten applications is to be random with respect to the phase of the 60 hertz output voltage. If three controlled applications are employed, one application is to be at essentially zero of the output voltage wave, one at positive peak and one at negative peak.

44.3 The impulse generator is to provide a 1.2 by 50 microsecond full wave impulse with a crest value of 5.0 kilovolt. The short-circuit current of the impulse generator shall be not less than 500 amperes.

44.4 Figure 44.1 shows a typical impulse generator.

FIGURE 44.1



1 Spark gap employs boiler electrodes

2 12 ohm surge resistor #22 nichrome wire wound on flat mount to reduce reactance.

3 Murata # MSR 2513-RRET0021CE22

Static Discharge

44.5 One sample of the power conditioning unit is to be subjected to this test which is to be conducted in an ambient temperature of 23±3°C (73±5°F), at a relative humidity of 10±5 percent, and a barometric pressure of not less than 700 mm of mercury (194 kPa). The power conditioning unit enclosure is to be connected to earth ground during this test. A 250 picofarad low leakage capacitor, rated 10,000 volts dc, is to be connected to two high-voltage insulated leads, 3 feet (0.9 m) long. A 1500 ohm resistor is to be inserted in series with one lead. The end of each lead is to be attached to a 1/2 inch (12.7 mm) diameter metal test probe with a spherical end mounted on an insulating rod. The capacitors are to be charged by touching the ends of the test leads to a source of 10,000 volts dc for at least 2 seconds for each discharge. One probe is to be touched to the power conditioning unit enclosure and the other probe is then to be touched to earth ground.

44.6 Ten discharges are to be applied to different points on the exposed surface of the power conditioning unit enclosure, recharging the capacitors for each discharge. Five of these discharges are to be made with one lead connected to earth ground and the other lead probed on the power conditioning unit enclosure surface followed by five discharges with the polarity reversed.

Extraneous Transients

44.7 One sample of the power conditioning unit is to be subjected to transients generated from each of the following devices located a distance of 1 foot (0.3 m) from the power conditioning unit. The time of application for each condition shall be at least 2 minutes.

A. Sequential arc (Jacob's ladder) generated between two 15 inches (381 mm) long, No. 14 AWG (2.1 mm^2) solid copper inductors attached rigidly in a vertical position to the output terminals of an oil burner ignition transformer or gas tube transformer rated 120 volts, 60 hertz primary; 10,000 volts, 60 hertz, 23 milliamperes secondary. The two wires are to be formed in a taper starting with a 1/8 inch (3.2 mm) separation at the bottom (adjacent to terminals) and extending to 1-1/4 inches (31.8 mm) at the top.

B. Energization of a transmitter-receiver unit (walkie-talkie) operating between 26-27 mega hertz frequency and having a 100 milliwatt output.

C. Energization of an electric drill rated 120 volts, 60 hertz, 2.5 amperes.

D. Energization of a switched induction type soldering gun rated 120 volts, 60 hertz, 2.5 amperes.

E. Energization of a buzzer rated 120 volts, 60 hertz.

45. Abnormal Operation

General

45.1 A power conditioning unit shall not emit flame or molten metal or become a risk of fire or electric shock when subjected to the tests specified in paragraphs 45.1-45.6. During these tests the power conditioning unit is to be placed on a softwood surface covered with white tissue paper and a single layer of cheesecloth is to be draped loosely over the entire enclosure. Dead metal parts are to be grounded through a 3 ampere fuse. The input and output circuits of the power conditioning unit are to be connected as specified in paragraph 38.1 during these tests. Fusing for the input and output circuits shall be provided in accordance with the instructions provided with power conditioning unit and the markings on the power conditioning unit. Each test is to be continued until further change as a result of the test condition is not likely. An unacceptable condition is considered to exist (1) if flame or molten metal is emitted from the enclsoure of the equipment as evidence by ignition, glowing or charring of the cheesecloth or tissue paper, or (2) the 3-ampere fuse to ground opens, (3) when the insulation breaks down when tested in accordance with paragraphs 40.1 and 40.2, or (4) live parts are made accessible -- see paragraph 7.1.

45.2 Temperature or current-sensitive devices or systems that are relied upon to comply with paragraph 45.1, shall comply with the requirements of such devices. Electronic temperature- or current-limiting circuits that are relied upon shall be subjected to conducting a component evaluation study as described in Section 26.

Forced Ventilation

45.3 A power conditioning unit having forced ventilation is to be operated with the rotor of a blower motor or motors locked.

45.4 A power conditioning unit having filters over ventilation openings is to be operated with the openings blocked to represent clogged filters. The test is to be conducted initially with the ventilation openings blocked approximately 50 percent, then to be repeated under a full-blocked condition.

Component Short- and Open-Circuit

45.5 Components, such as capacitors, diodes and solid state devices, and the like, are to be short- or open-circuited, any two terminals, one at a time. This test is not required:

A. Where circuit analysis indicates that no other component or portion of the circuit will be overloaded.

B. For components in low-voltage, limited-energy circuits, or other circuits that need not be investigated in accordance with this standard.

45.6 During the test described in paragraph 45.5:

A. The maximum backfeed current that flows from the utility into the PV array as a result of a faulted component shall not exceed the marked maximum utility backfeed fault current. See paragraph 48.1.

B. DC current from the power conditioning unit output terminals shall not flow for more than one period of the normal rated frequency as a result of this test.

46. Terminal Torque

46.1 To determine compliance with the exception to paragraphs 13.14 and 13.15, a terminal screw shall withstand the torque specified in Table 46.1 without stripping the threads.

TABLE 46.1

TIGHTENING TORQUE FOR WIRE-BINDING SCREWS

Size of Terminal Screw, Number	Wire Sizes to be Tested, AWG[a]	Tightening Torque	
		Pound-Inches	Newton-Meters (N·m) or Kilogram-Meters (kg·m)
6	16-22 (ST)	12	1.4 or 0.14
8	14 (S) and 16-22 (ST)	16	1.8 or 0.18
10	10-14 (S) and 16-22 (ST)	20	2.3 or 0.23

[a]ST - stranded wire; S - solid wire.

47. Grounding Impedance

47.1 The impedance at 60 hertz between the point of connection of the equipment grounding means and any other metal part that is required to be grounded (see paragraph 14.1) shall not be more than 0.1 ohm when measured in accordance with paragraph 47.2.

47.2 Compliance with paragraph 47.1 is determined by measuring the voltage when a current of 25 amperes derived from a 60-hertz source with a no-load voltage not exceeding 6 volts is passed between the grounding connection and the metal part in question.

RATING

48. Details

48.1 The input of a power conditioning unit shall be rated as follows: (1) maximum open circuit dc voltage, (2) range of operating dc voltage, (3) range of operating current, (4) maximum array short circuit current, and (5) maximum utility backfeed fault current (see item A in paragraph 45.6). The output ratings of a power conditioning unit shall include the following: (6) nominal output voltage, (7) output frequency, (8) output current, (9) output power, (10) maximum output fault current, and (11) maximum output overcurrent protection.

MARKING

49. General

General

49.1 All markings are required to be permanent, i.e., either by being molded, die-stamped, paint-stenciled; stamped or etched metal that is permanently secured; or indelibly stamped on a pressure-sensitive label secured by adhesive that, upon investigation, is found to comply with the requirements in the Standard for Marking and Labeling Systems, UL 969

Content

49.2 A power conditioning unit shall be plainly and permanently marked where it will be readily visible, after installation, with (1) the Listee's name, trademark, or other descriptive marking by which the organization responsible for the product may be identified — hereinafter referred to as the Listee's name, (2) a distinctive catalog number or the equivalent, (3) the electrical ratings specified in paragraph 48.1; and (4) the day or other dating period of manufacture not exceeding any three consecutive months. The repetition time cycle of a date code shall not be less than 20 years. The date code shall not require reference to the manufacturer's records to determine when the power conditioning unit was manufactured.

Exception No. 1: The Listee's identification may be in a traceable code when the power conditioning unit is identified by the brand or trademark of a private labeler.

Exception No. 2: The date of manufacture may be abbreviated in a nationally accepted conventional code, or in a code affirmed by the manufacturer.

49.3 If a power conditioning unit is produced or assembled at more than one factory, each power conditioning unit shall have a distinctive marking -- which may be in code -- by which it may be identified as the product of a particular factory.

49.4 The operating positions of a handle, knob, or other means intended for manual operation by the user shall be marked.

49.5 Wiring terminals shall be marked to indicate the proper connections for the power conditioning unit, or a wiring diagram coded to the terminal marking shall be securely attached to the equipment.

Exception: The terminals need not be marked if the wire connections are plainly evident.

49.6 Equipment field-wiring terminals shall be marked:

A. "Use Copper Conductors Only" if the terminal is acceptable only for connections to copper wire.

B. "Use Aluminum Conductors Only" or "Use Aluminum Or Copper-Clad Aluminum Conductors only" if the terminal is acceptable only for connection to aluminum wire.

C. "Use Copper Or Aluminum Conductors" or "Use Copper, Copper-Clad Aluminum, or Aluminum Conductors" if the terminal is acceptable for connection to either copper or aluminum wire.

50. Cautionary Markings

50.1 A cautionary marking shall be prefixed by the word "CAUTION," "WARNING," or "DANGER" in letters not less than 1/8 inch (3.2 mm) high. The remaining letters shall not be less than 1/16 inch (1.6 mm) high.

50.2 A cautionary marking shall be (1) located on a part that cannot be removed without impairing the operation of the power conditioning unit, and (2) visible and legible to the operator during the normal operation of the power conditioning unit.

50.3 A live heat sink or other part that (1) is likely to be mistaken for dead metal, (2) is considered to render a risk of electric shock in accordance with paragraph 2.2, and (3) is not guarded as specified in paragraph 8.6 shall be marked "CAUTION -- Risk of Electric Shock -- Plates (or other word describing the type of part) are live. Disconnect power conditioning unit before servicing." The marking shall be located on or near the live part so as to make the hazard known before the part is likely to be touched.

50.4 In accordance with the exception to paragraph 23.1, a power conditioning unit not having an isolation transformer, capacitor, or a direct current sensor having a high-speed disconnect switch shall be marked "CAUTION -- For Proper Circuit Isolation" and the following words or the equivalent "Connect a minimum ____ kVA rated isolating transformer between the output of the power conditioning unit and the utility power line connections. The transformer is to be an isolation type having separate primary and secondary windings."

50.5 For compliance with Exception No. 2 to paragraph 6.4, a power conditioning unit shall be marked with the following warning or equivalent "CAUTION -- Risk of Electric Shock, Do Not Remove Cover. No User Serviceable Parts Inside. Refer Servicing To Qualified Service Personnel."

50.6 There shall be a legible and durable marking for each fuse that is used to meet the requirements in this standard, indicating the ampere, voltage and "AC" or "DC" rating of the fuse to be used for replacement. The marking shall be located so that it is obvious as to which fuse or fuseholder the marking applies. In addition, the following prominent marking shall be provided -- a single marking is acceptable for a group of fuses: "WARNING -- For Continued Protection Against Risk Of Fire, Replace Only With Same Type And Ratings Of Fuse." An equivalent wording may be used provided it contains the word "WARNING," identifies the specific risk involved, and indicates the action to be taken.

50.7 A removable panel covering a capacitor in accordance with the exception to paragraph 21.3 shall be marked "CAUTION -- Risk Of Electric Shock" and the following or equivalent wording "Wait At Least __ Minutes After The Input And Output Circuits Of The Power Conditioning Unit Have Been Disconnected Before Removing Panel To Allow Discharge Of Capacitors." The time indicated in the marking is to be whatever time needed to discharge the capacitor to within the limitations specified in paragraph 21.3 but not greater than 5 minutes.

50.8 A power conditioning unit shall be marked with the word "CAUTION" and the following words "Risk Of Electric Shock -- and the following or the equivalent:

A. "Both AC and DC Voltage Sources Are Terminated Inside This Equipment. Each Circuit Must Be Individually Opened Before Servicing" and

B. "When The Solar Array Is Exposed to Light, It Supplies a DC Voltage To This Equipment."

51. Equipment Information and Instructions

Separation of Information

51.1 Installation and equipment information shall be provided with each power conditioning unit.

51.2 Operating and operator-servicing instructions shall be separated from servicing instructions.

51.3 Where servicing requires access to parts that could render a risk of electric shock, servicing instructions shall be preceded by a warning. The warning shall be worded as follows or the equivalent "Warning -- These Servicing Instructions Are For Use By Qualified Personnel Only. To Reduce The Risk Of Electric Shock, Do Not Perform Any Servicing Other Than That Contained In The Operating Instructions Unless You Are Qualified To Do So." The letter height shall be in accordance with paragraph 50.1.

Operating and Installation Instructions

51.4 The operating and installation instructions shall:

A. Describe the equipment installation, including specifically

1. Assembly, and mounting, if required,

2. Grounding means,

3. Ventilation consideration;

B. Explain equipment markings, including specifically

1. Symbols;

2. Controls;

3. Ratings;

C. Identify and describe interconnections with

1. The photovoltaic array;

2. The utility;

3. Auxiliary and accessory equipment;

D. Explain the operation of the equipment.

MANUFACTURING AND PRODUCTION TESTS

52. Dielectric Voltage Withstand

52.1 Each power conditioning unit shall withstand without electrical breakdown, as a routine production-line test, the application of a potential (1) from input and output wiring, including connected components, to accessible dead metal parts that may become energized, and (2) from input and output wiring to accessible low-voltage, limited-energy metal parts, including terminals.

52.2 Other than as noted in paragraph 52.3, the potential for the production-line test shall be in accordance with either Condition A or Condition B of Table 52.1 at a frequency within the range of 40-70 hertz.

52.3 A power conditioning unit employing circuitry that may be damaged by an alternating current potential may be tested in accordance with Condition C or Condition D of Table 52.1.

52.4 The power conditioning unit may be in a heated or unheated condition for the test.

52.5 The test shall be conducted when the power conditioning unit is complete -- fully assembled. It is not intended that the power conditioning unit be unwired, modified, or disassembled for the test.

Exception No. 1: A part such as a snap cover or a friction-fit knob that would interfere with performance of the test need not be in place.

Exception No. 2: The test may be performed before final assembly if the test represents that for the completed power conditioning unit.

Exception No. 3: The grounding connection of a grounded input terminal may be disconnected.

52.6 A power conditioning unit employing a solid-state component that is not relied upon to prevent a risk of electric shock and that can be damaged by the dielectric potential, may be tested before the component is electrically connected provided that a random sampling of each day's production is tested at the potential specified in Table 52.1. The circuitry may be rearranged for the purpose of the test to minimize the likelihood of solid-state-component damage while retaining representative dielectric stress of the circuit.

TABLE 52.1

PRODUCTION-LINE TEST CONDITIONS

Power Conditioning Unit Rating	Condition A		Condition B		Condition C		Condition D	
	Potential Volts, ac	Time Seconds	Potential Volts, ac	Time Seconds	Potential Volts, dc	Time Seconds	Potential Volts, dc	Time Seconds
250 v or less	1000	60	1200	1	1400	60	1700	1
More than 250 v	1000+2V[a]	60	1200+2.4V[a]	1	1400+2.8V[a]	60	1700+3.4V[a]	1

[a]Maximum marked voltage.

52.7 The test equipment for supplying an alternating current potential shall include a transformer having an essentially sinusoidal output. The test equipment shall include a means of indicating the test potential, an audible or visual indicator of electrical breakdown, and either a manually reset device to restore the equipment after electrical breakdown or an automatic reject feature of any unacceptable unit.

52.8 If the output of the test equipment transformer is less than 500 volt-amperes, the equipment shall include a voltmeter in the output circuit to directly indicate the test potential.

52.9 If the output of the test equipment transformer is 500 volt-amperes or larger, the test potential may be indicated (1) by a voltmeter in the primary circuit or in a tertiary-winding circuit, (2) by a selector switch marked to indicate the test potential, or (3) in the case of equipment having a single test-potential output, by a marking in a readily visible location to indicate the test potential. When marking is used without an indicating voltmeter, the equipment shall include a positive means, such as an indicator lamp, to indicate that the manually reset switch has been reset following a dielectric breakdown.

52.10 Test equipment, other than that described in paragraphs 52.7-52.9, may be used if found to accomplish the intended factory control.

52.11 During the test, the switches are to be in the on position, both sides of the input and output circuits of the power conditioning unit are to be connected together and to one terminal of the test equipment, and the second test-equipment terminal is to be connected to the accessible dead metal.

Exception: The switch is not required to be in the on position if the testing means applies full test potential from the input and output wiring to dead metal parts with the switch not in the on position.

53. Electronic Controls Requiring a Component Evaluation

53.1 The general workmanship of all critical components is to be checked on 100 percent of production to verify electrical and physical characteristics. Any critical component which is unmarked, improperly marked, out-of-tolerance or physically damaged (chipped or cracked cases, loose leads, and the like) are to be rejected.

53.2 Burn-in tests, consisting of a 24-hour or more operating period of the power conditioning unit shall be conducted on 100 percent of production. During this test the circuit used in lieu of direct grounding of the input circuit is to be operated to confirm that this circuit operates properly.

APPENDIX A

Standards for Components

Standards under which components of the products covered by this draft standard are judged include the following:

Title of Standards	UL Standard Designation
Standard for Safety:	
Electric Office Appliances and Business Equipment	UL 114
Electrical Analog Instruments -- Panelboard Type	UL 1437
Marking and Labeling Systems	UL 969
Motor-Operated Appliances	UL 73
Outlet Boxes and Fittings	UL 514
Polymeric Materials -- Short Term Property Evaluation	UL 746A
Polymeric Materials -- Long Term Property Evaluation	UL 746B
Polymeric Materials -- Use in Electrical Equipment Evaluation	UL 746C
Printed Wiring Boards	UL 796
Specialty Transformers	UL 506
Tape, Insulating	UL 510
Tests for Flammability of Plastic Materials for Parts in Devices and Appliances	UL 94
Thermal Protectors for Motors	UL 547
Tubing, Extruded Insulating	UL 224
Wire Connectors for Use With Aluminum Conductors	UL 486B

APPENDIX C

Article 690 of the 1984 National Electrical Code.

ARTICLE 690 — SOLAR PHOTOVOLTAIC SYSTEMS

A. General

690-1. Scope. The provisions of this article apply to solar photovoltaic electrical energy systems including the array circuit(s), power conditioning unit(s) and controller(s) for such systems. Solar photovoltaic systems covered by this article may be interactive with other electric power production sources or stand alone, with or without electrical energy storage such as batteries. These systems may have alternating- or direct-current output for utilization.

690-2. Definitions.

Array. A mechanically integrated assembly of modules or panels with a support structure and foundation, tracking, thermal control, and other components, as required, to form a direct-current power-producing unit.

Blocking Diode. A diode used to block reverse flow of current into a photovoltaic source circuit.

Interactive System. A solar photovoltaic system that operates in parallel with and may be designed to deliver power to another electric power production source connected to the same load. For the purpose of this definition, an energy storage subsystem of a solar photovoltaic system, such as a battery, is not another electric power production source.

Module. The smallest complete, environmentally protected assembly of solar cells, optics and other components, exclusive of tracking, designed to generate direct-current power under sunlight.

Panel. A collection of modules mechanically fastened together, wired, and designed to provide a field-installable unit.

Photovoltaic Output Circuit. Circuit conductors between the photovoltaic source circuit(s) and the power conditioning unit or direct-current utilization equipment. See Diagram 690-1.

Photovoltaic Power Source. An array or aggregate of arrays which generates direct-current power at system voltage and current.

Photovoltaic Source Circuit. Conductors between modules and from modules to the common connection point(s) of the direct-current system. See Diagram 690-1.

Power Conditioning Unit. Equipment which is used to change voltage level or waveform or both of electrical energy. Commonly a power conditioning unit is an inverter which changes a direct-current input to an alternating-current output.

Power Conditioning Unit Output Circuit. Conductors between the power conditioning unit and the connection to the service equipment or another electric power production source such as a utility. See Diagram 690-1.

Solar Cell. The basic photovoltaic device which generates electricity when exposed to light.

Solar Photovoltaic System. The total components and subsystems which in combination convert solar energy into electrical energy suitable for connection to a utilization load.

Stand-Alone System. A solar photovoltaic system that supplies power independently but which may receive control power from another electric power production source.

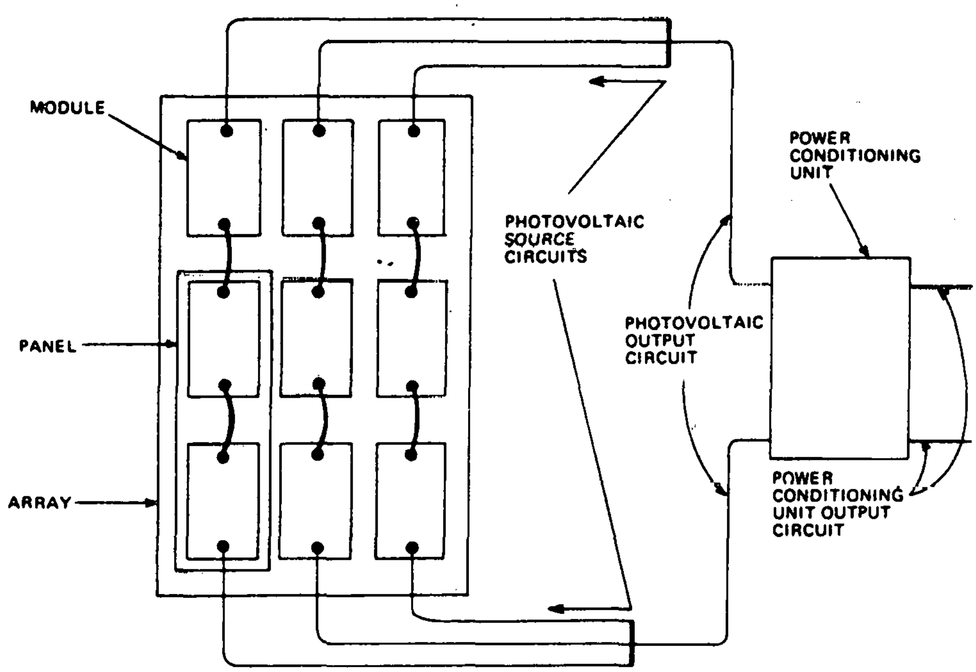


Diagram 690-1 Solar Photovoltaic Circuits

690-3. Other Articles. Wherever the requirements of other articles of this Code and Article 690 differ, the requirements of Article 690 shall apply.

690-4. Installation.

(a) Photovoltaic System. A solar photovoltaic system shall be permitted to supply a building or other structure in addition to any service(s) of another electricity supply system(s).

(b) Conductors of Different Systems. Photovoltaic source circuits and photovoltaic output circuits shall not be contained in the same raceway, cable tray, cable, outlet box, junction box or similar fitting as feeders or branch circuits of other systems.

Exception: Where the conductors of the different systems are separated by a partition or are connected together.

(c) Module Connection Arrangement. The connections to a module or panel shall be so arranged that removal of a module or panel from a photovoltaic source circuit does not interrupt a grounded conductor to another photovoltaic source circuit.

B. Circuit Requirements

690-7. Maximum Voltage.

(a) Voltage Rating. In a photovoltaic power source and its direct-current circuits, the voltage considered shall be the rated open-circuit voltage.

(b) Direct-Current Utilization Circuits. The voltage of direct-current utilization circuits shall conform with Section 210-6.

(c) Photovoltaic Source and Output Circuits. Photovoltaic source circuits and photovoltaic output circuits which do not include lampholders, fixtures or standard receptacles shall be permitted up to 600 volts.

(d) Circuits Over 150 Volts to Ground. In one- and two-family dwellings, live parts in photovoltaic source circuits and photovoltaic output circuits over 150 volts to ground shall not be accessible while energized to other than qualified persons.

690-8. Circuit Sizing and Current.

(a) Ampacity and Overcurrent Devices. The ampacity of the conductors and the rating or setting of overcurrent devices in a circuit of a solar photovoltaic system shall not be less than 125 percent of the current computed in accordance with (b) below. The rating or setting of overcurrent devices shall be permitted in accordance with Section 240-3, Exception No. 1.

Exception: Circuits containing an assembly together with its overcurrent device(s) that is listed for continuous operation at 100 percent of its rating.

(b) Computation of Circuit Current. The current for the individual type of circuit shall be computed as follows:

(1) Photovoltaic Source Circuits. The sum of parallel module operating current ratings.

(2) Photovoltaic Output Circuit. The photovoltaic power source current rating.

(3) Power Conditioning Unit Output Circuit. The power conditioning unit output current rating.

Exception: The current rating of a circuit without an overcurrent device, as permitted by the Exception to Section 690-9(a), shall be the short-circuit current, and it shall not exceed the ampacity of the circuit conductors.

690-9. Overcurrent Protection.

(a) Circuits and Equipment. Photovoltaic source circuit, photovoltaic output circuit, power conditioning unit output circuit, and storage battery circuit conductors and equipment shall be protected in accordance with the requirements of Article 240. Circuits connected to more than one electrical source shall have overcurrent devices so located as to provide overcurrent protection from all sources.

Exception: A conductor in a photovoltaic source circuit, photovoltaic output circuit, or power conditioning unit output circuit having an ampacity not less than the maximum available current under short-circuit or ground-fault conditions with the condition of a shorted blocking diode shall be permitted without an overcurrent device.

(FPN): Possible backfeed of current from any source of supply, including a supply through a power conditioning unit into the photovoltaic output circuit and photovoltaic source circuits, must be considered in determining whether adequate overcurrent protection from all sources is provided for conductors and modules.

(b) Power Transformers. Overcurrent protection for a transformer with a source(s) on each side shall be provided in accordance with Section 450-3 by considering first one side of the transformer, then the other side of the transformer as the primary.

Exception: A power transformer with a current rating on the side connected toward the photovoltaic power source not less than the short-circuit output current rating of the power conditioning unit shall be permitted without overcurrent protection from that source.

(c) Photovoltaic Source Circuits. Branch-circuit or supplementary type overcurrent devices shall be permitted to provide overcurrent protection in photovoltaic source circuits. The overcurrent devices shall be accessible, but shall not be required to be readily accessible.

C. Disconnecting Means

690-13. All Conductors. Means shall be provided to disconnect all current-carrying conductors of a photovoltaic power source from all other conductors in a building or other structure.

690-14. Additional Provisions. The provisions of Article 230, Part H shall apply to the photovoltaic power source disconnecting means.

Exception No. 1: The disconnecting means shall not be required to be suitable as service equipment and shall be rated in accordance with Section 690-17.

Exception No. 2: Equipment such as photovoltaic source circuit isolating switches, overcurrent devices, and blocking diodes shall be permitted ahead of the photovoltaic power source disconnecting means.

690-15. Disconnection of Photovoltaic Equipment. Means shall be provided to disconnect equipment, such as a power conditioning unit, filter assembly and the like from all ungrounded conductors of all sources. If the equipment is energized (live) from more than one source, the disconnecting means shall be grouped and identified.

690-16. Fuses. Disconnecting means shall be provided to disconnect a fuse from all sources of supply if the fuse is energized from both directions and is accessible to other than qualified persons. Such a fuse in a photovoltaic source circuit shall be capable of being disconnected independently of fuses in other photovoltaic source circuits.

690-17. Switch or Circuit Breaker. The disconnecting means for ungrounded conductors shall consist of a manually operable switch(es) or circuit breaker(s): (1) located where readily accessible, (2) externally operable without exposing the operator to contact with live parts, (3) plainly indicating whether in the open or closed position, and (4) having ratings not less than the load to be carried. Where disconnect equipment may be energized from both sides, the disconnect equipment shall be provided with a marking to indicate that all contacts of the disconnect equipment may be live.

Exception: A disconnecting means located on the direct-current side shall be permitted to have an interrupting rating less than the current-carrying rating when the system is designed so that the direct-current switch cannot be opened under load.

690-18. Disablement of an Array. Means shall be provided to disable an array or portions of an array.

(FPN): Photovoltaic modules are energized while exposed to light. Installation, replacement, or servicing of array components while a module(s) is irradiated may expose persons to electric shock.

D. Wiring Methods

690-31. Methods Permitted.

(a) Wiring Systems. All raceway and cable wiring methods included in this Code and other wiring systems and fittings specifically intended and identified for use on photovoltaic arrays shall be permitted. Where wiring devices with integral enclosures are used, sufficient length of cable shall be provided to facilitate replacement.

(b) Single Conductor Cable. Type UF single conductor cable shall be permitted in photovoltaic source circuits where installed in the same manner as a Type UF multiconductor cable in accordance with Article 339. Where exposed to direct rays of the sun, cable identified as sunlight-resistant shall be used.

690-32. Component Interconnections. Fittings and connectors which are intended to be concealed at the time of on-site assembly, when listed for such use, shall be permitted for on-site interconnection of modules or other array components. Such fittings and connectors shall be equal to the wiring method employed in insulation, temperature rise and fault-current withstand, and shall be capable of resisting the effects of the environment in which they are used.

690-33. Connectors. The connectors permitted by Section 690-32 shall comply with (a) through (e) below.

(a) Configuration. The connectors shall be polarized and shall have a configuration that is noninterchangeable with receptacles in other electrical systems on the premises.

(b) Guarding. The connectors shall be constructed and installed so as to guard against inadvertent contact with live parts by persons.

(c) Type. The connectors shall be of the latching or locking type.

(d) Grounding Member. The grounding member shall be the first to make and the last to break contact with the mating connector.

(e) Interruption of Circuit. The connectors shall be capable of interrupting the circuit current without hazard to the operator.

690-34. Access to Boxes. Junction, pull and outlet boxes located behind modules or panels shall be installed so that the wiring contained in them can be rendered accessible directly or by displacement of a module(s) or panel(s) secured by removable fasteners and connected by a flexible wiring system.

E. Grounding

690-41. System Grounding. For a photovoltaic power source, one conductor of a 2-wire system and a neutral conductor of a 3-wire system shall be solidly grounded.

Exception: Other methods which accomplish equivalent system protection and which utilize equipment listed and identified for the use shall be permitted.

(FPN): See Fine Print Note under Section 250-1.

690-42. Point of System Grounding Connection. The direct-current circuit grounding connection shall be made at any single point on the photovoltaic output circuit.

(FPN): Locating the grounding connection point as close as practicable to the photovoltaic source will better protect the system from voltage surges due to lightning.

690-43. Size of Equipment Grounding Conductor. The equipment grounding conductor shall be no smaller than the required size of the circuit conductors in systems: (1) where the available photovoltaic power source short-circuit current is less than twice the current rating of the overcurrent device, or (2) where overcurrent devices are not employed as permitted in the Exception to Section 690-9(a). In other systems, the equipment grounding conductor shall be sized in accordance with Section 250-95.

690-44. Common Grounding Electrode. Exposed noncurrent-carrying metal parts of equipment and conductor enclosures of a photovoltaic system shall be grounded to the grounding electrode that is used to ground the direct-current system. Two or more electrodes that are effectively bonded together shall be considered as a single electrode in this sense.

F. Marking

690-51. Modules. Modules shall be marked with identification of terminals or leads as to polarity, maximum overcurrent device rating for module protection and with rated: (1) open-circuit voltage, (2) operating voltage, (3) maximum permissible system voltage, (4) operating current, (5) short-circuit current, and (6) maximum power.

690-52. Photovoltaic Power Source. A marking, specifying the photovoltaic power source rated: (1) operating current, (2) operating voltage, (3) open-circuit voltage, and (4) short-circuit current, shall be provided at an accessible location at the disconnecting means for the photovoltaic power source.

(FPN): Reflecting systems used for irradiance enhancement may result in increased levels of output current and power.

G. Connection to Other Sources

690-61. Loss of Utility Voltage. The power output from a utility interactive power conditioning unit shall be automatically disconnected from all ungrounded conductors of the utility system upon loss of voltage in the utility system and shall not reconnect until the utility voltage is restored.

690-62. Ampacity of Neutral Conductor. If a single-phase, 2-wire power conditioning unit output is connected to the neutral and one ungrounded conductor (only) of a 3-wire system or of a 3-phase, 4-wire wye-connected system, the maximum load connected between the neutral and any one ungrounded conductor plus the power conditioning unit output rating shall not exceed the ampacity of the neutral conductor.

690-63. Unbalanced Interconnections.

(a) Single-Phase. The output of a single-phase power conditioning unit shall not be connected to a 3-phase, 3- or 4-wire electrical service derived directly from a delta-connected transformer.

(b) Three-Phase. A 3-phase power conditioning unit shall be automatically disconnected from all ungrounded conductors of the interconnected system when one of the phases opens in either source.

Exception for (a) and (b): Where the interconnected system is designed so that significant unbalanced voltages will not result.

APPENDIX D

GROUNDING SYSTEM RESISTANCE AND ASSOCIATED MEASUREMENTS

BACKGROUND:

Grounding electrodes whether they are dedicated rods, bonding to piping, reinforcing bars in concrete, metal mesh, all with or without treated earth, provide a conductive path between a circuit or structural metal and the surrounding earth surface. This conduction is used to keep the voltage between accessible metal or the circuit and earth to a minimum, to minimize shock hazard situations. The effectiveness of one grounding system at the Mead, Nebraska Photovoltaic Installation was considered by measuring various resistances.

EARTH RESISTIVITY MEASUREMENT:
DATES OF TESTING: October 15 and 16, 1980

METHOD

Four hollow copper rods were driven 12 inches into the depressions in the furrowed soil in the corn field immediately south-southeast of the photovoltaic array. The rods were hollow copper tubes, each 18 inches long by 5/8 inch diameter, and nominal 1/32 inch wall thickness. The four rods were in line, and were spaced 50 feet apart.

As Associated Research Vibroground 293 earth resistance meter was connected to the four driven copper rods, with the current leads of the meter connected to the two outer rods, and the potential leads of the meter connected to the two inner rods.

See Figure D.1.

Although the general area was irrigated, the soil into which the rods were driven was hard and dry, as there had been little rain.

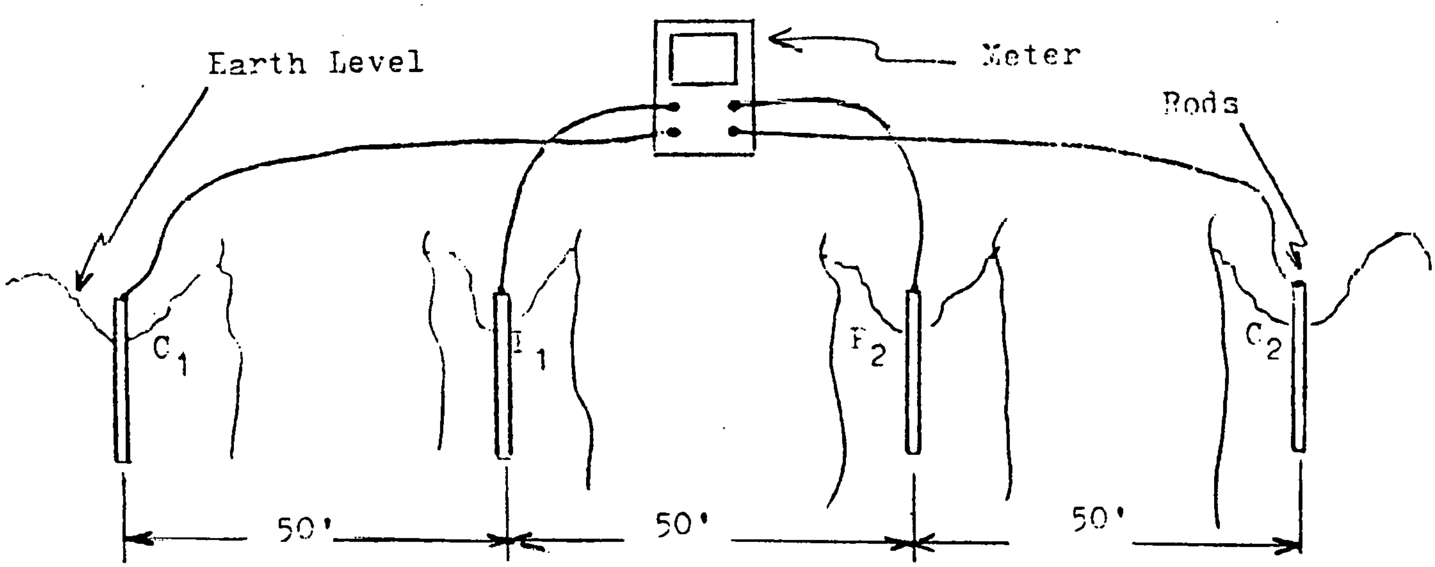


Figure D.1
Earth Resistivity Measurement

[The Vibroground 293 functions by creating a 97 hertz alternating current which is passed through the earth between the outer (current) rods. The voltage drop across the inner (potential) rods is balanced and nulled against a source within the Vibroground. The inner electrodes and their junctions to earth are not burdened with any voltage drop due to current flow.

The balancing is done with current as rectified by a mechanical rectifier, synchronized with the 97 hertz generator. The 97 hertz source, and the mechanical rectifier, work to eliminate any measurement errors that might be due to stray 60 hertz currents.]

RESULTS

With the meter balanced, a resistance of 0.41 ohms was indicated between the two potential electrodes.

By use of the formula:

$$\rho = DR \times 191.5$$

where: ρ is the soil resistivity in ohm-centimeters
D is distance in feet between the potential electrodes
and
R is resistance in ohms (indication of instrument)

therefore $\rho = (50)\ (0.41)\ (191.5)$
$\rho = 3920$ ohm-centimeters

EARTHING RESISTANCE MEASUREMENT:

COMMENTARY

The accuracy of ground resistance measurements is dependent upon the placement and size of the test electrodes with relation to the grounding network. Therefore, it is desirable to know detail on the grounding network before conducting the tests. In the case in question, except as noted following, particulars on the grounding network are unknown, therefore, estimations of its nature were made, and the test electrodes and their placement adjusted accordingly.

The array frame is grounded in part by the metal conduit that encloses the conductors to the control center. This conduit connects to the site service ground. There is no separate grounding conductor between the array frame and the site service ground. The array frame is also grounded by virtue of its resting on concrete pads in the earth. Each vertical supporting member is connected to a braided metal strap that is buried in the earth at each concrete pad.

The negative terminal is not connected to the array frame or to the earth at the array. It is connected to earth at the control center.

METHOD

Two hollow copper rods were driven 12 inches into depressions in the furrowed soil in the cornfield immediately south-southeast (case 1) and east-northeast (case 2) of the photovoltaic array. The rods were hollow copper tubes, each 18 inches long by 5/8 inch in diameter, and nominal 1/32 inch wall thickness. The two rods were in line with an array footing, with (in case 1) the closer rod 50 feet from the array footing and the farther rod 75 feet from the array footing, and with (in case 2) the closer rod 63 feet from the array footing and the farther rod 100 feet from the array footing.

An Associated Research Vibroground 293 meter was connected to the rods and (for each driven rod configuration) to the array footing and then to the array negative terminal. The current leads were run to the farther rod and the footing (or negative terminal), and potential leads to the closer rod and the array footing (or negative terminal). [The two meter leads ran separately to the footing (or terminal).] Each measurement was conducted with the array circuit switches both open and closed. Resistances were measured between the points in question.

See Figure D.2.

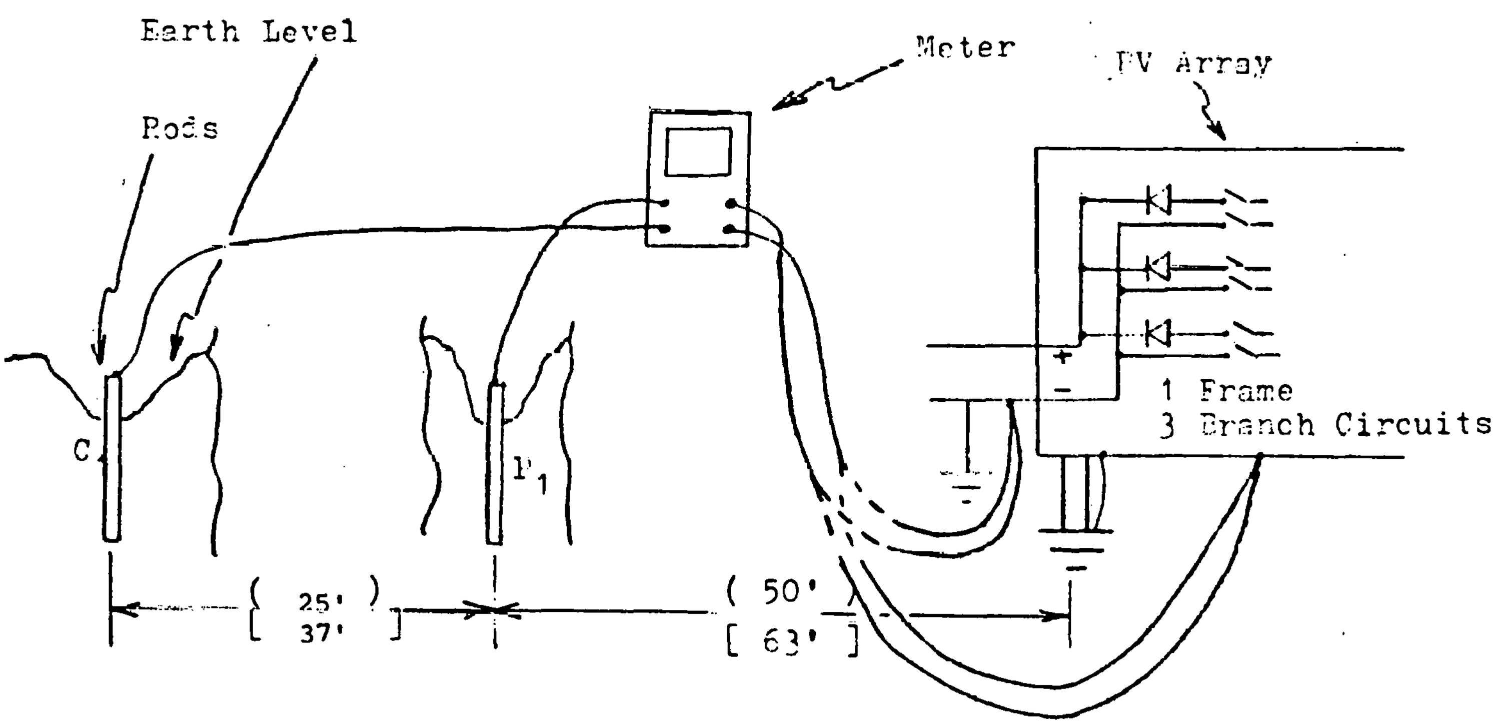


Figure D.2

Earthing Resistance Measurements

RESULTS

Electrode Grounding Resistance (Ohms)

	Array Branch Circuit Switches	Electrode Configuration Case (1)	Electrode Configuration Case (2)
Frame to earth	Open	1.5	1.3
	Closed	1.5	1.3
Negative terminal to earth	Open	0.89	0.84
	Closed	0.89	0.84

RESISTANCE-TO-EARTH MEASUREMENT (NEAR ARRAY):

COMMENTARY

This test is intended to determine the resistance likely to be involved in series with a person standing on earth ground and touching the array structure or terminal. The resistance represents that part of the earth path between the point of contact (by a person) with earth and (1) the array frame or (2) the negative terminal of the array circuit.

METHOD

A single hollow copper rod was driven 12 inches into the soil, 2 feet from an array footing. The rod was a hollow copper tube 18 inches long by 5/8 inch diameter, and nominal 1/32 inch wall thickness.

A pair of potential and current leads of an Associated Research Vibroground 293 earth resistance meter was connected in turn to (1) the array frame and (2) the array negative terminal; and the other pair of leads (potential and current) to the driven rod (two leads to each point). Resistances were measured between the points in question.

See Figure D.3.

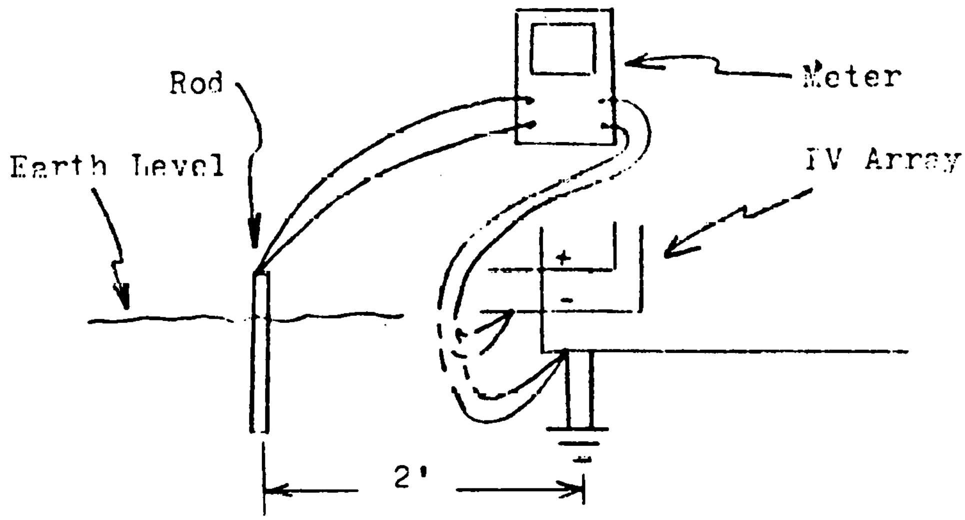


Figure D.3

Resistance to Earth Measurements

RESULTS

Resistances:	Negative terminal to ground:	620 ohms
	Frame to ground:	450 ohms

<u>OPEN CIRCUIT VOLTAGE AND LEAKAGE CURRENT MEASUREMENT</u>:

COMMENTARY

The active electrical parts of the array are supported on frames.

1 frame is 3 branch circuits in parallel.
1 branch circuit is 4 quads in series.
1 quad is 4 modules in parallel.
1 module is 44 cells in series.

The three branch circuits on a frame are connected together via blocking diodes and double-pole, three-position (on, open, shorting) switches; and then to the control center.

See Figure D.4.

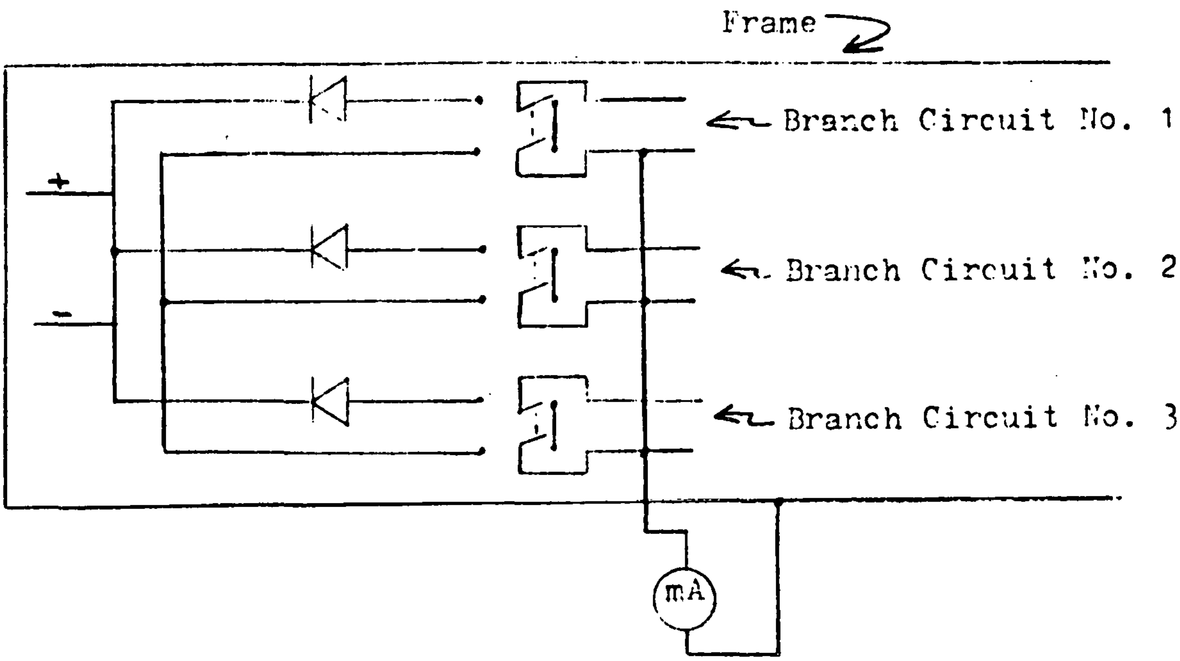


Figure D.4

Voltage and Current Measurements

METHOD I

The open circuit voltage of each branch circuit of one frame was measured with a dc voltmeter.

RESULTS I

The open circuit voltage of each of the three branch circuits, measured individually, was 190 volts.

METHOD II

With each of the three branch circuit switches in the open position, a micro ammeter was connected between the three negative branch circuit leads (of the particular frame) connected together, and the metal structure of the frame. No deliberate impedance was introduced in this circuit (Figure D.4). The current through the meter was measured.

RESULTS II

The current was 2.5 microamperes.

GROUND FAULT TEST:

COMMENTARY

Rain had occurred during the preceding night, and puddles remained around and under the array. The sun was shining brightly.

METHOD I

The short circuit current of one frame of the array (3 branch circuits) was measured.

RESULTS I

The short circuit current was 4.8 amperes.

METHOD II

The three branch circuit switches at the array frame were placed in the on position, and the "frame" switch at the control center placed in the on position, providing a circuit ground at this point.

The positive terminal of the frame was connected, via an external lead, to the metal of the frame, and the voltage between the frame and the "ground" measured. "Ground" was a copper rod in the puddle of water approximately 15 feet from the frame in question. See Figure D.5.

RESULTS II

The voltage between frame and ground was 2.6 volts.

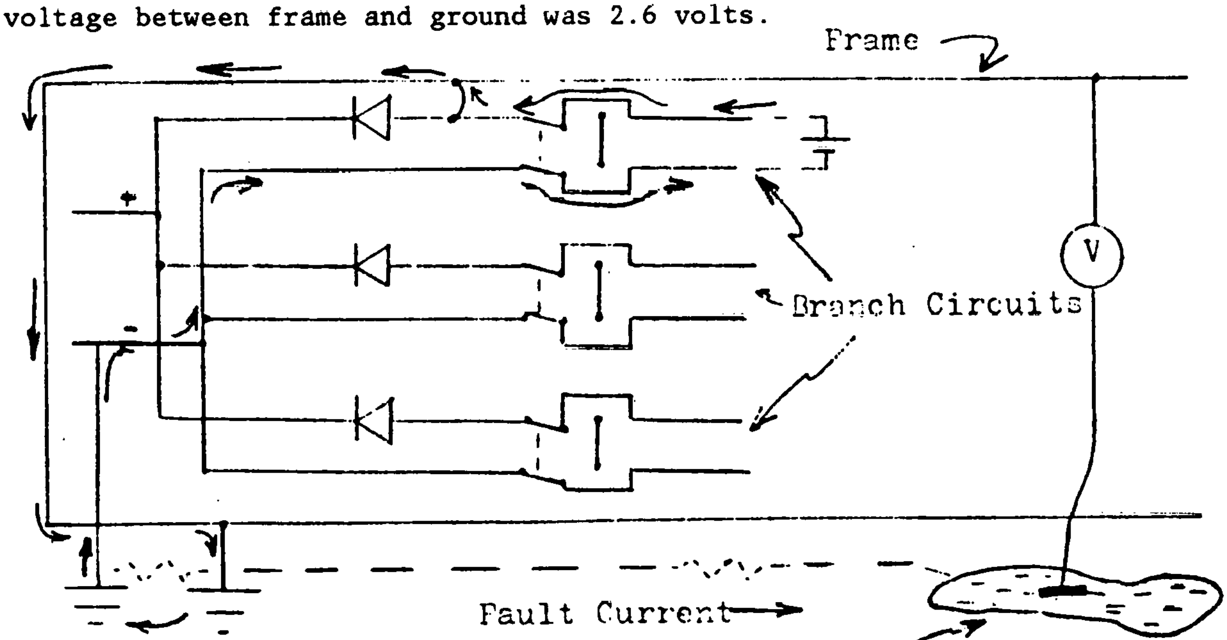


Figure D.5

Ground Fault Tests

APPENDIX E

PROVISIONS OF THE STANDARD FOR DOUBLE INSULATION SYSTEMS FOR USE IN ELECTRICAL EQUIPMENT, UL 1097-1978, THAT MAY BE CONSIDERED APPLICABLE TO PHOTOVOLTAIC MODULES AND SYSTEMS

INTRODUCTION:

Double insulation systems may be viable safety subsystems for photovoltaic modules and panels, and for photovoltaic system installations. Certain of the provisions in the Underwriters Laboratories Inc. Standard for Double Insulation Systems, as described below, are considered to be applicable to double-insulated photovoltaic modules, and other components covered by the Underwriters Laboratories Inc. Proposed Standard for Flat-Plate Photovoltaic Modules and Panels.

STANDARD PARTICULARS:

All material, except that in parenthesis () is a quotation from the Standard for Double Insulation Systems.

(Section 5 in Progress)

Power-Supply Cord (For Photovoltaic Systems, a Power Supply Cord May Be Considered to Include Integral Module Leads and Other Inter-Module Wiring.)

5.10 Reinforced insulation is acceptable in place of double insulation at points inside the equipment where the power-supply cord contacts supplementary insulation.

5.11 Inside the equipment, a nonjacketed power-supply cord (see paragraph 6.2) or the insulated individual conductors of a jacketed supply cord may be insulated from an accessible dead-metal part by supplementary insulation in any one of the following forms:

A. An insulating liner.

B. A coating of insulating material.

C. A sleeve around the cord, if the sleeve is loose-fitting and is secured to the enclosure.

5.12 If the nonjacketed flexible cord in a power-supply cord or one or more of the insulated individual conductors of a jacketed flexible cord in a power-supply cord contacts supplementary insulation inside the equipment, the cord insulation or the individual insulation and the supplementary insulation shall be such that they are not affected to the same degree by deteriorating influences such as heat, contaminants, etc. The flexible cord jacket itself may serve as the supplementary insulation for the insulated individual conductors provided that the conditions of use of the equipment are not likely to stress or degrade the physical properties of the jacket.

Internal Wiring

5.13 Reinforced insulation is acceptable in place of double insulation at points inside of the equipment where the insulated wiring -- including insulated splices -- contacts supplementary insulation.

5.14 Internal wiring that has basic insulation -- including an insulated splice -- shall be spaced 1/32 inch (0.8 mm) from an accessible dead-metal part.

5.15 If internal wiring that has basic insulation -- including an insulated splice -- contacts an enclosure of insulating material, the insulation on the wire and the enclosure of the insulating material shall be such that they are not affected to the same degree by deteriorating influences such as heat and contaminants.

5.16 Insulating tubing may be accepted as supplementary insulation between internal wiring that has basic insulation -- including an insulated splice -- and accessible dead-metal parts, if all of the following conditions are met.

A. The tubing shall be loose-fitting on the conductors.

B. The tubing shall be so fixed in position as to prevent relative movement between the tubing and the metal.

C. The length of the leads shall prevent any tension during assembly or repair.

D. The tubing shall not contact sharp bends, projections, corners, etc., nor shall it be subjected to tension or compression.

E. The wiring shall not be subject to flexing.

F. The materials of the tubing and the insulation on the wire shall be such that they are not affected to the same degree by deteriorating influences such as heat and contaminants.

G. The tubing shall be of a thickness that is acceptable for the application.

Other Locations

5.17 Reinforced insulation is acceptable in place of double insulation anywhere in the equipment if the reinforced insulation consists of one or more layers with a total thickness of not less than 5/16 inch (8 mm). In a multilayer assembly, contact between adjacent layers is acceptable.

6. Flexible Cord

6.1 A power-supply cord shall not include a grounding conductor.

6.2 A power-supply cord shall be a jacketed type.

Exception: Nonjacketed flexible cords may be investigated for use as a power-supply cord for specific equipment when the equipment standard does not require a jacketed cord.

6.3 Inside the equipment, a nonjacketed flexible cord or the insulated individual conductors of a jacketed flexible cord shall not contact an accessible dead-metal part.

7. Strain Relief

7.1 If an accessible metal strain-relief clamp is employed, it shall be provided with supplementary insulation located between the clamp and the flexible cord.

8. Bushings

8.1 A bushing of insulating material shall be provided at each point at which a flexible cord passes through a dead-metal part. A bushing of rubber, neoprene, polyvinyl chloride, or similar material is not acceptable for this application.

9. Capacitors (For Photovoltaic Systems, Applicable to System Capacitors Used in Conjunction With Certain Power Conditioning Units).

9.1 The dielectric in a capacitor shall not be depended upon as supplementary (protecting) insulation.

11. Spacings

11.1 Spacings shall be in accordance with Table 11.1 except that larger spacings may be required at points at which carbon dust or other conductive contaminants exist or might accumulate.

11.2 The spacing specified as the minimum acceptable in item 1 of Table 11.1 does not apply to the inherent spacings of a component (such as a snap switch) of equipment. The acceptability of spacings on a component is based on the requirements for that component.

FIGURE 11.1
METHOD OF COVERING ENCLOSURE
WITH FOIL FOR MEASUREMENT AND TESTS

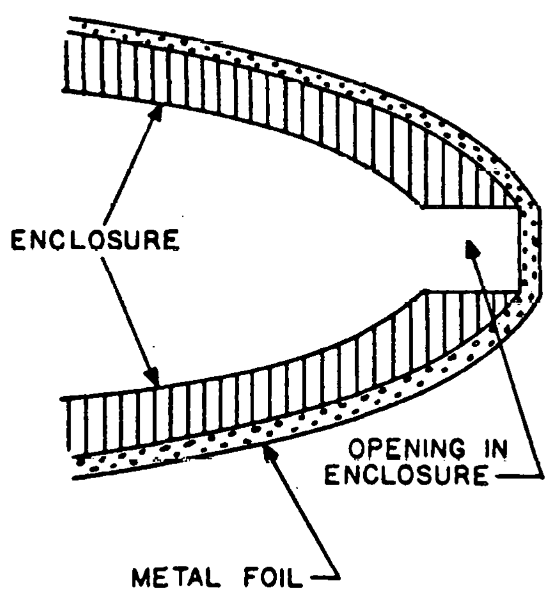


TABLE 11.1
MINIMUM SPACINGS

Parts between Which Spacings Are Measured	Minimum Acceptable Spacings
1. Uninsulated live parts and dead metal parts that are separated by basic insulation only (other than reinforced insulation)	Not less than the through-air and over-surface spacings required in the end-product standard
2. Accessible dead metal parts[a] and dead metal parts separated from uninsulated live parts by basic insulation only (this ordinarily is a spacing resulting from supplementary insulation)	Not less than the through-air and over-surface spacings required in the end-product standard
3. Uninsulated live parts and dead metal parts[a] separated by double insulation or by reinforced insulation (where acceptable), except as indicated in item 4	Not less than twice the through-air and over-surface spacings required in the end-product standard between uninsulated live parts and dead metal parts that are separated by basic insulation
4. Uninsulated live parts and accessible dead metal parts[a] at a commutator or other location in which foreign materials can build up	5/16 inch (8.0 mm) over surface
5. Uninsulated live parts, including enameled wire wound in the form of a coil and reliably held in place, and the interior surface of insulating material that serves as supplementary insulation	1/32 inch (0.8 mm)
6. Outer surface of a wrapped coil and the interior surface of insulating material that serves as supplementary insulation	1/32 inch (0.8 mm)

[a] If the outer surface of the enclosure consists wholly or partially of insulating material, the spacings applied to accessible dead metal also apply to metal foil wrapped tightly around and in intimate contact with the enclosure. The foil is to be drawn tightly across any opening in the enclosure to form a flat plane across such opening. See Figure 11.1.

12. Internal Wiring

12.1 Internal wiring shall be so located or restrained that breakage or loosening of the wire at a termination and subsequent displacement cannot reduce the spacings to values below those specified in Table 11.1.

(Exception that exists in standard not considered applicable.)

12.2 Compliance with paragraph 12.1 can be accomplished by any one or more of the following means:

A. The use of barriers.

B. Relative placement of parts.

C. Physical restraint of the conductor in addition to that resulting from its normal electrical connections.

D. Other equivalent means.

12.4 The connection of a lead to a switch or other component likely to require replacement and the connection of a lead to a conductor of the power-supply cord shall be so made that, if the component or power-supply cord is to be replaced, it shall not be necessary to do any of the following:

A. Cut a conductor.

B. Disconnect a soldered and taped splice between two conductors.

C. Disconnect a soldered joint between a lead and a bus bar, strap, or terminal.

12.5 A supplementary part such as an insulating barrier liner that is necessary to maintain the level of insulation shall be so secured to the equipment that it remains in place when the power-supply cord or a component, such as a switch, is being replaced.

Exception: A supplementary part need not be fixed to the equipment if its design precludes its being left out after servicing of the equipment.

PERFORMANCE

14. Dielectric Voltage-Withstand (For Photovoltaic System Components, the Applied Voltage Would Be DC Not 60 Hertz AC.)

14.1 The equipment shall withstand for 1 minute without breakdown the application of a 60-hertz essentially sinusoidal potential in accordance with Table 14.1.

TABLE 14.1
POINTS OF APPLICATION AND VOLTAGES
FOR DIELECTRIC VOLTAGE-WITHSTAND TEST

Points between Which Potential Is to Be Applied	Test Potential in Volts
1. Live parts and inaccessible dead metal parts	Voltage prescribed for dielectric voltage-withstand test in the end-product standard
2. Inaccessible dead metal parts and accessible dead metal parts (or for equipment with an outer enclosure of insulating material, metal foil wrapped tightly around the enclosure) – see Figure 11.1	2000 volts plus twice the rated voltage of the equipment
3. Accessible dead metal parts (or the foil mentioned in item 2) and metal foil in contact with the inner surfaces of insulating barriers provided to accomplish compliance with paragraph 12.1	2000 volts plus twice the rated voltage of the equipment
4. Accessible dead metal parts and: a. Metal foil wrapped around the power-supply cord inside the inlet bushings, cord guards, strain-relief clamps, and the like; or b. A metal rod of the same cross-sectional dimensions as the cord and inserted in its place	2000 volts plus twice the rated voltage of the equipment
5. Live parts and accessible dead metal parts (or the foil mentioned in item 2)	3500 volts plus twice the rated voltage of the equipment

15. Insulation Resistance

15.1 After conditioning as described in paragraph 15.4, the equipment shall have an insulation resistance not less than the following:

A. Between live parts and accessible dead-metal parts -- 7 megohms.

B. Between live parts and inaccessible dead-metal parts -- 2 megohms.

C. Between inaccessible dead-metal parts and accessible dead-metal parts -- 5 megohms.

15.2 For equipment having an outer enclosure consisting wholly or partly of insulating material, the term "accessible dead-metal parts" used in paragraph 15.1 signifies metal foil tightly wrapped around the exterior of the enclosure.

15.4 In preparation for the test, the sample is to be conditioned at 32.0±2.0°C (91.4±3.6°F) for 4 hours and then placed in an enclosure for 48 hours at 20.0-30.0°C (68.0-86.0°F) and a relative humidity of 88±2 percent. The specified relative humidity can be obtained by placing a supply of a saturated solution of potassium sulphate inside a tightly closed compartment.

15.5 The measurements of insulation resistance are to be made with the equipment still in the conditioning chamber.

15.6 In determinations of insulation resistance, a direct potential of 500 volts is to be employed, and the value of insulation resistance is to be determined 1 minute after application of the test potential. An acceptable megohmmeter can be used for conducting the insulation-resistance test, or other similar means can be employed. The sample is not to be energized during this test.

15.7 Following the insulation-resistance test, and while still humidity-conditioned, the sample shall be subjected to the dielectric voltage-withstand test in Section 14.

16. Resistance to Impact

16.1 The equipment shall withstand the impact tests applicable to the end-product standard without resulting in any of the following:

A. Reduction of spacings below the minimum acceptable values.

B. Making accessible to contact (1) live parts and (2) dead-metal parts that are insulated from live parts by only basic insulation.

C. Breakage, cracking, rupture, etc. that have an adverse effect on the insulation.

D. Producing any other condition that increases the risk of electric shock from the equipment. The equipment is to comply with the dielectric voltage-withstand requirements applicable to the equipment after being subjected to the impact.

APPENDIX F

DEVELOPMENT OF A DIFFERENTIAL DC GROUND-FAULT DETECTOR

BACKGROUND:

Ground-fault detection systems appear to be a practicable safety subsystem for photovoltaic power systems, to provide both shock hazard protection for personnel and fire hazard protection. In certain circuit configurations, differential type ground-fault detectors are the only type usable. In an effort to demonstrate the feasibility of dc differential type ground-fault detectors and to advance their commercial development, Underwriters Laboratories Inc. constructed and field tested such a device.

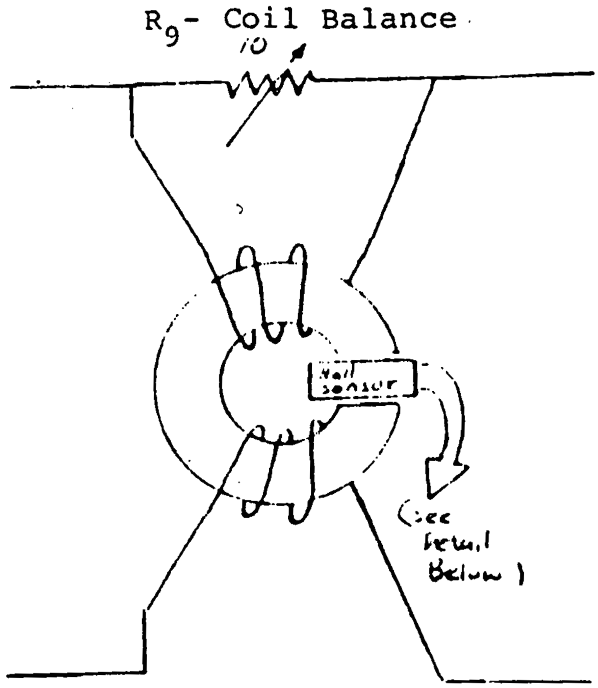
DEVICE DETAILS:

A design for a differential type dc ground-fault detector incorporating a Hall Effect sensor is shown in Figure F.1. The Hall Effect sensor is a semiconductor device which produces an output voltage proportional to an applied magnetic field. In this design, the Hall Effect device is positioned in the air gap of a toroid around which are wound two coils. Each of the coils comprises a portion of one side of the circuit between the protected and unprotected circuit areas. The coils are wound so that with equal current flowing in them, their magnetic fluxes cancel. (This corresponds to no difference current, and is the condition when no ground-fault currents exist.) Thus no output is produced by the Hall Effect device. The Hall Effect device output voltage is proportional to the strength of the magnetic field, and its polarity is a function of the direction of the magnetic field.

A difference in current between the two coils that might be caused by a ground fault would result in a net magnetic flux in one direction or the other, depending upon the relationship between the two currents. This magnetic flux is translated into a voltage output of the Hall Effect sensor.

The particular Hall Effect device used in the ground-fault detector is Sprague Electric Company Type UGN-3501M. Since the Hall Effect voltage is low (in the millivolt range), the Sprague device also incorporates a linear differential amplifier, differential emitter follower output and a voltage regulator, all in one monolithic package.

Under a condition of current imbalance, a magnetic flux is established in the toroid. If it is, for example, of south-north polarity, it will produce a voltage at pin 1 of the Hall Effect device more positive than at pin 8. If the flux is north-south, the voltage at pin 1 of the Hall Effect device goes more negative than that at pin 8.



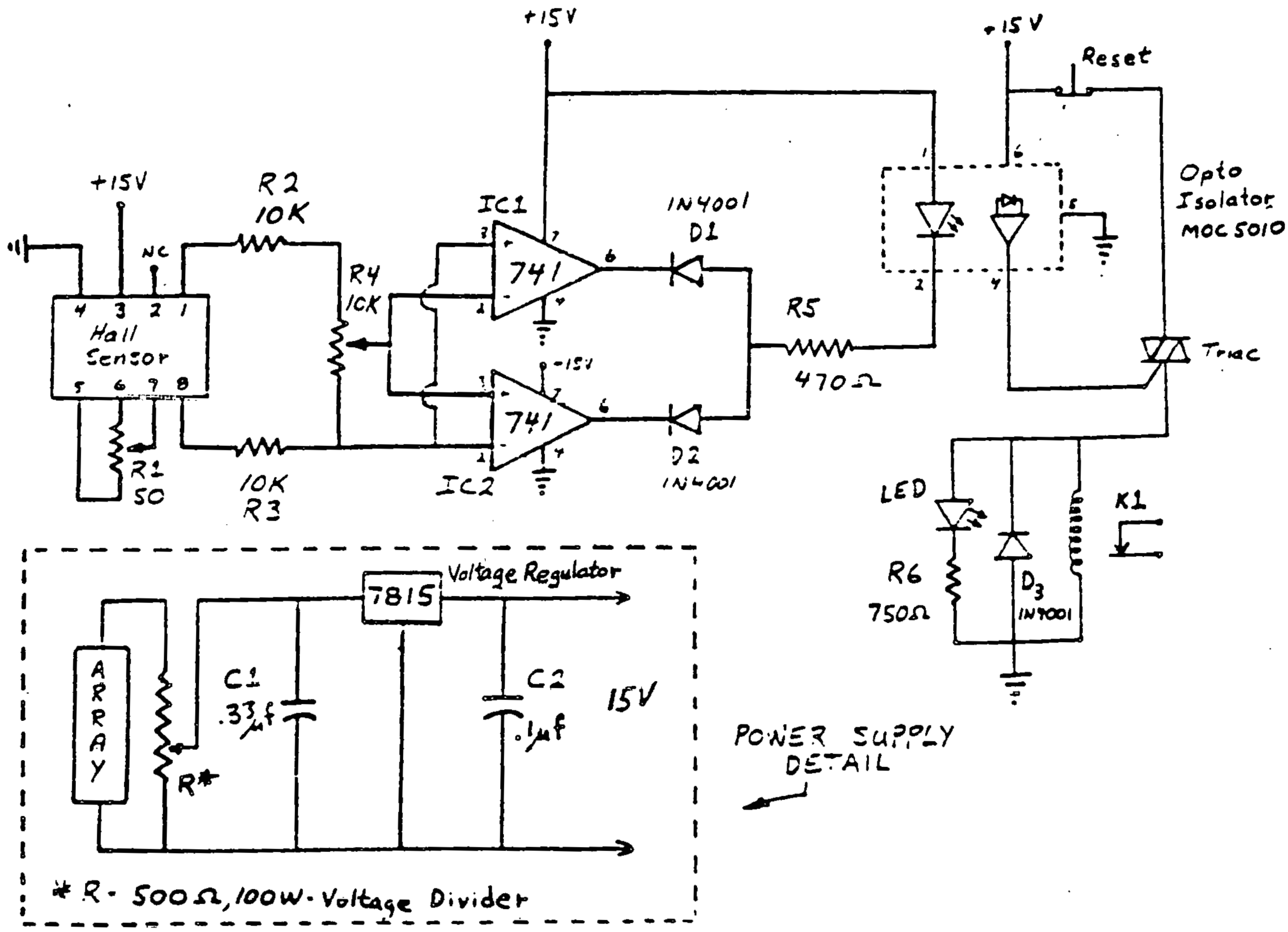


Figure F.1

DC Ground-Fault Detector

The output of the Hall Effect device is fed differentially, to two Type 741 integrated circuit operational amplifiers (IC_1 and IC_2). This integrated circuit normally requires both a positive and negative power supply, but when used as a comparator as in this circuit, the operational amplifiers may be properly operated by a single polarity supply. The 10,000 ohm potentiometer (R_4) allows the sensitivity of the ground fault detector to be varied. A 10 ohm resistor (R_9) allows balancing of the current through the two coils. With the output of the Hall Effect device nulled (by the potentiometer connected between pins 5, 6, and 7), the outputs of both operational amplifiers are positively saturated (high) and the LED in the opto-isolator does not light.

When a circuit imbalance occurs which generates a net flux, a Hall Effect voltage is generated. If the voltage at pin 1 of the Hall Effect device is more negative than pin 8, the non-inverting input (pin 3) of the operational amplifier IC_1 will be more negative with respect to the inverting input (pin 2) and this operational amplifier will go into negative saturation and the LED in the opto-isolator will light. If the voltage at pin 8 of the Hall Effect device is more negative than pin 1, the non-inverting input (pin 3) of the operational amplifier IC_2 will be more negative with respect to the inverting input (pin 2) and this operational amplifier will go into negative saturation and the LED in the opto-isolator will also light. Thus, a fault of either polarity will result in one or other of the two operational amplifiers going into negative saturation and in both cases the LED in the opto-isolator will light.

The MOC 5010 opto-isolator has a linear op amp output which may be utilized to gate a triac. In this particular circuit, the triac is used to control a relay and an indicator LED. Upon occurrence of a detected ground fault, the triac fires and will remain latched on until the principal current is interrupted by the reset button, even though the fault is removed. A contactor may be substituted for relay K_1 to directly control some other load.

Operation of the ground-fault detector using an array voltage between 150-250 volts dc is achieved by means of a voltage divider resistor and an integrated circuit voltage regulator to produce a nominal 15 volt dc output.

FIELD TESTS:

This ground fault sensing device was field tested at the MIT-Energy Laboratory prototype at the Northeast Photovoltaic Residential Experimental Station; Concord, Massachusetts. This structure is a simulated residence consisting of an array mounted on a roof of a house shell. The array consists of eight parallel strings of 14 modules each, each module containing 36 cells in series. Each string has an open circuit voltage of 250 volts dc and a short-circuit current of 4.8 amps.

This particular prototype was selected since it utilizes a transformerless power conditioning unit interactive with the utility supply. Neither side of the array is directly grounded, the electrical center point of the array being at a "virtual ground". In an array having a "virtual ground", a fault to ground is equally likely from either the positive or negative side of the array. It is therefore essential that a ground-fault detection system installed in this type of array be capable of detecting ground faults of both polarities.

The toroid in the ground-fault detection system built is wound with No. 20 AWG wire. Due to the current limitations of this toroid, it was necessary to install the ground-fault detection system in one source circuit (string) of the array rather than in the entire array.

When the testing was underway the sky was clear with an array output voltage of 190 volts dc and a source circuit current of 3 amperes. The ground-fault detector was installed in the source circuit and the various ground-fault currents abruptly introduced to determine the maximum sensitivity of the ground-fault detection system. The initial testing was conducted with the ground-fault detection system powered from a separate dc power supply adjusted for a 25 volt dc output. The integrated circuit voltage regulator packaged with the ground-fault detection system board maintained a 14.8 volt dc voltage for the operation of the circuit components. As differing ground faults were introduced, it was found that with the ground-fault detector set for maximum sensitivity, a ground fault of 11 milliamperes would trip the detector. The detector tripped when this ground fault was applied between the positive end of the array and ground and between the negative end of the array and ground. The ground-fault detector thus reacted properly to ground faults of either polarity.

The next phase involved operating the ground-fault detector directly from the array dc voltage. A 500 ohm, 100 watt adjustable vitreous enameled wire wound power resistor was connected across the array. The voltage divider tap was adjusted for an output voltage of approximately 25 volts which was supplied to the ground-fault detection system. The ground-fault detection system again reacted properly to faults of either polarity when powered from the array.

Next, it was sought to determine whether a gradually applied ground fault would operate the detector. For this experiment, a 200 K-ohm potentiometer (used as a variable resistor) was connected between the positive end of the array branch circuit and ground. The resistance was gradually decreased and again the ground-fault detection system operated. This test was repeated connecting the variable resistor to the negative end of the array. Again the ground-fault detection system operated.

In summation, the ground-fault detector performed well by responding to deliberately induced faults. No circuit interruption was attempted, nor was the response time measured. The device's principle failing was instability and erroneous responses due to temperatures changes when operated at higher sensitivity levels. This problem exists because the null point of the Hall Effect sensor shifts with temperature. Typically the offset voltage will vary 1mV/°C which corresponds to a shift of 2 mA/°C. The higher sensitivity current imbalance detection levels referred to are in the order of 11 milliamperes. When adjusted for sensitivities in the order of 40 milliamperes, the device was not nearly so temperature sensitive. It is expected that temperature compensation circuitry will need to be incorporated if this device is to be commercialized. In this regard, it is noted that the requirements for ac ground fault circuit interrupters as contained in the Underwriters Laboratories Standard for Safety - Ground Fault Circuit Interrupters, UL 943-1972 call for a ground fault circuit interrupter to operate to interrupt the current through the fault when it is in the temperature range -35°C to 66°C. It is expected that a comparable range would be used to evaluate any ground fault circuit interrupters manufactured for photovoltaic system use.

REACTION TO SENSED FAULT:

When a ground fault is sensed, the fault current may be eliminated by either terminating the source (short-circuiting or segmenting the array) or by eliminating the deliberately provided low-impedance ground where feasible.

UNWANTED GROUND DETECTION:

Figure F.2 describes the circuit of a photovoltaic array incorporating a differential type ground fault detector and having one side of the load (the unprotected circuit area) grounded. Figure F.3 illustrates this same array with the addition of an unwanted ground at point B. In the event of a ground fault such as by personal contact with shock hazard parts of the array while the ground at point B exists, a low impedance path bypassing the ground fault detector would be established and the ground fault system is defeated.

In contemporary ac ground fault circuit interrupters, ground fault protection even in the face of such an occurrence is provided, generally by an oscillator circuit which causes tripping of the ground fault circuit interrupter when the grounded and grounding conductors are connected together in the protected circuit area. This facility can be incorporated in ground fault detectors used with solidly grounded photovoltaic arrays by incorporating a pulse oscillator circuit which creates a circulating current through earth ground and one of the windings around the toroid influencing the Hall Effect device upon the occurrence of the unwanted ground connection, see Figure F.4. As this circulating current is only created and thus seen by ground-fault detector when there is a ground on the array (protected) side of the detector, it does not interfere with any other operation of the device.

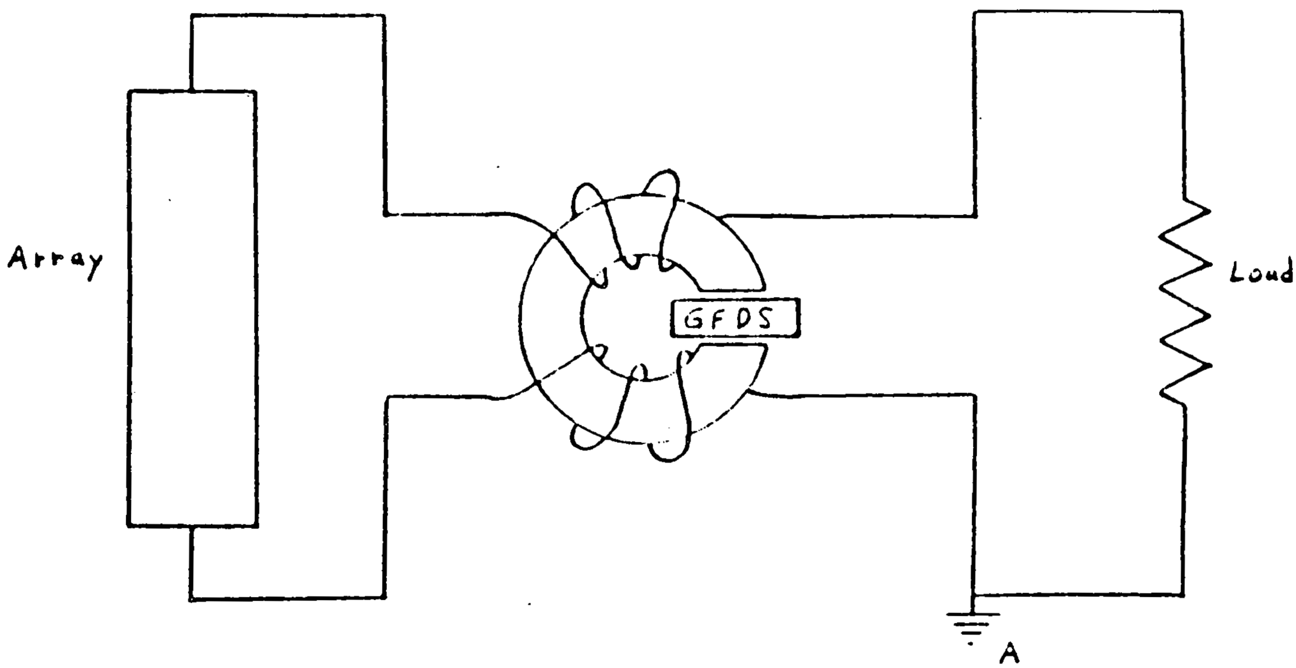


Figure F.2

Array with one side grounded load

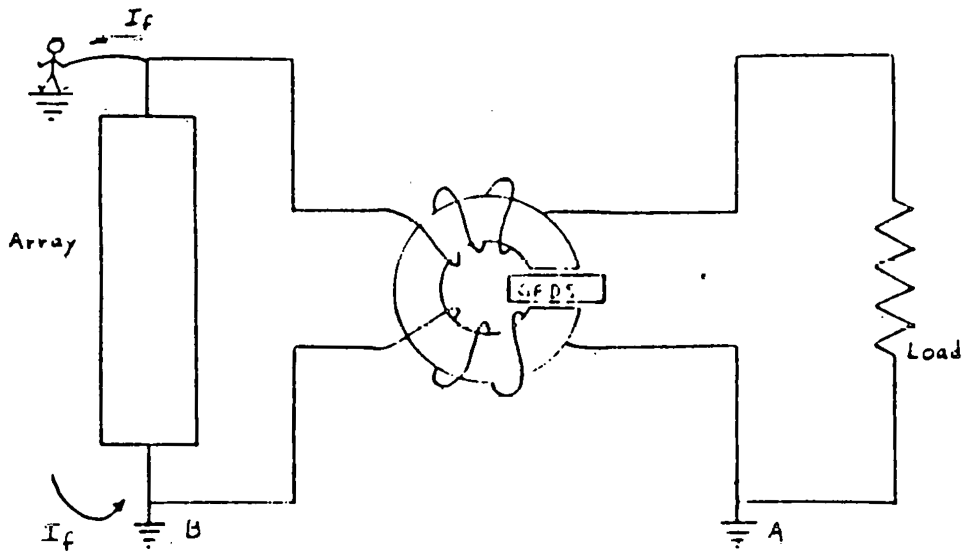


Figure F.3

Array with one side grounded load
Unwanted ground

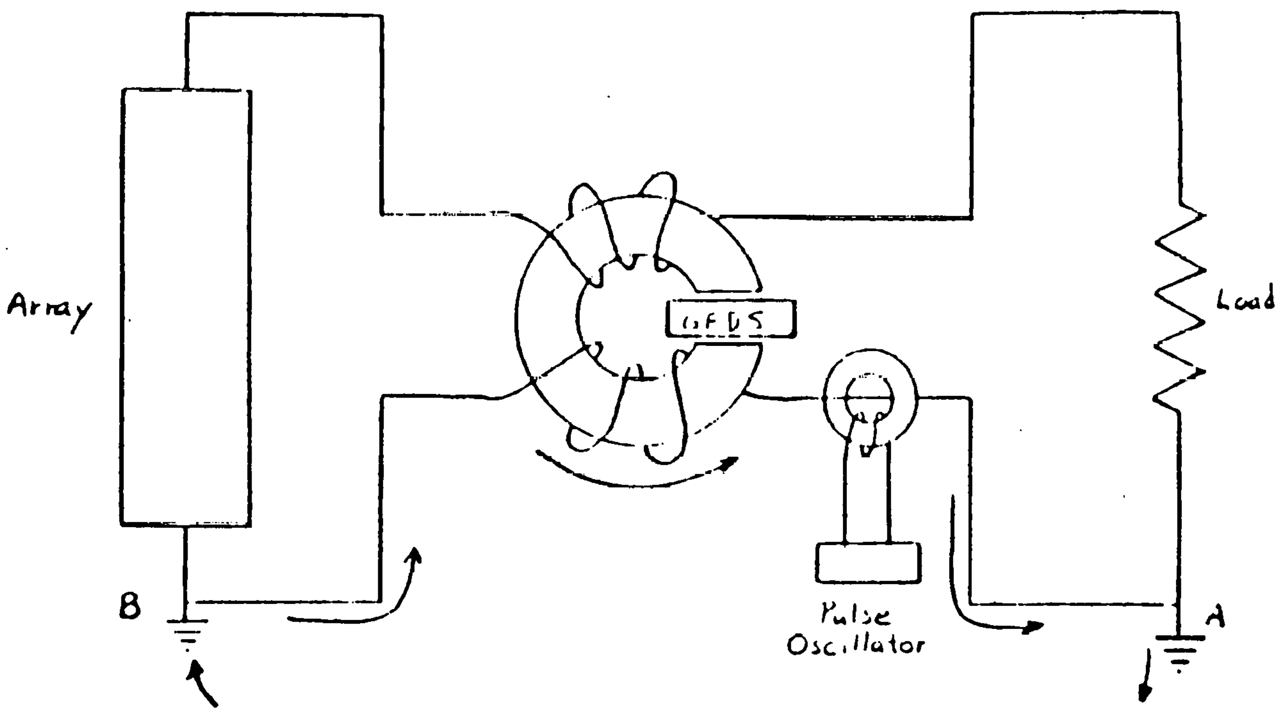


Figure F.4

Pulse oscillator for detection of
unwanted ground

Without the establishment of an unwanted ground, the voltage pulses induced on the line do not cause current pulses of an unbalanced nature (as seen by the Hall Effect sensor) as described above and do not activate the ground fault detector. For a dc ground fault detector with a response sensitivity of 40 milliamperes, and where the resistance of the ground path is 5 ohms, or less, a 200 millivolt voltage introduced on the line would be sufficient to produce a current imbalance which will create a signal at the output of the ground fault detector.

As an experiment, an ac ground fault circuit interrupter was modified so that its sensing circuit was operated from a dc supply, and a flasher LED was incorporated as a 5 kHz pulse oscillator operating from the same dc supply. The pulses were coupled to the sensed circuit through the primary of a transformer used in this particular ground fault circuit interrupter. When a ground was introduced on the grounded conductor on the protected (load) side of the ground fault circuit interrupter, the ground fault circuit interrupter tripped.

The ac ground fault circuit interrupter, even as modified, is not capable of detecting a dc differential (fault) current, it is only capable of detecting the unwanted ground. If it were to be used in a dc circuit of a photovoltaic array, it would remain necessary to utilize a dc sensitive device, such as the Hall Effect item to provide the remainder of the necessary protection.

REACTION TO UNWANTED GROUND:

Upon detection of the unwanted ground, the array must be disabled by its being short-circuited or segmented into non-hazardous pieces. The option of removing the deliberately provided low-impedance ground to provide protection does not exist.

UNWANTED GROUNDS, VIRTUAL GROUND ARRAYS:

In photovoltaic systems configured with a virtual ground, such as that of Figure F.5, detection of an unwanted ground at the ground point (physical grounding of the virtual ground point in this case) does not appear feasible, because the applied ac signal would have to traverse the modules and power conditioning unit.

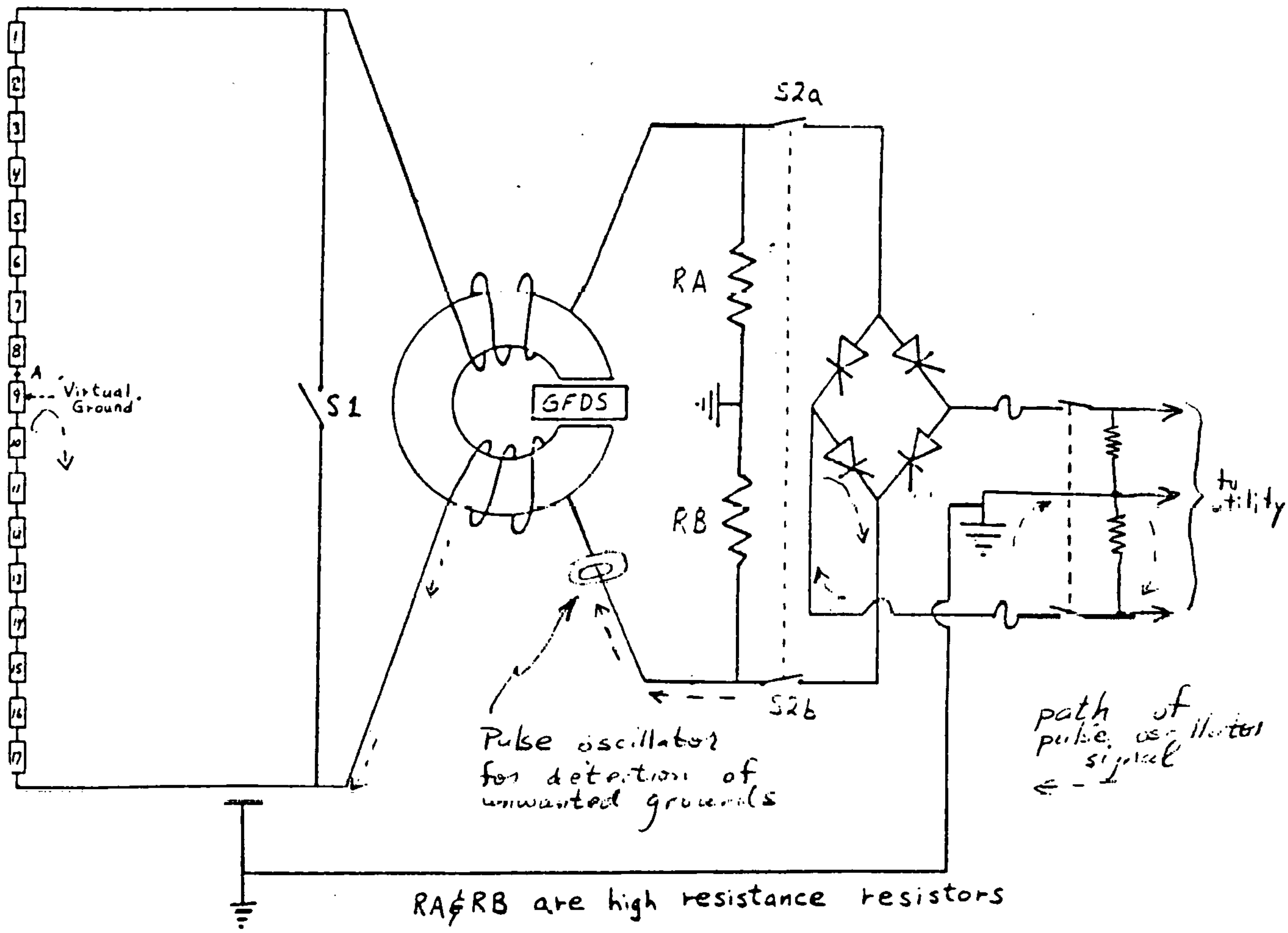


Figure F.5

Application of Ground-Fault Sensor in array with virtual ground

APPENDIX G

CURRENT AND VOLTAGE LEVELS ASSOCIATED WITH IN-CIRCUIT ARCING

Objective:

To determine current and voltage levels of arcs with energy just sufficient to cause ignition of a flame indicating material. This material is intended to represent materials likely to be found in or about photovoltaic installations.

Commentary:

It was not practical for Underwriters Laboratories Inc. to construct a photovoltaic array for use in determining voltage and current level points of arcs liable to cause ignition of materials. Rather, a power supply, simulating an array was used for this purpose. Because a photovoltaic module, and an array comprised of such modules has an output characteristic akin to that of curve A in Fig. G.1, the power supply used for arc tests should have a similar characteristic.

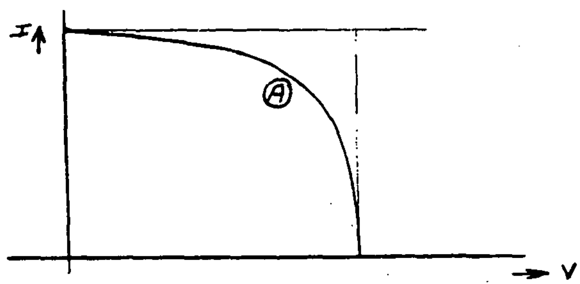


Figure G.1
Array I-V Characteristics

The first effort in providing such a power supply involved the direct use of a Sorensen DCR 80-10 regulated supply, 100 volts, 5 amperes max output. This supply also has a characteristic similar to that of A in Fig. G.1, in that the output voltage is maintained at a constant value for all values of current up to a preset level. Attempting to draw additional current causes the voltage to collapse rapidly to zero.

An attempt to use such a supply directly in conducting the arcing tests was unsuccessful, in that the supply overcurrent protector would operate to open the circuit upon the initiation of the arcs. Thus, it was necessary to introduce a resistor in the circuit to limit current on short-circuit, thereby avoiding operation of the device's overcurrent protector. Unfortunately, this also alters the supply current-voltage curve, so that is is less like that of the array.

However, the nature of the ignition indicator, readily ignitable surgical cotton, was felt to compensate for any loss in arc energy due to the source resistor.

APPARATUS

See Figure G.2.

Arcing Plate - Perforated steel, 0.041 inch thick. Perforations are circular, 0.125 inch diameter, on 0.150 inch centers.

Cotton (Flame Indicator) - Absorbent surgical cotton (Johnson & Johnson) oven dried at 60°C for a minimum of 48 hours and kept in a sealed plastic bag until ready for use.

Power Supply (Source) - Variable voltage regulated dc power supply, Sorensen DCR 80-10 Power Supply, 100 volts, 5 amperes maximum.

Resistor - Variable wire wound.

Arcing Wire - For currents of 8 amperes and less, No. 30 AWG solid copper wire (0.010 inch diameter). For currents of 9 amperes and more, No. 20 AWG solid copper wire (0.020 inch diameter). The heavier gauge wire was needed at the higher currents because the thinner wire began to glow due to I^2R heating.

METHOD

A cotton pledget approximately 1-1/2 by 1 inches was placed on the backside of the arcing plate and retained by a single strip of 3/8 inch wide masking tape. The cotton was then fluffed up through the perforations to the top side of the plate to a height of approximately 1/8 inch above the top surface. The fluffed up area was approximately 1 by 5/8 inches. An additional cotton pledget was placed on the top surface of the arcing plate, covering one-half of the fluffed up area. This pledget was also secured by masking tape.

The source was connected between the arcing plate and the copper wire. The source voltage was adjusted to the desired value, the source short-circuit current was adjusted to the desired value by the setting of the series resistor with the current control on the supply set to maximum. The copper wire was stroked across the arcing plate in the fluffed up area 100 times or until flaming of the cotton for each run of the test. Each time the wire left the plate and encountered a cotton filled perforation, a potential for an arc was present. The wire made approximately 8 arcs in the cotton fluffed up area on each stroke. On alternating strokes, the wire ran either between the top pledget and the fluffed up area or over the open fluffed area. The top cotton pledget served two purposes: a) to get the arc to occur in the immediate area of the cotton and b) to provide additional indicator material, for without it, when the cotton fluff ignited it generally flashed so quickly that it was difficult to determine if flaming had occurred.

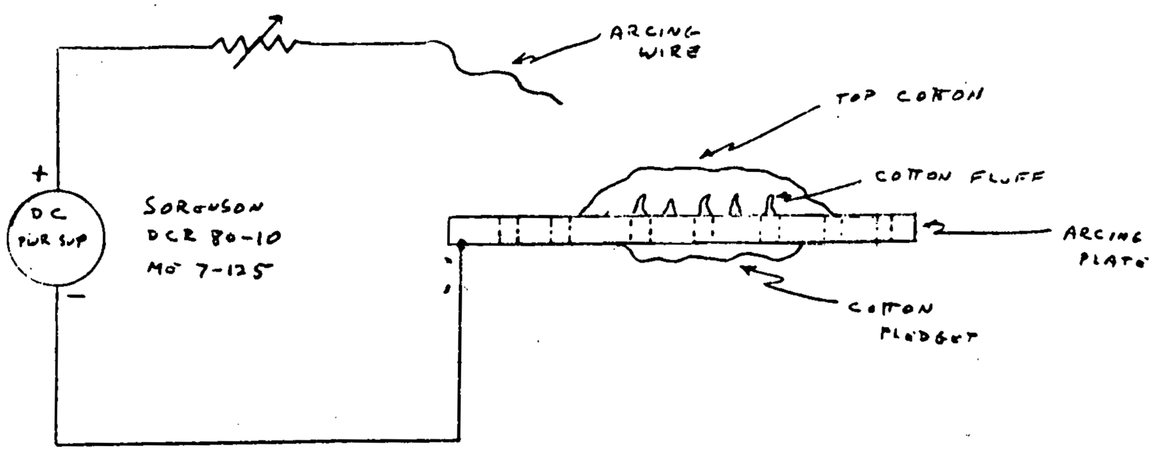


Figure G.2

Arcing Ignition of Cotton Setup

Each open-circuit voltage and short-circuit current combination described in the following tabulation was used for at least one run of the test. If the test results appeared borderline, or if results between tests at various levels were inconsistent, more than one run of the test was conducted at the particular values of voltage and current.

RESULTS

Combinations of voltage and current, and whether the arc ignited cotton.

Open Circuit Voltage (Volts)	Short Circuit Current (Amperes)	Flame
70	1	Yes
70	0.75	No, Yes, Yes
70	0.5	No
60	1	Yes, Yes
60	0.75	No
55	2	Yes
55	1.15	Yes
50	1.5	Yes
50	1	Yes, No, No
45	2	Yes
45	1.5	No, Yes
45	1	Yes, No, No
40	1.5	Yes
40	1	Yes, No, No
40	0.85	No
35	1.5	Yes
35	1	Yes, No, No, No
30	2	Yes
30	1.75	Yes
30	1.5	No, No, No
30	1	Yes, No
30	0.75	No
25	5	Yes
25	4	No, Yes
25	3.5	Yes
25	3.2	No, Yes
25	3	No, No
25	2.5	No, No
25	2	No
25	1.5	No
25	1	No
21.5	4.5	Yes
20	7	Yes
20	6.8	Yes

Open Circuit Voltage (Volts)	Short Circuit Current (Amperes)	Flame
20	6.5	No, No
20	6	Yes, No, No, No
20	5.5	No, No
20	5	Yes, No, No, No
20	4.5	No
20	4	No
15	20	No
15	15	No
15	12	No
15	10	No, No
15	9	No
15	8	No

A curve not defined by an equation, was fit to this data establishing a boundary between voltage-current points which would cause ignition, and those which would not. Points of current and voltage where only one, or consistent, results were obtained were placed on the "ignition" or "no ignition" sides of the curve, as appropriate. Majority result points (e.g. Yes, No, No, No) were also placed on the "ignition" or "no ignition" sides of the curve as determined by the majority of the entries. Points of equal weight may be on or about the curve, on either side. See Figure G.3.

CONCLUSION

The minimum open-circuit voltage necessary to ignite cotton with the current levels used appears to approach 15 volts. The current rises sharply with decreasing voltage at voltages under 30 volts, where at the current levels considered, it is extremely difficult to produce an arc that sustains for more than a few seconds.

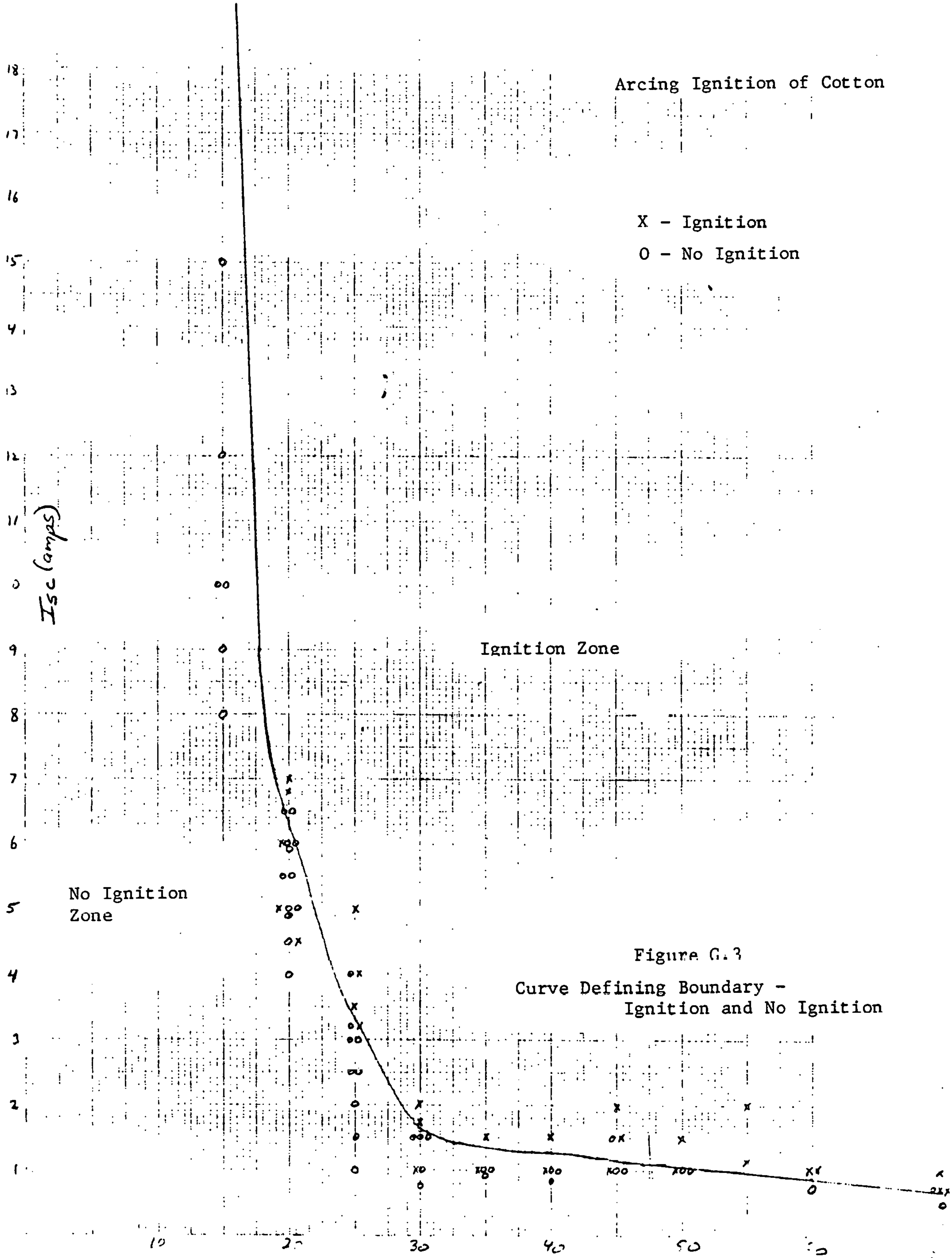


Figure G.3

Curve Defining Boundary - Ignition and No Ignition

APPENDIX H

SUPPRESSION OF IN-CIRCUIT ARCING WITH BYPASS DIODES

Objective:

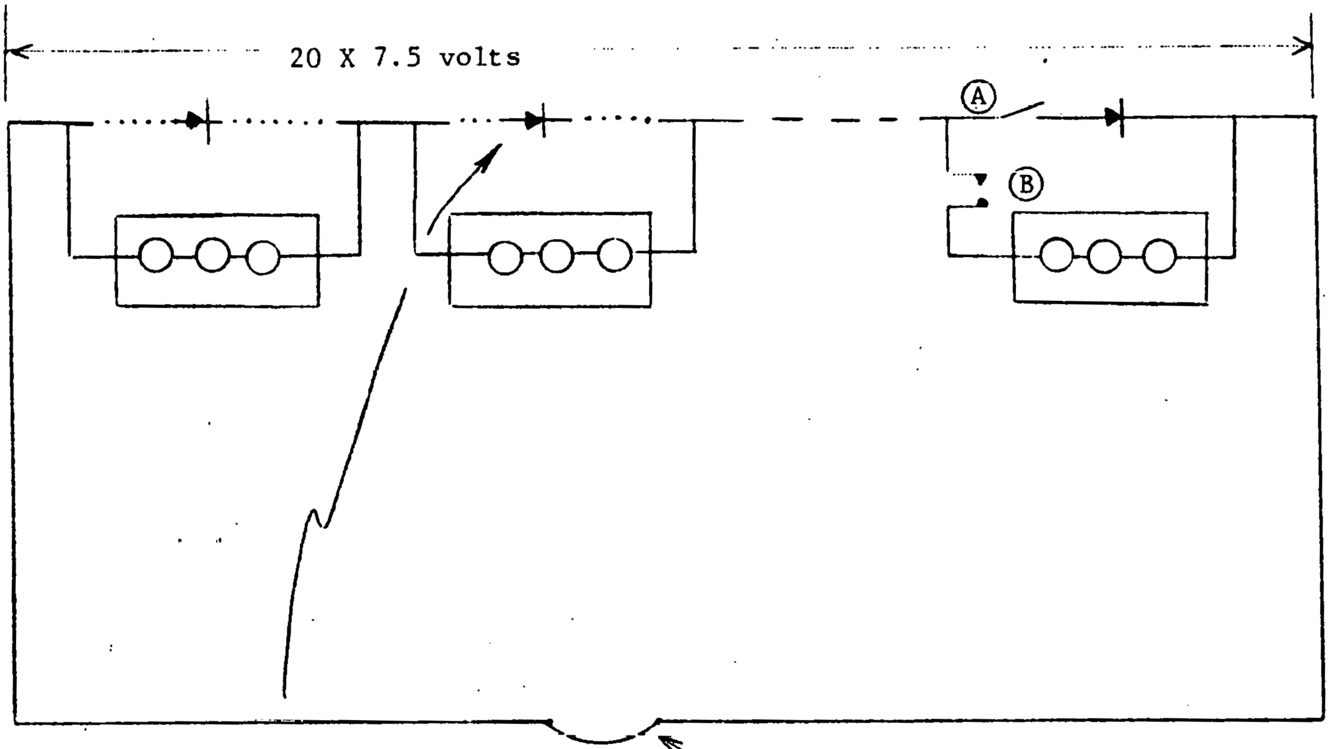
To determine whether or not bypass diodes are an effective means of suppressing in-circuit arcing.

APPARATUS

Twenty, Sensor Technology 7.5 volt photovoltaic modules, wire, switches, diodes.

METHOD

The twenty 7.5 volt Sensor Technology Block III photovoltaic modules were assembled into an array, with all modules in series. See Fig. H.1. A bypass diode was placed in parallel with one end module, the bypass diode being switchable, (Switch A) in or out of the circuit. Provision was left to create a gap (across metal electrodes) at point B. (In an array, diodes would normally be placed across each module, as shown by the dotted lines. This was not done in this case, as it was felt that such was not relevant to this work.)



Short-circuit as load.

Diodes not in place, but which would be provided in an actual array installation.

B - Arc gap formed from steel oil-burner electrodes.

Figure H.1

Test Set-Up In-Circuit Arcing

On a bright afternoon, with the modules tilted toward the south, the array open circuit voltage was 147 volts and the array short circuit current was 1.36 amperes.

An attempt was made to create an arc by opening and closing gap B. Switch A was both open and closed for this purpose.

RESULTS

With Switch A open, an arc could easily be initiated and maintained across Electrodes B. The arc could be extended to 1/4 inch in length.

When Switch A was closed (placing the bypass diode in the circuit) the arc was immediately extinguished and could not be reestablished. The voltage across Electrode B was measured as 8.5 volts under this condition.

Each of these procedures; starting the arc with Switch A open, closing Switch A and thereby extinguishing the arc, and attempting to restart the arc with Switch A closed; was conducted five times, with the same results in all cases.

CONCLUSION

Module bypass diodes provide an alternate path for current, thus preventing a voltage high enough to initiate and maintain an arc.

APPENDIX I

DEVELOPMENT OF AN ARC DETECTOR

BACKGROUND:

In an effort to explore the prospects for the use of an arc detection device, Underwriters Laboratories Inc. personnel constructed and field-evaluated a high frequency response network, basically a device responsive to steep rises in current. The device is as follows:

DEVICE SPECIFICS:

Theory of Operation - References are to the circuit of Figure I.1. The input terminal of the device is connected directly to the high voltage point of the photovoltaic source or output circuit. The input signal from the photovoltaic circuit is differentiated by capacitor C_1 and the input impedance of the operational amplifier (op amp) and fed to the input of the op amp. Diodes CR_1 and CR_2 prevent overloading the op amp input. Any pulses generated as a result of the differentiating process on the fast rise time currents (arc currents) are amplified by the op amp to approximately 3 volts. These pulses will trigger the retriggerable multi-vibrator (MMV).

The MMV output pulse width is set by resistor R_2 and capacitor C_2 to approximately 1.5 milliseconds, 5 volts. If another pulse from the differentiation process appears at the MMV input before the output pulse is completed, the MMV will restart, timing another 1.5 millisecond output pulse. Therefore, if the MMV input pulses are spaced less than 1.5 milliseconds apart, the output of the MMV will be a constant 5 volts. The output of the MMV drives the base of transistor Q_1 which is set up as a simple switch.

The solid state time delay relay (TD) is adjusted for a 5 second delay on turn on. That is, if transistor Q_1 is turned on for less than 5 seconds, there will be no output indication from the time delay relay. Upon turn-off of transistor Q_1 the relay will automatically reset its timing count to zero. Therefore, the input to transistor Q_1 (output of MMV) must be a minimum of 5 seconds in duration to fire the TD and signal that arcing is taking place.

The 1.5 millisecond MMV output pulse width was chosen to be shorter than the period of the normal current variations caused by the power conditioning unit, maximum power tracker, etc. This makes the circuit insensitive to 60 Hz components. The five second time delay is to prevent short duration line variations from causing false tripping. The times chosen will allow the circuit to actuate on continuous input signals having a pulse repetition rate greater than 660 per second (1.5 millisecond period).

The TD contacts may control a latching contactor which would disconnect the load from the array or perform other functions to stop the arcing condition.

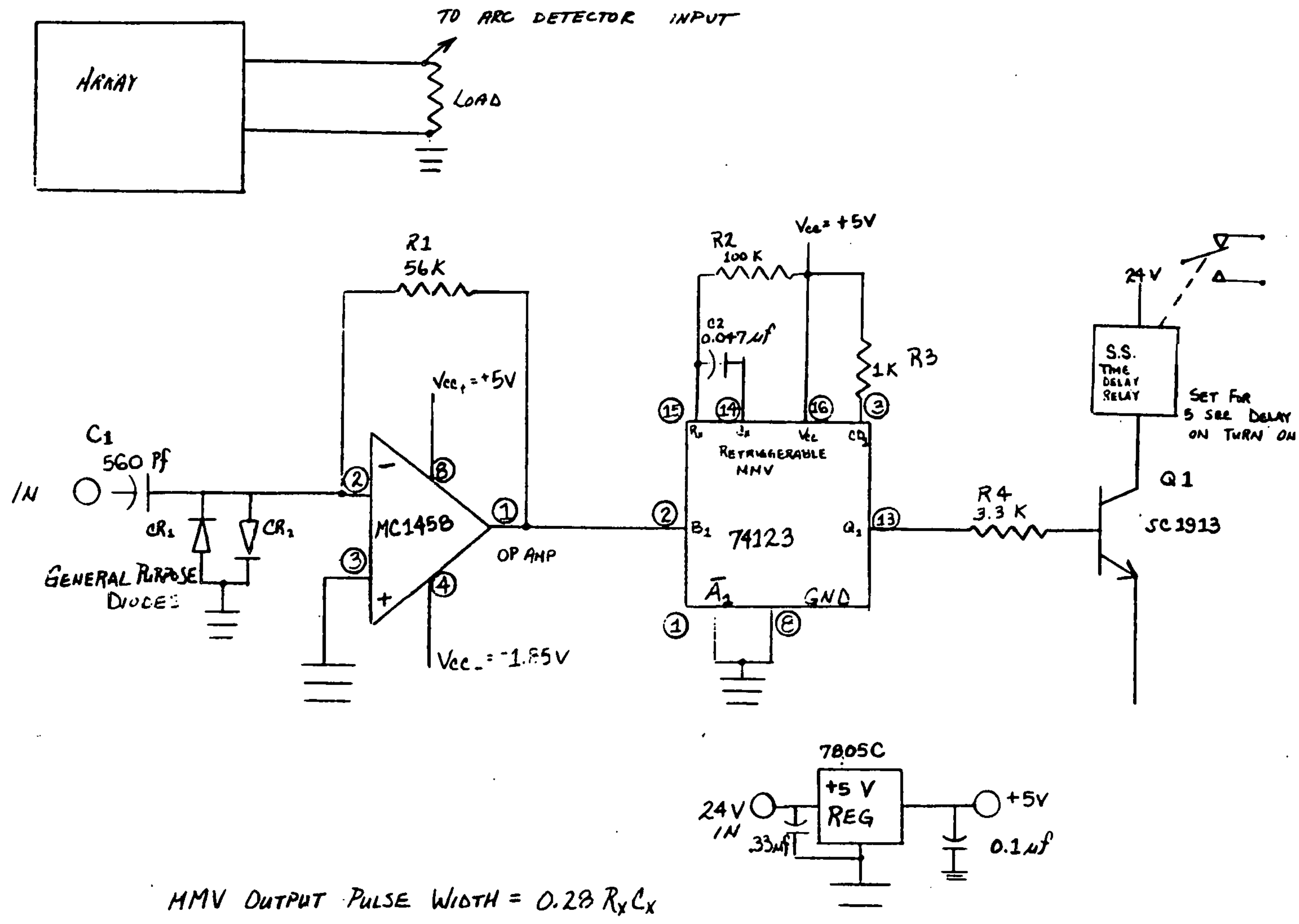


Figure I.1

Arc Detector

The arc detection device was laboratory tested using a dc power supply to simulate an array. Under this condition, the device indicated when an arc was present in the power supply circuit, and had no indication when the current was either steady state dc or zero.

FIELD TESTS:

On May 27, 1981 the arc detector device was taken to an array field of Solarex Block II photovoltaic modules at the Massachusetts Institute of Technology/Lincoln Laboratory flight facility, Concord, Massachusetts.

On that day, the sky was slightly hazy, the temperature was 80°F (27°C) with insolation at approximately 80 mW/cm^2. The Solarex modules have a silicone rubber superstrate, and the ones involved in the circuit being used had a fairly heavy layer of grime on the surface. Lincoln Laboratory personnel estimated that this cut the power output by approximately 10 to 15 percent. The photovoltaic source circuit of the array field used in the work had the configuration shown in Figure I.2.

The silicone rubber superstrate was removed from a section of one module and the connection between two cells broken (see Point A in Figure I.2). The bypass diode was removed from across that particular module. The power conditioning unit serving as the array load needs a minimum current to operate, so additional similar source circuits were connected in parallel with the source circuit to which the arc detector was connected. The power conditioning unit output was 15 amperes.

An attempt was made to create an arc across the break between the two cells by repeatedly making and breaking the circuit with a clip on the end of a lead. However, a sustaining arc or any arc of reasonable magnitude could not be created. Measurements showed that at the break between the two cells, the current through the completed connection was 0.7 ampere and the voltage across the open connection was 67 volts.

The source circuit was then opened at point B, Figure I.2 and it was then possible to cause a sustaining arc, approximately 1 inch long.

The arc detection circuit was then connected to the array field output at the power conditioning unit input terminals. With the arc generated at point B of the source circuit, the detector was <u>not</u> able to sense the presence of the arc. Examining the wave shape at the power conditioning unit input terminals with an oscilloscope showed that the signal caused by the arc at that point was approximately 50 mV peak-to-peak. This signal was not large enough to actuate the arc detection circuitry. The distance from the point of arcing to the power conditioning unit input terminals is approximately 200 feet.

The arc detector was then moved out to the array and connected at the complete source circuit. At this location, the detection circuit was able to detect the presence of the arc, and indicated when arcing was underway. The distance from the point of arcing to the detector input was approximately 5 feet.

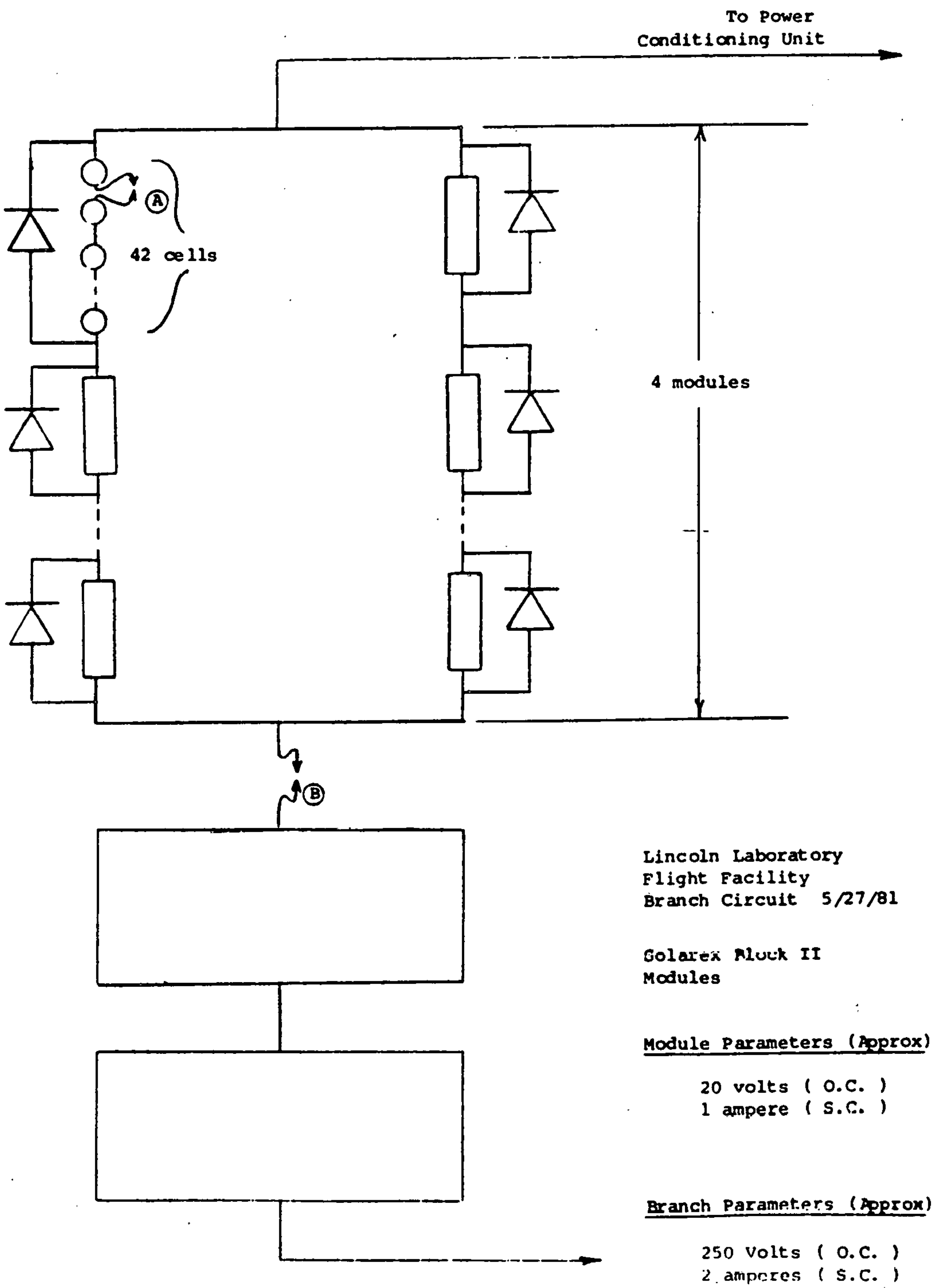


Figure I.2

Array Circuit for Arc Detector Field Testing

This performance raises the question as to what caused the difference in operation at the two locations. A possible cause may be that the distributed inductance and capacitance of the line from the array to the power conditioning unit attenuated the high frequency current components to the degree that they were below the sensitivity threshold of the detection circuit.

The results of these tests show that the arc detector will work as intended, provided that the arcing signal is large enough. Increasing the gain of the detection circuitry may be sufficient to cause the arc detector to work in this and many other cases. However, because of the many variables, and basically because of the unpredictable nature of the configuration and physical size of the array, it may be impossible to determine the level of sensitivity required for a detector in general. Further, as the sensitivity of the arc detector is increased, the detector becomes more susceptible to false tripping from rf produced by the power conditioning unit and other nearby sources.

CONCLUSION:

Based on this experience and the problems associated with threshold sensitivity, UL feels that the level of protection afforded by this circuit can be more readily achieved by other means. As a result, no further steps in developing the arc detection circuitry have been taken.

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