A Conceptual Design of a Battery Energy Storage Test (BEST) Facility

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ELECTRIC POWER RESEARCH INSTITUTE

ENERGY RESEARCH and DEVELOPMENT ADMINISTRATION

A CONCEPTUAL DESIGN OF A BATTERY ENERGY TEST (BEST) FACILITY

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Prepared for

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Section 1
INTRODUCTION

One of the most promising near-term prospects for efficient and economic energy storage in electric utility applications is the battery plant. In such plants, many battery cells will be connected in series and parallel to achieve desired capacities, and connections to the ac grid will be made through appropriate inverter/converter electronics. Off-peak electric energy will be used to charge the batteries, which will then discharge their stored energy back into the utility network during peak periods. Any of several advanced batteries currently under development for this purpose may be available for large scale testing in a utility application by as early as 1980.

Plants employing these batteries are expected to be compact, efficient, quiet and non-polluting. Consequently, siting problems should be minimal, and plants could be located near load centers so as to achieve maximum savings in transmission costs. Additionally, the batteries are expected to be supplied in modular form, which will enable a buildup of capacity in proportion to demand, thus affording an opportunity to avoid costly investments in unused excess capacity.

The ability of battery plants to vary power level rapidly in both the discharge and charge modes also offers a potential for improving the dynamic and transient stability and regulation of the utility system. Moreover, the inverter equipment can be designed to enable the plant to startup almost instantaneously under black start conditions, thus providing a capability for rapid system restoration.

1.1 PROJECT OBJECTIVES

The use of battery systems for energy storage on electric utility networks is currently being studied in a cooperative effort between the U.S. Energy Research and Development Administration (ERDA), the Electric Power Research Institute (EPRI), Argonne National Laboratory (ANL) and the electric utility members of EPRI. As a part of this effort, the construction of a Battery Energy Storage Test (BEST) facility has been proposed. The purpose of this facility is to provide for the large scale testing and evaluation of a spectrum of battery systems and requisite auxiliary equipment in an electric utility environment. Pursuant to these objectives, Bechtel Corporation has performed engineering studies and conducted a conceptual design, as presented herein. This design effort reflects some modification to past criteria, and it is aimed at establishing the design concepts, budgetary cost estimates and schedules needed in the process of bringing the BEST facility to fruition.

1.2 PROJECT ORGANIZATION

During the conduct of this design, Bechtel's efforts were guided by the BEST Project Team, which consists of representatives from EPRI, ANL and several of the electric utilities. The Project Team was, in turn, responsive to the BEST Planning Group, which is comprised of members from ERDA, EPRI, ANL and the electric utilities. This conceptual design was carried out by Bechtel Corporation under the sponsorship of a supplement to ANL contract No. 31-109-38-2962. Preparatory work for this effort was sponsored by EPRI under contract No. RP255-0-0.

The primary sources of information utilized by Bechtel in the conduct of this conceptual design were as follows:

- Studies and reports on the BEST facility, produced by both the Project Team and by Bechtel.
- Meetings and dialogue with the Project Team and individual members thereof.
- The evolved delineation of design criteria presented in Section 4.1.
- Reports from the several developers of battery systems.
- Visits to several battery facilities, battery developer's facilities and equipment manufacturer's plants.
- Vendor contact on specialized equipment required for the facility.
- Published vendor information and other literature relating to equipment, systems or system design concepts relevant to the facility and the the systems contained therein[1].

Additionally, standard engineering techniques and methods were employed in the conduct of the designs described herein. Information regarding the costing methods used are presented in Section 6.

1.3 REPORT FORMAT

An executive overview of the conceptual design and its principal features is provided in Section 2. This is followed in Section 3 by conclusions and recommendations addressing pertinent

[1]The subsequent naming of manufacturers in conjunction with the discussions of components and subsystems does not mean that these manufacturers have been selected to supply related items. Rather, it is intended to point out that the necessary items are commercially available.

technical, cost and implementation aspects of the design. Section 4, which is prefaced by the design criteria established for the facility, is devoted to descriptions of the systems, subsystems and major components comprising the conceptual design of the fully implemented BEST facility. These descriptions are supported by operational discussions and appropriate drawings and data. A description of the initial "Baseline" facility conceptual design is presented in Section 5, along with descriptions of several options that may be employed in the initial construction or future expansions. Cost estimates and schedules for design and construction of the Baseline facility are provided in Section 6, supplemented by costs for the various options. Section 7 contains a summary of environmental and safety considerations for the conceptual facility. Summary data for several types of dc bus evaluated during the design process are provided in the appendix.

Section 2
EXECUTIVE SUMMARY

Bechtel Corporation has completed a conceptual design for the BEST facility which incorporates the design criteria set forth by the Project Team. These criteria specify that the facility will be implemented in phases that will accommodate the projected development of battery systems. Initially, therefore, a "Baseline" plant will be constructed and partially equipped, with additional equipment to be added later to keep pace with developing needs for increased testing capability.

In its fully implemented state, the BEST facility will be capable of simultaneously testing three 10 MWh battery systems. Three inverter/converter units, each rated at 2.5 MW, will interface these battery systems to a utility network. A 1000 V dc bus system, comprised of three individual buses, will enable the independent connection of any battery to any one of the three inverters through a series of dc breakers, switches and fuses. Similarly, a 13.8 kV ac system will connect the inverters to either the utility network or to a synthetic load. A computer data acquisition system will be installed to facilitate handling the large amounts of data (mostly cell voltage and temperature measurements) to be derived in the conduct of test programs. This computer system will also be capable of controlling circuit breakers upon the detection of out of tolerance data, and it will be capable of providing control of inverter functions. Additionally, systems will be installed to provide for functions such as battery cooling, building heating-ventilating-air-conditioning (HVAC), station auxiliary power and safety.

Figure 2-1 presents a perspective view of a reinforced concrete structure to house BEST facility and its systems. A pre-engineered metal building is also considered as an option. The layout of the building and site are shown in Figure 2-2.

The principal building areas are the three battery rooms, an area for three inverter/converter systems, a control room, offices and a shop.

The Baseline facility design calls for the complete construction of the building, ready for full implementation. However, only one inverter will be installed in the Baseline facility, and it will be connected through appropriate switching to a single dc bus in a manner that will allow batteries in any of the three rooms to be individually connected to the inverter. The ac side of the inverter will be completely wired and switched to enable its connection to either the utility network or the synthetic load. The computer system to be installed will include a completed central unit and the entire complement of peripherals required in the control room by the fully implemented facility. However, the initial Baseline facility calls for just one battery system (a lead-acid type) to be installed and tested. Accordingly, only one of the three battery room computer satellite systems will be initially supplied. In addition to the above installations, the building HVAC, the station auxiliary power system and all building fire and safety systems will be completed to the requirements of the fully implemented facility.

With this combination of components and systems installed, the initial Baseline facility will be capable of running complete tests on the lead-acid battery system described herein. As other battery systems are installed in the remaining battery rooms, it will be necessary to add the corresponding computer satellite equipment to test these batteries as well. However, in the Baseline facility, it will not be possible to test more than one battery system at a time due to limitations imposed by having only one inverter and one dc bus. Further testing flexibility can be achieved only by installing the additional dc bus bars, inverters and other associated equipment called for by the fully implemented design.

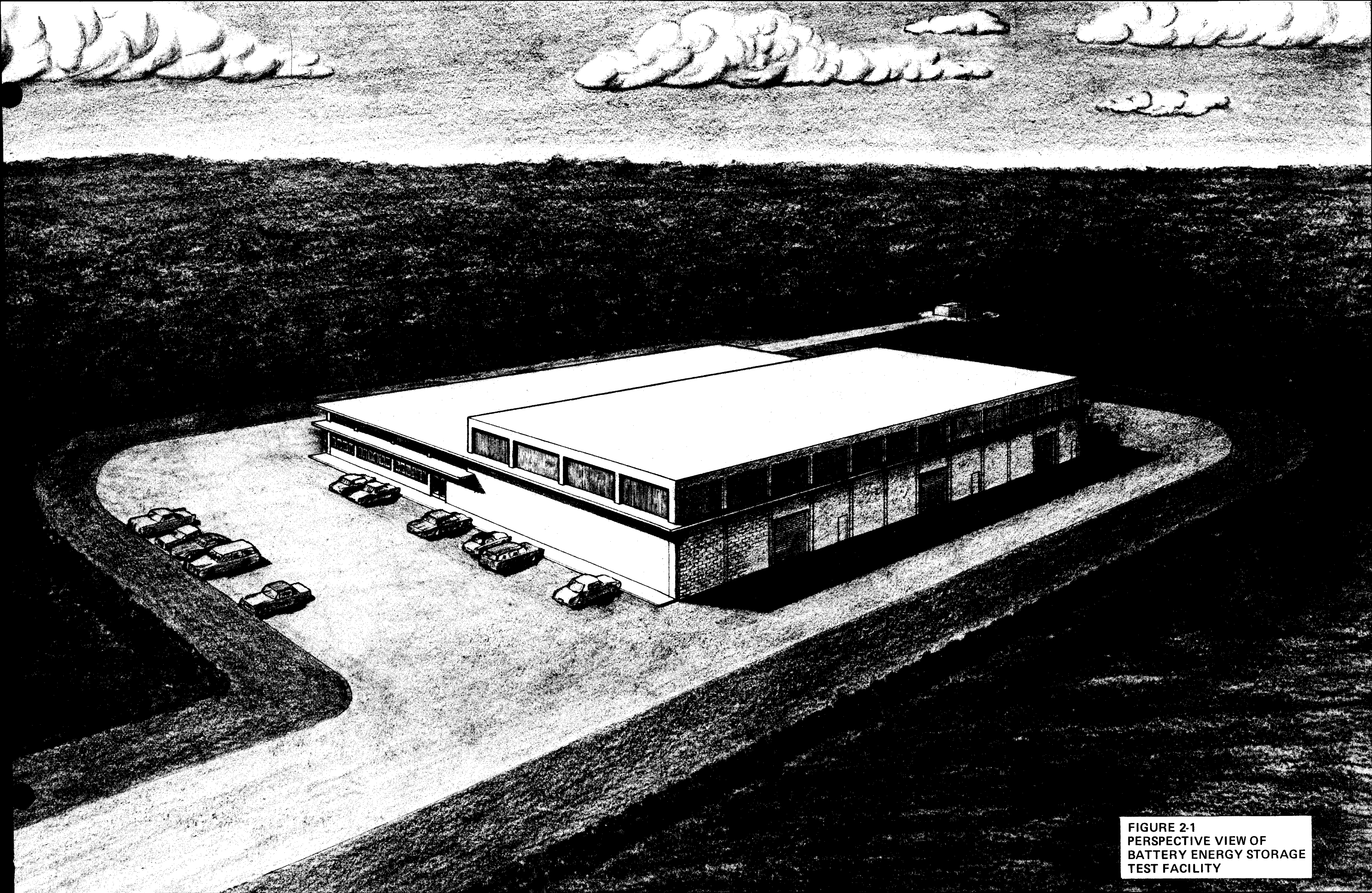
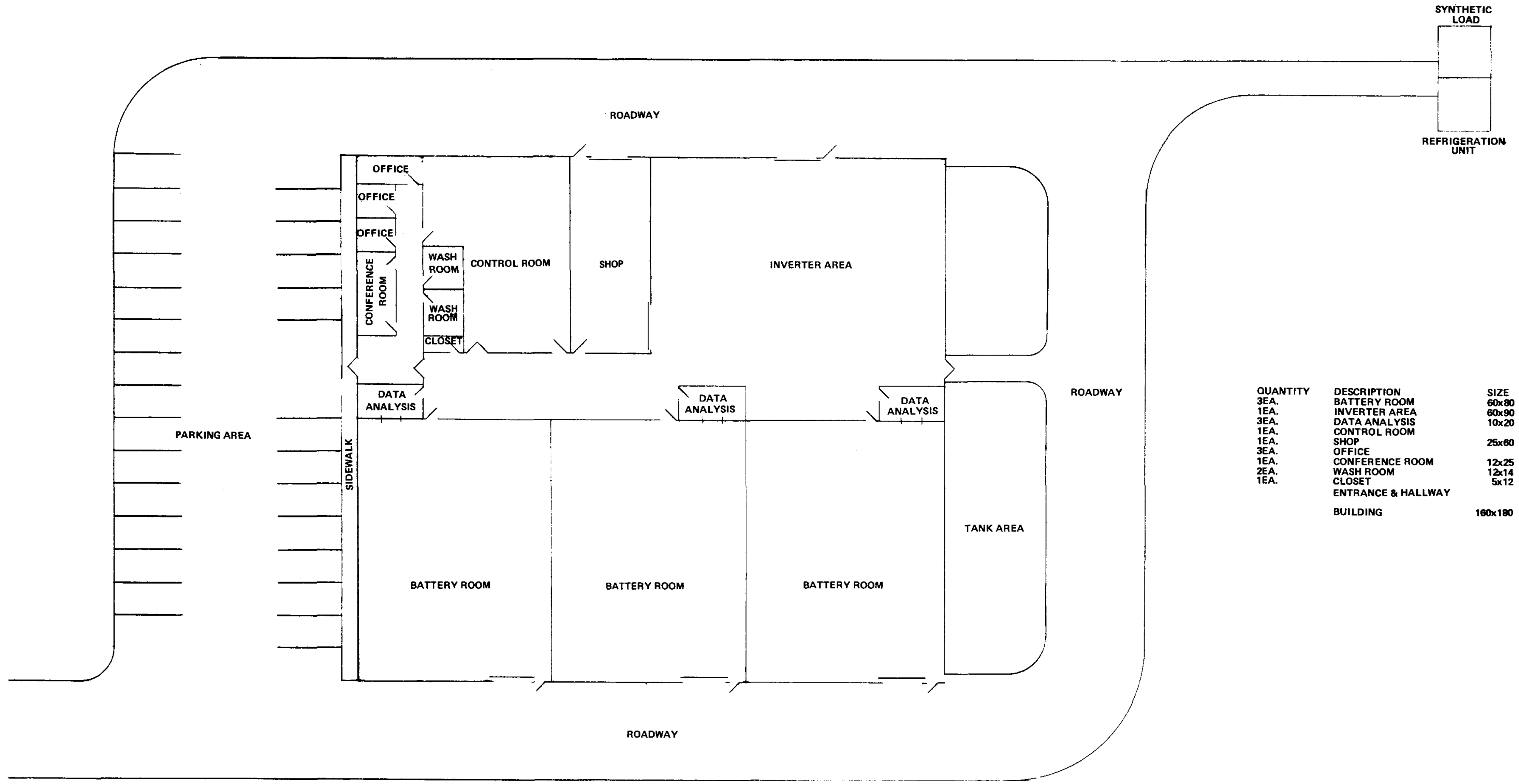


FIGURE 2-1
PERSPECTIVE VIEW OF
BATTERY ENERGY STORAGE
TEST FACILITY



QUANTITY	DESCRIPTION	SIZE	TOTAL
3EA.	BATTERY ROOM	60x80	14,400
1EA.	INVERTER AREA	60x90	5,400
3EA.	DATA ANALYSIS	10x20	600
1EA.	CONTROL ROOM		2,316
1EA.	SHOP	25x60	1,500
3EA.	OFFICE		660
1EA.	CONFERENCE ROOM	12x25	300
2EA.	WASH ROOM	12x14	168
1EA.	CLOSET	5x12	60
	ENTRANCE & HALLWAY		3,396
	BUILDING	160x180	28,8[illegible]

20 10 5 0 5 10 20 40

No.	DATE	REVISIONS	BY	CHKD	DESIGN SUPV	ENGR	PROJ ENGR	APPR
△								
△								
△								
△								
△								

SCALE — DESIGNED W. O. Fenner — DRAWN L. W. — CHIEF ENGR

BECHTEL
SAN FRANCISCO

BEST FACILITY CONCEPTUAL DESIGN

BUILDING AND SITE LAYOUT

JOB No.	DRAWING No.	REV.
11088-001	C-100	

FIGURE 2-2

22 x 34 "D" SIZE

Several options are considered in the conceptual design, including the use of the pre-engineered metal building, installation and deferred installation of dc bus, and expansion of the computer system.

Initial implementation of the Baseline BEST facility, exclusive of the lead-acid battery system, is estimated to cost $5.88 million (May, 1975 dollars). This figure includes Title I, II and III engineering and a 15% contingency. Approximately 33 months will be required for the engineering and construction of the Baseline facility.

Past studies and re-evaluations during the conduct of this conceptual design have indicated that there will be no significant hazards to the environment or to personnel caused by the implementation of the BEST facility.

Section 3

CONCLUSIONS AND RECOMMENDATIONS

3.1 CONCLUSIONS

Significant findings and conclusions resulting from the BEST facility conceptual design effort are summarized below:

- Implementation of the conceptual design presented herein will meet the design criteria set forth by the BEST Project Team.

- The estimated cost of the Baseline facility will be $5.88 million (May 1975 dollars). This includes a 15% contingency and $148,000, $398,000 and $111,000 for Title I, II and III engineering, respectively (Title definitions per AEC Manual 6101).

- Three items included in the design are not commercially available at present, and must be developed. These are the station inverter, dc fuses with the desired ratings, and higher voltage isolation for the data channel inputs on the computer. However, the manufacturers of such equipment indicate that the necessary developments can be accomplished within the time frame for implementation of the Baseline BEST facility.

- Pending coincident development of the required inverter, dc fuses and voltage isolation equipment, the Baseline facility as defined herein can be operational within 33 months. Some compromise to facility protection would result if the fuses are not used, but the inverter and computer voltage isolation are essential items.

- A modular inverter approach can be utilized to test at the limits specified for the dc bus system, and be rated at one fourth the power (and cost) of a comparable single bridge inverter.

- While neither type of building construction considered in the conceptual design (i.e., reinforced concrete and pre-engineered metal) is intended to meet any specific tornado or earthquake codes, the concrete building would be the better choice for a site where tornadoes may be encountered. Neither building is superior from the standpoint of earthquakes.

- Future implementation of the expansion options that were considered during the design would not appreciably effect on-going testing operations in the Baseline facility. However, if the initial facility is equipped with the optional 5000 A dc bus (as opposed to the Baseline 10,000 A bus), later upgrading of this bus to 10,000 A would require complete shutdown of testing operations.

- Possible alternative uses of the BEST facility include the testing of other types of dc energy systems, such as fuel cells or photovoltaic cells, which also require inverter equipment to interface with a utility network. In particular, since it is equipped to accommodate hydrogen systems, Battery Room 1 could suitably house a hydrogen fuel cell system.

- Contingent upon final site selection, the BEST facility, as presently conceived, will have only a minor impact on the environment. Similarly, evaluations of the safety aspects of the facility indicate that no problems will exist when normal precautions are exercised.

3.2 RECOMMENDATIONS

The following recommendations are offered to assist the Project Team in guiding development of the BEST facility:

- Timing for implementation of the Baseline facility should be such that the initially installed lead-acid battery system has been tested, and the overall performance of the facility verified, by the time the first advanced battery system is ready for testing.

- Preliminary design (Title I Engineering) must be based on site specific information. Accordingly, a site for the BEST facility should be selected on a schedule that will not delay initiation of preliminary design efforts.

- Efforts should be continued to develop an inverter suitable for the BEST facility.

- Efforts should be initiated to develop dc fuses with the ratings required for the facility. This effort should also include development of any dc fuses which may be required for commercial battery energy storage load leveling plants.

- Further evaluation of the computer system should be initiated to assure that the modifications needed to produce the desired voltage withstand capability can be achieved. Also, investigations should be made of possibilities for reducing computer system costs.

- Battery developers should be asked to re-assess and further define their testing requirements, based on BEST facility capabilities. Further, a clarifying delineation of what equipment is to be supplied by the facility should be accomplished.

- A manual of operating and safety procedures applicable to the facility should be written prior to startup of the BEST facility.

- Similarly, each battery developer should supply a performance and safety manual on his battery system before it is installed in the facility.

Section 4

FULLY IMPLEMENTED BEST FACILITY

A conceptual design of the BEST facility has been completed and is presented hereafter in two parts. The first covers the fully implemented ("ultimate") facility, meeting all of the design criteria delineated below in Section 4.1. The second part describes an initial "Baseline" facility that incorporates the principle features of the ultimate facility, but at a reduced testing capability. Design of the Baseline facility is such that equipment can be added later, as needed, to bring it up to the full testing capability of the ultimate plant.

The balance of this section, following the design criteria, describes the design of the fully implemented BEST facility. The Baseline facility design is described in Section 5, along with several technical options that may be selected for initial or future implementation.

4.1 DESIGN CRITERIA

Through meetings with the BEST Project Team, and through past design efforts supported by ANL and EPRI, the following items have evolved as desired characteristics of the BEST Facility:

- The facility structure will house three battery rooms, an inverter area, a control room, offices, a conference room and a shop area. Further, each of the three battery rooms will contain a data analysis room, an area for maintaining spare cells on float and a work area in addition to the battery system area.
- The facility structure will be sized so as to permit the eventual installation of three 1 MW, 10 MWh batteries, and inverters, bus systems, cooling systems, etc., required to accommodate such batteries.

- The initial installation of lead-acid cells may be in two battery rooms.

- Cooling systems will be sized to dissipate the waste heat generated at maximum discharge rates.

- The facility will provide supply and exhaust air ducts for the cooling of battery systems and allocate space for fans. A complete cooling system will be provided for the lead-acid station battery.

- The facility will provide louvers in the advanced battery air cooling supply and exhaust ducts which will permit the cooling duct system to be flooded with an inert gas in the event of a fire or other anomaly. The facility will supply inert gas for this type of safety system, but not for normal cooling operations.

- Waste heat not disposed of by air cooling of individual systems will be dissipated by means of a cooling water system and a dry cooling tower.

- Seismic and tornado stress loading specifications have been eliminated as the result of a cost reduction study conducted in August, 1974.

- The facility's water and sewage will not be connected to local utilities.

- TV cameras and intercoms will be provided in the inverter area and in each battery room.

- The facility will supply heater power for batteries through a fused disconnect switch. The facility will not supply heaters, temperature controls or wiring from the disconnect switch to the heaters or heater controls. The voltage for the heaters has not yet been set, but may be 480 V ac, 3ø.

- Initially one air-cooled, modular inverter system will be installed as the station inverter.

- Space will be allocated so as to provide for the option of installing two additional inverters.

- By series and parallel interconnection of modules, the station inverter will be capable of operating at voltages up to 1 kV and at currents up to 10 kA but it will not be capable of operating at both of these ratings simultaneously. The initial installation may be at less than the above maximum ratings.

- The inverter will be capable of continuous operation at 2.5 times the batteries' nominal 10 hour rate discharge power.

- Inverter power level and mode of operation (e.g., charge/discharge; constant current, voltage or power) will be set manually or remotely by a signal from a computer. Internal inverter electronics will determine and generate the SCR gate signals required by the various modes of operation.

- The maximum operating voltage of the dc bus system will be 1000 V.

- The dc bus will be designed to withstand sustained overvoltages of 2 per unit and transient overvoltages of 3 per unit.

- The maximum dc bus operating current will be 10 kA and the dc bus will be braced to withstand momentary overcurrents of 200 kA.

- Circuit breakers in the dc bus system will have ampacity ratings of 10 kA at 750 V and 8 kA at 1000 V.

- Each battery developer will provide its own string fuses, switches or breakers. The facility will provide fused disconnect switches and breakers for the dc bus.

- The facility and facility inverters will not provide any means to control current sharing among battery strings.

- Each battery developer will supply its own internal (i.e., inside of modules, cabinets or circulating air/gas cooling ducts) fire, gas or particulate detectors which will provide an electrical input to the facility computer and safety systems. In the event of an operating condition which can present a potential hazard to batteries or personnel, these detectors will cause battery developer supplied devices to disconnect one or more appropriate strings or cause the facility supplied dc circuit breaker to disconnect the entire battery system. The facility will supply appropriate detectors in the battery rooms and air cooling exhaust ducts. Activation of these facility supplied detectors will cause the dc breaker to disconnect the battery.

- Emergency shutdown initiation circuits will be provided to each battery room for battery developer's use.

- Initially, one dc bus system will be installed to connect the lead-acid battery room(s) to the station inverter, with stubs provided for future connection of the remaining battery rooms.

- Space will be allocated so as to provide for the option of eventually installing a total of three dc bus systems as described above.

- The data acquisition portion of the computer should be modularly expandable to permit the adding of units as required by the development of battery systems.

- The number of cells to be monitored will be based on the results of the statistical analysis given by Table IV in J. Birk's March 1975 report (Ref. 1).

- All series cell voltages will be computer monitored with 0.1% accuracy or better and scanned once every 5 minutes.

- Dc bus currents, string currents (for those systems providing their own shunts) and bus voltages will be computer monitored once per second or faster to permit accurate determination of charge and power.

- Monitoring of ac system parameters, inverters, cooling systems, etc., will be provided.

- For safety reasons, 10% of the voltage points will be scanned every 15 seconds (approximately) in order to detect shorted or out of tolerance cells. Additionally, hardwired voltage monitors will be provided if needed.

- Computer tie into safety equipment and detectors will be provided. Computer output signals will alarm any anomaly to control room operators and data analysis room personnel and/or cause circuit breakers or other equipment to operate as required.

- Computer data for each battery system will be made available to that system's data analysis room.

- Each of the battery rooms will have terminal strips to which battery manufacturers will connect test leads emanating from their modules in order to accomplish computer monitoring of their battery.

- Analog (or digital, if appropriate) computer outputs will be provided to set inverter power level and mode of operation (e.g., charge/discharge; constant current, voltage or power). The computer will not directly control the SCR firing angles required for the various modes of operation.

- Input/output will be provided by means of 4 high speed keyboard display terminals, a high speed tape punch reader (or tape cassette units), a high speed line printer and a high resolution graphic plotter (9" x 12"). Additionally, there will be a magnetic tape data storage unit(s) with the output formatted to permit data processing by IBM compatable computer and a modem to transmit data.

- Part of the computer data acquisition system will include periodic scanning of a Weston Cell or similar standard to provide a check on system performance and accuracy.

4.2 DESIGN FEATURES

The conceptual design that follows is for a test facility which incorporates all of the criteria delineated in the preceeding section for the fully implemented BEST facility. This design is for a facility which can simultaneously test three 10 MWh battery energy storage systems under controlled conditions representative of utility service.

A 30,000 square foot building will be used to house the facility and will be completed for the Baseline. The building and site layouts are shown in Figure 2-2. The building will include three battery rooms, an inverter area, three offices for the facility staff, a conference room and a general shop area. To facilitate the installation and changing of the systems to be tested, all of the major equipment areas will be accessible by means of large equipment doors and the roadway surrounding the building. The layout of the building has been configured to permit expansion to even larger capacities with a minimum of disruption of on-going testing should this become warranted by the pace of future battery development.

Each of the battery systems to be tested will be housed in one of the three battery rooms. In recognition of the current developmental nature of these batteries, all rooms were sized to provide ample space to accommodate the projected sizes of any of the battery systems. Additional space has been allocated in the battery rooms to provide a work space and an area to store and maintain spare battery modules. Space exterior to the building has been allocated for the chemical storage tanks required for the flowing electrolyte batteries such as the zinc/chloride system. Each of the three battery rooms will have a data analysis room adjacent to it. These rooms will serve as on-site field offices for the battery developer's personnel, and house a remote data terminal which will enable the developers to monitor the performances of their systems during testing.

Inverters will serve to interface the batteries with the host utility's grid. The 13.8 kV switchgear in the facility's ac bus system will also allow an inverter's output to be connected to a synthetic load. A 1000 V, 10,000 A dc bus system will permit any battery to be connected to any inverter through a series of switches and breakers.

A prime purpose of the facility is to obtain data on the performance of battery and inverter systems in utility service. A computer will be used to monitor, record and process information obtained from test system instrumentation. The computer will also monitor auxiliary systems (e.g., coolant flow rates); provide control signals for the conduct of programmed tests; and serve a safety function, warning of and acting on potential or existing malfunctions. For the conduct of special tests, such as determining a system's response to transients, the computer will be supplemented by high speed recorders. Control room meters and recorders will provide additional means for supervision of the facility's performance.

Most of the systems to be tested will be air cooled and served by duct systems. Heat exchangers will be used for any liquid cooled battery systems. Ventilating and air conditioning systems to serve the building needs will be roof mounted with a central cooling unit supplying cold water for air conditioning radiators. This air cooled central cooling unit and the synthetic load will be located away from the building so as to prevent the hot exhaust air of these units from entering building air intake ducts. Final rejection of all waste heat from all sources will be to the atmosphere by means of plume-free hot air.

The following sections discuss in detail the subsystems and components which comprise the facility design briefly described above.

4.3 BATTERY SYSTEMS

4.3.1 Battery Rooms

Each of the three battery rooms in the BEST facility will be capable of accommodating any of the proposed battery system designs currently under consideration. However, Battery Room number 3 (Ref. Figure 2-2) has been selected to also house any flowing electrolyte battery, such as EDA's zinc/chloride system, thus permitting the tanks and sumps associated with this type of system to be located outside of the building. Also, Battery Room number 1 will house the initially installed lead-acid station battery and thus have an atypical ventilation system as will be needed to cool the lead-acid battery and remove hydrogen. When testing of either of the above two batteries is completed, removal of the battery system and its auxiliaries would allow any of the other battery systems to be installed in its place. All three battery rooms will be virtually identical. Identification of their common features is provided in the following discussion.

All of the battery rooms will be sized to accommodate the largest single battery installation of any type, within the specified 1 MW, 10 MWh range. Each room will be 80 feet long by 60 feet wide, with a ceiling height of 28 feet. Floors will be concrete and slightly sloped (1 inch per 20 feet) so as to direct any spilled chemicals away from the interior of the building. The high end of each floor will be 4 inches lower than the remainder of the building in order to further inhibit chemical flow past the interior end walls. Underground sumps are provided at the low end to collect any spills. Personnel access is provided at both ends of the rooms by means of outward opening fire doors. Additionally, each room has a 12 x 12 foot steel roll door to facilitate installation or removal of equipment. A data analysis room will be located adjacent to each battery room, fitted with a window to permit viewing of the battery operations. These windows will be 2 x 3 feet and made up of eight laminations of one-fourth inch plate glass. The battery rooms can also be viewed from the control room by means of remote TV cameras.

Each battery room will be serviced by a 3 ton overhead crane to facilitate the initial installation of modules and other equipment, and for servicing modules during the course of the testing program. Hook clearance to the floor will be 16 feet. Controls will be hand held and suspended from the crane carriage. These cranes will be capable of two speed operation to allow for rapid movement of equipment, while also providing a slow speed for critical positioning maneuvers. Stops will be installed to prevent the cranes from hitting ventilation ductwork or walls. Roof penetrations for ducts and conduits will be positioned against the end walls of the battery rooms so as to permit crane travel over the full length of the room. The crane in Battery Room 1 will be suitable for use in a hydrogen atmosphere, National Electrical Code Class I, Division 1, Group B operation.

There will be several wall penetrations for battery room connections to the remainder of the facility. Each room will have a penetration area to a motor control center (MCC) on the other side of the wall. One portion of this area will be for the wiring and conduit used to supply power to facility auxiliaries such as lighting, cranes, wall electrical outlets, etc. The remaining MCC penetration area will be for use by the battery manufacturers to obtain power for high temperature battery heaters, fans, and other battery system auxiliaries, with connections made to the battery room side of the MCC when a battery system is installed. Separate wall penetrations will be provided for safety related systems such as fire or gas detectors, emergency lighting, and the TV monitoring system. The facility dc bus system will be brought into each room with a two-pole wall penetration and a switch. Manufacturers will connect their batteries to this switch as they install their system. Further descriptions of the electrical systems are given in Section 4.5.

Each battery room will have a terminal strip cabinet and wall penetration for all wiring required for computer monitoring of battery temperatures, voltages, or other parameters. Each manufacturer will connect to this interface during the installation of his system. If required, any hardwired over or undervoltage relay equipment would be installed and connected in this area. It is assumed that each battery manufacturer will supply series resistors or fuses to limit current on voltage monitoring leads, and that they will insulate their thermocouples for up to three times the charge cut-off voltage of their battery system. Further descriptions of the computer system are presented in Section 4.6.1.

Each battery room will be serviced by a heating, ventilating, and air conditioning (HVAC) system that will be used for controlling room air temperature and for exhausting any toxic or explosive gases. The HVAC service to Battery Room number 1 will be of a special design to accommodate the lead-acid battery system's requirements for cooling and hydrogen removal. The air-conditioning units for operation with the high temperature batteries will be designed to remove the heat transferred from the surfaces of high temperature battery insulation packaging and exhaust ducts, and the normal heat load from the structure's walls. Battery room air conditioning will be derived from a common refrigerated water line located on the roof, via individual heat exchangers and circulation fans above each room. Each system will be designed to produce a slight negative pressure in order to prevent any gas or vapor in a battery room from flowing into the remainder of the building. Heat will be provided for winter operations. Further discussion of the facility HVAC system is presented in Section 4.7.3.

Each of the battery rooms will be fitted with external ceiling or wall penetrations of sufficient size to accommodate battery cooling air supply and exhaust ducts of the largest size currently specified by the high temperature battery manufacturers. Inasmuch as the battery room internal ducting and circulating fan capacities will vary between types of batteries, the manufacturers will be expected to provide this part of the cooling system when they install their batteries.

Flame detectors that sense the infrared radiation emanating from flames will be mounted on the ceiling of the battery rooms. If a fire should occur, these detectors will respond quickly to flames that are not concealed by the batteries or their housings. Flame detectors will be located to provide maximum angular coverage of the room and to prevent the blinding effect of obstructions such as the overhead crane.

The battery systems will be positioned close to the interior end wall of each battery room in order to minimize the lengths of the cooling ducts and various wiring required to interface the battery with the facility.

4.3.2 Proposed Battery Systems

Sizing of the facility was based on data supplied by battery developers' reports (see References 2 thru 7). Subsequent to the issuance of these reports, the facility's dc bus voltage limit was specified at 1000 volts. It is assumed that those proposed battery systems having charge cut-off voltages that exceed 1000 volts can be reconfigured into lower voltage, higher current systems without appreciably altering the batteries' energy density or heating and cooling requirements. Table 4-1 summarizes heating and cooling requirements and system parameters for the several battery systems, nominally 1 MW at the 10 hour rate. The lead-acid system for the facility station battery, as specified, is comprised of the minimum number of cells required to achieve a 1000 V dc bus voltage at charge cut-off. For the MAZ-31A cell, used to typify large lead-acid cells, this results in a 0.5 MW system at the 10 hour rate.

TABLE 4-1

BATTERY SYSTEM DATA

(VALUES BASED ON LABORATORY CELLS AS PRESENTED IN RECENT REPORTS FROM BATTERY DEVELOPERS)

	MAZ-31A[1]	ANL	AI	TRW	GE	ESB	EDA	Units
Cell Parameters:								
Chemistry	Pb/PbO_2	Li-Al/FeS	$Li/FeS_{1.5}$	Na/S	Na/S	Na/Cl	Zn/Cl	
Temperature	25	400-450	400	315	300	200	32	°C
Charge Cut-off Voltage (V_{cc})	2.65	1.55	2.4	2.75	2.35	3.7	2.23	Volts
Maximum Voltage	-	1.62	-	2.75	2.50	3.9	-	Volts
Discharge Cut-off Voltage (V_{eod})	1.68	0.85	1.0	1.83	1.60	2.3	1.90	Volts
Minimum Voltage	1.27	0.65	0.1	1.04	1.0	2.0	-	Volts
Maximum Current/Cell	6500+	500	500	114	400	300+	-	Amps
Short Circuit Current	50,000+	1750	3000	610	3750[6]	1200	2500	Amps
Average Power (10 hr rate)	1310	92	260	95.4	250	358[8]	4000	Watts
V_{cc}/V_{eod}	1.58	1.82	2.4	1.5	1.47	1.61	1.17	
Battery Parameters								
Cells/Module	376	30[3]	40	300[4]	25	12[9]	250	
Modules/String	1	174	12	1	20	240	1	
Strings/Battery System	1	2	8	35[5]	8	1	1	
Power (10 hr rate)	493	960	1000	1000	1000	1030	1000	kW
Bus Voltage @ V_{cc}	996	1350	1150	825	1175	888	558	Volts
Bus Voltage @ V_{eod}	632	740	480	549	800	552	475	Volts
Bus Current @ eod, 10 hr rate	780	1300	2080	1820	1250	1870	2100	Amps
Bus Current @ eod, max. rate[2]	1950	3250	5200	4450	3125	4680	5250	Amps
Current limited by amps/cell	6500+	6000	4000	3990	3200	3600+	-	Amps
Short Circuit Bus Current	50,000+	21,000	24,000	21,350	30,000	14,400	2500	Amps
Battery System Heating and Cooling								
Start-up Heating	N.A.	48@162	14@60	24@147	10@320	-	N.A.	Hrs @ kW
Standby Heating	N.A.	20	14.4	-	64	-	N.A.	kW
Cooling - Charge	79	244	(11.5)	95.5	226[7]	100[10]	469[12]	kW
Discharge	44	118	211	220	88[7]	144[11]	-	kW
Max. Discharge	110	295	528	550	592[7]	360[11]	-	kW

*Footnotes on following page

TABLE 4-1 (continued)

Footnotes:

(1) Based on the minimum number of cells required to obtain 1000 volts at the charge cut-off condition and results in a 0.5 MW system for the Exide MAZ-31A cell used as an example.

(2) Maximum power (2.5 MW, nominal)/bus voltage for cell voltages = V_{eod}. Some battery types may not be able to be fully discharged at the maximum rate.

(3) ANL module is comprised of 5 submodules in series, each submodule in turn comprised of 6 cells in parallel.

(4) TRW module is composed of 30 submodules in series, each submodule a 10-cell stack connected in series.

(5) The TRW system consists of 35 modules plus 5 additional modules in reserve.

(6) This value calculated by dividing the system short circuit current (30,000 amps) by 8 parallel strings.

(7) These values represent heat to 50% of full charge and will increase substantially below a 50% state of charge (refer to Figure 7 of Ref. 4).

(8) This value based on a module power rating of 4.3 kW.

(9) Module consists of 12 cells in parallel.

(10) Based on heat rate of 35 watts per cell during charge as estimated from graph (Figure 3 of Ref. 5).

(11) Based on heat rate of 50 watts per cell during discharge as estimated from graph (Figure 3 of Ref. 5).

(12) This heat rate obtained by increasing the condensing unit cooling rate of 426 kW by 10% to account for cooling the electrolyte during charge (Ref. 6).

Sheet 2 of 2

4.3.2.1 Lead-Acid Batteries. Several options are currently being considered for the initial lead-acid station battery. These options include use of commercially available cells, developmental or modified cells, and military surplus submarine cells such as the MAZ-31A (Exide Industries, Division of Electrical Storage Battery Company, version of the Guppy I Model B). Generally, commercial cells and newer versions of the MAZ-31A are air cooled. Older MAZ-31A cells have provisions for water cooling. The type of cooling and cell capacity affect the packing density which can be used in the BEST facility. Water cooling will permit closer cell spacing and therefore a smaller room size would be possible; although, even with water cooling, space must still be allowed for the system of air ducts needed to disperse the hydrogen which is evolved.

The use of cells with a large capacity would require less floor space than an installation of the same total capacity utilizing smaller capacity cells. A previous study (Ref. 8) considered the effect of doubling individual cell capacities by using C&D's RHA8000 cell type instead of their RHA4000 and resulted in halving of floor space requirements. Another parameter that affects floor space requirements is the manner in which cells are supported. The construction of the MAZ-31A and C&D's RH series is such that the case material will support the weight of the plates and electrolyte. Thus, the cell may be installed free standing. Some cell types must be installed in racks or left in shipping crates in order to keep them from collapsing or deforming under their own weight. Leaving cells in shipping crates is undesirable since the floor space requirements are nearly doubled and the effectiveness of forced air cooling is greatly decreased.

In order to test the facility dc bus system and inverter equipment, the initially installed station lead-acid battery should be capable of operating at the specified design voltage limit of 1000 volts. Charge finishing voltages of 2.65 volts/cell are specified (Ref. 9) for the TLX-39B and similar lead-calcium cells. Setting this charge cut-off voltage equal to the bus system voltage limit yields 376 as the minimum number of cells required to achieve a 1000 volt system (at end of charge). The initial discharge voltage of this configuration would be about 760 V. The power represented by a single series string of 376 cells is, of course, directly proportional to the power of the individual cells. Thus, power of the station lead-acid battery will depend on the rating of cell selected and the number of strings installed. The nominal power of 376 MAZ-31A cells is 0.5 MW at the 10 hour rate.

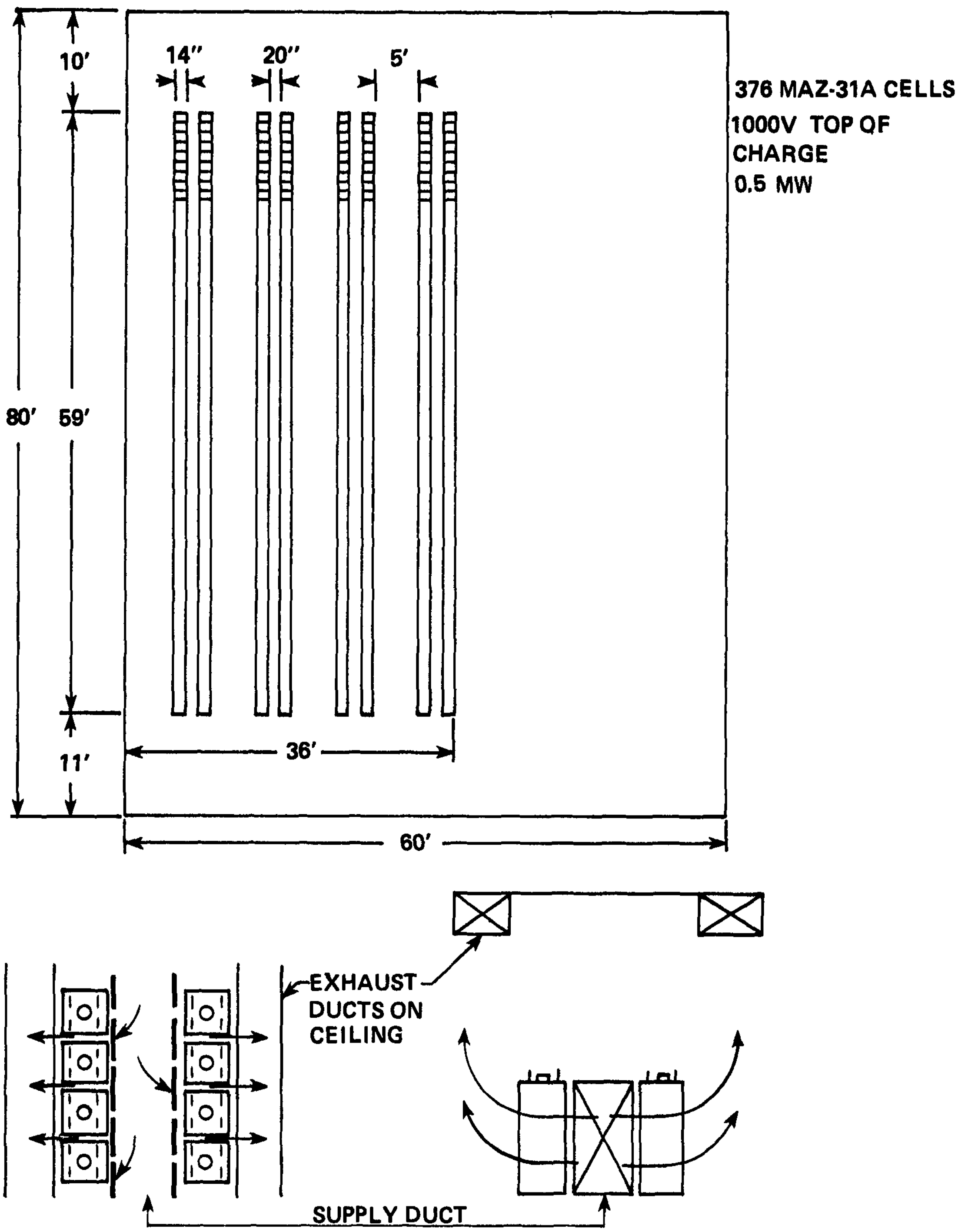
Since the station inverter and bus system need not be operated at their maximum voltage and current ratings simultaneously, their ampacity ratings may be tested at a lower voltage. To accomplish this testing at minimum cost, the single series string of 376 lead-acid cells could be easily reconnected to form four parallel strings of 94 cells each. The charge cut-off voltage for this battery system would be 250 volts. MAZ-31A cells have a nominal discharge current of 680 amps at the 10 hour rate. Four parallel strings would then produce a total of 2720 amps (at an average 180 volts). To test the facility equipment, the four string battery could be discharged near the two hour rate in order to produce 10,000 amps (at an average of 165 volts). This battery configuration could also draw 10,000 amps in the charging mode. A current of 2500 amps (10,000 amps for the total system of four parallel strings) is on the order of the current obtained during the first hour of normal charging of shipboard installations of MAZ-31A cells. Continued operation at these high currents would likely require the use of water cooled cells or coordination of testing schedules to start with cells at room temperature if an air cooled battery system is installed.

A possible floor plan that embodies an air cooled version of the battery system described above is presented in Figure 4-1. The dimensions of an MAZ-31A cell are used as an example. Cooling air is supplied through four ducts. Rows of cells (47 cells long) are positioned along both sides of the rectangular ducts. Slot orifices cause cooling air to impinge on the cells; flow between the cell and duct walls; then flow between adjacent cells; and finally exhaust into an aisleway. Thus, three sides of the cell are cooled by forced convection. Additional cooling is provided by air flow around the battery terminals and bus.

Air from the batteries will contain some amounts of hydrogen. This air is exhausted from the room through return ducts on the ceiling. The inlet air temperature is controlled by an air conditioning system located on the roof. The air distribution system will circulate 50,000 scfm. Further details of this system are given in Section 4.7.3, HVAC System.

Calculations (Ref. 10) indicate that with the above air system the temperature of the batteries will increase over a five-day cycling period. The cooling system will limit the battery temperature to about 30 to 45^{o}F above ambient, depending on the value of cell's heat transfer coefficient. The temperature of the cooling air is expected to rise about 3^{o}F as it flows between the batteries.

Referring to Figure 4-1, each two rows of cells is separated by five feet so that a side-loading fork lift truck (manufactured by several companies) can install and remove cells. Alternatively, cells such as the MAZ-31A are amenable to handling by overhead crane and lifting harness.



TOP VIEW - EXPANDED

END VIEW

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LEAD-ACID BATTERY LAYOUT NO. 1

FIGURE 4-1

A more compact forced convection cooled system is illustrated in Figure 4-2. In this variation of the first arrangement, rows of cells are configured into two-row groups with inlet and exhaust air ducts in between. Since the temperature of the cooling air increases about $3^{\circ}F$ per cell, it is recommended that no more than two rows of batteries be placed together in order to maintain a uniformity in cell temperature. The exhaust duct in the center of the system is sized to accommodate the cooling air exhaust from both sides. With this configuration, baffles and exhaust ducts are placed so that cooling air will not flow upward before contacting both cells, thus maintaining temperature uniformity along the height of the cells.

As can be seen from Figure 4-2, this cell arrangement is sufficiently compact to permit installation of a second set of cells in order to obtain a 1 MW, 10 MWh lead-acid battery system in a single 60 ft by 80 ft room. This configuration requires an overhead crane to install or remove cells, since the interior cells would not be accessible to a fork lift truck; cells would be lowered into position by the overhead crane. Use of smaller cells with lower individual capacities (e.g., 3000 Ah) would require a tiered configuration in order to install a 10 MWh system in a single room.

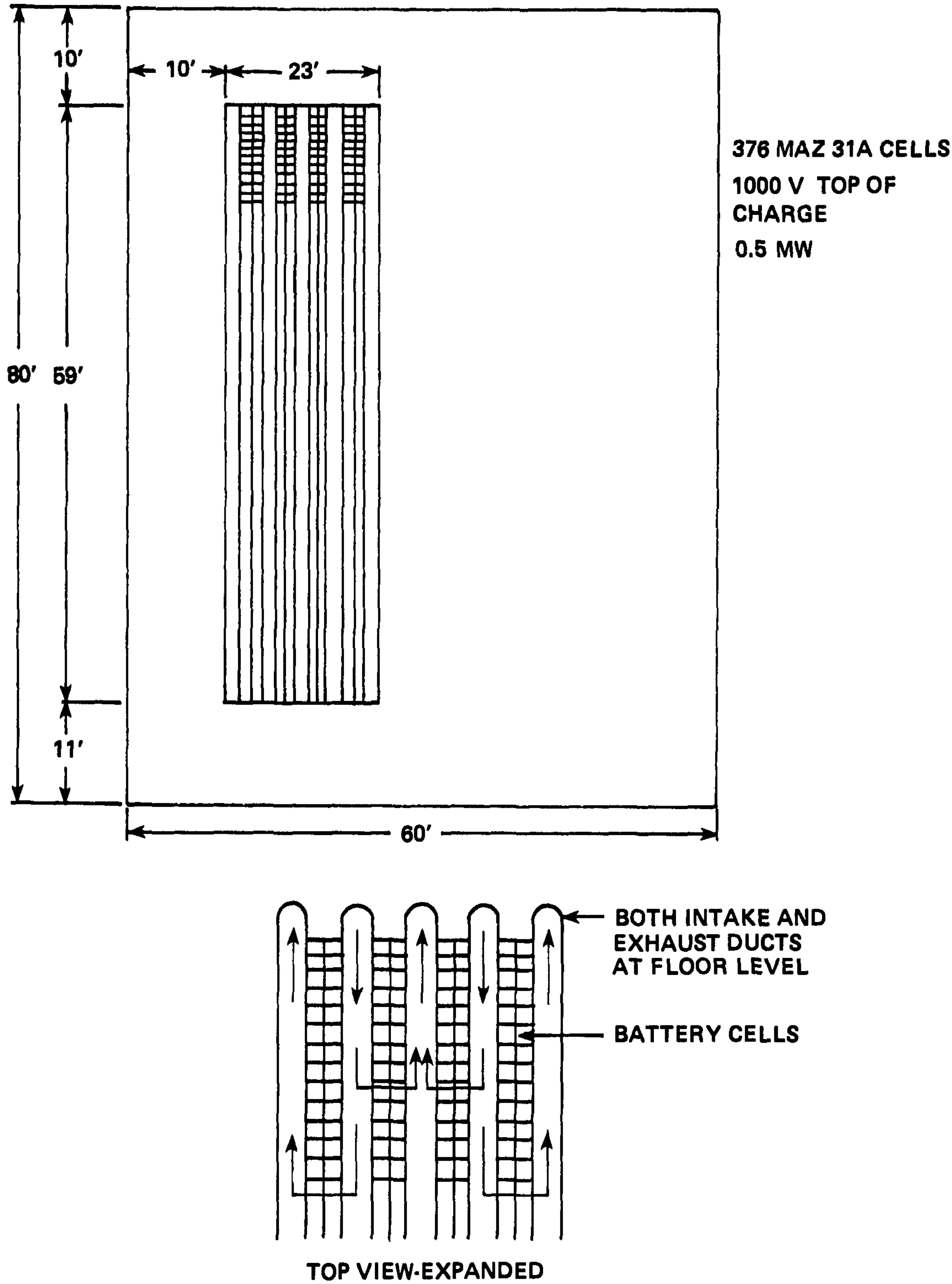
Water cooled cells can also be configured in a compact arrangement. The cells are cooled by running distilled water through channels within the plate on top of the cell. The water is circulated through a heat exchanger and the shell side of the heat exchanger is cooled by water from the central system.

Based on the size of water cooling systems recommended for Navy submarine batteries, a flow rate of 150 gpm would be required for the 5 MWh battery system of 376 MAZ-31A cells. Discharge at the 4 hour rate would result in about a $5^{\circ}F$ rise in the temperature of the cooling water. The cell temperature will be determined by the heat transfer characteristics of its internal design. Calculations indicate that a

5 hp motor would be sufficient to drive the pump on the battery side of the heat exchanger.

The forced convection cooling system described earlier will also serve as the battery room ventilation system. A separate room ventilation system will be provided if a water cooling system is used. In either case, the ventilation system will maintain hydrogen concentrations in the lead-acid room below the maximum acceptable level. Calculations (Ref. 9) indicate that as much as 175 scfm of hydrogen can be evolved from a system of lead-acid batteries during the end of charge at the currents required by constant power charging. Hydrogen detectors (such as the 500 series system available from Mine Safety Appliance Co.) will be located at various places within the room and also within the ventilation system itself. The detectors will be wired into the alarm system and monitored in the control room. Additionally, the hydrogen detector in the exhaust duct will be computer monitored to record gas evolution data.

Lead-calcium cells, such as the MAZ-31A, do not emit arsine or stibine gases (Ref. 9, pg. 2). However, these toxic gases can be emitted from lead-antimony type cells during charging. Hand operated detectors which sample the air and have a chemically treated filter that changes color if these gases are present are available from Mine Safety Appliances Company. These detectors cannot distinguish between arsine and stibine, and can only measure the sum of the concentrations of both gases. Battery charging should stop and precautions should be taken whenever a reading indicates that the threshold limit value for these gases has been exceeded. The threshold limits values of arsine and stibine are 0.05 and 0.1 ppm, respectively, averaged over 8 hours. These detector kits should be located at convenient places in the lead-acid battery room so that the



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LEAD-ACID BATTERY LAYOUT NO. 2

FIGURE 4-2

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presence of these gases can be checked if lead-antimony type cells are installed. The concentration of arsine gas could also be continuously monitored with the Miran II gas analyzer (available from Wilkes Scientific Company), which senses the infrared wavelength bands that correspond to arsine. The gas analyzer can be set up to draw samples of room air from six or more locations. A bank of solenoid valves is sequentially operated to sample from each location. The equipment would be connected to an alarm to warn when the threshold limits have been reached.

There will be eyewash stations and deluge showers located at several places in the lead-acid battery room. All electrical equipment in Battery Room 1 will be suitable for National Electrical Code Class I, Division 1, Group B, hydrogen atmosphere. Other safety considerations are discussed in Section 7.2.

4.3.2.2 High Temperature Battery Systems. The high temperature battery systems have features in common which are taken into consideration in the design and layout of the battery rooms. All the high temperature batteries are cooled by the circulation of air or an inert gas through a system that will be sealed from the room environment. Because of the possibility of sodium or lithium fires, safety considerations for the high temperature batteries are similar.

In the battery rooms, adequate space will be provided for high temperature battery cooling system ducts and their wall penetrations. The ductwork will be completed by the manufacturers as part of the battery installation process. The exhaust duct and its roof penetration must be constructed to withstand the interior operating temperatures up to 400°C and insulated to maintain a safe exterior temperature of about 90°F. Insulation is not required on the ducts supplying make-up air to circulating air cooling systems. In the event of a fire, the battery's cooling system will be flooded with an inert gas. Bottles of argon or other inert gas will be available in the rooms for that purpose. The inerting will be accomplished by closing cooling duct louvers or valves to seal the system from the outside and by opening valves on the gas supply.

Caution must be exercised when any of the high temperature modules are moved while at temperature. At these times, they are removed from the protection of their insulated housings and cannot be immersed in an inert atmosphere in the event of a cell rupture. Also, the possibility of mechanical damage may be increased when these modules are moved about. However, the thermal shields, required for the protection of personnel, may also be designed to afford mechanical protection for the modules.

Because of the possibility of liquid metal leaking from any of the high temperature batteries, precautions will be taken against sodium and lithium fires. It is assumed that the submodules and insulated housing will contain the battery materials in the event of a cell rupture. However, Underwriters Laboratory approved portable fire extinguishers containing MET-L-X (available from the Ansul Co.) will be available in the battery rooms. This dry chemical powder acts to form an oxygen excluding barrier on the surface of burning metals such as lithium.

Photoelectric and ionization type smoke detectors are available from companies such as Pyrotronics. Unfortunately, these devices are not designed for use at the 200 to 400°C temperatures present in the cooling system ducts. Photoelectric detectors contain a photocell and a light source positioned so that visible smoke particles will diminish the intensity of the light on the photocell. The occurrence of smoke causes a change in conductivity and results in an alarm. It is conceivable that a fire detection system employing this principle could be protected from the high temperature environment by using windows to separate the detector components from the hot air inside of the duct. Some development effort would be required to produce such a detection system, but the system could be available by the time the high temperature batteries are ready to be installed in the BEST facility.

Protective clothing will be available for fire-fighting in the battery rooms. Since sodium fires can ignite other materials in the battery and generate caustic smoke and sulfur fumes, face masks and breathing apparatus will also be included so that this fire approach suit is self contained.

Descriptions of the high temperature battery systems currently under consideration for testing in the BEST facility follow, supported by discussion of special application problems.

The ANL Battery System. A conceptual design of Argonne National Laboratory's (ANL) lithium-aluminum/iron-sulfide battery system is described in their January 1975 report (Ref. 2). The nominal 1 MW, 10 MWh configuration described is comprised of two strings, each housed in an insulated structure. Each structure contains a 6 x 29 array of modules connected in series which in turn are made up of 5 submodules each.

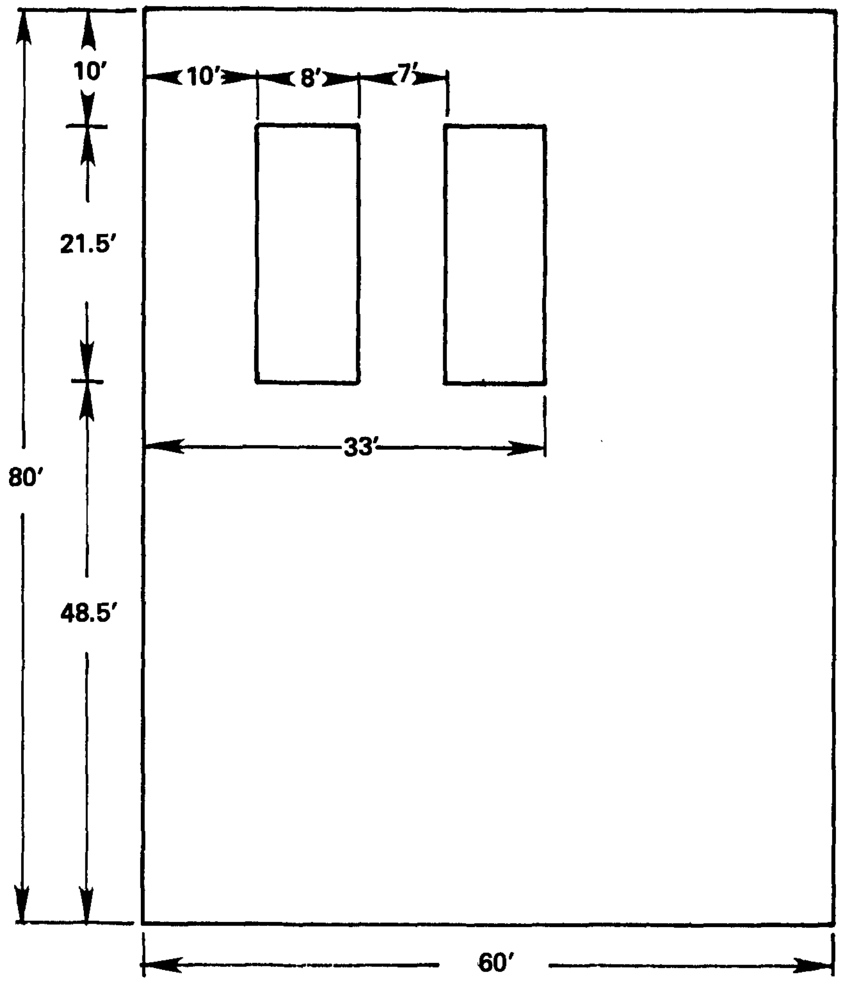
To maintain a cell operating temperature of between 400 and 450°C, the submodules and modules are cooled by the use of counter-current air flow in the cooling annulus surrounding each module. A portion of the exhaust air flow at 375°C is recirculated and mixed with makeup air at room temperature to provide 300°C air at the blower inlet. The remainder of the 375°C air is exhausted.

This battery system is designed for a nominal operating voltage of 1000 volts. Subsequent to the issuance of the ANL report (Ref. 2), the facility's dc bus voltage limit was specified at 1000 volts and thus a reconfiguration of cells would be required in order to have the system's present 1350 volt (1.55 volts/cell) charge cut-off voltage capability match the recently specified facility voltage limit. It is assumed that the interconnection of cells could be reconfigured into a lower voltage, higher current system for testing in the BEST facility and that such a reconfiguration would not appreciably alter the battery's energy density or efficiency. Therefore, the characteristics of the 1 MW, 10 MWh system described in ANL's January report were used in evaluating the interface and auxiliary requirements of the ANL battery. As shown by Figure 4-3, there will be ample space in the battery room for the ANL battery system.

The use of solid Li-Al electrodes mitigates any potential spillage problem. Also, the cells have iron housings which in turn are encased in a stainless steel to form submodules. The array of modules is further contained in an insulated housing. The proposed cooling system would be amenable to the inert gas flooding scheme previously described. Since lithium can react with nitrogen, it is recommended that argon be used for the inert gas.

The AI Battery System. Characteristics of Atomic's International's (AI) lithium/sulfide battery for the BEST facility are presented in their January 29, 1975 report (Ref. 3). The recently specified 1000 volt dc bus voltage limit can likely be accommodated by reconnecting cells, or possibly by use of AI's developmental lithium alloy electrode, with minimum impact on the values of the system requirements listed in their report.

AI's proposed 10 MWh battery system consists of eight parallel strings, each housed in a thermally insulated structure. It



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THE ANL BATTERY LAYOUT
FIGURE 4-3

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is assumed that the trays containing the modules can slide out of the housing (with a heat shield in place) and be lifted by overhead crane. A string has 12 modules in series and a module is comprised of 40 series cells. Figure 4-4 illustrates how AI's proposed system could be positioned in a battery room. As is evident from the figure, ample space will be available for extra batteries, a work area, and additional system equipment. Furthermore, the battery room is large enough to permit variations of the proposed system configuration.

The cooling system proposed by AI for their lithium/sulfide battery is similar to the ANL cooling system. Air is blown around the battery module inside a closed, insulated housing. Most of the heated air is recirculated, but a portion is exhausted through outlet ducts in the battery room. Cold air entering through inlet ducts is mixed with the recirculated air at the negative pressure side of the blower. Cell temperatures are maintained at 400^{o}C. Figure 10 in the AI report indicates that their system will be amenable to the use of louvers to seal off the cooling system and flooding with an inert gas.

<u>The TRW Battery System</u>. The 1 MW TRW sodium/sulfur system, described in TRW's January 1975 report (Ref. 7), contains 10,500 disk-shaped cells operating at 300^{o}C. There are 300 series cells per module, and 35 modules in parallel constitute a 1 MW, 10 MWh system. Figure 4-5 shows how these 35 modules plus 5 reserve modules are arranged in the battery room. In this configuration, each module is a string and has a charge cut-off voltage of 825 volts. The TRW system is unique in that it is always inerted. Cells are heated or cooled by nitrogen that is circulated through one of three duct circuits. Cell temperature is closely controlled by restricting the coolant temperature rise to 3^{o}C per module. This results in a nitrogen

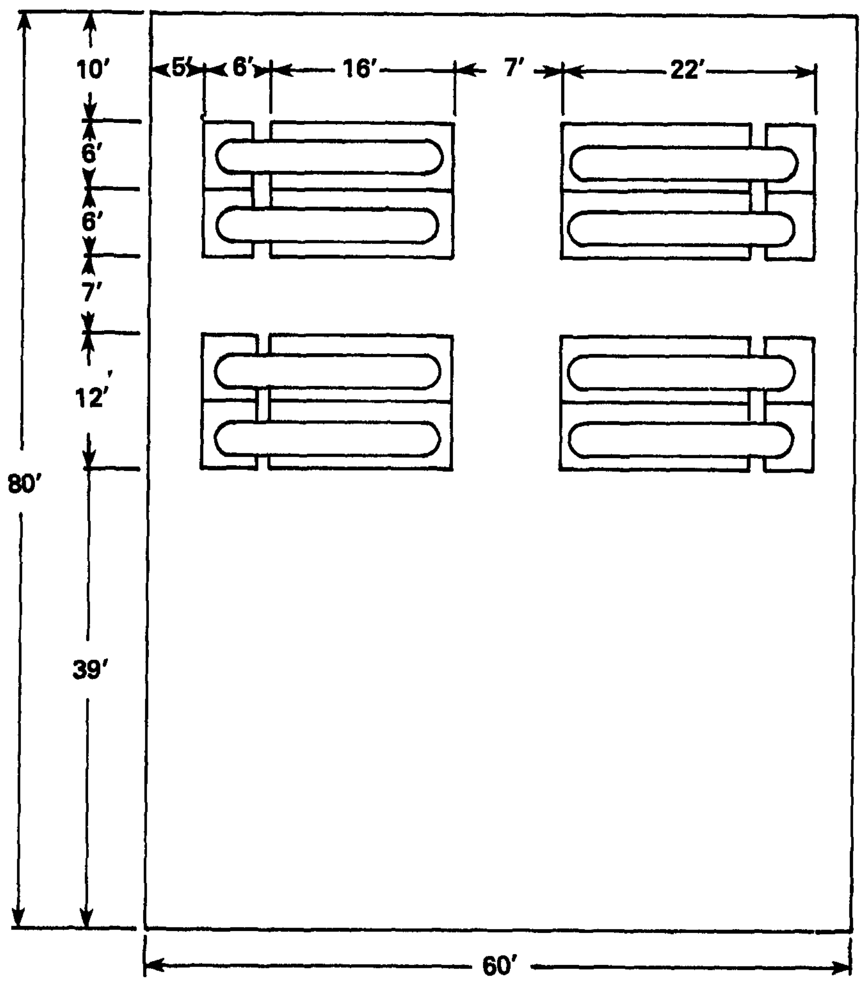
coolant flow rate of 240,000 cfm. Six separate ducts are needed in the battery room to provide inlet and exhaust flow from each of the three duct circuits. Heat exchangers for the TRW cooling system will be located in the battery room and will be air cooled by a supply/exhaust duct system.

The 10-cell submodules will be moved on a cart or small lift truck. Modules will be lifted by the overhead crane.

The GE Battery System. The sodium/sulfur battery system configuration proposed by GE in their December 1974 report (Ref. 4) consists of 20 modules per string. With a charge cut-off voltage of 2.35 volts per cell and 25 cells per module, this system configuration results in a string voltage of 1175 volts. The 1000 volt limit recently established for the dc bus can possibly be accommodated by employing fewer modules per string and more cells per module, without affecting the energy density of the GE battery system. Figure 4-6 illustrates how the proposed GE system could be positioned in the battery room.

General Electric proposed cooling their batteries by a natural convection process. The proposed module contains 25 cells that are spaced one-half inch apart. Holes in the bottom and top of the surrounding insulation are equipped with convection valves. When the valves are closed, the module is well insulated and tends to retain its heat. When the valves are open, air is permitted to flow up between the cells and cool the battery. Cooling ducts connect to flanges on the module to supply cool air to the bottom and exhaust hot air from the top. Cells are operated at $300^{o}C$.

The ESB Battery System. The ESB sodium/chloride battery module is comprised of twelve cells in parallel. A string of 240 modules, connected in series and housed in a single battery compartment,



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THE AI BATTERY LAYOUT

FIGURE 4-4

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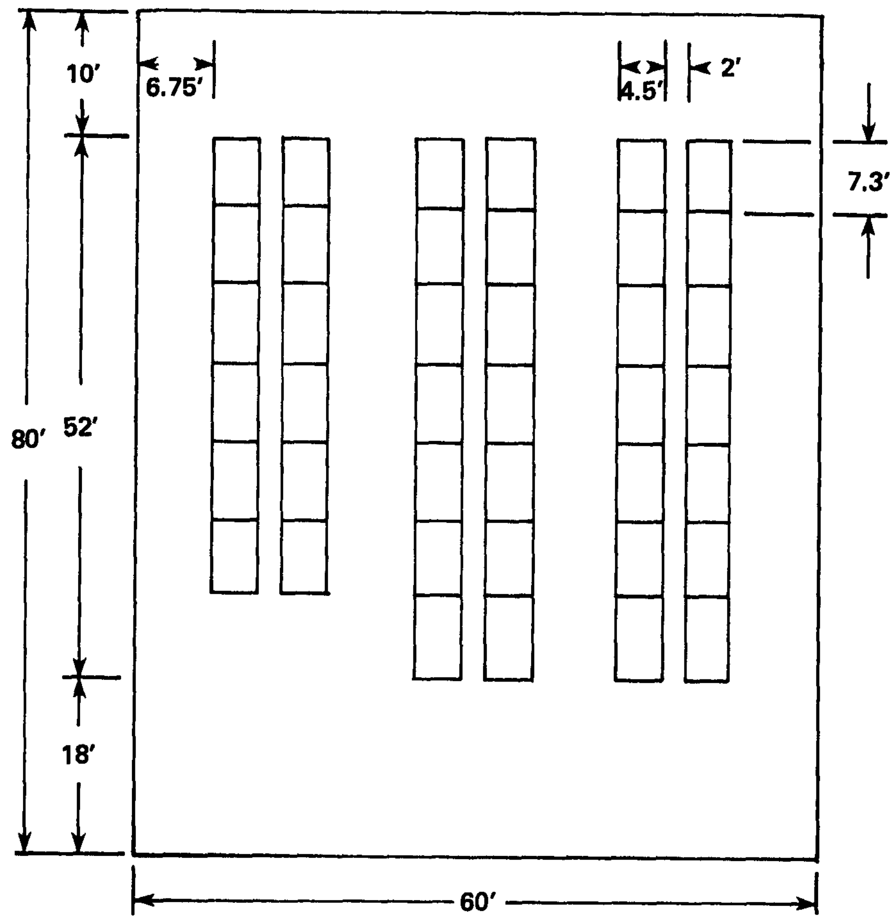

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THE TRW BATTERY LAYOUT
FIGURE 4-5

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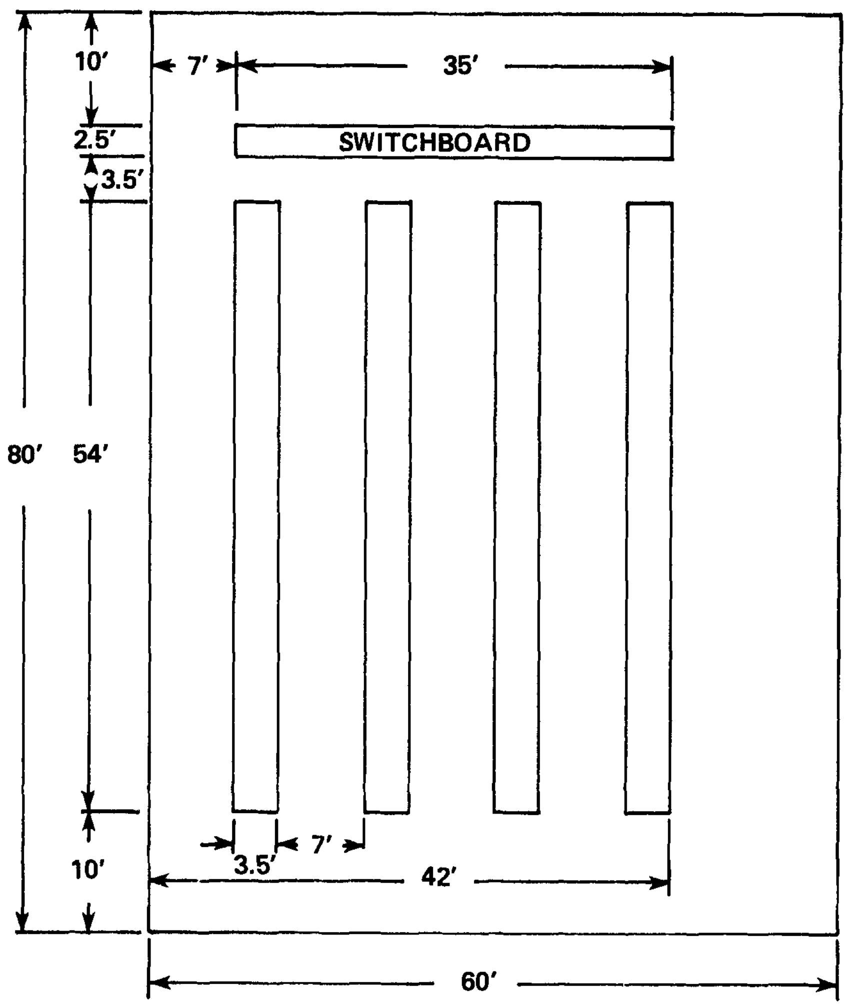

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THE GE BATTERY LAYOUT

FIGURE 4-6

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has a charge cut-off voltage of 888 volts. ESB's January, 1975 report (Ref. 5) shows a battery compartment that is 20 feet high, and fans on the top of the compartment would probably add another few feet to its height. However, the current building conceptual design includes a 16 ft clearance for the hook of the overhead crane. Consequently, it has been assumed that the ESB modules can be rearranged in a lower height rack so as to preserve a 16 ft clearance in the battery room. It has been assumed, further, that any rearrangement of the ESB battery can be done without modifying the basic modules or affecting the energy density of the system as described in the January report.

The battery compartment was shown to occupy a floor space of 350 ft^2. An additional 400 ft^2 of access space is required alongside the compartment to permit the replacement of modules with a fork lift truck or crane lifting device. Another 1000 ft^2 is recommended for a work area and a storage area. The sum of these floor space requirements is 1750 ft^2 and can easily be accommodated in a 60 by 80 ft room. There appears to be ample floor space in the battery room to accommodate a rearranged, lower height battery compartment. The battery room and the floor space requirements of ESB's proposed battery compartment are shown in Figure 4-7.

The ESB modules, operating at $200^{\circ}C$, are held in racks with the end and side surfaces in contact to permit heat conduction in horizontal planes. The vertical spacing of about 10 cm between module levels provides channels for forced air circulation. Consequently, heating and cooling occur through the top and bottom surfaces of the module. One or more blowers will be used for circulating air through the insulated compartment housing. It is estimated that a flow rate of 20,000 cfm will be required at the maximum expected current rate.

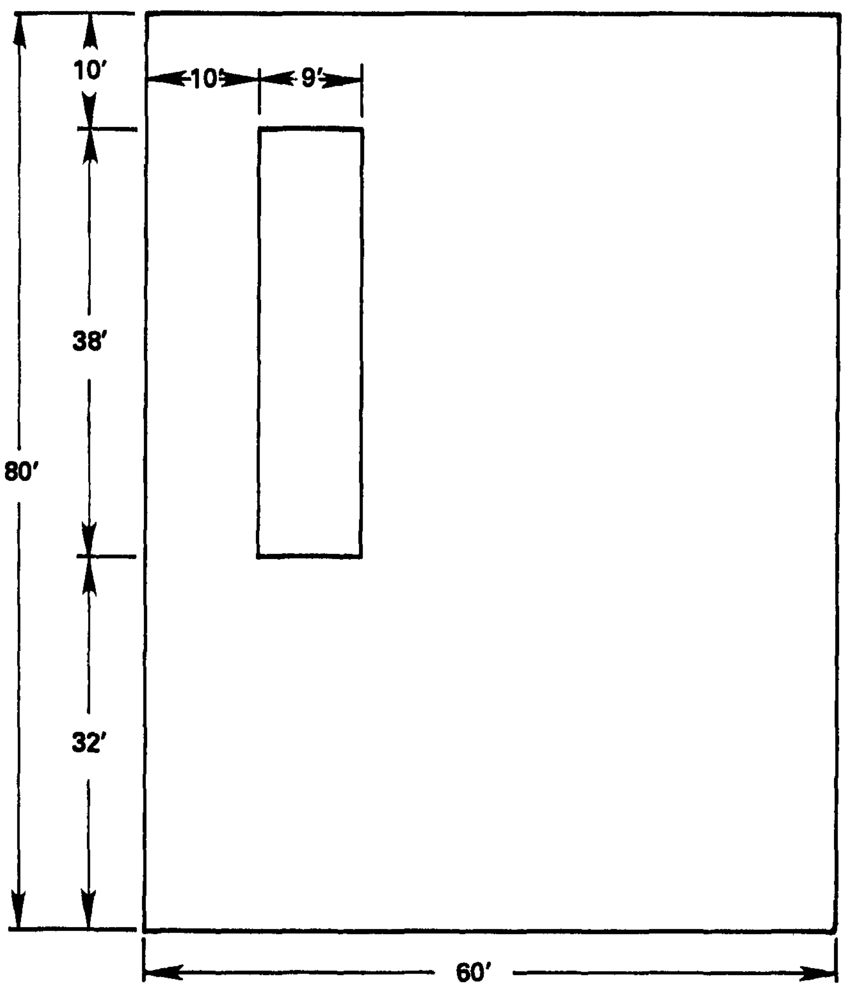
The size and weight of the proposed ESB module is such as to permit its installation or removal with a fork lift truck or overhead crane.

The ESB battery cell, when overcharged for a period of time, will eventually form chlorine gas. A pressure buildup within the positive compartment could lead to a rupture of seals and to leakage of chlorine gas into the room air. As a safety measure, the room will be provided with chlorine detectors (such as MSA's Toxgard toxic gas detector). This device functions as an area monitoring instrument and warns of an increase in the concentration of chlorine before the level of toxicity reaches the maximum allowable concentration.

4.3.2.3 <u>The EDA Zinc/Chloride Battery System</u>. The EDA zinc/chloride battery is unique in that a room temperature electrolyte solution circulates through a stack of 250 cells in the battery room. Electrolyte storage tanks will be located in an area adjacent to the facility building as shown in Figure 4-8.

Chlorine gas produced at the positive electrode during charge is removed from the cell by the flowing electrolyte. A special tank is designed so that in the event of a system failure, the tank will capture escaping chlorine gas from a collection manifold system and force the gas under pressure (2 psig) into a caustic solution.

To maintain the zinc/chloride battery temperature at about 90°F, the electrolyte is cooled by a heat exchanger in the electrolyte circulation loop. In addition, a refrigerator unit (to be supplied by the manufacturer) is needed for hydrate formation in the hydrate loop. It is assumed that the refrigeration unit is air cooled and that the expected cooling load will be 426 kW. Furthermore, it is assumed that the cooling load of the heat exchanger in the electrolyte loop will be 10% of the above load



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THE ESB BATTERY LAYOUT

FIGURE 4-7

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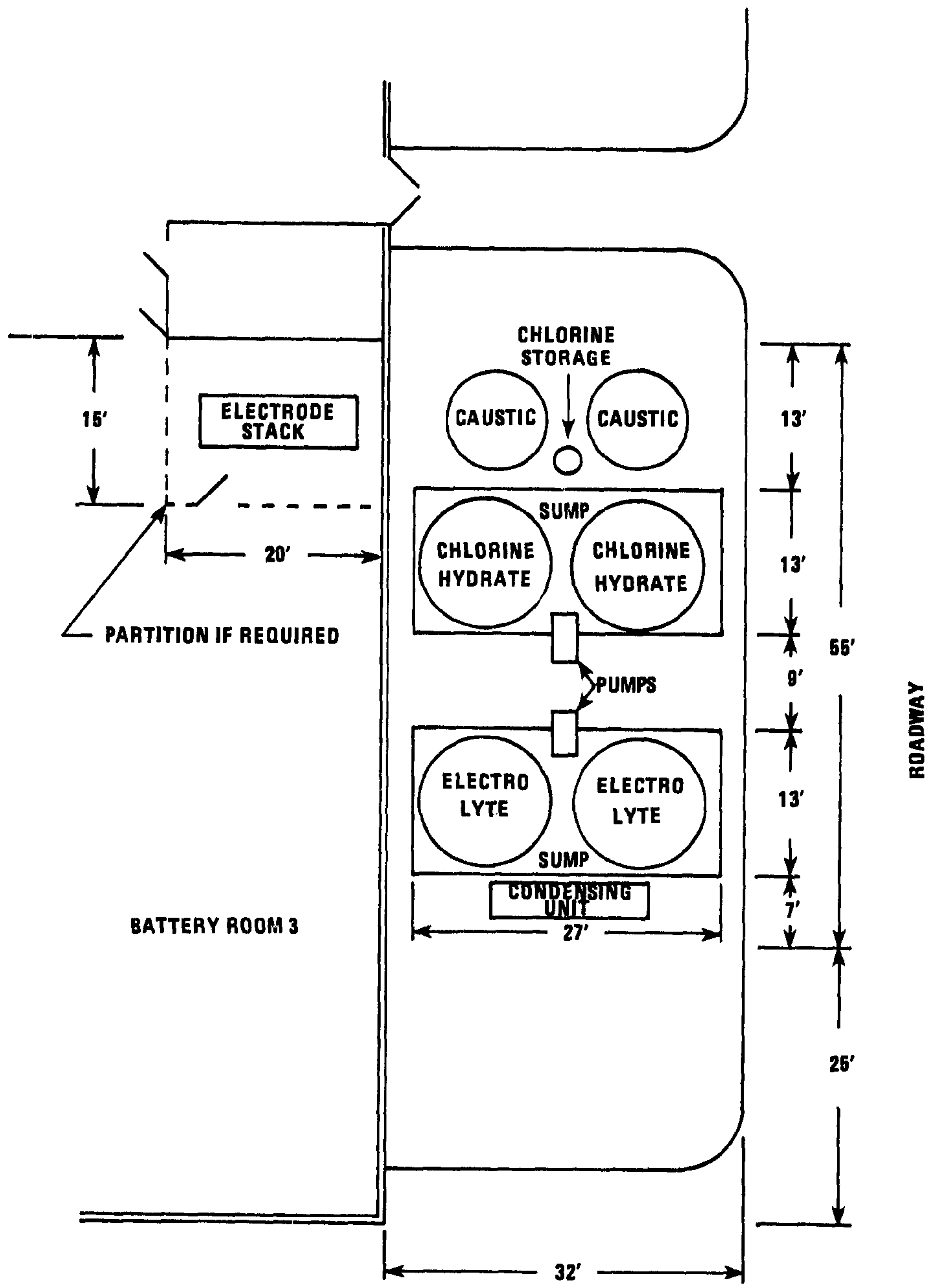

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THE EDA BATTERY SYSTEM LAYOUT
FIGURE 4-8

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(or about 43 kW) and that this additional heat will be dissipated by the air cooled radiator included with the refrigeration unit. The facility will provide power for pumps, fans, and refrigeration at the MCC penetration in the battery room.

The facility will provide for the EDA battery design defined in an EPRI memo (Ref. 11) and in correspondence (Ref. 6). Sufficient space will be provided outside the facility building for tanks, pumps, heat exchangers, and the refrigeration unit. Figure 4-8 illustrates the proximity of this outside space to the third battery room in the facility building, where the battery stack will be located. The outside area will include space for four 12 ft diameter tanks (two electrolyte storage tanks and two hydrate storage tanks), two 10 ft diameter caustic tanks, and a 3 ft diameter chlorine storage tank. Sumps will be provided for local containment of liquid in the electrolyte and hydrate storage tanks in the event of a system failure.

The battery stack will be located in the corner of Battery Room number 3 adjacent to the data analysis room in order to minimize the length of piping and electrical conduit running between the stack and the outside area. If necessary, a partition can be installed (as shown by the dotted lines) to separate the battery stack area from the rest of the room. This partition can be coated with materials that are compatible with an aqueous solution of $ZnCl_2$ to concentrations of 35% by weight and wet or dry chlorine gas. The battery room will be designed for a slightly negative pressure to prevent leaking chlorine gas from getting outside the boundaries of the battery room. Chlorine detectors such as the MSA Toxgard gas detector will be provided in the battery room. In the event of a system failure whereby chlorine gas escapes, the exhaust flow of the battery room ventilation system will be diverted to the chlorine storage tanks, where it will be forced into the caustic solution. Disposal of chlorinated liquid in the battery or caustic tanks will be accomplished by tank truck.

4.4 INVERTERS

Inverters are the means by which the dc batteries will be interfaced with the ac grid of a utility system. As discussed herein, the term inverter is taken to mean a bidirectional inverter/converter unit which serves to both discharge and, in turn, charge a battery. Initially, one inverter will be installed as the BEST facility station inverter. Provisions will be made for the future installation of two additional inverter systems and thus provide the fully implemented BEST facility with the capability to simultaneously and independently test three battery systems.

In addition to providing the basic function of charging and discharging a battery, inverter equipment will play an important role in determining a battery system's response to utility grid stimuli. Moreover, the equipment installed as the BEST facility station inverter must serve as a testing device with sufficient flexibility to accommodate various types of battery systems in their initial large scale application under both simulated and actual electric utility conditions. It follows, therefore, that the test-oriented station inverter described herein may differ from the inverters that will eventually be installed in commercial energy storage plants.

As stated in the design criteria, Section 4.1, the BEST facility must be capable of accommodating and testing battery systems with nominal ratings of 1 MW at the 10 hour rate. Planned tests include subjecting these battery systems to a discharge rate of 2.5 MW. Thus, the inverter must be capable of discharging the batteries at a 2.5 MW rate. Constant power charging of these 10 MWh batteries in the planned 7 hour period will only require 2 MW (assuming a 75% energy efficiency for the battery). Based on these considerations, a bidirectional inverter used to perform these charge and discharge functions must be capable of delivering a maximum power of 2.5 MW.

To afford the flexibility needed to test various battery types and configurations in the BEST facility, the dc voltage and current operating limits were set at 1000 V and 10,000 A. It is clear that these limits need not be met simultaneously to provide the nominal 2.5 MW maximum power required for the BEST facility inverter. However, since inverter transformer windings and SCR elements must be designed to meet both the voltage and current limits, use of a single bridge inverter would require a unit with an inherent rating of 10 MW. With battery discharge powers of 1 to 2.5 MW, such a single bridge inverter would be operated at only 10 to 25% of its capacity. Not only would this excess capacity be unnecessarily large and costly, but phasing of SCR conduction angles into this region would result in a high percentage of harmonic voltage and low efficiency.

An alternate approach that improves upon the single bridge inverter system, from both a technical and an economic viewpoint, is the installation of the facility's inverter in modular form. Figure 4-9 presents a four module scheme capable of attaining the dc voltage and current limits (not simultaneously). Also, the system's maximum capacity can be made to match the 2.5 MW maximum discharge rate. Using a 2.5 MW inverter arrangement of this type, the percentage of capacity used during tests would be increased, with resulting decreases in harmonic voltage and increases in efficiency.

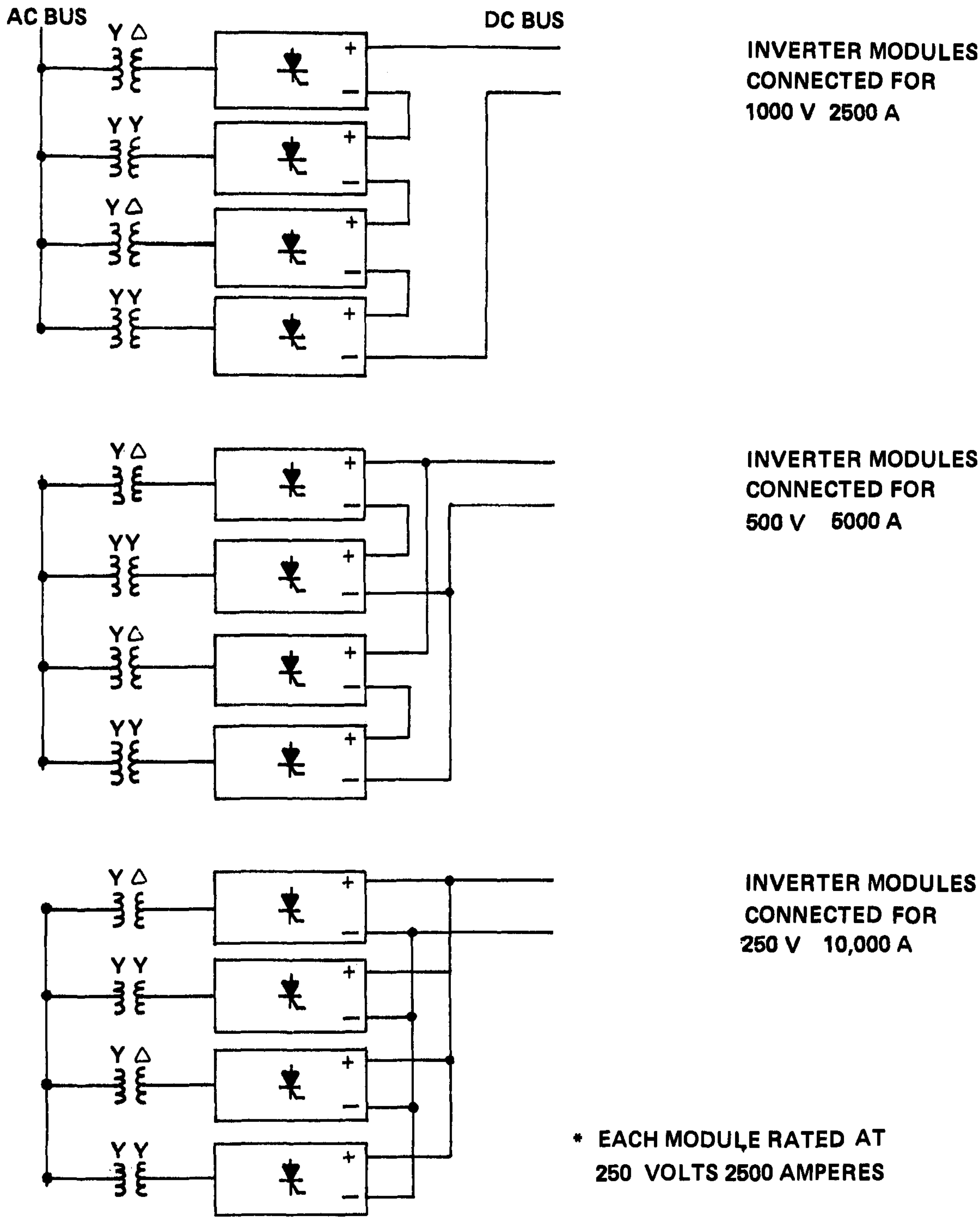
A two module system could also be used but it would require the use of 500 volt, 5000 amp units in order to enable interconnections that can attain the bus system limits of 1000 V and 10,000 A. The combined power of two such modules would be 5 MW and thus would be twice that needed for maximum charge/discharge conditions. Four modules, each rated at 250 V and 2500 A, is the minimum number that can be used to form a facility inverter system that can be interconnected to reach the system voltage and current limits (not simultaneously) without exceeding the power specified for the maximum discharge. More than four modules could be used to provide even finer increments in operating voltage, but in order to take advantage of the harmonic cancellation provided by the wye-delta/wye-wye transformer arrangement, modules should be used in pairs. The four module inverter system described is well suited for expansion to higher voltage or current limits if needed for future testing.

The three configurations illustrated in Figure 4-9 offer a flexible 2.5 MW inverter system which can be interconnected to operate with simultaneous maximum ratings of:

- 1000 V, 2500 A, or
- 500 V, 5000 A, or
- 250 V, 10,000 A

For purposes of this conceptual design it is assumed that the above ratings can be achieved without the need for external voltage or current sharing networks. If desired, less than the full complement of four modules could be operated to produce several other system ratings.

It is unlikely that the dc operating limits of the batteries to be tested will be changed very often. Therefore, the requisite module interconnections for the facility station



NO.	DATE	REVISIONS	DR.	SUPVR.	ENG.	PROJ. ENG.	CLIENT

BECHTEL

INVERTER MODULE CONNECTIONS
FIGURE 4-9

JOB No.

DRAWING No. | REV.

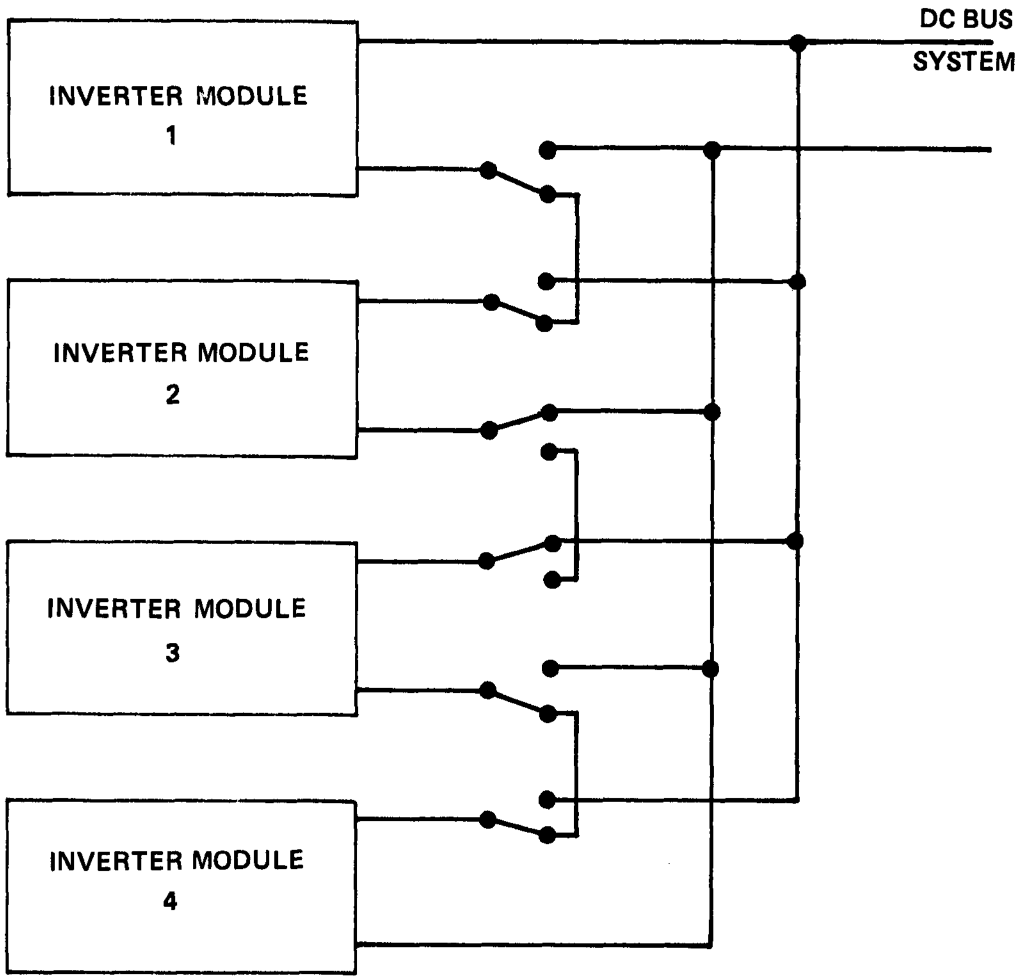
inverter could be accomplished by means of unbolting and reconnecting a set of dc bus bar segments as needed. However, much greater convenience could be achieved by use of a switch arrangement. A scheme using 6 single-pole, three position (center off) switches is presented in Figure 4-10. Since each switch is connected directly in series with a 2500 A inverter module, the ampacity of each switch need not exceed 2500 A. Switch position for the three inverter configurations shown on Figure 4-9 are listed on Figure 4-10. Additional variations (e.g., 750 V, 2500 A) are attainable by the use of the center off switch position, but operation of an odd number of modules can increase the harmonic content. Micro-switches or other position indicators and control relaying would be used to assure that the dc switches are in an acceptable position before allowing breakers to activate the system. Also, since the switches would be of a non-load-break type, opening any switch cabinet door would operate the dc breaker and turn off the inverter.

Thyristors are currently available (Ref. 12) which would allow construction of a 250 V, 2500 A module with a single SCR per bridge leg, thus obviating the need for current sharing or voltage grading networks within the modules. However, these ratings are currently available only with water-cooled heat sinks. Use of air-cooled heat sinks may require two parallel SCR's per bridge leg. Analysis of existing air-cooled SCR equipment indicates that these units typically require air flows of 200 to 300 scfm for each kW of waste heat generated. Thus, a 2.5 MW, 96% efficient inverter would require approximately 30,000 scfm of cooling air. The exact air flow required will depend on the unit selected, the design of the heat sink, the allowable temperature on the SCR junction and the conservatism of the design.

The modular inverter system illustrated in Figure 4-9 utilizes wye-delta and wye-wye transformer pairs to achieve an effective 12 pulse output from 6 pulse inverter modules. This technique is utilized by utilities in HVDC inverter systems, and it effectively eliminates the 5th and 7th harmonics when the units are operated in pairs. The transformers for a 250 V, 2500 A module would be special in order to achieve the exact voltages specified and accommodate the high harmonic content, but the turns ratios and pcwer level are very close to those of conventional type single-phase distribution transformers, 13.8 kV-240/120 V (Ref. 13).

Alternatively, reductions in harmonic control can be achieved by use of a specially constructed summing transformer. This type of configuration (Figure 4-11, Ref. 14) is used in uninterruptible power supplies (UPS). One UPS system manufacturer using this approach has stated that approximately one half of his component costs is allocatable to the transformer. The circuit shown yields a 24 pulse output, with the 23rd and 25th being the lowest harmonics present. However, all four units must be operated at the same power in order to achieve this harmonic performance. This system is less amenable to expansion since units must be added in groups of four. Both of the above transformer schemes require phase shifts between the SCR firing angles of the modules in order to compensate for the different phase shifts through the transformer windings. Filters are added to bring the harmonic content down to an acceptable level in both the charging and discharging modes.

In addition to harmonics, an inverter can generate unwanted electromagnetic interference (EMI). This problem can be overcome by packaging the inverter equipment in EMI-proof cabinetry and using suitable filters on cabinet penetrations. Alternatively, the entire room of inverter equipment may be



SWITCH POSITIONS	INVERTER SYSTEM LIMITS	
ALL SWITCHES IN DOWN POSITION	1000 VOLTS	2500 AMPS
TWO CENTER SWITCHES UP, OTHER FOUR IN DOWN POSITION (AS DRAWN)	500 VOLTS	5000 AMPS
ALL SWITCHES IN UP POSITION	250 VOLTS	10,000 AMPS

* CONTROL RELAYING WILL PREVENT BREAKER CLOSURE FOR UNACCEPTABLE SWITCH POSITIONS

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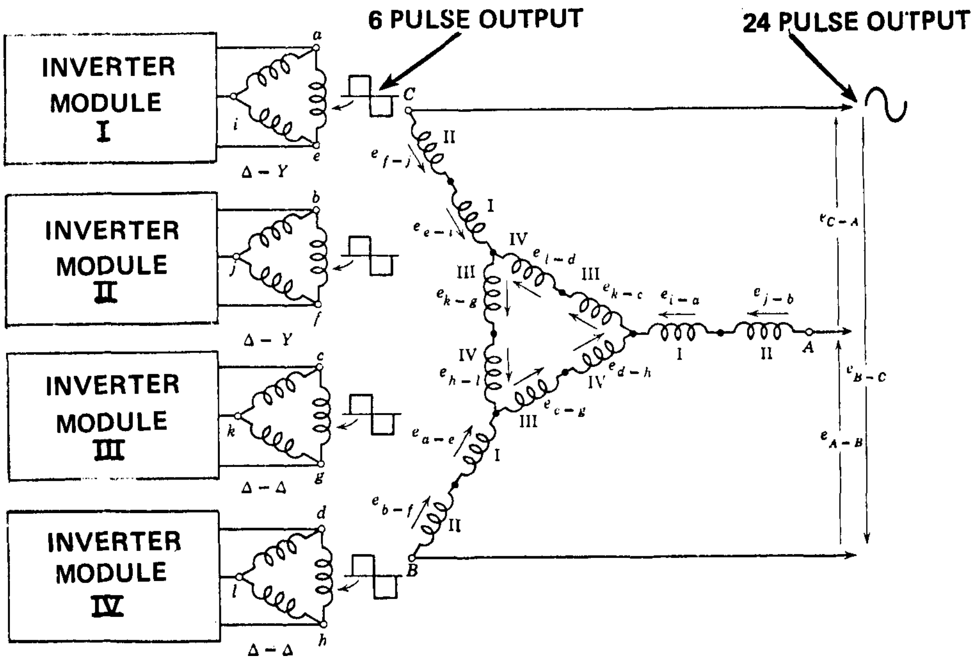
INVERTER MODULE DC SWITCHING

FIGURE 4-10

JOB No.

DRAWING No. REV.



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SUMMING TRANSFORMER CONFIGURATION

FIGURE 4-11

JOB No.

DRAWING No.

REV.

enclosed in a Faraday cage, as with HVDC stations. Since the exact nature of the BEST facility inverter equipment is unknown at present, provisions have been made to provide for the future installation of shielding. Accordingly, a suitable wire screen (i.e., a mesh with good electrical contact at node points) or expanded metal screen will be buried in the floor of the inverter room. Metal strips will be brought to the surface of the floor to facilitate the installation of a Faraday cage should it become desirable to do so at a later date. Similarly, the dc bus (Ref. Section 4.5.1.1) will be enclosed to reduce EMI and the inputs to the data acquisition computer will be equipped with low pass filters (Ref. Section 4.6.1).

The modular inverter approach discussed would apply to both line and self-commutated inverters. Both types of equipment have their merits and shortcomings. Line-commutated circuits have been successfully used on utility systems for HVDC stations. Self-commutated inverters have the ability to operate into a black load and its electronics can reverse current flow "instantaneously", a characteristic which can be useful in enhancing utility system dynamic stability. Although the facility building and switchgear will be capable of accommodating either type, it is recommended that the initially installed station inverter be a self-commutated type since it must operate into a synthetic ac load.

For this conceptual design, the system selected for the initially installed station inverter is a 2.5 MW, self-commutated, four module system with a switching arrangement as shown in Figure 4-10. Building floor space for this system (and future inverters) has been allocated on the basis of 0.1 ft^2/kW. This value was derived from consideration of the requirements of similar equipment, such as 0.21 ft^2/kW for the average UPS systems, and the high density 0.02 ft^2/kW attained by Udylite's Megaverter. The 0.1 ft^2/kW includes space for all equipment such as harmonic filters or capacitors added to supply reactive power. No provisions have been made for the switching of filters or capacitors since this is considered to be an internal part of the inverter. In addition to the equipment requirements, allowances have been made for aisleways. The system will be air cooled and it is assumed that the cooling air will be provided by a supply and exhaust duct system which is independent of the room HVAC. Also, it is assumed that the inverter will not require any external sources of low voltage power for fans, pump, control circuitry, etc., although, if required, such requirements could easily be accommodated by the facility MCC.

This system will be included in the Baseline facility as described in Section 5. Floor space has been provided in the Baseline facility to accommodate the installation of future inverters and associated equipment.

4.5 ELECTRICAL SYSTEMS

The facility's electrical systems will be comprised of a dc system, an ac system and a station power system. The dc system will interconnect the battery systems with the inverter systems. The ac system will interconnect the inverter systems with the utility grid and synthetic load. The station power system will be connected to the utility service and distribute power to the facility's electrical loads. These electrical systems are shown on the single-line diagram, Figure

4-12[1]. Physical arrangements of major electrical equipment are shown on the equipment layout, Figure 4-13. The metering and relaying diagram, Figure 4-14, shows a typical electrical system power flow control.

4.5.1 Dc System

The dc system will connect a battery system under test to an inverter. The design criteria established by the Project Team and listed in Section 4.1 herein include the following specifications:

- The maximum operating current of the dc system will be 10,000 A.
- The maximum momentary current which the dc system must withstand will be 200,000 A.
- The maximum operating voltage of the dc system will be 1000 V.
- The maximum sustained (0.032 seconds or longer) overvoltage which the dc system must operate through will be 2000 V.
- The maximum transient surge voltage which the dc system must withstand will be 3000 V.

Components of the dc system include buses, switches, circuit breakers and fuses. Commercially available equipment in each of these categories was evaluated with respect to acquisition costs, installed costs, advantages and disadvantages, and compliance with the design criteria.

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[1] In this report, reference to a single dc equipment item such as a dc switch or a dc bus is to be interpreted as meaning the pair of positive and negative polarity items, and reference to a single ac equipment item such as an ac switch or an ac bus is to be interpreted as meaning the set of phase items as required by three phase and single phase circuits.

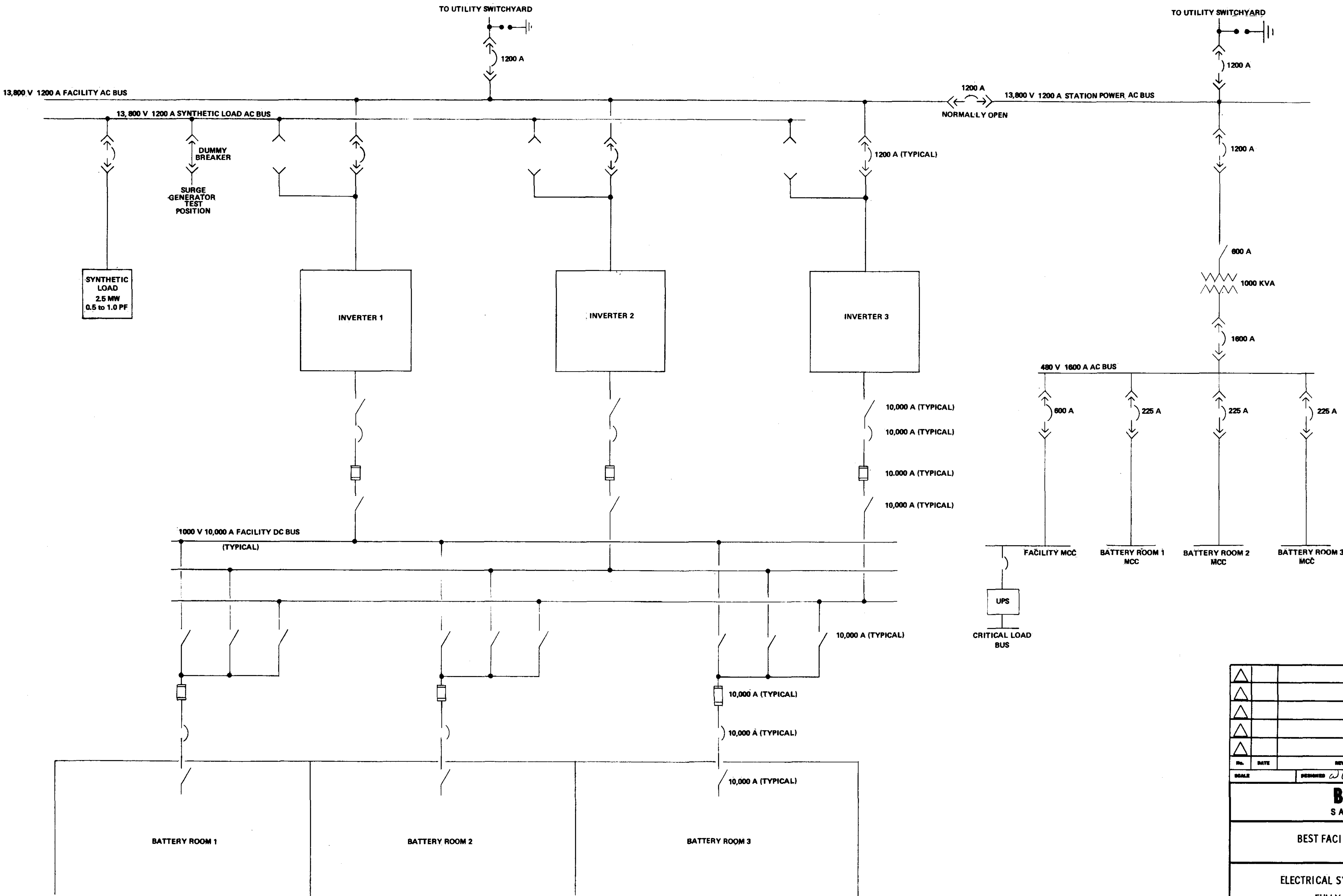
4.5.1.1 Dc Bus. Seven basic types of bus were evaluated for insulation, bracing, comparative ease of expansion, current carrying capacity and installed cost. A summary of this evaluation is given in the appendix. The bus types evaluated were:

- metal-protected, laminated-bar bus
- metal-enclosed, non-segregated, two-pole bus
- metal-protected, log bus
- metal-enclosed, iso-phase bus
- metal-enclosed, segregated, two-pole bus
- cable-in-tray bus
- cable-in-trench bus

All seven bus types can meet the design criteria requirements for insulation, bracing and current carrying capacity. Electromagnetic interference (EMI) suppression can be accomplished on each of the seven bus types. When the seven bus types were ranked for material cost, labor cost, and ease of expansion the metal-protected, laminated-bar bus was lowest in installed cost and easiest to expand.

Costs for the metal-protected, laminated-bar bus were based on quotations from the Electric Materials Co. dated February 6, 1975. The Electric Materials Co. based their quotations on total bus weight. This bus system is smaller in ampacity and less complex than their average job.

Second in overall ranking of the seven bus types is the metal-enclosed, non-segregated, two-pole bus similar to that quoted by Artwel Electric, representing the Calvert Company. This bus system's material cost was quoted significantly higher than the metal-protected, laminated-bar bus. Even considering installed



No.	DATE	REVISIONS	BY	CHKD	DESIGN SUPV	ENGR	PROJ ENGR	APPR

SCALE | DESIGNED W Q [illegible] | DRAWN L. W. | CHECKED [illegible]

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SAN FRANCISCO

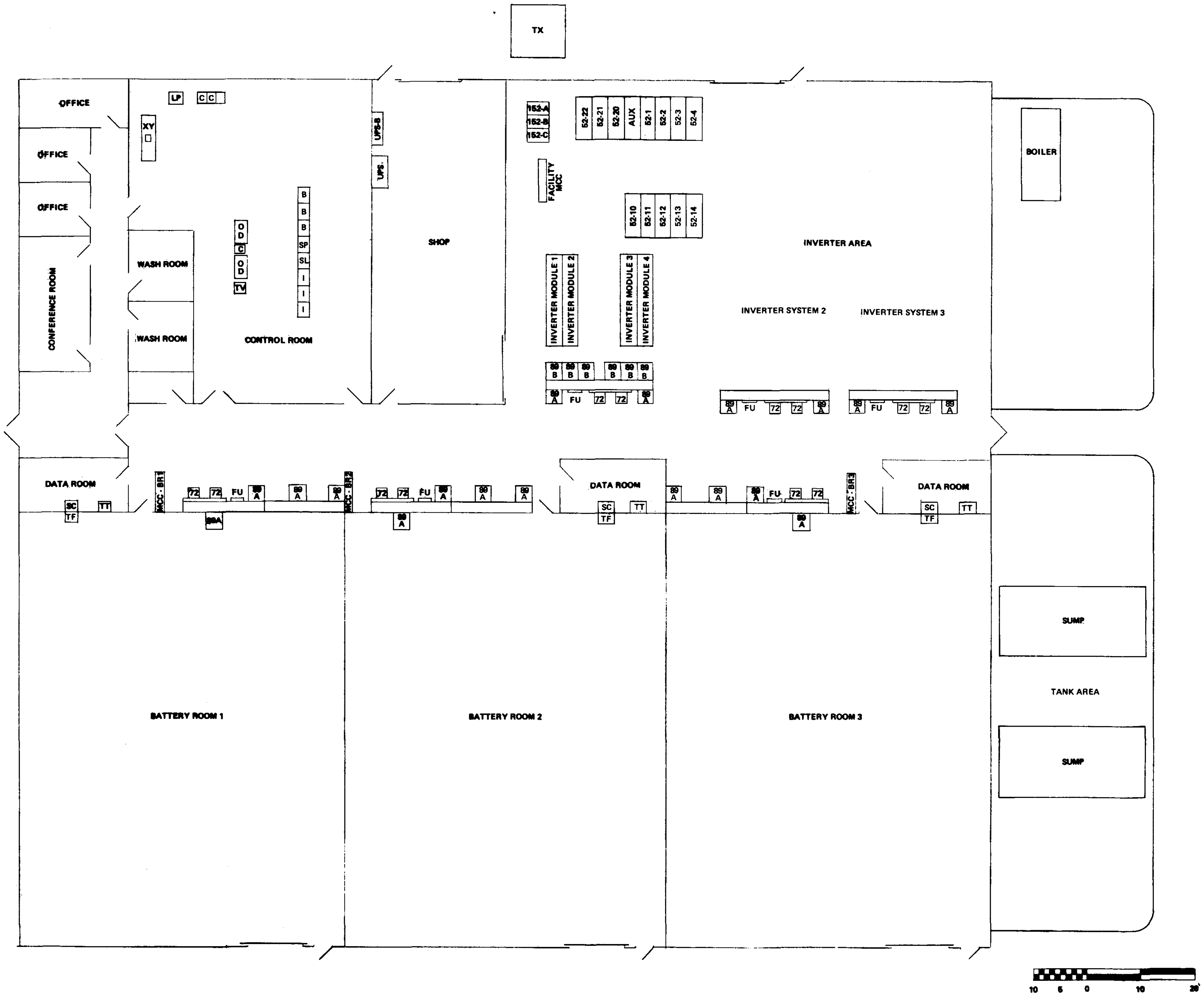
BEST FACILITY CONCEPTUAL DESIGN

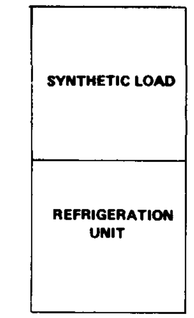
ELECTRICAL SYSTEMS SINGLE LINE DIAGRAM
- FULLY IMPLEMENTED FACILITY -

JOB No.	DRAWING No.	REV.
11088-001	E-100	

FIGURE 4-12

22 x 34 "D" SIZE





SYMBOL	SYSTEM	DEVICE
TV	CONTROL	TELEVISION MONITOR
I	CONTROL	INVERTER CONTROL PANEL
SL	CONTROL	SYNTHETIC LOAD CONTROL PANEL
SP	CONTROL	STATION POWER CONTROL PANEL
B	CONTROL	BATTERY ROOM CONTROL PANEL
OD	CONTROL	OPERATORS DESK
C	COMPUTER	CRT TERMINAL
XY	COMPUTER	XY PLOTTER
LP	COMPUTER	LINE PRINTER
CC	COMPUTER	CENTRAL COMPUTER TERMINAL
SC	COMPUTER	SATELLITE COMPUTER
TT	COMPUTER	TELETYPE TERMINAL (TTY)
TF	COMPUTER	TERMINATION FACILITY
52-AUX	13.8 KV	FACILITY AUXILIARY CUBICLE
52-1	13.8 KV	FACILITY MAIN ACB
52-2	13.8 KV	FACILITY FEEDER ACB
52-3	13.8 KV	FACILITY FEEDER ACB
52-4	13.8 KV	FACILITY FEEDER ACB
52-10	13.8 KV	SYNTHETIC LOAD ACB
52-11	13.8 KV	SURGE GENERATOR DUMMY BREAKER
52-12	13.8 KV	ALTERNATE FEEDER POSITION FOR ACB 52-2
52-13	13.8 KV	ALTERNATE FOR ACB 52-3
52-14	13.8 KV	ALTERNATE FOR ACB 52-4
52-20	13.8 KV	STATION POWER TIE ACB
52-21	13.8 KV	STATION POWER MAIN ACB
52-22	13.8 KV	STATION POWER TRANSFORMER ACB
152A	480 V	1600 A ACB SECTION
152 B	480 V	600 A ACB SECTION
152-C	480 V	225 A ACB SECTION
72	DC	CIRCUIT BREAKER
89 A	DC	SWITCH 10,000 A
89 B	DC	SWITCH 2 500 A (PART OF INVERTER SYSTEM)
UPS	120/240V	UNINTERRUPTIBLE POWER SUPPLY
UPS-B	DC	UPS BATTERY
FU	DC	FUSE (FUTURE)
TX	13.8 KV/480V	TRANSFORMER, 1000 KVA

No.	DATE	REVISIONS	BY	CHKD	APPR

SCALE | DESIGNED W O Jemm | DRAWN L. vC | 1175

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BEST FACILITY CONCEPTUAL DESIGN

MAJOR EQUIPMENT LAYOUT
- FULLY IMPLEMENTED FACILITY -

JOB No.	DRAWING No.	REV.
11088-001	E-101	

FIGURE 4-13

LEGEND

A	AMMETER
AS	AMMETER SHUNT
AUX	AUXILIARY RELAY
76	DC OVERCURRENT RELAY
67	DIRECTIONAL OVERCURRENT (SET FOR DISCHARGING)
81	FREQUENCY RELAY
LS FUSE	FUSE OPERATION INDICATOR
51G	GROUND OVERCURRENT TIMED
	SURGE PROTECTION
50G	INSTANTANEOUS GROUND OVERCURRENT
50/51	INSTANTANEOUS-TIME OVERCURRENT (SET FOR CHARGING)
LS 89	LIMIT SWITCH USED ON DC SWITCH DOOR INTERLOCK
86	LOCKOUT RELAY
59/68	OVERVOLTAGE BLOCKING RELAY
59	OVER-VOLTAGE RELAY
pf	POWER FACTOR METER
51	TIME OVERCURRENT (SET FOR CHARGING)
27/59	UNDER-VOLTAGE/OVER-VOLTAGE RELAY
VT	VOLTAGE TRANSDUCER
V	VOLTMETER

No.	DATE	REVISIONS	BY	CHKD	DESIGN SUPV	ENGR	PROJ ENGR	APPR

SCALE | DESIGNED W. A. Fenner | DRAWN L. W. | CHIEF ENGR

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SAN FRANCISCO

BEST FACILITY CONCEPTUAL DESIGN

TYPICAL ELECTRICAL SYSTEMS
METERING AND RELAYING DIAGRAM

JOB No.	DRAWING No.	REV.
11088-001	E-102	

FIGURE 4-14

22 x 56 "S" SIZE

cost, the "Calvert" bus is still 65 percent more expensive than metal-protected, laminated-bar bus.

The metal-protected log bus is about equal in material cost with the metal-protected, laminated-bar bus but ranks third in overall bus-type comparison because it requires welded connections and is not easily expandable. Metal-protected, log bus becomes attractive at ampacities above 30,000 amps.

The remaining bus types studied, in order of their overall ranking, were: iso-phase bus, fourth; metal-enclosed, segregated, two-pole bus, fifth; cable-in-tray, sixth; and cable-in-trench, seventh. Cable-in-tray and cable-in-trench would have a distinct advantage at ampacities below 500 A, but become too bulky at ampacities above 2000 A. Maintenance costs of all of the systems compared are so small as to be neglected.

In evaluating the bus types, both copper and aluminum were considered for the metal-protected, laminated-bar bus type. However, it would appear that when design and installation costs are taken into account, current prices of copper and aluminum result in systems of about equal cost. In their quotation, Electric Materials Co. stated "on a job of this size we do not feel the price difference between copper and aluminum would be that great; so we are not submitting a price for an aluminum system". Copper connections are easier to make. Aluminum has less total weight but larger cross-sectional area for the same current-carrying capacity. The decision to use copper or aluminum bus-bar material should be made on the basis of prices-in-effect at the time of purchase. The price of copper was $ .65 per pound in the Electric Materials bid, which is only 15 percent of the estimated installed cost of the bus. Copper is preferred over aluminum if the installed costs of the two alternative materials are about equal.

4.5.1.2 Dc Switches. Switches facilitate the connection of any battery to any inverter and provide a visible, padlockable, disconnecting means to assure that any dc bus or equipment being worked on is, and remains, de-energized. Several dc switches will be employed to permit multi-configuring of the inverter modules, but these switches are considered to be part of the inverter system and are discussed in Section 4.4. Switches are utilized on either side of each stationary dc circuit breaker and at the battery room taps from each of the three 10,000 A, 1000 V buses. The switches on either side of each dc circuit breaker would be eliminated if draw-out type 10,000 A dc circuit breakers become available (see Section 4.5.1.3).

The dc system switches all are two-pole, single-throw, manually-operated, non-load-break type rated for 1000 V and 10,000 A. Switches will be metal-enclosed and provided with a door interlock to protect personnel from energized equipment. This interlock will assure that the switch is not operated under load by activating the trip circuit of the dc breaker serving the switch when its door is opened. The model MP, bolted-contact switch currently available from the Pringle Electrical Manufacturing Company would be suitable for this application. Competitive switches are available from other manufacturers.

Voltmeters and their voltage sensors will be provided at each dc switch to alert operators against switching into energized buses.

Ammeters and their current sensors will be provided at each dc switch to alert operators against opening enclosure doors of switches that are carrying load.

4.5.1.3 Dc Circuit Breakers. Circuit breakers will be used for local and remote dc circuit switching and for automatic interruption of fault and overload currents. Circuit breakers will be used on each pole of each dc source (battery or inverter) to protect against the hazard of an overcurrent or fault current through any pole independent of other sources.

Dc circuit breakers with ratings of 10,000 A and 750 V have been readily available for some forty years. Only recently, as in the case of the Bay Area Rapid Transit (BART) System, have 1000 V dc circuit breakers been sought by users. General Electric Company has up-graded their 750 V Type MC circuit breaker and now offer it as a Type MC-6A, 1000 V, 10,000 A, panel-mounted, stationary switchgear with interrupting ratings of up to 250,000 amperes. BART is using this type of breaker on their 1000 V system. Other suppliers offer series-parallel arrangements of dc circuit breakers and/or fuses to provide overload and fault current interruption at the 1000 V, 10,000 A rating specified by the design criteria. These units depend on the simultaneous operation of component sub-units to provide protection.

The MC-6A breaker will meet the requirements of the BEST facility; therefore, equipment space and cost estimates are based on this General Electric breaker.

Draw-out circuit breaker construction would be preferred because it affords complete metal enclosure, reduces operating noise, and eliminates the need for isolation by disconnect switches; but, at present, the ampacity rating of 1000 V draw-out dc circuit breakers is limited to 8000 A. General Electric is investigating the possibility of forced-air cooling their 8000 A, 1000 V draw-out breaker to attain a 10,000 A capacity, but they are concerned about the draw-out stabs themselves becoming overheated. Until that problem is solved, standard-construction, stationary-type dc circuit breakers will be specified.

Standard dc circuit breaker overcurrent relaying will be provided. Interchangable current shunts will provide the capacity for a full range of variable settings for overload and fault protection of the system in any of the modes of operation including the 250 V, 10,000 A; 500 V, 5000 A; and 1000 V, 2500 A modular inverter system configurations described in Section 4.4.

Lockout relays will be used to alert operators of automatic tripping of dc circuit breakers due to overloads or fault currents. Remote and local operator tripping will bypass the lock-out relays.

Blocking relays will be used to block the tripping of dc circuit breakers during an overvoltage in excess of the breaker's rating. The same overvoltage relay which initiates blocking will alarm the operators and they can remove the overvoltage by controlling the ac source to the inverter affected (see Figure 4-14).

4.5.1.4 Dc Fuses. Current-limiting fuses, if available, could be used to interrupt rapid rate-of-rise dc fault currents and back-up normal circuit breaker fault protection. Unfortunately, fuses rated at 1000 V and 10,000 A dc are not commercially available at present (mostly due to a lack of demand). The ratings of currently available dc fuses are limited to 5000 A at 250 V, 2000 A at 500 V and 1000 A at 1000 V. However, both Bussman Manufacturing Division of McGraw-Edison Company and the Chase-Shawmut Company (I-T-E Imperial) have stated that they would be willing to develop a 10,000 A, 1000 V fuse. On this basis, space has been provided for the installation of such fuses. Circuit breakers would still provide the primary function of remote-controlled switching and low magnitude, long duration fault interruption.

4.5.2 Ac System

The ac system will connect the inverter systems with the utility network. During specific test periods the ac system will connect an inverter to the synthetic load bus. Current planning calls for the BEST facility to be sited adjacent to a 13.8 kV utility substation. Therefore, the ac system will utilize this voltage level for all of its components. Connection to the utility substation will be by means of an underground feeder cable. Surge arrestors will be provided on the feeder cables at the facility in order to protect against outside transients. Since surge testing is one of the tests planned, the inverters will also be specified with similar devices. Station power will be connected to the utility substation by a separate 13.8 kV feeder cable as discussed in the following section.

Cables will connect the filtered 13.8 kV ac terminal of each inverter to a circuit breaker position on the synthetic load bus and to a corresponding breaker position on the facility ac bus. Each inverter will have associated with it, a single 13.8 kV draw-out circuit breaker element which will be capable of connecting that inverter to either of these buses. Use of a single draw-out breaker for each inverter system prevents the inadvertent connection of the synthetic load to the utility; although, if desired, such a connection could be accomplished by use of a spare breaker element (not included). Breaker elements will be mounted on wheels and will be capable of being racked into either of the two breaker positions located directly across the aisle from each other. All 13.8 kV switchgear will be of the 1200 A type, with a 750 MVA interrupting capacity. These are available from several companies as standard items.

The synthetic load bus can have any combination of inverters connected to it. The synthetic load will consist of a 2.5 MW static load with a power factor variable from 0.5 lagging to

1.0 in ten discrete steps (motor operated), similar to the "Load Bank" made by the Transrex division of Gulton Industries. To minimize the effect of the heat generated by the synthetic load upon the facility, the synthetic load will be located away from the building. An underground 13.8 kV feeder cable will be provided for connection of the synthetic load to the synthetic load bus.

The synthetic load bus can also be utilizied as a transfer bus so that two of the inverters can be used to drive each other while the remaining inverter operates on the utility system. In this case, the driving inverter would have to be self-commutated.

A voltage surge generator, to be rented when surge testing is performed, will be connected to the synthetic load bus through a dummy breaker.

Design of the ac system will be based upon the National Electrical Code. Minimum wire sizes of 13.8 kV cable will be Number 00 American Wire Gauge copper. Minimum conduit size for cable feeders will be 3-inch rigid steel. The ac system's feeder cable to the utility substation is sized at 600 A to provide for the maximum load of three 2.5 MW inverter systems (capable of operating at a 0.7 power factor) with spare capacity for future expansion to carry a fourth such unit.

The facility ac bus and the station power ac bus can be connected through the normally-open tie circuit breaker located in the station power 13.8 kV switchgear lineup. When closed, this connection affords the capability of having a self-commutated inverter supply the BEST facility station power from a charged test battery, thereby keeping the facility supplied with station power during a complete loss of utility power. This connection also provides an alternative path for power flow from the utility substation to either the facility ac bus or the station power ac bus should one or the other lose its feeder cable.

The 13.8 kV facility ac circuit breakers will be used for local and remote circuit switching and for automatic interruption of fault and overload currents.

All utility metering is assumed to be located in the utility switchyard. This metering will be required to accommodate reverse power flow (from discharging battery systems), and thereby provide a means to account for reverse power flow credit. The utility will own and have sole control of the circuit breakers (located in the utility substation) feeding the ac system's facility bus, and will thereby have complete control of the BEST facility input to the utility system. There will also be a voice communication link between the utility's dispatcher and the BEST operators.

4.5.3 Station Power System

The station power system will connect the BEST facility's 480 volt and 120 volt ac loads to the utility system. All facility loads will be served by one of the four motor control centers (MCC). The four motor control centers are fed by a single 480 volt switchgear lineup which is fed in turn by an outdoor 1000 KVA transformer served from the 13.8 kV station power ac bus. The station power ac bus may receive its power from the same utility 13.8 kV substation that feeds the ac system bus, but through an independent underground 13.8 kV feeder cable sized at 600 A to carry both the ac system and station power system loads. Surge arrestors will also be provided on this feeder cable. The station power 13.8 kV switchgear will include one main circuit breaker, one tie circuit breaker and one transformer feeder circuit breaker. The tie circuit breaker provides an alternative source to both the ac system and the station power systems as described in Section 4.5.2.

Standby power will be provided by a 30 kVA uninterruptible power supply (UPS), with a 60-minute battery capability. The UPS will serve the facility computer, the fire alarm systems, fire-fighting systems, detection systems, standby lighting, ventilation fan (Ref. Section 4.7.3.2), and other loads where a high degree of reliability is desirable.

Metering and relaying of the station power service is similar to the ac system metering and relaying. Revenue metering of the station power service is assumed to be located in the utility switchyard. All 13.8 kV and 480 volt switchgear circuit breakers will be remote controllable, but MCC circuit breakers will be manually-operated only.

The station power system design will be based upon the National Electrical Code. All 120 volt and 480 volt cable and wire will be THW in rigid-steel conduit supported by channels. Battery room receptacles, switches and lighting fixtures will be explosion-proof (Class B for hydrogen atmosphere in Battery Room 1 only). Office and control room lighting will be office-type fluorescent. Shops, inverter room and equipment aisle lighting will be industrial type fluorescent. Outdoor lighting will be mercury vapor or sodium halide. All lighting levels will conform with Illuminating Engineering Society standards.

All Battery Room 1 electric loads will be served by an MCC designated MCC-BR1 located adjacent to that battery room.

Similarly, all loads within Battery Room 2 will be served by MCC-BR2 and all loads within Battery Room 3 will be served by MCC-BR3. The power consumed by each battery room will be independently metered and recorded for use in calculating that battery system's efficiency.

All remaining facility loads are served by the facility MCC. The facility MCC also serves as the normal power source to the UPS system.

4.6 INSTRUMENTATION AND CONTROL SYSTEMS

The BEST facility is, by definition, a battery system test facility. A secondary purpose of the facility is to test inverter systems. In view of the wide range of such systems currently being proposed for use in utility applications, the BEST facility design emphasizes testing flexibility as a principal design feature. Consistent with these testing goals is the need for a flexible and responsive system for data acquisition and processing to measure system performance, and to control normal and abnormal test conditions. The following discussion addresses the instrumentation and control requirements for the BEST facility, and describes the various systems that are provided in the BEST design to satisfy these requirements. It should be noted that the extensive instrumentation and control capabilities required of the BEST facility far exceed those which will ultimately be needed in commercial battery load-leveling plants.

4.6.1 Computer System

4.6.1.1 Functional Summary. A computer data acquisition system has been included for the BEST facility in order to facilitate the handling of the large amounts of data that will be obtained in testing the several proposed battery systems.

In addition to providing a convenient and accessible repository for data, the computer system will process data, converting the outputs of transducers (such as thermocouples) into appropriate units. The majority of the computer's data acquisition channels will be dedicated to the measurement of battery cell temperatures and voltages (approximately equal numbers of each). The computer will also serve a safety function, comparing measured data with programmed limits; detecting and acting upon out of tolerance values; and forecasting trends in data. In addition to these control/safety functions, the computer will be capable of controlling the facility inverter by setting dc voltages, currents and power levels for any selected mode of operation (e.g., charge, discharge, load following, etc.). This capability will provide a means (i.e., by stored programs) by which the performance of all battery systems to be tested can be compared under identical test conditions. It will also serve to emulate a utility dispatcher's control and monitoring of an unattended, commercial battery energy storage load-leveling plant.

4.6.1.2 System Criteria. Criteria for the computer system are included in the general facility design criteria presented in Section 4.1. These are repeated here in an expanded form, along with additional items, in order to present a delineation of the basis used to establish a tentative computer system design. These same criteria were used to obtain price quotations from computer manufacturers.

As presently conceived for this conceptual design, the computer system for the BEST facility will meet the following criteria:

- The computer system will be capable of being modularly expanded from an initial (Baseline) installation in order to handle increased numbers of measurement channels as required by the installation of future battery systems.

- Approximately half of the measurement channels will be connected to the thermocouples on battery cells. An equal number of channels will be allocated to the measurement of battery cell voltages.

- There will be 100 (nominally) data channels to provide a measurement capability for other facility or battery developer supplied transducers such as dc ammeter shunts, ac current transformers, ac voltage potential transformers, gas detectors, flow meters, etc.

- A nominal cell voltage of 0 to 4 volts dc is expected. Voltages less than 0 (i.e., negative) may be present upon the occurance of a cell reversal. This would be an out of tolerance condition for the cell and cause an alarm.

- Although the cell voltage to be measured by any wire pair is on the order of 4 volts, a potential difference equal to the full dc bus voltage (nominally 1000 V and transients to 3000 V) will exist between the sets of wire pairs connected to the opposite ends of a battery string. The computer hardware must be capable of accommodating these conditions. All voltage leads to battery cells will have current limiting devices such as series resistors or fuses (supplied by the battery developer). Similarly, battery developers will insulate thermocouples for transient voltages up to 3000 V (or 3 times the nominal charge cut-off voltage).

- The minimum acceptable accuracy will be $\pm$ 0.1% on voltages and $\pm$ 0.5°F on converted temperature data.

- All of the voltage and temperature points for each battery system under test will be scanned at least once every 5 minutes.

- In order to provide for rapid detection out of tolerance cells, the voltages on groups of cells will be scanned once every 15 seconds.

- DC bus currents, string currents and bus voltages will be scanned at a rate of once per second or faster.

- The computer will have analog or relay closure outputs for activating and/or controlling facility equipment, such as circuit breakers.

- The computer will provide analog signals (or digital if appropriate) to set inverter power level and mode of operation (i.e., charge or discharge) as described above. The computer will not generate the SCR control signals for inverters.

- The computer will be amenable to having portions of its equipment easily moved to provide a means of increasing the data capacity of one battery room at the expense of another.

- Terminal strip cabinets will be included as part of the computer system. Battery manufacturers will connect the test leads emanating from their modules to these cabinets which will be located in the battery rooms.

- The computer will be capable of being programmed by facility staff in Fortran, Basic or similar language.

- The computer will be capable of providing output to magnetic tape or through a modem in a format which will permit processing of data on an IBM 360/70 or similar system.

- By programming, the computer will be capable of accomplishing a two level check of data for out of tolerance conditions. Limit values for data will be set by facility staff, based on information supplied by battery developers. Upon the measurement of slightly out of tolerance data (first limit), the computer will alert the station operator. If a data value exceeds the second limit, the computer will activate an appropriate relay closure (e.g., to open a circuit breaker, etc.) without waiting for operator action.

- In scanning the voltages on groups of cells every 15 seconds, any cell group found to be slightly out of tolerance (first limit) will cause a scan of the individual cells in the group to be started immediately. As with other data, if a group voltage exceeds the programmed second limit, the computer will cause the appropriate dc circuit breaker to open and stop the test which is in progress at the time.

- The computer scanning of battery data will be programmed so that each cell's voltage and temperature will be measured at approximately the same time.
- By programming, the computer will print a hard copy of any trouble found or action taken (e.g., operate circuit breaker). Further, the computer tie to equipment, such as circuit breakers, will enable a sequence of events to be determined (e.g., whether a breaker was opened by computer action or by other relaying).
- For safety reasons, any computer control enabling a circuit breaker will be capable of being locked out.
- The computer will have sub-routines to drive an XY recorder and to perform a statistical analysis of the measured data.
- The computer will be programmed so that only the control room terminals can access all of the data. The terminals in each of the data analysis rooms will be restricted to data generated in the associated battery room.
- Programming will be such that only the facility staff can initiate a program change.
- Computer system peripheral equipment will include:
  - A CRT terminal in the control room to afford the station operator(s) interactive supervisory control.
  - A TTY type terminal in the control room for the development of programs, without interferring with the supervisory function served by the CRT terminal.

- One TTY type terminal in each of the three data analysis rooms to provide hard copy of processed data and facilitate limited interaction with the computer.
- A line printer for the high speed output of data.
- A tape punch/reader.
- Two magnetic tape units to facilitate the long term storage of data on magnetic tape.
- A modem to permit a tie over telephone or leased line to a remote computer system.

As a further qualifying criterion, it was specified by the BEST Project Team that the number of battery cells to be monitored will be based on the results of a statistical analysis by J. Birk, as reported in Table IV of his March, 1975 report (Ref. 1). In that report, the reliability of various parallel and series cell configurations was analyzed, and a statistically significant number of cells for test was identified. Table 4-2 is based on that analysis, and it indicates the required number of cell voltage and temperature measurement points to be accommodated for each of the battery systems under consideration. It should be noted that a charge cut-off voltage of 700 V was used in the report (Ref. 1). If a higher dc bus voltage is desired, the expandable computer system design defined herein can accommodate the increased number of cells.

In addition to the voltage and temperature measurement points specified on Table 4-2, each battery system will also require several data channels for string ammeters, coolant temperature and flow, gas monitoring equipment, etc.

4.6.1.3 System Hardware. Two computer manufacturers were contacted for technical information and costs relative to the

TABLE 4-2

MEASUREMENT REQUIREMENTS

Developer	Capacity (MWh)	Number of Cells	Cells Per Module[1]	Series Modules Per String	Parallel Strings Per Battery	Number of Measurement Points	
						Voltage[2]	Temp.[3]
AI	3.0	1120	40	7	4	1152	1120
EDA	2.4	1200	50	6	4	1228	100[4]
GE	4.4	1100	25	11	4	1148	1100
TRW	1.2	1200	300	1	4	1204	1200
Westinghouse Pb/PbO_2	7.2	1036	1	259	4	1040	1036
ANL	2.5	2700	6p, 5s	90	1	541	2700
ESB	8.2	2280	12p	190	1	191	380[5]

(1) Unless noted otherwise, cells are connected in series. p denotes parallel connections and s denotes a series connection.

(2) The number of voltage points is taken as one per series cell, plus one per module, plus one per string.

(3) The number of temperature points is taken as one per cell unless noted otherwise.

(4) The developer estimates that very few temperature measurement will be required with his flowing electrolyte system.

(5) As per Ref. 5, two thermocouples per module are included.

required computer system; these were the Hewlett-Packard Company and Digital Equipment Corporation. Each of these manufacturers recommended that a "Distributed System" design be used. With this approach, a central computer unit would be located in the facility control room, and each of the three data analysis rooms would contain a satellite unit. Each satellite unit would include terminal strip cabinets, a scanning mechanism, A/D converters or DVM's, processing equipment, memory, I/O terminal equipment and the requisite interface equipment. Hewlett-Packard proposed the use of a cross bar scanning system, while Digital Equipment utilizes "flying capacitors" and mercury wetted relays in their approach.

For either case, the central unit would provide system control and establish program execution priorities. All of the peripheral equipment listed under System Criteria (with the exception of the three data analysis room TTY terminals); inputs to data channels for the inverters, ac system, safety equipment, etc.; and control outputs (e.g., relays or analog outputs to operate circuit breakers) would be located in the control room.

An area of difficulty exists in accommodating the possibility of having the full bus voltage (including transients) between sets of wire pairs used to measure cell voltages at opposite ends of a battery string. Hewlett-Packard's standard equipment will tolerate the full normal bus voltage of 1000 V, plus 500 V. For the scanning equipment and A/D units to withstand 3000 V transients, special equipment design will be required. Initially, it appears that for Hewlett-Packard this redesign would mostly involve improving the insulation characteristics of their crossbar scanner and, possibly, further protection of the A/D unit by increased chassis isolation. For the Digital Equipment Corporation system, the spacing of elements on the printed circuit board of their AFC11 may have to be increased.

All other computer criteria delineated above can be met by the standard equipment of either manufacturer. The computer systems for this conceptual design, as costed in Section 6, are standard equipment with, for the present, no allowance for redesign. For the Baseline facility computer system (Ref. Section 5.1), the vendors quotes were within 10% of each other.

4.6.2 Transient Recorder

Investigation of the effects of transient phenomena is included as part of the testing planned for the BEST facility. Transients may derive from several sources, including line transients from the utility, circuit breaker operation, inverter commutation failure and bus faults. In order to observe such transients, a portable high speed recording system will be included in the BEST facility. Several types of hardware could be used, but in this case it appears that the required measurement functions can best be implemented by use of a magnetic tape recording system, such as the model 5600 produced by the Test Instruments Division of Honeywell. This device functions by first recording the desired data on magnetic tape. This data is then transcribed on a six-channel strip chart recorder at a relatively slow playback speed, resulting in an expanded hard copy of a dc to 100 kHz bandwidth (nominal), a 30 db signal to noise ratio and affords several minutes of high speed record time. The signal to record with this system must be externally triggered, which should be no particular problem since all transient tests in the BEST facility will be pre-planned. Differential input signal conditioning amplifiers are required for measurements not made to ground. A further degree of isolation can be obtained by supplying the approximately 300 watts required for the recorder from a battery pack.

When not in use for transient testing, the six-channel strip chart recorder associated with this system could also serve as a general purpose recorder in applications which do not require the higher bandwidth and speed.

4.6.3 Operator Control Systems

Operators will be able to monitor battery systems, inverters and the electrical systems by means of meters, indicating lights, annunciators and alarms to be hard-wired into the control room panel. Control functions may be accomplished by means of hard-wired switches on this panel, with the capability of overriding computer control. Also, switches located on critical equipment throughout the facility will enable operators at the equipment to override both the control room panel and computer remote control. This lock-out feature on local controls will permit maintenance work on any electrical equipment without hazard of accidentally energizing equipment.

The control room panel will be 32 feet long, with 12 feet dedicated to the battery systems, 12 feet to the inverter systems and 8 feet dedicated to the synthetic load and station power systems. The dc and ac systems' monitoring devices will be distributed over the entire length of the control panel on mimic buses, showing the status of all electrical interconnections. Indicating lights on the mimic will show status by a colored steady light, then show a change-in-status by a different colored flashing light, which, when acknowledged by the operators, becomes steady in the new status color. Annunciators, alarms and control switches will also be distributed along the entire length of the panel, adjacent to the mimic representation of the equipment to which they relate. Annunciators and alarms will be located at the top of the panel, while control switches will be located at a convenient operating height. Battery and inverter control sections will be grouped on opposite ends of the panel so that either may be readily expanded.

Two control console desks will be located directly across from the control panel so that two operators will be able to view the entire control panel array. A CRT type computer terminal will be shared between these two consoles and allow either operator to access the computer.

A single TV monitor, capable of being switched, will enable the facility operators to select any of the three battery rooms or inverter areas for viewing, and an intercom system will give operators voice contact with personnel in these areas.

4.6.4 Instrumentation and Control Wiring

Instrumentation and control wiring will be compatible with the signals being transmitted. These signals will be physically separated from the facility's power circuits and, in addition, the signals related to safety systems will be isolated in separate raceways from all other wiring. "Hard-wired" circuits will directly connect signal senders and receivers by a dedicated pair of wires with no more than one interposing terminal strip. Hard-wired circuits will connect the control room to all safety devices including fire detectors and gas detectors. Hard-wired circuits will also connect the control room to selected battery systems, inverter systems and electrical systems instrumentation and control devices. The balance of the circuits will utilize standard instrumentation wiring convention, with common returns and as many interposing terminal strips as desired, except that the television cameras will have dedicated coaxial cables to the control room monitor.

Instrumentation and control wiring that connects the battery systems to the satellite computer terminals in the battery rooms will not be provided with the facility. Thermocouple leads, temperature sensors, temperature to milliampere signal conditioners, voltage sensors and current sensors associated with the battery systems are also excluded.

It has been stipulated that the battery manufacturers will install such wiring and components at the time of battery system installation.

4.7 BUILDING AND CIVIL FACILITIES

4.7.1 Building Structure

This section describes the general design approach and design loads used for the analysis of the building structure and also identifies the several Building Codes used. Two designs, one using reinforced concrete construction and the other using pre-engineered metal components, are developed for the same building. The relative merits of the two designs are discussed in this section and the cost comparisons are dealt with in Section 6 of this report.

A description of the associated civil design is provided in Section 4.7.2.

4.7.1.1 Design Basis. The dimensional basis for individual areas of the building is derived from the requirements for housing the designated components and systems (Ref. Figure 4-13). The building structural designs are based on the requirement to safely house these components and to provide protection against the elements.

The structures were designed in such a way that release of internal pressures caused by a tornado, or an explosion in the battery rooms, would be accomplished by the collapse of the exterior end wall of the room. The standard structural theory and methods of design were applied to proportion all components of the building. The following manuals and codes of practice were used to develop the designs:

- The American Concrete Institute (ACI) - ACI 318-71, "Building Code Requirements for Reinforced Concrete".
- The International Conference of Building Officials - Uniform Building Code (UBC), 1973 Edition.
- The U.S. Atomic Energy Commission - Regulatory Guide 1.76.
- The American Society of Civil Engineers (ASCE) - Paper No. 3269, "Wind Forces on Structures".
- The American Institute of Steel Construction (AISC) - "Specifications for the Design, Fabrication and Erection of Structural Steel for Buildings", 7th Edition, 1970.
- The American Iron and Steel Institute (AISI) - "Specification for the Design of Cold-Formed Steel Structural Members", 1968.

Each building design was based on the worst combination of various conditions that might act on it. The following notations were used in the load combination equations:

U = Required ultimate load capacity

D = Dead load of structure and equipment, plus any other permanent loads contributing to stresses. An allowance was also made for future permanent loads.

L = Live load

W = Wind load, normal as well as due to a tornado

E = Earthquake load, as calculated by UBC formula

f_s = Allowable stress for structural steel

f_y = Yield strength of structural steel and reinforcing bar

For the design of the concrete building, the most severe of the following loading combinations based on the load factor, was used:

$$U = 1.4\ D + 1.7\ L$$

$$U = 0.75\ (1.4\ D + 1.7\ L + 1.7\ W)$$

$$U = 0.75\ (1.4\ D + 1.7\ L + 1.87\ E)$$

For the design of the pre-engineered steel structure, the following load combinations were used without exceeding the specified stresses:

D + L	Stress limit = f_s
D + L + W	Stress limit = 1.25 f_s
D + L + E	Stress limit = 1.25 f_s

The structure was proportioned to maintain elastic behavior when subjected to the various load combinations mentioned above. The upper limit of elastic behavior was considered to be the guaranteed minimum given in appropriate ASTM specifications. The yield strength for reinforced concrete structure was considered to be the ultimate resisting capacity as calculated from the ACI 318-71 Code.

The following major structural materials were used for developing designs for the building:

Concrete - cylinder strength f_c	4000 psi
Reinforcing steel	Grade 40
Hot rolled structural steel	ASTM Grade 36
Steel for built-up sections f_y	50,000 psi
High strength bolts	ASTM A325
Concrete masonry blocks	ASTM Gap C90, Grade PI

4.7.1.2 Reinforced Concrete Building. The following design loads were considered in the structural design of the reinforced concrete building:

- Dead Loads. These consist of weights of concrete roof, walls, beams, columns and base slab. The weights used for dead load calculations were concrete - 145 lb/ft^3, steel reinforcing and plate - 489 lb/ft^3. The weights of HVAC equipment, piping and ceiling were also treated as dead loads. Floor loadings of 1000 psf were assumed.

- Live Loads. These consist of all loads except dead, seismic and wind loads. Live load of 20 psf was used in calculations. Proper loading for the overhead cranes was taken into account.

The reinforced concrete building, shown on Figure 4-15, consists of a 5 in thick solid concrete roof slab supported by a series of reinforced concrete frames spaced 15 ft apart. The beams are 37 in deep by 18 in wide, and columns are 36 in deep by 18 in wide. These sections were designed to withstand the worst combination of superimposed and environmental loads. The exterior end wall of the battery rooms is of 12 in thick cement masonry blocks with dry mortar joints. Under severe environmental conditions, and in the case of an explosion or a fire inside the battery rooms, this wall will collapse and release internal pressure. The exterior walls on the remaining three sides of the building and the remaining battery room walls are also of 12 in thick masonry blocks, reinforced with steel bars. These walls, in addition to separating the service area and battery rooms, also serve as fire walls and blast dampeners (energy absorbers). The partitions in office areas, the control room, data rooms and the shop are of 6 in thick masonry blocks. The thickness of concrete floor slabs in the battery rooms and the service/office areas are 12 in and 6 in, respectively, and are reinforced with #4 bars. The floors of the battery rooms slope towards the exterior of the building. Underground sumps are provided at the exterior walls in each of the three battery rooms. All columns are supported on individual spread footings resting on sound soil. The 12 in thick walls are supported on a continuous footing while the 6 in thick walls rest on locally thickened floor slabs.

There is a 3 ton crane in each of the battery rooms. The crane runways are wide flange beams supported on brackets attached to columns spaced along the partitions between the battery rooms. The crane columns are also founded on individual spread footings resting on sound soil. A 12 ft by 12 ft roll-up door and two 3 ft by 7 ft outward opening fire doors are provided in each battery room.

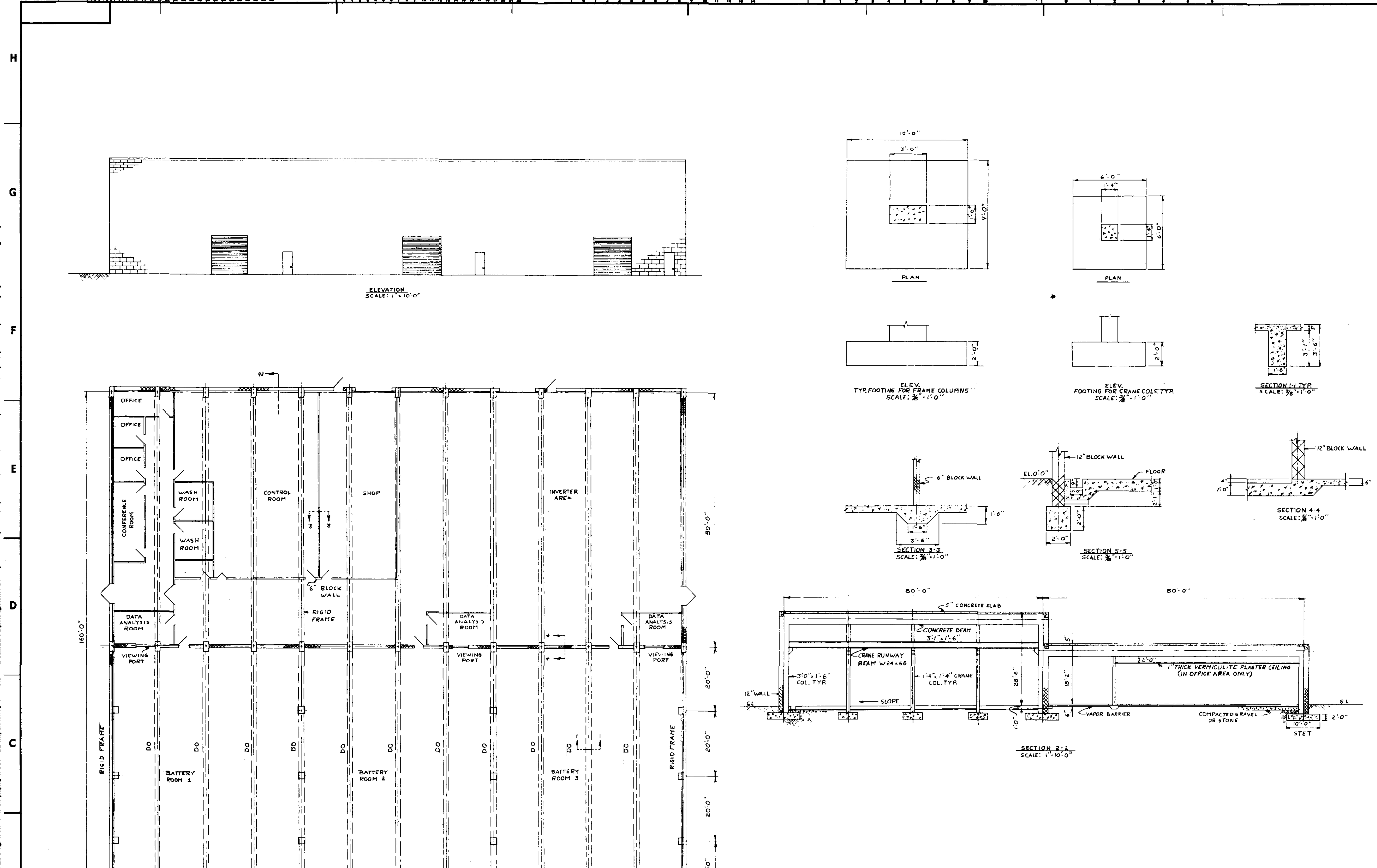
Standard structural theory and methods were employed to accomplish the design described above and, although not specified, it was found that the building, as designed, would withstand a tornado, to some extent, and an earthquake of moderate intensity.

4.7.1.3 Pre-Engineered Metal Building. The following design loads were considered for the structural design of the pre-engineered building.

- Dead Loads. These consist of weights of built-up roofing on metal deck, light gauge steel frames, ceiling, HVAC equipment, piping and busbars. Floor loadings of 1000 psf were assumed.

- Live Load. Roof live load of 40 psf was used in calculations. Proper loading was assumed for the overhead cranes.

- Wind and Tornado Loads. Wind load of 20 psf (corresponds to 100 mph windspeed) was used to select the pre-engineered frame from vendor catalogs. A building constructed with light gauge pre-engineered metal frame is unable to withstand the wind pressure and the associated pressure drop of a tornado.



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BECHTEL
SAN FRANCISCO

BEST FACILITY CONCEPTUAL DESIGN

STRUCTURAL DRAWING
- CONCRETE BUILDING -

JOB No.	DRAWING No.	REV.
11088-001	C-101	

4-89

FIGURE 4-15

The roof of the pre-engineered building, shown on Figure 4-16, consists of 1.5 in deep steel decking with flexible insulation. The roof is supported on purlins which, in turn, are supported on light-gauge steel frames spaced at 20 ft. The frames have two bays and each bay is 80 ft long. The height of the building from the floor to the eaves is approximately 28 ft. The vendor will design the frames to withstand all superimposed and environmental loads except pressure loading due to a tornado.

The exterior walls of this building are of 12 in thick masonry blocks. Under pressure loading due to high velocity wind accompanied by a drop in atmospheric pressure, the exterior end wall of the battery rooms will collapse. The walls between the adjacent battery rooms and the remainder of the building, and the exterior walls on the remaining three sides of the building, are of 12 in thick reinforced masonry blocks. The partitions in the building are of gypsum plaster applied on metal lath tied to steel studs. The crane runway beams are supported on brackets attached to columns along the walls between the battery rooms. All columns are supported on individual spread footings resting on sound soil. The thickness of floors are the same as those of the concrete building.

There is a 12 ft by 12 ft roll-up door and two 3 ft by 7 ft outward opening fire doors in each of the battery rooms. This building, as designed, would withstand moderate amounts of wind and seismic loading.

4.7.1.4 Comparison Between the Two Structural Systems.
As the concrete building will be custom made, designs can be prepared to satisfy all safety related aspects of regional and/or national codes. Protection against high wind, tornado, earthquake, snow loading, etc., can be easily accommodated in the design without substantially increasing construction costs.

With proper treatment of the facade, the building can blend with the surroundings.

The fire hazard in this type of construction is a minimum and can provide protection for at least 4 hours. Since the building was designed as a framed structure and the exterior walls are of non-load bearing type, openings, as required, can be provided on the walls without sacrificing the structural integrity of the building as a whole. Therefore, the serviceability requirements can easily be met for this type of construction.

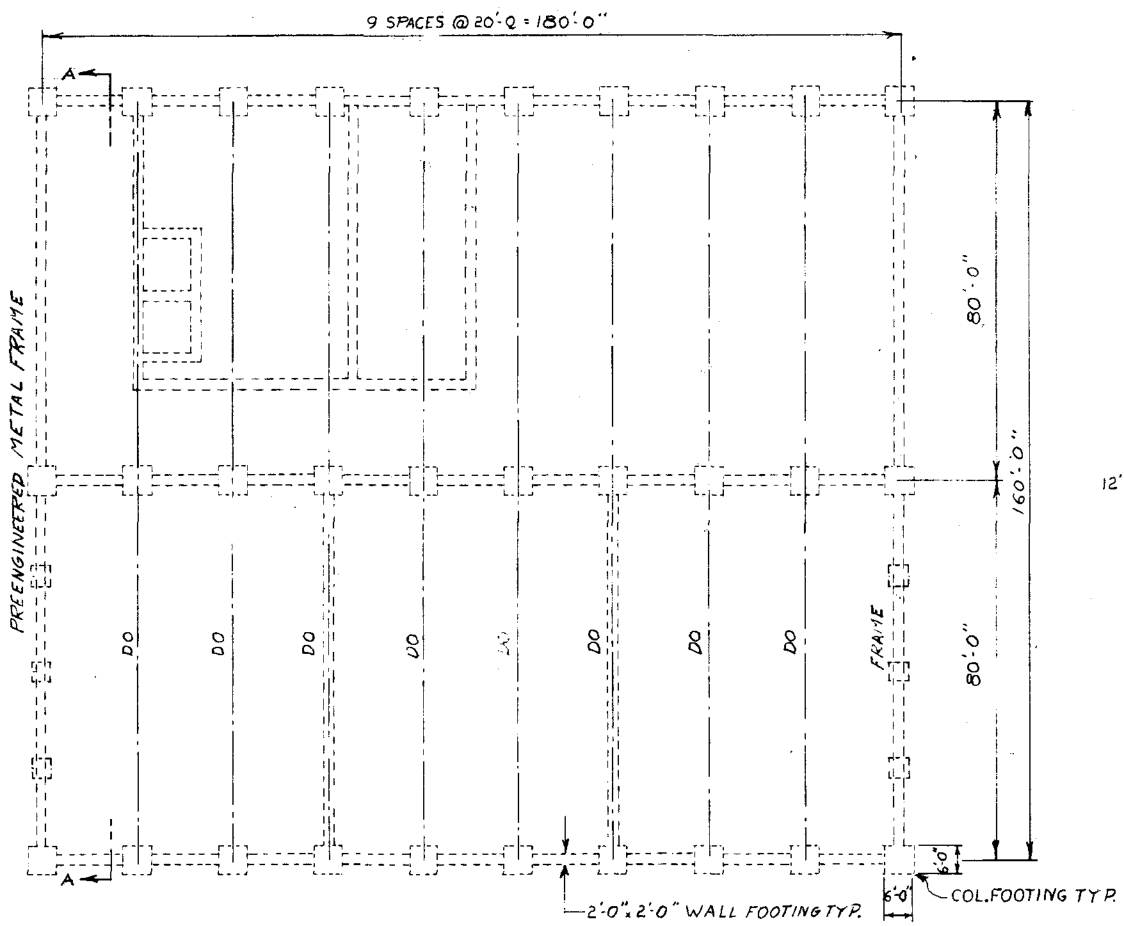
The life of a well-built concrete building is indefinite. However, a conservative estimate is 40 years.

Pre-engineered buildings are designed to meet the local and/or regional building code requirements. Most building codes do not require protection against tornado. Moderate amounts of wind loading (to about 100 mph wind speed) and earthquake loading can be accommodated in the design.

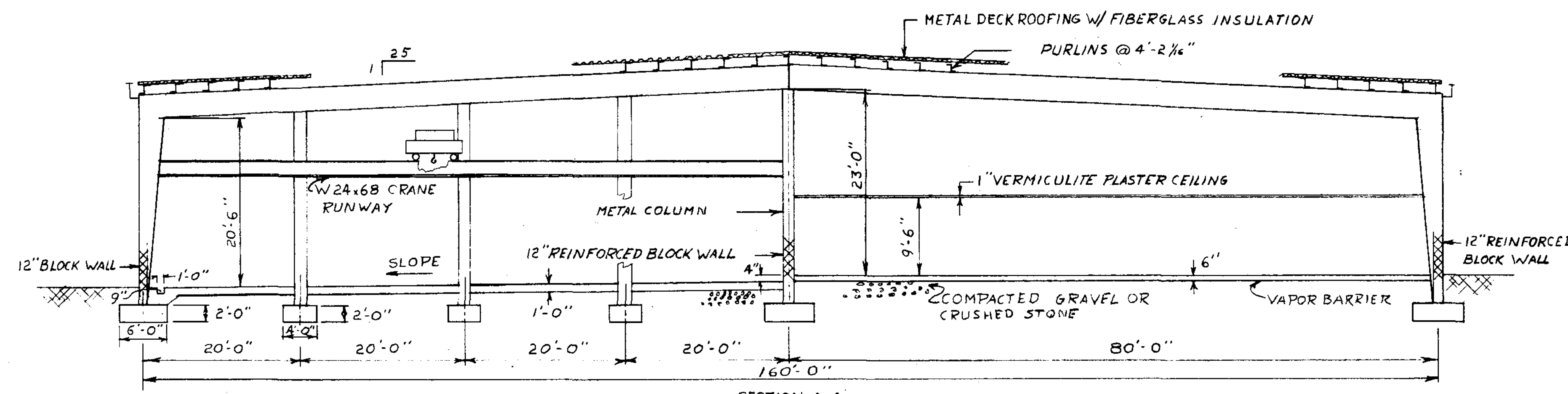
For safety against fire, steel columns and members in pre-engineered buildings must be protected with a non-combustible insulating material. Vermiculite gypsum plaster, 1.5 in thick, over metal lath wrapped around columns will provide protection against fire for approximately 4 hours.

The pre-engineered building is a framed structure and all the walls are of non-load bearing type. The serviceability requirements can be met with this type of construction.

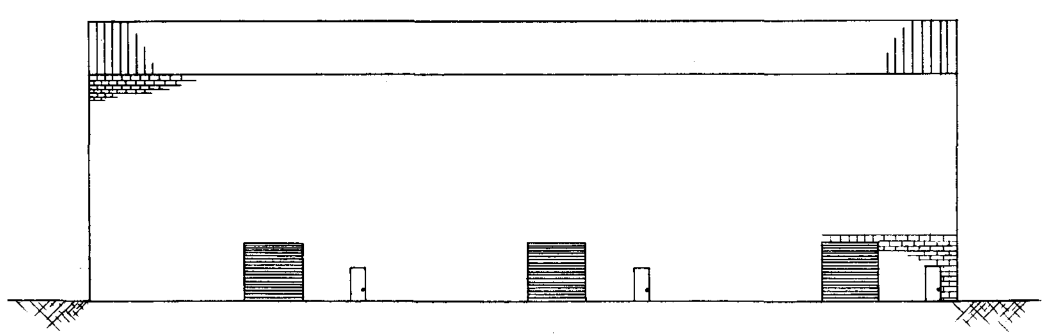
The life of a pre-engineered building is indefinite; with proper maintenance, a conservative life estimate is approximately 40 years. As with the concrete building, the appearance of the building can be made suitable for the surrounding area.



FOUNDATION PLAN
SCALE: 1"=20'-0"



SECTION A-A
SCALE: 1"=10'-0"



ELEVATION
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BECHTEL
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BEST FACILITY CONCEPTUAL DESIGN

STRUCTURAL DRAWING
PRE-ENGINEERED METAL BUILDING

JOB No.	DRAWING No.	REV.
11088-001	C-102	

FIGURE 4-16

Since this type of building is shop-fabricated, it can be erected at the site very quickly, and thus reduce the facility's construction time.

The type of construction used for the BEST facility will be influenced by the location of the site. For example, if the facility is located in a high tornado risk area, concrete construction would be preferable. A concrete building has been included for the Baseline facility in this conceptual design since this type of construction would be basically suitable for any site location that may be selected.

4.7.2 Civil Design

The location of the site for this plant is unknown. Consequently, a hypothetical location has been assumed and all site data, such as geology, seismology, hydrology and wind conditions are assumed to be average. For this study, it was assumed that the site would be level and clear of heavy growth, and only a nominal allowance was made for clearing and operations. It was also assumed that the material from excavation will be acceptable for fill.

The plant access road, surrounding roadway and parking area, as shown on the plot plan (Fig. 2-2), are a 12 in thick gravel base, 6 in thick concrete and a 2 in thick asphalt wearing course. The roadways are 30 ft wide, with a 20 ft wide unpaved shoulder on the side.

The air cooled refrigeration unit and the synthetic load will be located away from the building and accessible by a 10 ft wide asphalt paved roadway.

Also, due to a lack of specific site information, it has been specified that municipal water and sewage treatment facilities will not be available. Accordingly, a well and pump system, and a sewage treatment plant, are planned for the BEST facility. The water system is nominally rated at 40 gallons per day per person. The sewage system is sized to accommodate 95% of the output of the water system.

4.7.3 Building Heating-Ventilating-Air-Conditioning (HVAC) System

The building HVAC system consists of four separate cooling, heating, and air distribution systems. One system is provided for each of the following parts of the building:

- All the building except for the battery rooms
- Battery Room 1 (lead-acid battery)
- Battery Room 2
- Battery Room 3

Each of the four systems is operationally independent of the others so that the HVAC system in any battery room can be separated or shut down without affecting the testing schedule in any of the other battery rooms.

The ventilating systems are designed such that any noxious gases produced in the battery rooms are carried away without polluting any other portion of the building. Each battery room is maintained at a pressure slightly below atmospheric, and the rest of the building is operated at slightly positive pressure. This prevents flow of air from any of the battery rooms into the rest of the building. In addition, the battery room exhaust fans direct flow away from the building on the side opposite from the fresh air intakes.

The air cooling and heating are accomplished by one recirculating chilled water system, cooled by mechanical refrigeration, and by one recirculating hot water system, heated by a packaged hot water boiler unit.

In the chilled water system, the water is circulated from the refrigeration system through each set of cooling coils and returned. The refrigeration condenser is an air cooled unit to avoid the possibility of a visible plume of water mist which is likely using a water cooled condenser with a cooling tower. The refrigeration system is located away from the building to minimize flow of hot air from the condenser back into the building (Ref. Figure 2-2).

To keep the offices, data analysis rooms, and conference room at comfortable temperatures during periods of cold weather, a thermostatically controlled supplementary hot water heating unit is provided in each of those rooms.

4.7.3.1 Design Conditions. The summer indoor design conditions are taken as 75°F dry bulb temperature and 50% relative humidity.

The winter indoor design conditions are 75°F dry bulb temperature in the offices, conference room and data analysis rooms with 65°F dry bulb temperature in the rest of the building.

The summer outdoor design conditions are 91°F dry bulb temperature and 77°F wet bulb temperature. Those are the summer 1% conditions for New York City; they also apply as the 2.5% to 5% summer conditions for Washington, D.C.; Atlanta, Georgia, and most other locations in the Eastern United States. The overall heat transfer coefficients (U factors) are 0.39 Btu/hr-ft^2-$^\circ$F for the roof, and 0.40 Btu/hr-ft^2-$^\circ$F for the exterior walls for summer design conditions.

The winter outdoor design conditions are taken as 12°F with coincident wind velocity of 15 miles per hour. Again the design conditions are for New York City (winter 99% temperature), but they apply as the 97% to 99% winter temperature conditions for most locations in the Eastern United States. For winter design conditions the overall heat transfer coefficients are 0.65 Btu/hr-ft^2-$^\circ$F for the roof and 0.47 Btu/hr-ft^2-$^\circ$F for the exterior walls. The assumption of a 15 mph wind accounts for the higher values for winter than for summer.

To summarize, the outdoor design conditions are representative of conditions at most locations in the Eastern United States.

The durations of the winter heating season and the summer cooling season vary considerably in that area, but the temperature extremes for winter and for summer are virtually uniform. Since the capacity of the heating and cooling systems is determined by the temperature extremes, the capacities of the heating and cooling units are appropriate for any location in the Eastern United States.

4.7.3.2 Special Design Considerations. The building HVAC system is designed to provide battery cooling for the lead-acid battery system. Sufficient room air flow is provided in Battery Room 1 to carry away the heat generated during charging and discharging.

The hydrogen generated during charging of the 5 MWh lead-acid battery system described in Section 4.3.2.1 is removed by the room ventilation system. The estimated maximum hydrogen generation rate is 175 scfm. The room ventilation system is designed for 10,000 scfm of fresh air. Thus, the maximum hydrogen concentration is limited to 1.75% which is well below the flamability limit of 4.1%. The exhaust fan is connected to an uninterruptable power supply to allow the flow of fresh air for at least 30 minutes after a power failure, thus assuring that the hydrogen concentration is kept at a safe level. The room volume to fresh air flow rate magnitudes are such that 30 minutes after hydrogen generation at the above maximum rate ceases the hydrogen concentration is less than 0.2%.

As an added safety measure, additional fresh air flow is provided at the command of a hydrogen concentration detector. The 50,000 cfm circulating fan is converted to an exhaust fan by closing one set of louvers and opening another. With both the exhaust fan and the circulating fan introducing fresh air, 60,000 scfm of outdoor air is flooded into the room and will very quickly reduce the hydrogen concentration. With that much fresh air flow the hydrogen concentration can be reduced from 3% (a likely alarm setting) to 1% in less than 2.5 minutes, if no hydrogen is being generated, or in approximately 3 minutes if hydrogen is generated at the maximum estimated rate of 175 scfm. The alarm procedure includes discontinuing the charging so that hydrogen generation ceases with only some after-bubbling of hydrogen already generated.

Based on the proposed designs of the high temperature batteries, Battery Rooms 2 and 3 are designed to allow for a 205,000 Btu/hr (60 kW) equipment-to-room heat flow. That is sufficient to cope with the heat leakage through the insulation of the high temperature batteries, but it is not enough to cool the batteries themselves. Each battery system used in those two rooms will also have a battery cooling system that is independent of the building HVAC system.

The control room air conditioning is designed for 170,000 Btu/hr (50 kW) equipment-to-room heat flow.

Inverters will be equipped with separate cooling systems and will not be dependent on room air for cooling.

4.7.3.3 Heating and Cooling Capacities. The required winter heating and summer cooling capacities are summarized in Table 4-3. Converted to more familiar terms, the cooling system must have a capacity of 318 tons of air conditioning, and the heating system must furnish the equivalent of 1.2 MW of heat.

The quantity of fresh air specified by the AEC General Design Criteria handbook (AECM 6301) causes a relatively large part of the heating and cooling design capacities. The applicable fresh air requirement is specified as 1 cfm/ft^2 for shops and warehouses. Heating and cooling the fresh air accounts for approximately 50% of the total heating and cooling capacity. In view of the intended use of the buildings, the fresh air requirement could probably be reduced to 0.5 cfm/ft^2 (approximately one air change per hour) except in Battery Room 1 where the fresh air is needed to keep the hydrogen concentration at a safe level. That would save 17% on both the heating and cooling capacity specified in Table 4-3.

TABLE 4-3

HEATING AND COOLING CAPACITIES

	Winter Heating Capacity (Btu/hr)	Percent of Total Heating Capacity	Summer Cooling Capacity (Btu/hr)	Percent of Total Cooling Capacity
Battery Room 1	949,000	23.4	1,009,000	26.4
Battery Room 2	641,000	15.8	629,000	16.5
Battery Room 3	652,000	16.0	659,000	17.3
Building Excluding Battery Rooms	1,821,000	44.8	1,518,000	39.8
TOTAL	4,063,000		3,815,000	

Section 5

BASELINE FACILITY AND OPTIONS

5.1 BASELINE FACILITY

The scheduled development of advanced battery systems is such that the ultimate testing capability of a fully implemented BEST facility may not be needed immediately. Nevertheless, current battery development schedules may be shortened by technical developments in the many on-going battery research programs, or by the energy situation accelerating the demand for energy storage systems. Therefore, the initial, or Baseline, BEST facility will be one to which equipment can be easily added in order to increase testing capacity and flexibility as the needs arise. This section delineates which of the equipment and subsystems discussed in the previous sections are to be included in the Baseline BEST facility, and forms the basis for the corresponding cost estimate presented in Section 6.

5.1.1 Building and Civil Facilities

The facility building will be a 160 x 180 ft reinforced concrete structure as described in detail in Section 4.7.1.2 and will include lighting, receptacles, plumbing, storm drains, sumps, fixtures and the battery room cranes (Ref. Section 4.3.1). Site work (improvements to land) will include all necessary grading and paving as described in Section 4.7.2, and a moderate amount of landscaping to make the facility aesthetically commensurate with the surrounding area. As specified, a well and sanitary sewage system (Ref. Section 4.7.2) will be provided due to the absence of municipal services.

All buidling, site work and civil facilities will be complete. No further work will be required on the building or site to expand this Baseline facility to a fully implemented testing capacity, with the possible exception of minor modifications dictated by specialized future requirements of an advanced battery system design.

5.1.2 Station Battery

A lead-acid battery system will be installed as the station battery in Battery Room 1. However, as specified, this system is treated as any other battery system and is not costed in Section 6, with the exception that the air cooling system (described in Section 4.3.2.1), hydrogen detectors and satellite computer system (Ref. Section 4.6.1) are installed (and costed). Items and services that will be required for installation of the lead-acid station battery in the Baseline facility (but which are not costed) include:

- The battery (e.g., 376 MAZ-31A cells)
- Flash arresters (if not included as part of the cell)
- Jumper cables between cells
- Thermocouples
- Wiring to connect the ammeter shunts, thermocouples and cell terminals to the computer terminal strip
- Fuses or current limiting resistors on wire pairs used to measure system voltage
- Ammeter shunt elements required when the system is configured into more than one string
- Cable or bus to connect the battery system to the dc bus terminal
- Deionizer and automatic make-up water system
- Shipping and installation labor cost
- Battery formation (if required)

5.1.3 Station Inverter

A four module inverter system, as described in Section 4.4, will be installed as the station inverter in the Baseline facility. Each module will have dc ratings of 250 V and 2500 A so that the total combined system power capability will be 2.5 MW. This system of modules will be capable of operation as: a 1000 V, 2500 A; a 500 V, 5000 A; or a 250 V, 10,000 A inverter. Also included in this inverter system will be the dc switching network, as shown by Figure 4-10, which will facilitate module interconnection to obtain the desired set of system ratings.

The inverter's internal control electronics will generate all SCR gates and other signals necessary for its operation. Further, the inverter electronics and internal transducers will enable it to be set for operation in the constant current, constant voltage, or constant power modes, for both charging and discharging. The setting of these modes, and the required dc voltage, current and power levels, may be accomplished manually by controls in the facility control room, or by duplicate controls located on the inverter cabinets. The inverter settings may also be made by means of signals from the facility computer. Additionally, the control system internal to the inverter may have the ability to reduce inverter output voltage in order to limit current in the event of an external fault. Similarly, the inverter may have an internal capacity to compare its input and output power to detect and act on any internal faults.

5.1.4 Dc System

The Baseline facility's dc system will be built around a single facility dc bus, with components and connections to permit any one of the three battery rooms to be connected to the station inverter. The normal operating limits of the dc system will be

1000 V and 10,000 A. Further, it will be able to withstand 200,000 A momentary currents, sustained overvoltages of 2000 V and transients of 3000 V. Component connections are shown on the single line diagram of Figure 5-1, and their physical locations are given in the equipment layout shown by Figure 5-2. Details of these components and the reasons for their selection are presented in Section 4.5.1. Specifically, the Baseline facility dc system will include the following major components:

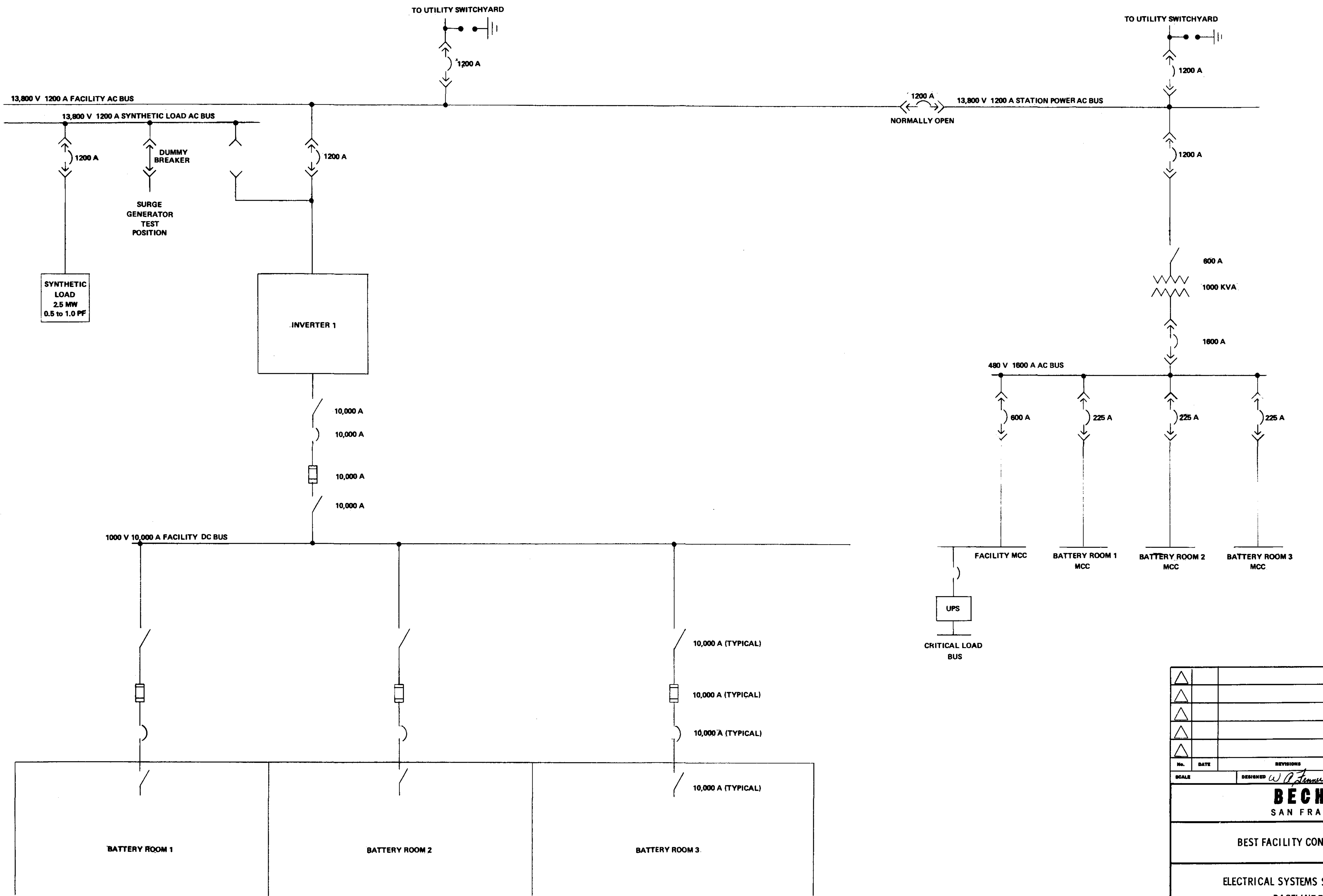
- The dc bus will be metal-protected laminated-bar bus such as is available from Electric Materials Co. The combined total length of both poles will be 460 feet. This length includes the main run of the bus, stubs to battery room and the station inverter areas, vertical risers and interconnections between switches and breakers.

- As discussed in Section 4.5.1.3, a single-pole circuit breaker will be used on each leg of the dc system. Thus, eight breakers, such as the General Electric MC-6A, will be used at the four breaker locations.

- Similarly, eight double-pole, single-throw switches, such as the MP series from Pringle Electric, will be used at the eight switch locations.

- Space has been provided in the design for the installation of eight fuse bases. Although fuses with the required ratings are not available at present, it is assumed that they can be developed before the facility is activated.

Sufficient space will be provided to install two similar 10,000 A dc systems in the future and accomplish the fully implemented dc system shown by Figure 4-12. Other elements of the dc system include instrumentation, such as ammeter shunts, voltmeters, breaker relaying, door and switch interlocks, etc., as shown on Figure 4-14.



No.	DATE	REVISIONS	BY	CHKD	DESIGN SUPV	ENGR	PROJ ENGR	APPR

SCALE | DESIGNED W. A. Fenner | DRAWN | CHIEF ENGR

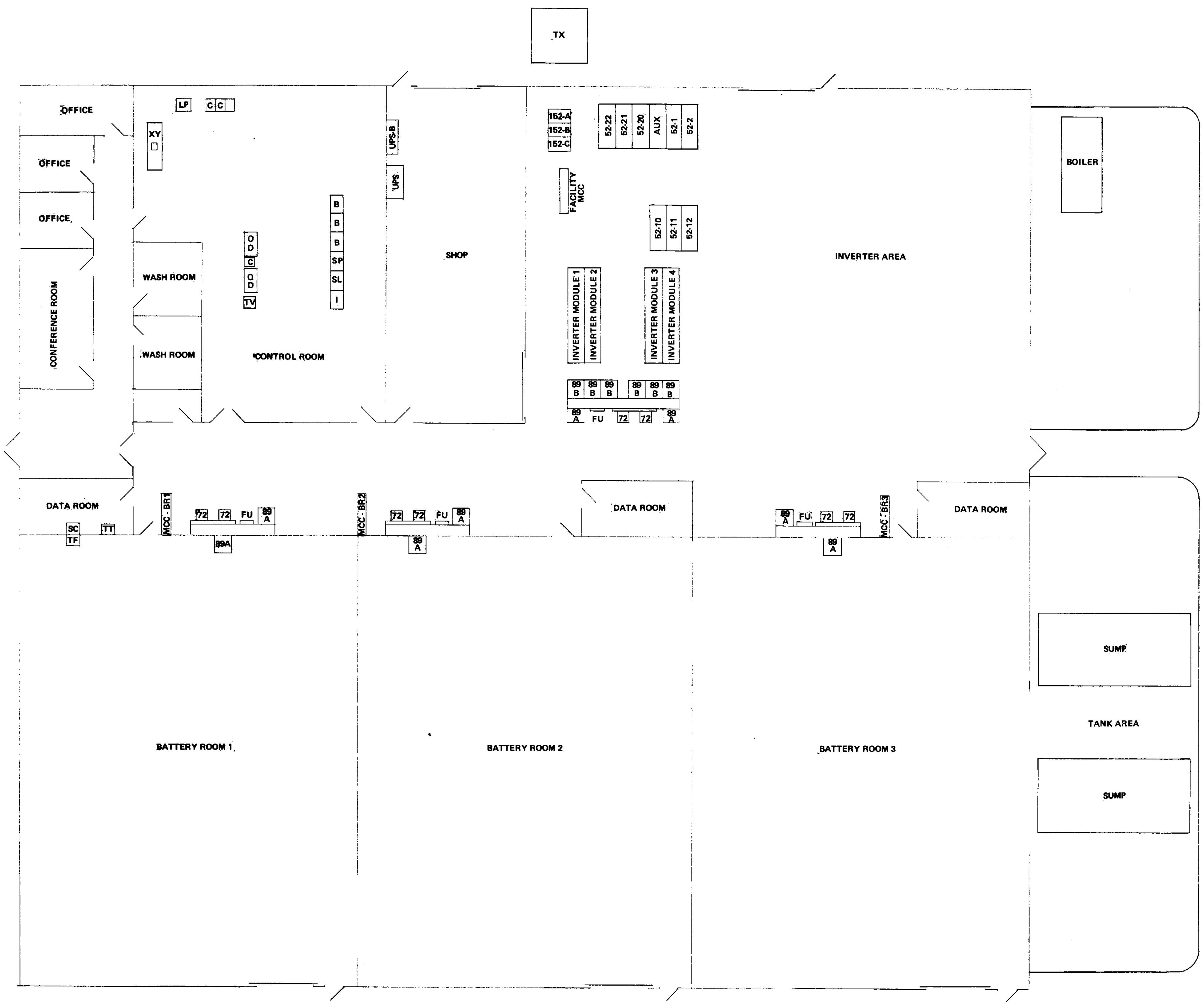
BECHTEL
SAN FRANCISCO

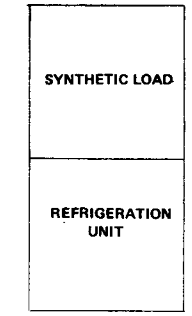
BEST FACILITY CONCEPTUAL DESIGN

ELECTRICAL SYSTEMS SINGLE LINE DIAGRAM
- BASELINE FACILITY -

JOB No.	DRAWING No.	REV.
11088-001	E-200	

FIGURE 5-1





10 5 0 10 20'

SYMBOL	SYSTEM	DEVICE
TV	CONTROL	TELEVISION MONITOR
I	CONTROL	INVERTER CONTROL PANEL
SL	CONTROL	SYNTHETIC LOAD CONTROL PANEL
SP	CONTROL	STATION POWER CONTROL PANEL
B	CONTROL	BATTERY ROOM CONTROL PANEL
OD	CONTROL	OPERATORS DESK
C	COMPUTER	CRT TERMINAL
XY	COMPUTER	XY PLOTTER
LP	COMPUTER	LINE PRINTER
CC	COMPUTER	CENTRAL COMPUTER TERMINAL
SC	COMPUTER	SATELLITE COMPUTER
TT	COMPUTER	TELETYPE TERMINAL
TF	COMPUTER	TERMINATION FACILITY
52-AUX	13.8 KV	FACILITY AUXILIARY CUBICLE
52-1	13.8 KV	FACILITY MAIN ACB
52-2	13.8 KV	FACILITY FEEDER ACB
52-10	13.8 KV	SYNTHETIC LOAD ACB
52-11	13.8 KV	SURGE GENERATOR DUMMY BREAKER
52-12	13.8 KV	ALTERNATE FEEDER POSITION FOR ACB 52-2
52-20	13.8 KV	STATION POWER TIE ACB
52-21	13.8 KV	STATION POWER MAIN ACB
52-22	13.8 KV	STATION POWER TRANSFORMER ACB
152A	480 V	1600 A ACB SECTION
152 B	480 V	600 A ACB SECTION
152-C	480 V	225 A ACB SECTION
72	DC	CIRCUIT BREAKER
89 A	DC	SWITCH 10,000 A
89 B	DC	SWITCH 2500 A (PART OF INVERTER SYSTEM)
UPS	120/240V	UNINTERRUPTIBLE POWER SUPPLY
UPS-B	DC	UPS BATTERY
FU	DC	FUSE (FUTURE)
TX	13.8 KV/480V	TRANSFORMER, 1000 KVA

No.	DATE	REVISIONS	BY	CHKD	DESIGN SUPV	ENGR	PROJ ENGR	APPR

SCALE | DESIGNED W. J. Ferrer | DRAWN L. K. | CHIEF ENGR W.S.

BECHTEL
SAN FRANCISCO

BEST FACILITY CONCEPTUAL DESIGN

MAJOR EQUIPMENT LAYOUT
- BASELINE FACILITY -

JOB No.	DRAWING No.	REV.
11088-001	E-201	

FIGURE 5-2 22 x 34 "D" SIZE

5.1.5 Ac System

The 13.8 kV ac system will connect the station inverter to either the host utility grid or to the facility synthetic load. Details of this system are discussed in Section 4.5.2, and the elements of the baseline facility ac system are seen on the single-line diagram presented in Figure 5-1 and in the equipment layout, Figure 5-2. This baseline ac system will include the following major items:

- A 2.5 MW synthetic load with a power factor that is adjustable (motor-operated) between 0.5 and 1.0 in ten steps, such as is available from Transrex Division of Gulton Industries.
- A 1200 A feeder breaker for the synthetic load, a 1200 A feeder breaker for the station inverter and a 1200 A main breaker to connect the facility ac bus to the utility.
- A breaker position to enable connection of the station inverter's output to the synthetic load bus, and a breaker position with a dummy breaker for use in connecting a surge generator to the synthetic load bus.
- A cabinet for the auxiliaries required for all of the above breakers and breaker positions.
- All wiring and conduit needed to connect the above components, including underground cable runs of 800 feet (with surge arrestor) to the adjacent utility substation and 200 feet to the synthetic load. Wiring will be sized to accommodate the fully implemented facility.
- All metering and relaying (as typified by Figure 4-14) associated with the above components.
- A surge generator, which will be rented as needed for testing.

5.1.6 Station Power System

The Baseline facility station power system will be essentially as described in Section 4.5.3, with the exception that portions of the battery room MCC's will not be completed. This system will supply and distribute all facility power, except that which is connected to the ac system on the inverter output. This system will be sized to accommodate the fully implemented facility. Elements of the Baseline station power system are shown on Figures 5-1 and 5-2, and will include the following:

- An 800 foot underground feeder cable run (with surge arrestors) to the adjacent utility substation
- A 1200 A, 13.8 kV main breaker to connect the facility ac bus to the utility, a 1200 A tie breaker to the Baseline facility ac bus, and a 1200 A feeder breaker to the station power 13.8 kV - 480 V transformer
- A 600 A, 13.8 kV, outdoor disconnect switch on the primary of the station power transformer
- A 1000 KVA, 13.8 kV-480 V transformer with a 5 A neutral grounding resistor
- A 1600 A, 480 V main breaker
- A 600 A, 480 V feeder breaker for the facility MCC
- Three 225 A, 480 V feeder breakers for the battery room MCC
- Two compartments for the auxiliaries needed to serve the breakers
- Two 600 A and one 225 A spare breaker compartments
- One facility and three battery room MCC's as described below
- One 30 kW uninterruptible power supply for the computer, fire detection and safety equipment, and standby lighting

The facility MCC will be completed for the Baseline facility. It will include a transformer and panel for the facility lighting and receptacles (exclusive of the battery rooms), and circuit breakers for:

- The well water pump
- Cooling system
- Building HVAC (exclusive of battery rooms)
- Uninterruptible power supply

Power will be brought to the three MCC's adjacent to the battery rooms. Transformers and panels will be installed for battery room lighting and receptacles, and circuit breakers will be installed for the three overhead cranes, HVAC fans and heaters and sump pumps. Vertical MCC sections for battery auxiliary power (e.g., high temperature battery heaters, air cooling circulation fans, pumps, etc.) for Battery Rooms 2 and 3 are not included in the Baseline facility, but will be installed as part of the battery installation process. However, the MCC and all wiring will be completed for Battery Room 1, which will house the lead-acid station battery.

Additionally, the Baseline station power system will include all lighting, receptacles, and the wiring and conduit necessary to interconnect the components delineated above.

5.1.7 Instrumentation and Control

The Baseline facility control room will have installed and wired, all of the control panels (as described in Section 4.6.3) which are associated with the facility, Battery Room 1 and the station inverter. The initially installed computer will include the central unit; a single satellite unit (with 800 data channels) to instrument the lead-acid station battery; 100 data channels associated with the central unit to permit monitoring of facility parameters; and all peripheral equipment, as listed in Section 4.6.1, except the TTY terminals for Data Analysis Rooms 2 and 3. Also included will be a six-channel recording system as described in Section 4.6.2, and the completed TV monitoring and intercom systems.

5.1.8 Building HVAC and Cooling Systems

The building HVAC system described in Section 4.7.3 will be installed and completed. This includes the special subsystem installed in Battery Room 1 to cool and ventilate the air-cooled lead-acid station battery described in Section 4.3.2.1.

Most of the proposed high temperature batteries will be cooled by an air system which recirculates the major portion of the cooling air. In the event of a cell rupture, the exhaust and make-up air ducts for the cooling loop will be sealed by louvers or valves, and the cooling loop will be flooded with an inert gas. In order to minimize the containment area, the louvers should be located at the junctions between the cooling loop duct-work and the supply and exhaust ducts. Moreover, most of the proposed high temperature batteries will have more than one string and each string will have an individual cooling loop. Thus, in order to restrict any airborne reaction products to the loop with a ruptured cell, louvers should be installed on each individual cooling loop. Therefore, it is expected that such individually tailored duct systems, sealing louvers and gas inerting safety systems will be installed by the battery manufacturers as part of the installation process for the high temperature battery systems, and not as part of the Baseline facility. However, two roof penetrations, one for a cooling supply duct and one for exhaust, will be provided in each of the three battery rooms. These penetrations will be capped off until a high temperature battery and its cooling duct system are installed. Also included are wire runs in conduit from the exhaust duct penetrations to the corresponding battery room MCC's to provide power for exhaust fans.

5.1.9 Safety Systems

A summary of the safety systems to be installed in the Baseline facility follows. Further descriptions are provided in Section 7.2.

- All ceiling-mounted fire detectors
- H_2 detectors in Battery Room 1
- A Halon gas system for the control room and all three data analysis rooms
- A standard water sprinkler system for the office area
- Appropriate portable dry chemical fire extinguishers for the remainder of the building
- Such safety features (e.g., wall fire resistance and pressure release design) as are afforded by the design of the building

5.2 OPTIONS

This section presents brief discussions of the technical aspects of several options and deferred equipment installation for the Baseline facility. The cost implications of these items are presented in Section 6.3.

5.2.1 Building Structure

5.2.1.1 Reinforced Concrete Vs. Pre-Engineered Metal Construction. Details for both a reinforced concrete structure and a pre-engineered metal building are presented in Section 4.7.1. As discussed in that section, the primary reason for the selection of a reinforced concrete structure for this conceptual design is its relatively superior ability to resist tornadic forces. This type of construction would afford the maximum protection for the substantial investment in equipment and battery systems at any site location in the U.S. which may be selected.

If the location selected for the BEST facility is not subject to tornadic or other weather disturbances, a pre-engineered metal building would be suitable. The principle advantages of this type of construction are a substantially lower cost (Ref. Section 6.3) and a shorter construction schedule. It is estimated that use of this type of structure could shorten the construction schedule presented in Section 6.2 by up to 10 weeks. The insulation and roof construction of the metal building will also result in a reduction in the HVAC system load. The fire resistance of each of the two types of construction is comparable. The methods of design and construction for pre-engineered buildings offer less flexibility in producing a custom design, but this factor will result in only a minor impact on the BEST facility.

Other costs associated with the building such as site preparation, civil facilities, lighting, etc., are assumed to be the same for either type of construction.

5.2.1.2 Existing Building. It is possible that the BEST facility could be housed in an existing building. At present, any discussion of an existing building must be very general in nature. However, an evaluation of the general suitability and cost implications of housing the facility in a specific building would include the following initial steps:

- Obtain copies of existing blueprints for the building and a site layout.
- Assess how the equipment and systems slated for the BEST facility could be configured in this building.

- Visit the site to verify features shown on the blueprints, re-assess the assumed configurations for BEST equipment and systems, and assess the condition of the building.
- Determine what equipment (if any) in the building can be used for BEST and what must be removed (e.g., lighting, plumbing, HVAC, old process equipment, etc.).
- Determine what general structural changes would be required.
- Estimate the cost differential for housing the facility in the existing structure vs. a new structure.

It is estimated that such a preliminary evaluation would require an effort on the order of 500 manhours. The actual number of manhours required will be highly dependent on the characteristics of the specific building and on the level of detail required as the output from the evaluation.

5.2.2 Dc Bus Systems

The question of what type of construction would be optimum for the dc bus in the BEST facility is addressed in Section 4.5.1. Considerations discussed therein led to the selection of a laminated-bar type of bus. Further, vendor contact indicated that the current price difference between copper and aluminum construction for this type of bus is relatively small. Copper is more readily amenable to bolt-together construction and was selected for use in this current conceptual design. Accordingly, the options and deferred installation discussed below are for a copper, laminated-bar type construction, insulated for a nominal operating voltage of 1000 V and transients of 3000 V.

5.2.2.1 Initially Installed 5000 A Expandable dc Bus. A portion of the cost of a 10,000 A dc bus could be deferred by initially installing a 5000 A bus in the Baseline facility, with provisions for expanding it to a 10,000 A rating in the future. In this option, switches and circuit breakers would be initially installed with full 10,000 A capability since these devices are not expandable (5000 A devices could be installed initially, then sold for salvage value and replaced in the future by 10,000 A devices, but this is not an attractive alternative). The short pieces of dc bus interconnecting the 10,000 A switches and circuit breakers would also be installed initially as 10,000 A bus because of the difficulty of paralleling their many angles and offsets. The main length of dc bus runs are readily expandable, especially if designed for expansion, but it would be necessary to shut down test operations during the changeover. Essentially one-half of the main dc bus material cost could thus be deferred. The initial installation labor costs of an expandable 5000 A bus are about the same as for a 10,000 A bus.

Instrumentation and metering would be initially installed for 10,000 A ratings. The 10,000 A circuit breakers would be set to provide protection for the 5000 A bus. Space for 10,000 A, 1000 V dc buses would be provided, and 5000 A, 1000 V dc fuses would be installed to protect the 5000 A bus. However, since these fuses do not exist at present, their cost is not included in Section 6.3. Since a 5000 A, 1000 V bus can accommodate a 2.5 MW battery and inverter (but at lower maximum ampacity), the battery and inverter systems and all related facility systems (HVAC, instrumentation, etc.) will not be directly effected by this option.

5.2.2.2 Expanding the 5000 A dc Bus to 10,000 A. Assuming an initially installed 5000 A bus is designed to be expanded to 10,000 A in accordance with the preceding discussion, then the actual expansion will only require purchasing the deferred dc bus material and installing it. However, a complete shutdown of the dc bus would be required during the process of bolting on the expansion bus material. Labor costs of adding the expansion are about equal to the cost to install the initial 5000 A bus.

5.2.2.3 Addition of a 10,000 A dc Bus. The Baseline facility (with all computer satellite equipment installed) will be capable of individually testing any 2.5 MW battery system installed in any one of the three battery rooms. Thus, to achieve the added testing flexibility afforded by a second 10,000 A dc bus, the addition should logically be accompanied by the installation of a second inverter, its associated cooling system, ac system equipment and requisite instrumentation and relaying.

As described in Section 5.1, the Baseline facility will have a single 10,000 A dc bus which will be connected to each of the three battery rooms and to the station inverter. Referring to the electrical single line diagram, Figure 4-12, it can be seen that the addition of a second 10,000 A dc bus system will require the installation of the following: 5 double-pole switches (one for each of the three battery rooms and one disconnect switch on each side of the inverter dc breaker); 2 dc circuit breakers (one per pole) for the new inverter; a bus run and vertical risers, etc. (approximately the same length as the initial bus); and instrumentation and realying as typified by the equipment shown in Figure 4-14. Again, fuses are indicated, but not costed in Section 6.

Requisite additions to the ac system include: two ac breaker positions, one draw-out ac breaker element; instrumentation and relaying (refer to Figure 4-14); and wiring and conduit, as needed to connect the above components.

For the most part, facility operation and testing could continue while these additions are made and would have to be stopped only when the final connections are made to the dc and ac buses.

5.2.2.4 Addition of a 5000 A, dc Bus. This addition would be essentially the same as above, Section 5.2.2.3. However, based on the assumption that the addition is intended to be a permanent installation, a permanent 5000 A bus would be installed and all other components of the dc system would be rated at 5000 A. An advantage of a permanent 5000 A installation is that it allows the use of standard draw-out breakers. These breakers, due to an integral capability to disconnect upon withdrawal, would eliminate the need for separate disconnecting meand (as is required for 10,000 A dc breakers). While a "permanent" 5000 amp system of this type could be expanded later to a 10,000 A rating, such a change would be more costly time consuming than if an expandable system had been installed initially (see Sections 5.2.2.1 and 5.2.2.2).

5.2.3. Expanding the Computer System

The Baseline facility will have a central computer unit in the control room, and one satellite computer unit with 800 data channels in Battery Room 1. Expansions of this system will entail adding another satellite unit with a sufficient number of data channels to accommodate the installation and testing of the battery system which prompted the expansion. A second type of expansion might only involve increasing the number of data channels on an existing satellite system (i.e., for the case when a new battery installation replaces one that required fewer data channels).

Each satellite addition would also require the installation of its associated TTY terminal at the corresponding battery room location. The costs provided in Section 6.3 for the addition of satellite units includes the cost of this TTY equipment.

The impact of these expansions will be an increased testing capability, and the installation of the requisite hardware should not interfere with the on-going testing of existing systems.

5.2.4 Synthetic Load

If the initially installed station inverter is of a design which cannot operate into a synthetic load, installation of the synthetic load system could be deferred. This would delete the labor and material cost allocated for the synthetic load, a 13.8 kV draw-out circuit breaker element, two breaker cabinets and associated wiring and instrumentation.

However, by so eliminating the synthetic load, the surge generator would have to operate with the inverter connected to the utility network. Based on the assumption that the host utility would allow this, the breaker position for the surge generator would be moved to the ac system bus (see electrical single line diagram, Figure 5-1).

5.2.5 Forklift

The modules in some battery systems may be best suited for handling by a forklift. This item is not included in the Baseline costs, but is presented here as an option.

Since battery systems may be configured with relatively narrow aisles, a side-loading forklift has been selected. These units are capable of traveling in a 5 foot wide (nominal) aisle and of extending the forks sideways (i.e., perpendicular to the direction of travel) in order to pick up loads. Lift capacities of 2000 to 4000 lb are available. A 4000 lb unit is costed in Section 6.3.

Section 6
COST AND SCHEDULING

6.1 BASELINE FACILITY COSTS

6.1.1 Estimate Basis

General. This estimate represents a joint effort of the cost engineers and design engineers to determine the major cost features of the project. The cost engineers have attempted to convert the conceptual design information that will enable them to forecast what the construction costs might be after the design has been developed in much greater detail.

Electrical single-line diagrams, structural drawings, building/facility layouts, and informal sketches and notes provided the basic estimating data.

As specified in AEC Manual Appendix 6101, the Estimate Summary, Table 6-1, is formatted to generally conform to appendix 1301, part II, C.2., Schedule 44, Construction Project Data Sheet, f(10). A further breakdown of construction costs is provided in Table 6-2.

Pricing. Vendor telephone quotations were obtained for major equipment such as dc bus and switching, ac switches, and the synthetic load. Two written quotations were obtained for the computer equipment. The estimate of inverter purchase price was supplied by the client as $100/kW (assumed to include self-commutated capability). Other equipment such as heating, ventilating and air conditioning, and cranes, were obtained by informal telephone quotes, current catalog pricing and vendor contact. Major bus duct, cable tray, 13.8 kV connections and support quantities were estimated from layout sketches and priced from current estimates and vendor contacts. Instrumentation connections and supports were estimated by number of points

TABLE 6-1

ESTIMATE SUMMARY

- BASELINE FACILITY -

	$ Thousands	
ENGINEERING, DESIGN & INSPECTION		657
Title I	148	
Title II	398	
Title III	111	
LAND & LAND RIGHTS		N.A.
CONSTRUCTION COSTS		4,445
Improvements to land	154	
Building	1,491	
Other structures	0	
Special Facilities	2,762	
Utilities	38	
STANDARD EQUIPMENT[1]		13
REMOVAL & SALVAGE		N.A.
CONTINGENCY		765
TOTAL ESTIMATED PROJECT COST, MAY 1975		$5,880

[1] Includes items such as office furniture and shop equipment.

TABLE 6-2

SUMMARY OF CONSTRUCTION COST

- BASELINE FACILITY -

Ref.[1] Pg. No.		$ Thousands: Equipment, Materials & Subcontracts	Construction and Installation	Subcategory Total	Category Total
5-1	IMPROVEMENTS TO LAND	112	42	154	154
5-1	BUILDING				
5-1	Structure	386	758	1,144	
5-1	Plumbing and Drains	55	36	91	
5-1	Cranes	216	40	256	
				1,491	1,491
	OTHER STRUCTURES	None	-	-	-
	SPECIAL FACILITIES				
5-3	Station Inverter				
5-3	Inverter modules	250	20	270	
5-3	Inverter dc switching & bus	47	43	90	
				360	
5-3	Dc System				
5-4	Bus	110	59	169	
5-4	Switchgear, breakers	146	35	181	
				350	
5-9	Ac System				
5-9	Switchgear, breakers	84	4	88	
5-9	Synthetic load	135	23	158	
5-9	Wire, cable, etc.	43	55	98	
				344	
5-10	Station Power System				
5-10	Transformers & switchgear	120	19	139	
5-10	Uninterruptible power supply	62	10	72	
5-11	Lighting and receptacles	89	46	135	
5-11	Wire, cable, etc.	79	120	199	
				545	
5-11	Instrumentation & Control				
5-11	Computer	250	18	268	
5-11	Control panels	84	39	123	
5-12	Other instruments, wiring	80	58	138	
				529	
5-12	Process & Building HVAC	405	138	543	

[1] Further details of items included in the cost categories are presented on the pages noted.

TABLE 6-2 (cont'd.)

Ref.[1] Pg. No.		Equipment, Materials & Subcontracts	Construction and Installation	Subcategory Total	Category Total
		$ Thousands			
5-13	Fire Safety Systems				
5-13	Halon system	25	35	60	
5-13	Other fire protection	19	12	31	
				91	2,762
5-1	UTILITIES				
5-1	Water supply (including well)	10	3	13	
5-1	Storm drain system	5	10	15	
5-1	Sanitary sewer system	10	-	10	
				38	38
	TOTAL ESTIMATED CONSTRUCTION				4,445

[1] Further details of items included in the cost categories are presented on the pages noted.

required and approximate coverage lengths. Civil work was based on preliminary engineering sketches and employed current price data from current project data.

Direct labor hours were estimated at unit rates for this type of work if carried out in the San Francisco Bay area. Distributable field costs were factored as a percentage of direct labor costs in accordance with normal practice, then divided between Title III services and Indirect Field costs. Engineering, and other home office costs, including fee, were estimated at 12% of field costs, and constitute Title I and II engineering services.

Contingency. An allowance of approximately 15% of the total field and engineering cost was added for project contingencies.

Escalation. All costs are presented as current day, May, 1975 with no allowance for future escalation.

Exclusions. Owner costs of land, staff engineering, training of personnel, development of computer software, startup, and interest during construction are excluded from the estimate.

The costs of the station lead-acid battery (Ref. Section 5.1.2) and of the dc fuses (Ref. Section 5.1.4) are excluded from the estimate.

The cost of an Environmental Impact Report (or Statement) and environmental data acquisition is excluded from this estimate since the site location and funding organization are unknown at present.

6.1.2 Site Assumptions

The following assumptions apply to the development of site costs:

- Site is accessible by improved road
- Site is level and clear of heavy growth

Excavation

- No rock to be encountered
- No water to be encountered
- No piling required

Site Fill

- The material from excavation will be acceptable for fill
- No allowance has been made for fill areas for access roads, etc.

Paving

- Specifications for paving are 12" gravel base, 6" concrete and 2" of asphalt wearing course
- Allowance of $10,000 for curbs, road signs and lines other than shown on plan

Other

- Landscaping is strictly an allowance as a part of improvements to land
- Construction work-week will be to local custom but not to exceed 40 hours per week.

6.2 BASELINE FACILITY SCHEDULE

The overall design and construction schedule for the Baseline BEST facility is presented in Figure 6-1.

With the exception of the inverters, there is nothing unique in the facility; the schedule might therefore be described as typical for the design and construction of a factory-type building. The construction time shown for the building may be somewhat less than normal, but is economically feasible.

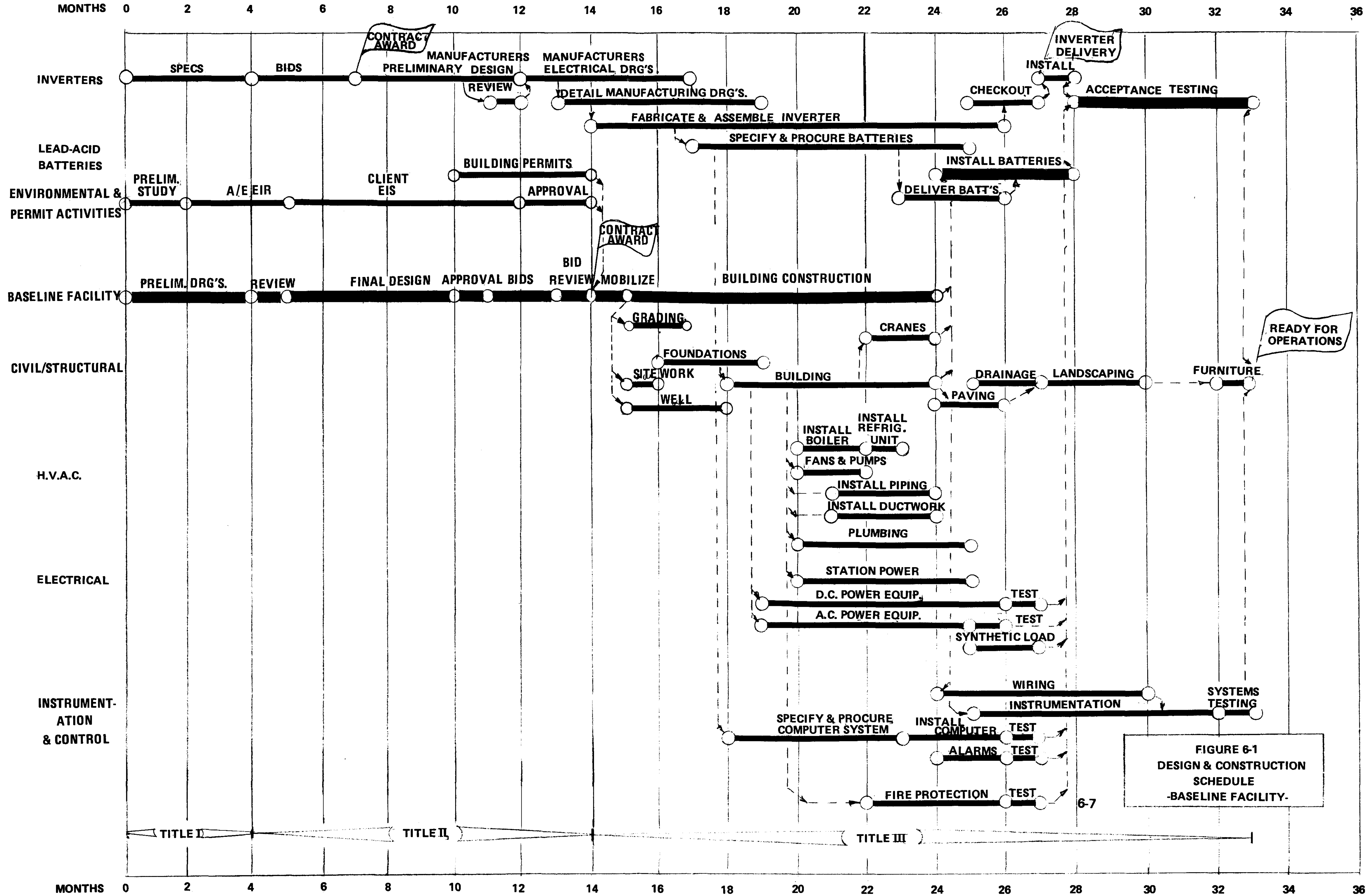


FIGURE 6-1
DESIGN & CONSTRUCTION SCHEDULE
-BASELINE FACILITY-

Generally, the sequencing of activities in the building construction are determined by the preferences of the prime contractor. Thus, the method of installing the electrical equipment is not shown, since the sequencing of busbars, transformers and switchgear equipment is not crucial and is a function of contractor choice of method, provided that delivery times are not governing.

The lead-acid batteries would be installed as soon as possible after completion of the main structure. Overhead cranes would be required, but provided there is no electrolyte in the cells, the ventilation and fire equipment would not be necessary. Four months have been allowed for the installation of the cells and connections for instrumentation.

Once the cells are installed, the inverter can be tested. As a prerequisite, both dc and ac power equipment would be fully operative, as would be the ventilation and fire systems. The computer and instrumentation would be capable of providing basic monitoring of the lead-acid batteries and inverters.

The successful development and acceptance of the inverter is the key to the early availability of the TEST Facility. However, the facility construction is shown as the critical activity since it is assumed that with expeditious preparation of specifications and sufficient incentive, inverter manufacturers could reasonably be expected to meet the schedule shown. The schedule is consistent with similar development requirements for fuel cell inverters.

Review and approval time can vary substantially, depending on the number of reviewing agencies, and whether the review period is concurrent with the design period. The times shown are therefore those assumed to be a reasonable allowance.

Broadly interpreted, Title I of the AEC Management Construction Handbook (appendix 6101) covers the requirements for preliminary design; Title II covers the requirements for definitive design; and Title III covers the services required during construction. The periods spanned on the schedule by Titles I, II and III correspond to the appropriate functions for the design and construction of the Baseline facility.

6.3 COST OF OPTIONS

This section presents costs for the options described in Section 5.2.

6.3.1 Building Structure

6.3.1.1 Reinforced Concrete Vs. Pre-Engineered Metal Construction. Use of a pre-engineered metal building instead of a reinforced concrete structure, as described in Section 5.2.1.1, pg. 5-13, would reduce the total estimated project cost (Table 6-1) by $440,000.

	$ Thousands		
	EMS[1]	C&I[1]	Total
Building-Structure Cost Reduction	118	143	261
HVAC Cost Reduction	50	18	68
Engineering, Design, Inspection Reduction			51
Contingency Reduction			60
Total Cost Reduction			440

[1] EM&S = Equipment, materials and subcontracts
C&I = Construction and installation

6.3.1.2 Existing Building. The estimated cost of performing a preliminary evaluation of an existing building, as described in Section 5.2.1.2, pg. 5-14, is $20,000.

	$ Thousands
Engineering Contract	20

6.3.2 Dc Bus System

6.3.2.1 Initially Installed 5000 A Expandable dc Bus. If a 5000 A expandable dc bus were initially installed instead of the 10,000 A bus included for the Baseline facility (as described in Section 5.2.2.1, pg. 5-15), the total estimated project cost (Table 6-1) would be reduced by $55,000.

	$ Thousands		
	EM&S	C&I	Total
dc Bus Cost Reduction	40	3	43
Engineering, Design, Inspection Reduction			5
Contingency Reduction			7
Total Cost Reduction			55

6.3.2.2 Expanding the 5000 A dc Bus to 10,000 A. The later expansion of the 5000 A bus, as described in Section 5.2.2.2, pg. 5-16, would cost a total of $90,000 (to same cost baseline as total estimated project cost, Table 6-1).

	$ Thousands		
	EM&S	C&I	Total
dc Bus	40	28	68
Engineering, Design, Inspection			10
Contingency			12
Total Cost			90

6.3.2.3 Addition of a 10,000 A dc Bus. The addition of a 10,000 A dc bus system, as described in Section 5.2.2.3, pg. 5-17, would cost a total of $690,000 (to same cost baseline as total estimated project cost, Table 6-1) if installed in conjunction with installing the Baseline facility.

	$ Thousands		
	EM&S	C&I	Total
Inverter	250	20	270
Dc System			
dc Bus	101	55	156
dc Breakers	30	6	36
dc Switches	20	5	25
Ac System			
ac Breakers	18	1	19
ac Breaker Positions	7	1	8
Wiring, Conduit	6	4	10
Instrumentation	3	3	6
HVAC	5	-	5
Engineering, Design, Inspection			60
Contingency			95
Total Cost if Installed in Conjunction With Baseline			690

The same system will cost a total of $720,000 if installed after the Baseline facility is completed.

Inverter	250	25	275
Dc System			
dc Bus	101	65	166
dc Breakers	30	6	36
dc Switches	20	5	25
Ac System			
ac Breakers	18	1	19
ac Breaker Positions	7	1	8
Wire, Conduit	6	6	12

	$ Thousands		
	EM&S	C&I	Total
Instrumentation	3	4	7
HVAC	6	-	6
Engineering, Design, Inspection			66
Contingency			100
Total Cost if Installed After Baseline Construction			720

6.3.2.4 Addition of a 5000 A dc Bus. The addition of a 5000 A dc bus system, as described in Section 5.2.2.4, pg. 5-18, would cost a total of $582,000 (to same cost baseline as total estimated project cost, Table 6-1) if installed in conjunction with installing the Baseline facility.

	$ Thousands		
	EM&S	C&I	Total
Inverter	250	20	270
Dc System			
dc Bus	50	50	100
dc Breakers	17	4	21
dc Switches	7	3	10
Ac System			
ac Breakers	18	1	19
ac Breaker Positions	7	1	8
Wire, Conduit	6	4	10
Instrumentation	2	2	4
HVAC	6	-	6
Engineering, Design, Inspection			53
Contingency			81
Total Cost if Installed in Conjunction with Baseline			582

The same system will cost a total of $606,000 if installed after the Baseline facility is completed.

	$ Thousands		
	EM&S	C&I	Total
Inverter	250	25	275
Dc System			
dc Bus	50	60	110
dc Breakers	17	4	21
dc Switches	7	3	10
Ac System			
ac Breakers	18	1	19
ac Breaker Positions	7	1	8
Wire, Conduit	6	6	12
Instrumentation	2	3	5
HVAC	6	-	6
Engineering, Design, Inspection			56
Contingency			84
Total Cost if Installed After Baseline Construction			606

6.3.3 Expanding the Computer System

The Baseline facility computer system will be capable of testing one battery system. Therefore, as explained in Section 5.2.3, pg. 5-18, an expansion would entail the addition of a satellite computer system (including a TTY terminal) with the required number of data channels. A second type of expansion would entail adding data channels to an existing satellite computer system. Since there may be variations in this option, the following table (Table 6-3) presents cost data from the manufacturers in terms of purchase price, and not in terms of ultimate installed cost.

TABLE 6-3

COMPUTER SYSTEM EXPANSION COSTS

(Purchase Price Only)

	Digital Equipment Corp.	Hewlett-Packard
Satellite System	$32,990	$24,790
Cost per data channel[1]	$91 to $98	$101 to $104

From Table 6-3, it can be seen that the nominal purchase price of a Digital Equipment Corporation satellite system with 2500 (Ref. Table 4-2) data channels (at $95/channel) would be $270,000. These systems are factory wired and require negligable installation labor. However, adding the cost of engineering to plan the addition and a 15% contingency to the purchase price yields a total cost increase of $348,000 at the same cost basis as the total estimated project cost (Ref. Table 6-1). Installation at a future date would result in approximately the same cost in terms of May 1975 dollars.

The equipment required for the addition of 1700 data channels to an existing satellite system (e.g., increasing the 800 channels initially installed in Battery Room 1 to 2500 channels) would have a purchase price of $162,000. When engineering and contingency are added, this becomes $209,000 at the same cost basis as the total estimated project cost (Ref. Table 6-1).

6.3.4 Synthetic Load

Omitting the synthetic load and its associated equipment, as described in Section 5.2.4, pg. 5-19, will reduce the total estimated project cost (Table 6-1) by $255,000.

[1]Due to the nature of the hardware designs, the data channels must be added in groups of up to 1000 to achieve this price range.

	$ Thousands		
	EM&S	C&I	Total
Ac System Cost Reduction			
ac Breaker	18	1	19
ac Breaker Positions	7	1	8
Synthetic Load	135	23	158
Wire, Cable, Conduit	5	6	11
Engineering, Design, Inspection Reduction			24
Contingency Reduction			35
Total Cost Reduction			255

6.3.5 Forklift

The addition of a side-loading guided forklift, as described in Section 5.2.5, pg. 5-19, would cost a total of $45,000 (to same cost baseline as total estimated project cost, Table 6-1).

	$ Thousands		
	EM&S	C&I	Total
Forklift	35	-	35
Engineering, Design, Inspection			4
Contingency			6
Total Cost			45

Section 7
ENVIRONMENTAL AND SAFETY ASSESSMENT

A preliminary environmental and safety assessment for the BEST facility was conducted by Bechtel and presented in detail in a September, 1974 report (Ref. 15). The changes made in the BEST facility design as a result of the current conceptual design effort result in no specific impacts on the considerations, conclusions, and recommendations presented therein, except that the tornado and seismic design requirements no longer apply (see Design Criteria, Section 4.1).

Nevertheless, it should be noted that the environmental and safety aspects of new operations are receiving ever-increasing public attention, and new laws and regulations are continuously promulgated. Hence, the type of environmental report which will eventually be required, and the various environmental and safety regulations to which the operating BEST facility must conform, may be expected to change. Such requirements will also be strongly dependent on the location of the site, and on the agencies involved in its construction and operation. While environmental and safety considerations are presented in Reference 15, and discussed in various other sections of this report, pertinent highlights of those considerations are included here as a general summary of the issues as they relate to the present Baseline facility.

7.1 ENVIRONMENTAL CONSIDERATIONS

Provisions for the control of all forms of environmental pollution must be considered in the early stage of site planning and preliminary design. Potential sources of water and air pollution should be designed or planned to conform with the policy, objectives, standards, and requirements of AECM 0510, "Prevention, Control, and Abatement of Air and Water Pollution". No significant air pollution from the plant is expected during normal operation. Mishap conditions could produce noxious gases and, when a state has been selected for the site, a check of the state air pollution regulations should be made to see whether an air cleaning device is needed under such conditions. In general, control of all forms of pollution during construction and operation phases of the project will be performed as follows:

7.1.1 Air Quality

- During construction, care will be taken to reduce emissions from the heavy construction equipment and any open burning used for site preparation.
- Areas or main roads traversed regularly by heavy equipment will be wetted down and in some cases graveled to prevent dust from becoming airborne at the construction site.
- During normal operation, the principal effluent emitted by the facility will be warm air, and no national or state emission limit exists in regard to this heat release.
- The principle emissions from the lead-acid batteries will be hydrogen and oxygen, and possibly some small quantities of arsine or stibine gases. Ambient air quality standards do not exist for these gases at the state or national level. The minute amount of acid mist evolved should be only a small fraction of that allowed by emission regulations or standards.
- A fire or the accidental escape of chemicals from the interior of a battery cell could result in the release of toxic gases or toxic smoke into the atmosphere. As a rule, states require that an upset condition that results in the release of pollutants be reported to the local air pollution control agency, but no state requires that control equipment be installed for the sole purpose of collecting the gases that could be released as the result of a mishap.

- As battery system designs become more fixed, the probability of a mishap and the amounts of pollutant which may be released can be better evaluated. A determination can then be made as to whether or not a dispersion calculation should be made for the site. Selection of a remote site would mitigate the need for such calculations.

7.1.2 Water Quality

- Precautions will be taken to protect the quantity and quality of any ground water and surface water at the site during construction.

- An appropriate sewage treatment plant will be provided to treat the effluent from the BEST facility.

- Standards of the Water Pollution Control Federation, the Conference of State Sanitary Engineers, and the American Society of Civil Engineers pertaining to sewage systems and sewage treatment methods will be used as guides in designing the sewage treatment plant.

- Since some ground water will be used by the BEST facility, tests will be made to determine what effect withdrawal might have on the depth of the water table in surrounding area. However, the amount of water required for the facility can be expected to produce only a minor impact on the local water table.

- Sumps will be provided to collect any liquid chemicals which may be spilled as a result of mishap. Should a spill occur, the quantity of chemicals released is expected to be small. Any chemicals collected in the sumps would be removed and trucked to a facility for their proper disposal.

7.1.3 Noise

- Some states, such as Oregon, require that no new industrial or commercial noise source shall increase the ambient noise level by more than 10 dB. Other states, such as Illinois, require that no facility noise shall exceed the noise levels specified for the land zone where the facility is built. Since noise regulations differ from state to state, prevailing regulations of the state selected for the site of the BEST facility will be adhered to.

- Proper noise control will be performed to meet applicable community noise ordinances, Regulations of the Occupational Safety and Health Act concerning occupational noise exposure, and any other applicable legislation or regulations.

7.1.4 Solid Wastes

- Combustible solid waste generated by clearing and devegetation of the project site during construction will be burned if the local regulations allow open burning, or a local contractor will be hired to haul the materials to a sanitary landfill or other appropriate disposal site, along with non-burnable wastes of no salvage value.

7.1.5 Biological Aspects

- The site selection process will take into consideration the presence of any rare, endangered, or unique species and the existence of habitats or other wildlife species whose disruption may ultimately affect such critical species. Although, due to the size of the facility, it is anticipated that the impact on terrestrial ecology will be insignificant.

- If the BEST facility is located near natural surface water and rains can be expected during construction, measures will be taken to remove suspended materials and turbidity from storm runoff.
- The impact of the completed facility on aquatic ecology is expected to be insignificant.

7.1.6 Social/Economic Aspects

- A land-use analysis and impact assessment of the chosen site and its surroundings may be required to satisfy federal, state, or local requirements. The permit requirements for the BEST facility would be determined as an early activity in the site selection phase of project development.
- The area where the BEST facility is located will be studied for any possible changes that might occur in the economic structure of the region due to the operation of the facility. It is unlikely that the BEST facility will produce significant impact on local economic structure.
- A review of the National Register of Historic Places will be made as a part of the site selection process as required by Public Law 93-291, if a federal agency is involved with the construction. Similar requirements exist in many states for any new construction. The appropriate state liaison officer for historic preservation will be consulted concerning properties under consideration for nomination to the National Register of Historic Places. An archaeologist familar with the area will review the selected site and make recommendations about ways to mitigate the loss of any important historic or prehistoric resources.

In summary, it is anticipated that the impact on the environment resulting from the construction of the BEST facility will be minimal and far outweighed by the benefits to be derived from the successful development of battery energy storage. However, environmental considerations must continue to be taken into account during future phases of the facility's development in order to assure compliance with applicable regulations.

7.2 SAFETY CONSIDERATIONS

The design of the BEST facility will meet the occupational safety and health standards required by the Occupational Safety and Health Act (OSHA) of 1970, the National Fire Codes of the National Fire Protection Association (NFPA) and other such codes as will be applicable.

Protection of personnel from energized electrical equipment will be accomplsihed by metal enclosures, cabinet door interlocks and lockable switchgear. Protection of the equipment itself will be afforded by the design of the electrical system. Additionally, the computer will detect abnormal system operations and initiate corrective action.

Fire protective measures in the Baseline facility will vary according to the special needs of individual rooms. The presence of electrical, electronic, and chemical equipment precludes the use of water as a fire extinguisher for most of the building. However, a standard sprinkler fire protection system will be installed for the office area. Because of the computer equipment installed therein, a Halon gas system will be used in the control and data analysis rooms. If desired, a system to flood the inverter cabinets with Halon gas could be designed but this is not currently included for the Baseline conceputal design. Portable dry chemical fire extinguishers will be provided in the shop and inverter areas and in Battery Room 1 (while the lead-acid system is installed). Portable fire extinguishers, charged with MET-L-X, will be provided for the high temperature battery rooms. In addition, the Baseline facility will be provided with a self contained, fire approach suit.

The Baseline facility will provide fire detectors and alarm systems in all areas. In battery rooms which will house high temperature batteries, the special fire detectors for cooling ducts and toxic gas detectors will not be installed as part of the Baseline facility since the schedule and order of arrival of the batteries requiring such systems are not known at present. Similarly, the chlorine detectors required for the ESB sodium/chloride battery and for EDA's zinc/chloride battery will not be installed initially. These detectors will alarm upon detection of chlorine gas concentrations at the threshold limit value of 1 ppm. Upon such an alarm, battery charging or discharging will be stopped.

A hydrogen detection system will be installed with the station lead-acid battery. Also, a hand-operated detector for arsine and stibine will be available in the lead-acid room. If lead-antimony type cells are installed, the concentration of stibine should be checked whenever cell voltages exceed 2.45 volts during charging. Detector systems will be tied into the facility control and relaying network as required.

TV cameras in the battery rooms and monitors in the control rooms will assist in determining the status of each room.

Other safety features will be provided by the design of the building. These include:

- Sloped floors and sumps to collect chemical spills
- Fire resistant walls
- Exterior walls designed to collapse and relieve pressure in the event of explosions or tornados (the remainder of the building will be designed to remain intact during such occurrances)
- Outward opening fire doors

A designed flow rate of 50,000 scfm for the HVAC system in the lead-acid battery room will be sufficient to keep the concentration of hydrogen in the room below 1.75% to prevent combustion. Furthermore, the system will be designed to eliminate any localized concentration of hydrogen. In this regard, ventilation duct ports will be located flush with the ceiling to avoid places where hydrogen might accumulate. During normal battery operation, 80% of the air ventilated from the room will be recirculated in the HVAC system. However, the HVAC system will also be capable of exhausting the entire ventilation flow. If an excess concentration of hydrogen is detected in the room, battery charging will cease and room ventilation will be exhausted rather than recirculated. The power for the exhaust fan will be supplied by the UPS so that hydrogen can still be removed from the room during loss of normal power.

The lead-acid battery room will be provided with special equipment for working in the presence of acid. Rubber aprons, boots, gloves, and a face shield will be available in the room. In addition, the room will be equipped with eyewash stations and deluge showers. Sodium bicarbonate in dry powder form will be available for neutralizing spilled battery acid. The battery cells will be equipped with flash arresters to prevent flame propagation into a battery cell. These arresters will also mitigate the release of acid mist from the cells.

An emergency lighting system will provide adequate lighting in the event that all normal power to the building is lost.

In addition to safety considerations in the design of the facility, precautions should be taken during operation of the facility. For example, since water will react with sodium or lithium, water should not be permitted in the high temperature battery rooms. It is recommended that the battery manufacturers provide safety manuals that list various safety measures to be followed when working with their batteries.

Also, a safety manual should be written for the BEST facility to establish safety measures (such as the insulation of metal tools for use in the vicinity of any exposed bus or terminals on the lead-acid battery system) and delineate procedures to be followed during normal operation and for an upset condition.

APPENDIX

COMPARISON OF ALTERNATIVE DC BUS SYSTEMS

During the conceptual design, seven basic dc bus types were found that satisfy the design criteria. In order to determine the optimum bus type for the Baseline facility, a comparison of these seven bus types was made and is summarized on the attached table. The optimum bus type is the laminated-bar type designated "Base System" in the table.

COMPARISON OF ALTERNATIVE DC BUS SYSTEMS

FOR THE BASELINE FACILITY

DC Bus Type	Cable-in-Tray	Cable-in-Trench	Iso-Phase-Bus	Segregated-Bus	Non-Segregated-Bus	Laminated-Bar-Bus (Base System)	Log-Bus
Physical protection of bus	Covered tray and cable insulation	Covered trench and cable insulation	Metal-enclosed per NEMA	Metal-enclosed per NEMA	Metal-enclosed per NEMA	Metal-protected on all sides by expanded screening	Metal-protected on all sides by expanded screening
Insulation							
Phase-to-Phase:	6000 V Rubber	6000 V Rubber	6000 V Porcelain	6000 V Plastic	3000 V Plastic	3000 V Porcelain	3000 V Porcelain
Phase-to-Ground:	3000 V Rubber	3000 V Rubber	3000 V Porcelain	3000 V Plastic	3000 V Plastic	3000 V Porcelain	3000 V Porcelain
Bracing	Inherent 200,000 A +	Inherent 200,000 A +	Inherent 200,000 A +	Inherent 200,000 A +	Compression Bracing 200,000 A	Compression Bracing 200,000 A	Inherent 200,000 A +
Extending	Wye-splice cables, 16 splices and extend 8 cables	Wye-splice cables, 20 splices and extend 10 cables	Tee connection on bus and on enclosure	Tee connection on bus and on enclosure	Tee connection on bus and on enclosure	Bolted connection on bus	Butt-weld on bus
Incremental cost above base system(1)							
5000 A	+ $ 20,000*	+ $ 55,000*	+ $140,000*	+ $185,000*	+ $ 85,000**	BASE FOR 5000 A**	+ $ 40,000*
10,000 A	+ $130,000*	+ $185,000*	+ $175,000*	+ $215,000*	+ $130,000**	BASE FOR 10,000 A**	+ $ 75,000*
Advantages	Ideal for dc/ac at 2000 A or below Easy to modify routing	Out-of-the-way	Ideal for ac bus from 6000 A to 20,000 A	Ideal for ac bus from 4000 A to 6000 A	Ideal for ac bus from 1200 A to 4000 A Easy to expand	Ideal for dc bus from 2000 A to 30,000 A Easiest to expand	Ideal for dc bus 30,000 A and above
Disadvantages	Difficult to expand Largest cross-sectional area	Most difficult to expand	Difficult to expand Largest bus system cross-sectional area	Difficult to expand Requires close tolerances			Difficult to expand Only available in aluminum bus

(1) Does not include engineering and is based on copper bus systems (except log bus) as received in verbal* or formal quotations** between February and May, 1975

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