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A Study To Investigate the Basic Switching Impulse Insulation Level Requirements for a 1200 kV CGIT Cable System

July 1979

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Prepared for:

U.S. Department of Energy
Assistant Secretary for
Energy Technology
Electrical Energy Systems

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A Study To Investigate the Basic Switching Impulse Insulation Level Requirements for a 1200 kV CGIT Cable System

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A STUDY TO INVESTIGATE THE BASIC SWITCHING IMPULSE INSULATION LEVEL REQUIREMENTS FOR A 1200 kV CGIT CABLE SYSTEM

1. SUMMARY

A study was performed to determine the switching surge voltages a prototype 1200 kV CGIT cable may be exposed to under service conditions. The results of this study were used to establish the system's basic switching impulse insulation level requirements.

An investigation was made of a suitable CGIT model to be employed for use on the Westinghouse transient network analyzer. The model chosen was applicable for the cable when its sheaths are solidly grounded. This model was employed for each of the four cable lengths investigated. Cable lengths of 600 ft, 2 miles, 10 miles and 50 miles were investigated in four general system configurations, in all 47 systems were studied.

The overhead systems which the cables will be used in conjunction with require the switching surge voltage to be limited to 1.5 p.u. This is accomplished with the use of multiresistor insertion circuit breakers. The reduction of breaker generated switching surges reduced the overall importance of the normal switching operations performed in the system as compared with those generated by contingency switching and fault initiation. The maximum overvoltages to which the cables were exposed to were generated by reclosing into single line to ground faults and by single line ground faults occurring on the adjacent overhead system.

The maximum normal switching surge overvoltage the cables were subjected to was 1574 kV which resulted from high speed reclosing operations. The maximum overvoltages resulting from the contingency switching operation was 2165 kV.

The recommended switching impulse insulation level was established using the surge arrester protection characteristics. The resulting insulation level requirements are 2031 kV based upon the use of a conventional surge arrester and 1806 kV based upon the use of a ceramic oxide arrester.

The initial surge arrester discharge currents appear to be excessive for two conventional arrester designs. In addition, the electrical characteristics and energy capabilities of the "Gapless" arrester were not available. It was recommended that the arrester manufacturers be contacted to verify the adequacy of these surge arrester applications.

2. THE 1200 kV TRANSMISSION SYSTEM

The main objective of our analysis was to define the electrical stresses to which the cable may be exposed as a result of switching operations which occur in the system. In order to accurately define these maximum cable transient overvoltages, however, the specifications of the system to which the cable will interface were first defined.

2.1 The Overhead System

The two specifications of the 1200 kV overhead system which were important in guiding the study were the permissible transient overvoltages which determined the overhead line insulation levels and the overhead line configuration itself.

Although commercially operating UHV systems are not yet in service, typical specifications for a 1200 kV system have been established.(1) The characteristics of the 1200 kV overhead system were assumed to be similar to the BPA's prototype 1100 kV three phase test line. The overhead design employs a triangular configuration with each phase constructed of an eight conductor (chukar) bundle. Figure one indicates the construction from which the overhead line parameters were calculated for use throughout the analysis. Insulation levels in UHV systems are largely determined by the switching surge stresses. Specifications indicate economic insulation levels for the 1200 kV system are realized with the switching surge overvoltages limited to 1.5 pu. These relatively low switching overvoltages have been achieved in the past with the use of multistep resistor insertion.(2)

The source from which the line was switched was chosen to have a short circuit capability of 40,000 MVA with the ratio of positive to zero sequence source impedance equal to unity.

2.2 Cable Systems Studied

Four general cable-overhead configurations were considered in the study. These configurations (Figure 2) were chosen to reflect typical applications of the cable in the system.

The first system was chosen to simulate underwater river crossings or underground links through populated areas. Cable lengths of 600 ft and 2 miles were simulated in conjunction with overhead line lengths of 50, 100 and 150 miles.

The second and third configurations were chosen to represent "Get-aways" from UHV substations. These configurations represent the two typical switching operations to which a cable may be subjected while applied to an overhead line terminal. Cable lengths of 600 ft, 2 miles, 10 miles and 50 miles were each simulated with overhead line lengths of 50, 100, and 150 miles.

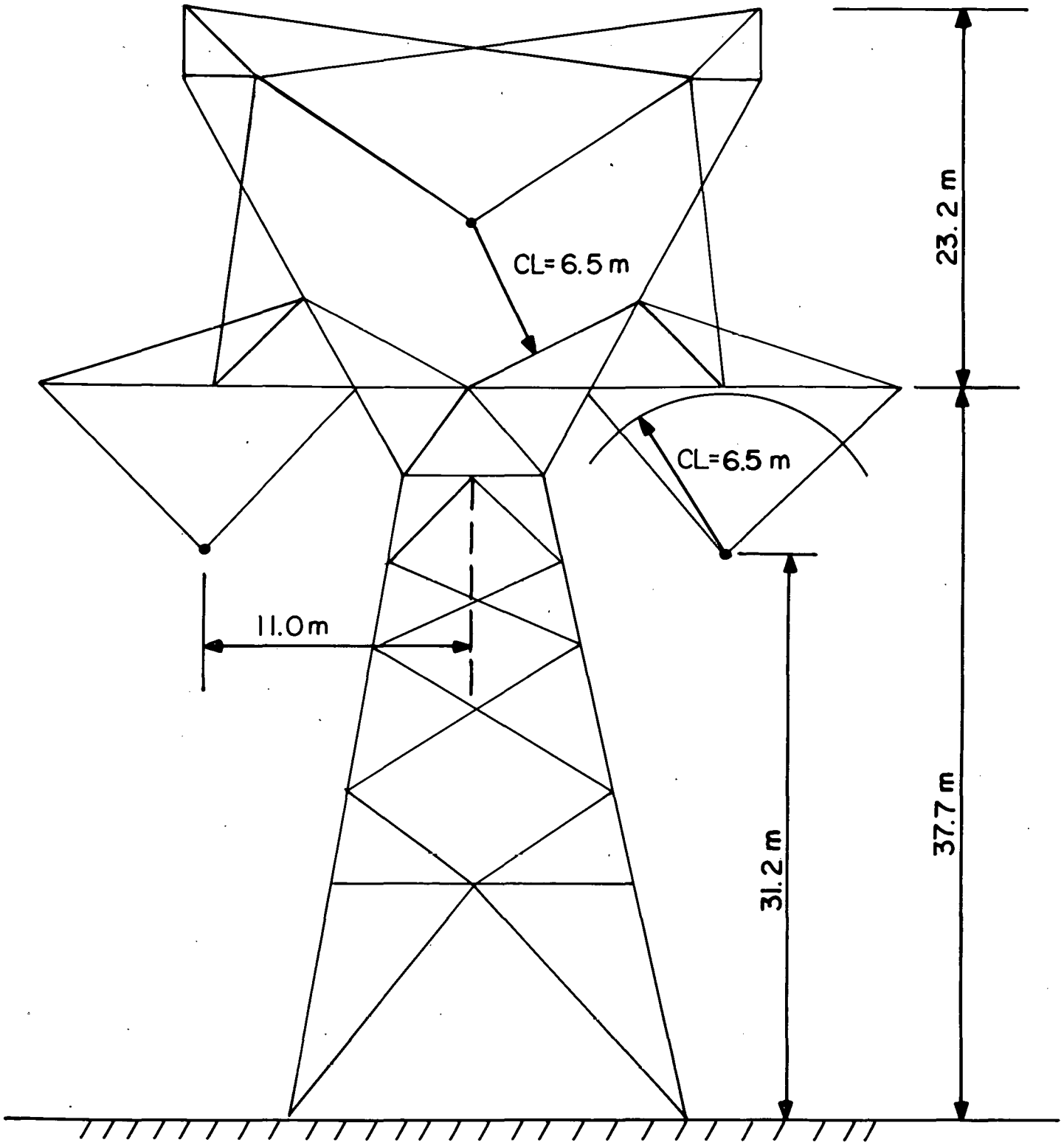


FIGURE 1 - Proposed Configuration for Bonneville Power Administration's 1100 kV Lyons Test Facility

The fourth system was composed of two lengths of cable applied at both overhead line terminals. Again, the overhead line lengths of 50-100-150 miles were each simulated with cables at each terminal. Cable lengths at the line sending terminal of 10 and 50 miles were simulated in conjunction with 600 ft, 10 miles and 50 miles of cable applied at the line receiving terminal.

GENERAL SYSTEM CONFIGURATIONS

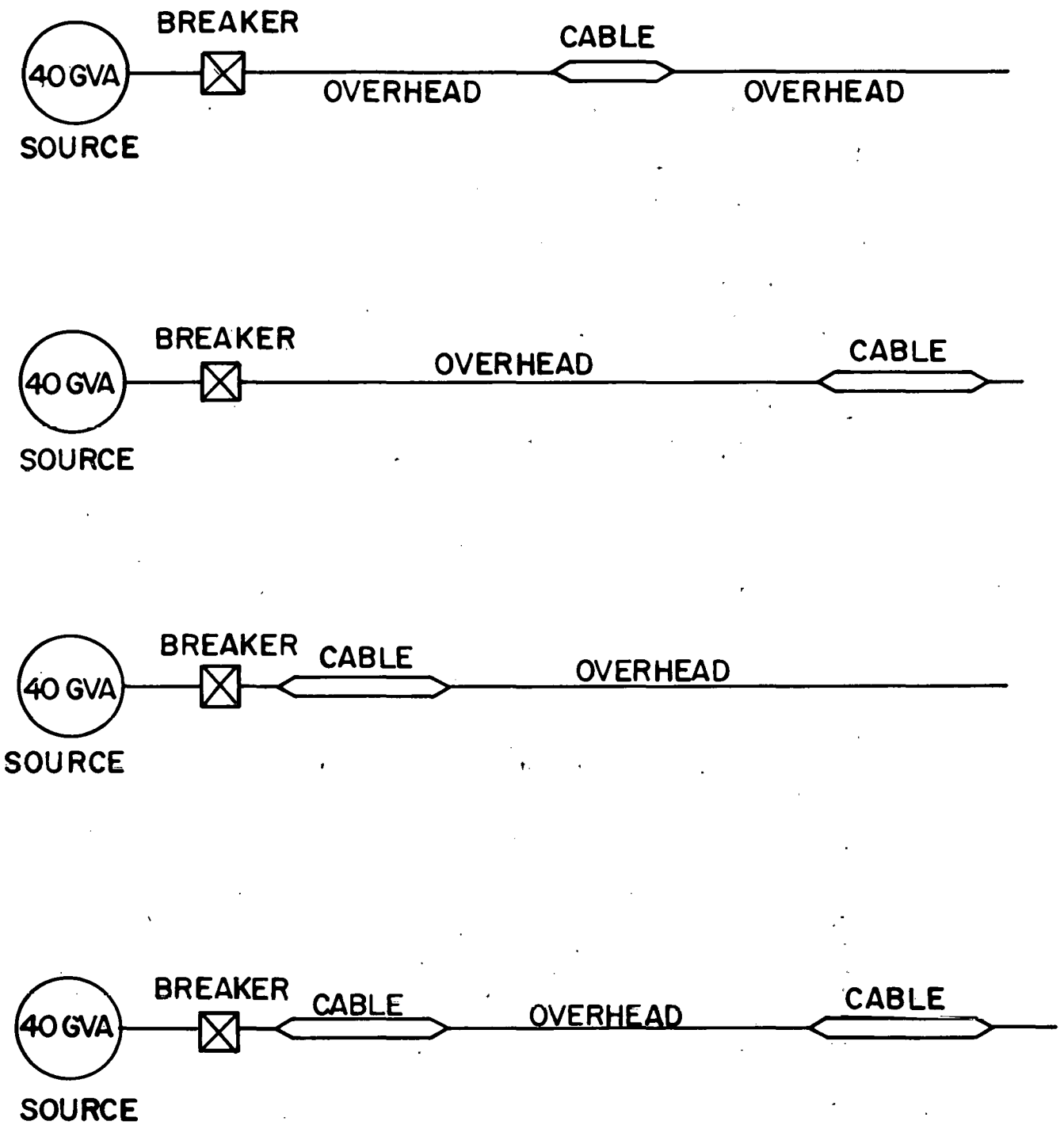


FIGURE 2

3. SYSTEM MODELING

The Westinghouse Analog Computer (ANACOM) specifically designed for use in the study of power system transient phenomena was employed as our analytical tool throughout the study. The ANACOM is primarily a passive element device. Models are comprised of resistive, inductive and capacitive elements in a manner to accurately represent various power system components. The following sections will define the models which were utilized.

3.1 Overhead Transmission Line Model

As indicated in Figure 2 each of the systems studied were composed partly of overhead 1200 kV lines. Analog devices typically model distributed parameter elements such as overhead transmission lines and cables using "Pi" or "L" sections. These sections when arranged in a cascaded network closely approximate the transient performance of the line. Figure 3-A depicts such a "Pi" section.

The specific model utilized to simulate the overhead has the added capability of representing the frequency dependent nature of the earth return impedance in addition to modeling electrostatic and magnetic unbalances inherent in lines which are nontransposed.

Each of the "Pi" section's parameters were adjusted to represent 5 miles of overhead line. Thus, a minimum of 10 "Pi" sections were used for the 50 mile line with a maximum of 30 being utilized for the 150 mile line.

3.2 The 1200 kV Source

The source from which the overhead-cable lines were switched was chosen to have a short circuit (3 phase) capability of 40,000 MVA with an X_0/X_1 ratio of unity. The source was represented with the lumped network elements as shown in Figure 4.

3.3 1200 kV Circuit Breakers

In order to limit overvoltages to acceptable magnitudes, a circuit breaker design utilizing 2 step resistor insertion was modeled. Figure 5 shows schematically one pole of the breaker. The resistive elements themselves were elements available on the ANACOM with the breaker contacts simulated with mercury wetted relays. The relays are controlled electronically to precisely control closing times and breaker pole spans.

Each resistor insertion time was chosen as 6 ms with the pole span chosen to be 5 ms.

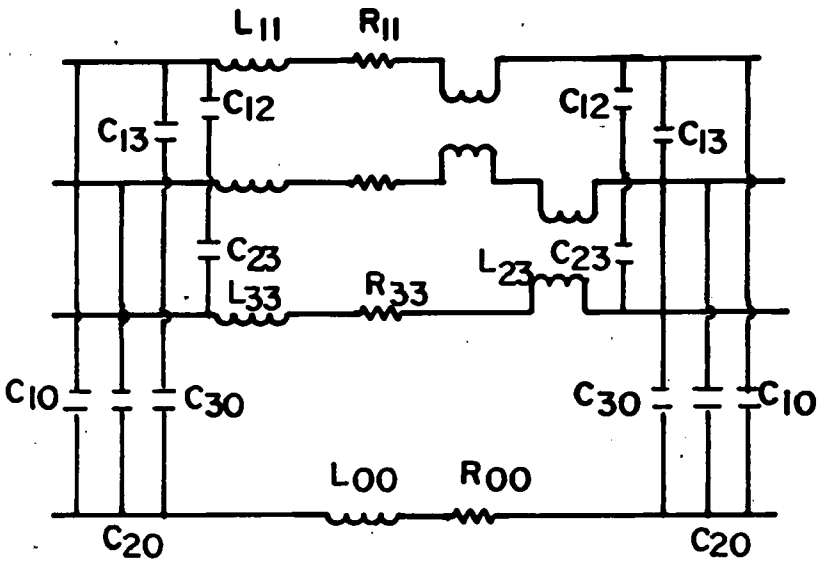


FIGURE 3A Non-transposed Pi Section Model

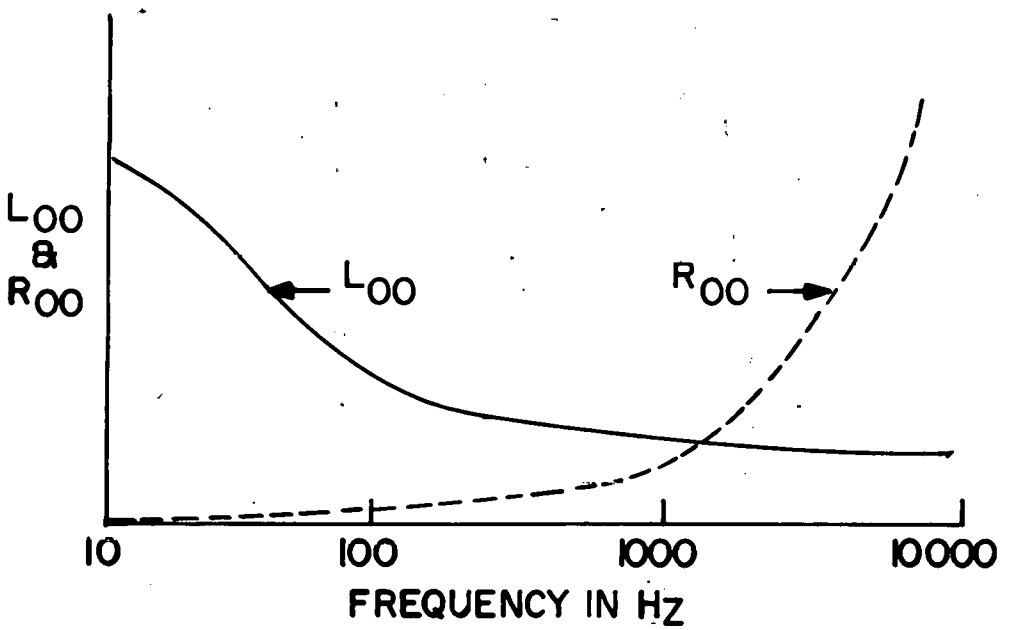
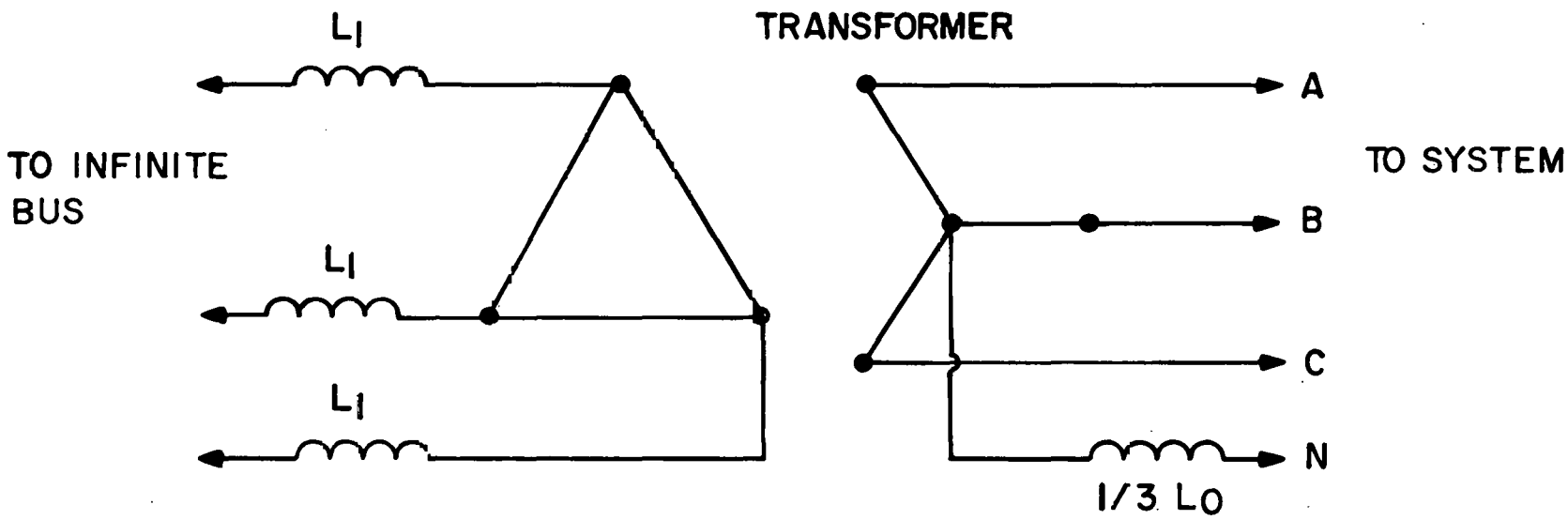


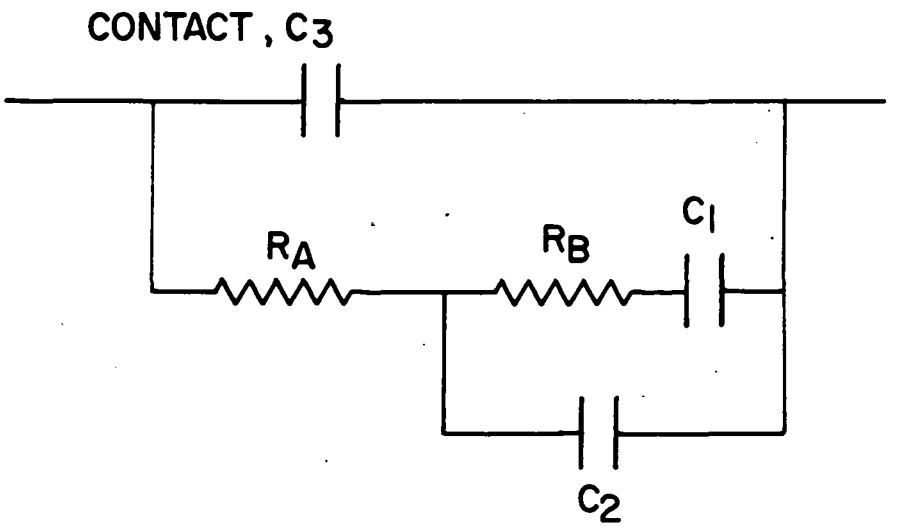
FIGURE 3B Typical characteristic of Earth Return Inductance and Resistance vs Frequency.



SOURCE REPRESENTATION

FIGURE 4

ONE POLE OF MULTISTEP RESISTOR INSERTION BREAKER



CONTACT CLOSING SEQUENCE $C_1 - C_2 - C_3$

FIRST RESISTANCE INSERTION VALUE = $R_A + R_B$
SECOND RESISTANCE INSERTION VALUE = R_A

FIGURE 5

3.4 Cable Model

Initial modeling efforts for the CGIT cable were aimed at developing parameters for three isolated phase configurations. The three proposed systems were the totally and partially buried system in addition to a overhead cable system. Figure 6 indicates these configurations.

The exact nature of the grounding scheme which will be utilized was not uniquely defined. Our initial efforts were thus aimed at developing an isolated phase model general enough for adaptation to various sheath grounding schemes.

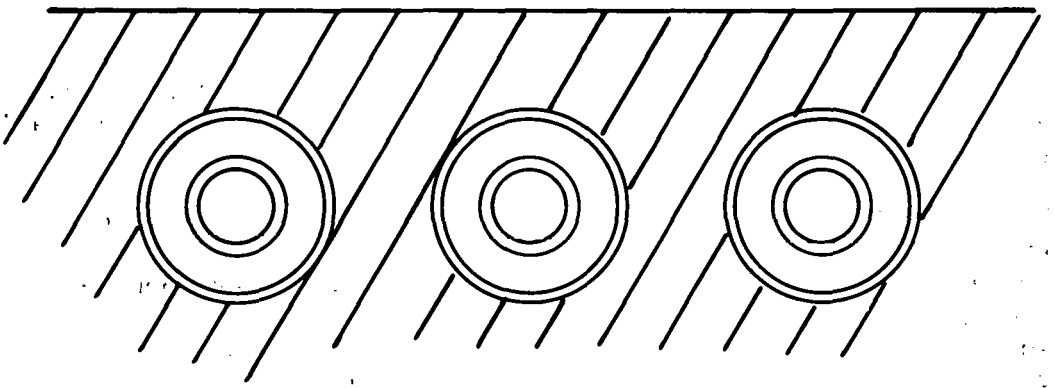
The grounding schemes of particular interest were the solidly grounded systems which would be applicable for relatively short cable lengths due to the high sheath losses and cross bonding schemes which may be suited for longer cable systems due to the inherent lower sheath losses. Efforts were first directed at determining the model parameters for the cross bonding system due to the generality of the model.

In the cross bonding scheme, both the phase and sheath conductors are treated separately necessitating the calculation of the self and mutual inductance and capacitance parameters. In each of these configurations, therefore, six conductors were situated with respect to a conducting plane (earth). This rather formidable geometry made the calculation of the interconductor parameters a complex problem.

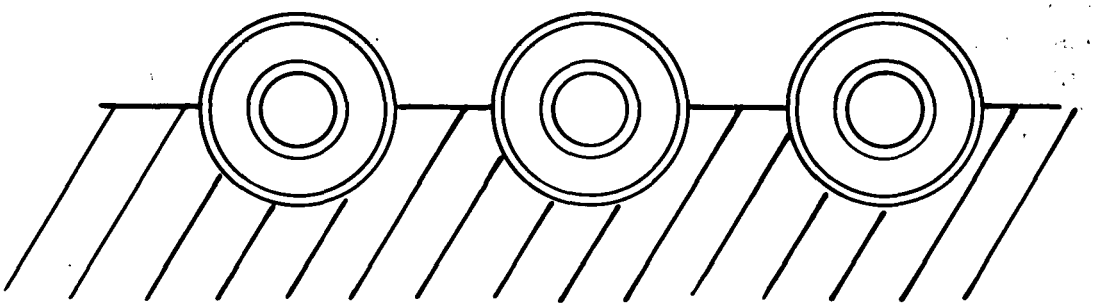
In an effort to accurately define these parameters, the first technique which was applied was conformal mapping method. It was hoped with the use of combinations of mappings transformations, the geometry of the system would be simplified to a point where the system parameters could be readily determined. In concept form, this approach can be applied to the simple geometry of a cylinder located very close to the Earth's surface. Such a Geometry would partly exist for example in the overhead cable systems. Applying the transformation indicated in Figure 7 the surge impedance of the coaxial system was first calculated and then transformed to the original system.[5]

The geometry of the above ground system contains six such cylinders above a conducting plane. It was hoped each of these conducting boundaries could be taken into consideration with a technique similar to the one above. The underground system from a transformation standpoint was comprised of exactly the same geometry with merely the conductivities of the various regions interchanged. Therefore, the same transformation would be utilized for these two configurations. The partially buried system would then require a second transformation. This technique was studied by trying to apply several transformations in succession in efforts to simplify the system's geometry. Although conceptually appealing, our efforts failed in introducing a suitable "Set of Transformations". A second method was thus tested.

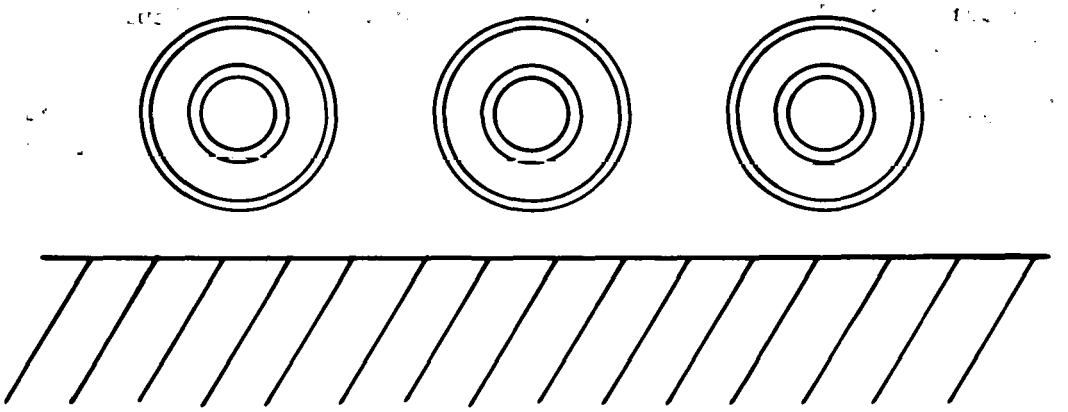
CABLE CONFIGURATIONS



UNDERGROUND SYSTEM



PARTIALLY BURIED SYSTEM



ABOVE GROUND SYSTEM

APPLICATION OF CONFORMAL MAPPING

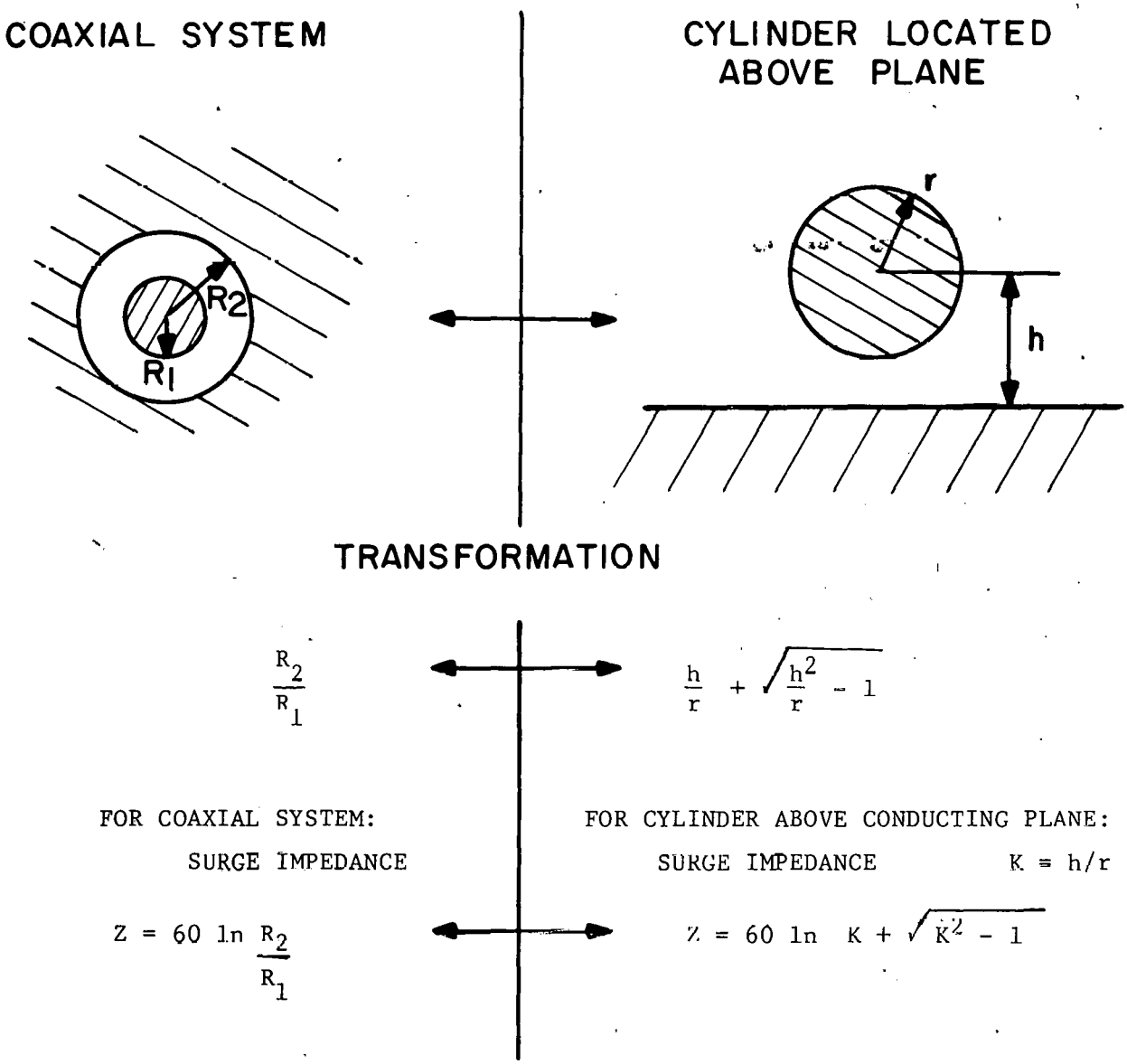


FIGURE 7

The second method tested was the use of a Pseudo Finite element technique which consisted of "Stranding" each of the phase and sheath conductors. Figure 8 illustrates this technique for the above ground configuration. This method essentially treats each strand of the phase and sheath cylinders as separate conductors. The interconductor parameters are then calculated and with suitable assumptions reduced to an equivalent system of self and mutual inductance and capacitance parameters.

It was originally felt the existing overhead line parameter programs with minor revisions could be utilized to estimate these parameters. A small routine was prepared to calculate the coordinates of the strands comprising the conductors and adjustments were made to accommodate a large number of strands. Unfortunately, the large number of conductors became one of the limiting features of this method of calculation. In addition, major programming changes were necessary to properly reduce the large number of conductors (strands) to an equivalent system of sheath and phase parameters. For the underground system representations, changes were again required to modify the Earth return correction factors. Due to the amount of development required to estimate the cross bonding parameters, it was decided model parameters for the solidly grounded system would be calculated for use in the system analysis portion of the study.

The solidly grounded cable system was modeled on a single phase basis. Each of the phases were assumed to be electromagnetically decoupled from the adjacent conductor system. This assumption eliminated the mutual inductive and capacitive parameters between adjacent sheaths and phases reducing each phase to a coaxial conductor system. Figure 9 indicates the ANACOM "Pi" section representation for solidly grounded CGIT cable in addition to the inductance and capacitance parameters.

Cable parameters are typically characterized by low surge impedances or low inductance, high capacitance values. The ANACOM has available "cable" models whose elements accurately simulate their trends in parameters and were thus used for the CGIT cable model. Cable lengths of 600 ft, 2 miles, 10 miles and 50 miles were considered. Since the parameters for the 600 ft section were insignificant when composed to the overhead line parameters, a separate model was not employed to simulate a 600 ft section. Instead, the overhead line was modeled and the transient overvoltages measured at the locations of the 600 ft cable. This was tantamount to assuming the cable being stressed uniformly over its length. This is justified due to its short length, high propagation velocity and the relatively long switching surge fronts typically imposed by an overhead system. The remaining lengths of cable were modeled with a minimum of ten Pi sections to closely simulate the distributed parameter nature of the cables.

APPROXIMATE REPRESENTATION OF THE ABOVE GROUND CABLE SYSTEM

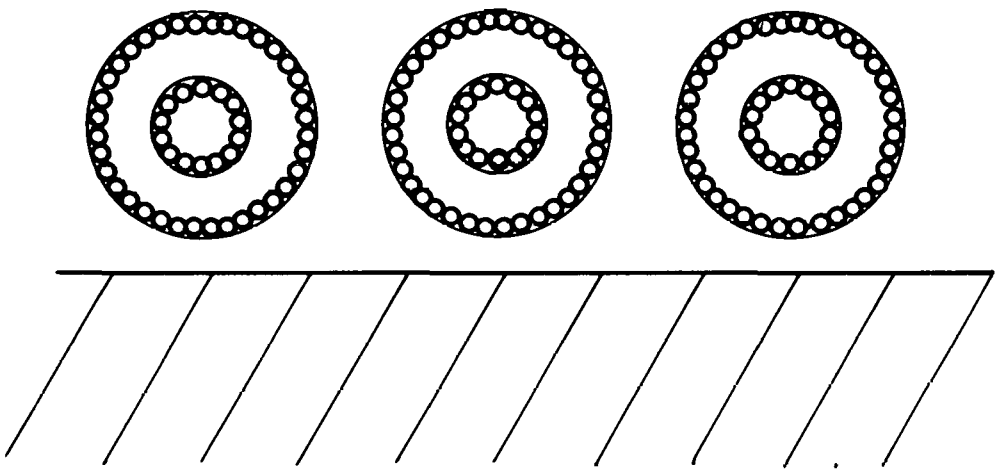
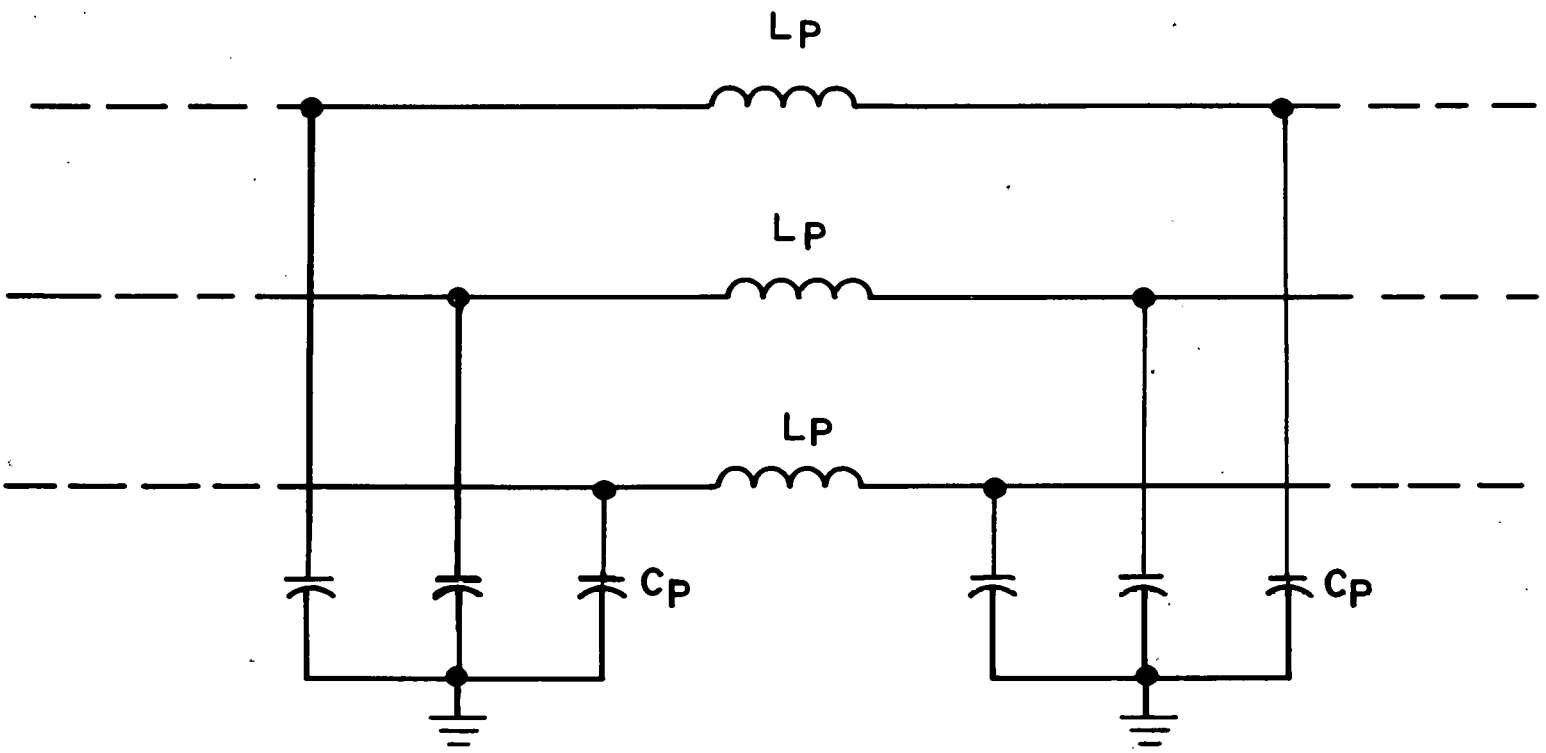


FIGURE 8

ANACOM REPRESENTATION OF THE CGIT CABLE



FOR THE ISOLATED PHASE - SOLIDLY GROUNDED SYSTEM

R_2 = inner radius of sheath

R_1 = outer radius of phase conductor

$$C_P = \frac{2\pi E_o}{\ln R_2/R_1} = 0.09 \ \mu F/mile$$

$$L_P = \frac{\mu o}{2\pi} \ln \frac{R_2}{R_1} = 0.322 \ mH/mile$$

FIGURE 9

4. SYSTEM STUDIES

The specifications which were established for the overhead system limited the switching surge overvoltages to 1.5 p.u. These levels play a major role in determining the insulation levels of the overhead system and are thus established with the normal circuit breaker operations of energizing and reclosing. Since the cables will be directly applied to the overhead system, these limited switching surge magnitudes are also impressed across the CGIT cable.

The analysis was to establish typical overvoltage levels which the cable will be exposed to under service conditions. The insulation levels established for the overhead line have restricted the energizing and reclosing overvoltages to 1.5 p.u. It was found, however, the cable will be exposed to more severe overvoltage magnitudes such as those associated with contingency switching operations such as energizing and reclosing into single line to ground faults and fault initiated overvoltages.

4.1 Study Procedure

The general procedure which was followed for each configuration was to first establish the above switching levels that were required to meet the overhead line insulation requirements. It was assumed some form of multistep resistor insertion would be required to limit the overvoltages imposed by circuit breaker operation. It was found, two step resistor insertion limited the overvoltages to the specified levels. This was accomplished by adjusting the resistor values in the circuit breaker for the energizing and reclosing operations. Since standard resistor values do not yet exist for the class of equipment, the range of these values remained flexible throughout the study. Once acceptable levels were found, these values were then used for the contingency switching cases to establish the "worst case" cable overvoltages. Fault initiated overvoltages were also investigated. Faults were placed at various points throughout the system to generate the maximum cable overvoltage. In most instances these levels were higher than the normal switching magnitudes. The data derived from the above analysis served to define the environment in which the cable may be required to operate.

4.2 Study Results

The study results summarizing the switching surge cases are shown in Figure 10 through 13. These figures tabulate the maximum transient overvoltages the cable may be exposed to for each of the systems investigated.

The Appendix contains the documented results of each of cases which were analyzed and the associated overvoltage curves. These curves serve as a graphical summary of the overvoltages for each system by indicating the maximum cable overvoltages as a function

of the circuit breaker resistor values. The fault initiated overvoltages are included on these curves to serve as a comparison with the breaker generated values.

In each of the systems studied, a great deal of control was exercised over the transient overvoltage magnitudes with two step resistor insertion. The 1.5 p.u. overvoltage specification was achieved for each of the overhead systems resulting in the maximum cable overvoltages being generated in the contingency switching and fault initiated cases.

4.2.1 River Crossing Application

The summary of the maximum transient overvoltages associated with the system simulating the river crossing cable application is shown in Figure 10. The cable length had virtually no effect on the maximum overvoltage values. In the shorter overhead line lengths considered, the fault initiated (F.I.) overvoltages proved to be the worst situation. Two cases were studied for this configuration to determine the worst fault initiated overvoltages. Faults were first located at the end of the line with one source feeding the system and was then located on the cable with two sources feeding the system. In each of the cases involving the 50 mile overhead system, the case of one source feeding the system proved to be the worst case condition. The maximum overvoltages measured in this cable application was 1715 kV (1.75 p.u.) which was produced by energizing the line with a solid line to ground fault (E-SLG) located at the receiving end of the 150 mile line. High speed reclosing with a solid line to ground fault at the receiving end of the line (RC-SLG) produced comparable results of 1666 kV (1.7 pu).

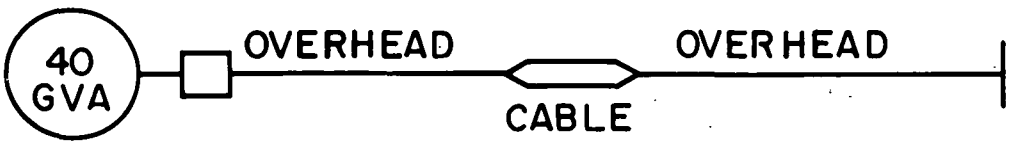
4.2.2 "Getaway" Application

The study results for the cable applied as "Getaways" are summarized in Figures 11 and 12. Although the cable transient overvoltages generated by circuit breaker operation are higher when cable is at the receiving end of the line, the fault initiated overvoltages remain relatively constant for each cable location. In cases where the cable was switched at the line sending terminal, all of the overvoltage levels were less than 1.5 p.u. Thus, a detailed analysis was not required. The maximum overvoltages for these cases is considered to the maximum levels imposed by the overhead insulation levels of 1470 kV (1.5 p.u.).

The system configuration involving 150 miles of overhead line in conjunction with 50 miles of cable required shunt compensation to limit the ferranti rise along the line. In order to limit the line rise to less than 10 percent, shunt reactors were applied which effectively compensated 20 miles of the cable. The effect of the shunt reactor was to slightly lower the fault initiated and contingency switching overvoltages.

In addition to the cable-overhead systems, cable systems alone were switched. In two of these cases considered, one step

MAXIMUM CABLE TRANSIENT OVERVOLTAGES



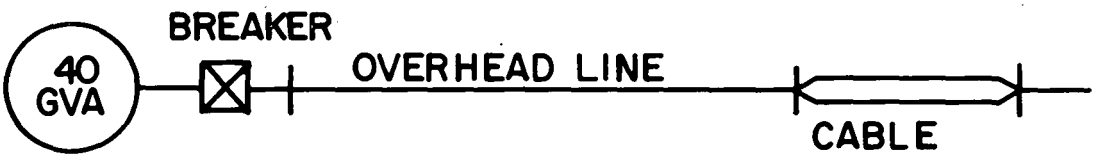
CABLE LENGTH

TOTAL OVERHEAD LINE LENGTH MILES	600 FT.	2 MILES
50	1470 kV (1.5 p.u.) F.I.	1470 kV (1.5 p.u.) F.I.
100	1568 kV (1.6 p.u.) E-SLG	1568 kV (1.6 p.u.) E-SLG
150	1666 kV (1.7 p.u.) E,RC-SLG	1715 kV (1.75 p.u.) E-SLG

$$1 \text{ p.u.} = \frac{\sqrt{2}}{\sqrt{3}} (1200 \text{ kV}) = 980 \text{ kV}$$

FIGURE 10

MAXIMUM CABLE TRANSIENT OVERVOLTAGE



CABLE LENGTH

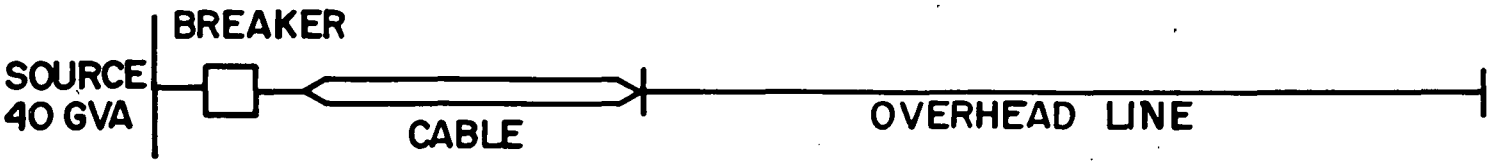
OVERHEAD LINE LENGTHS (MILES)

	600 FT.	2 MILES	10 MILES	50 MILES
50	1568 kV FI	1470 kV FI	1372 kV, 1470 kV FI , RC-SLG	1470 kV, 1568 kV FI , RC-SLG
100	1764 kV FI	1764 kV FI	(1568 kV) FI	1666 kV, 2156 kV FI , RC-SLG
150	1960 kV E-SLG	1960 kV* E-SLG	1764 kV FI , RC-SLG	1470 kV, 1813 kV FI , RC-SLG

* EXTRAPOLATED FROM 600 ft CABLE CASE

FIGURE 11

MAXIMUM CABLE TRANSIENT OVERVOLTAGE



CABLE LENGTH

OVERHEAD LINE LENGTHS (MILES)	600 FT.	2 MILES	10 MILES	50 MILES
0		1274 kV E	1274 kV E	1372 kV E
50	1470 kV FI	1274 kV FI	1274 kV E-SLG	1274 kV RC-SLG
100	1470 kV FI	1470 kV* FI	1274 kV, 1470 kV FI , RC	1176 kV, 1372 kV FI , E
150	1666 kV FI	1666 kV* FI	1323 kV, 1470 kV FI , RC	1176 kV, 1470 kV FI , RC

* EXTRAPOLATED FROM 600 ft CABLE CASE

FIGURE 12

resistor insertion served to limit the overvoltages to the point where all of the resulting magnitudes were less than 1.5 p.u. A detailed investigation was thus omitted, no resistor variations were made since virtually any practical resistor sizes controlled the transient voltages to acceptable levels. The maximum overvoltages for these cases can again be considered to be 1.5 p.u.

The largest overvoltage recorded was 2156 kV (2.2 p.u.), which resulted from reclosing into a single line to ground fault (RC-SLG). In the majority of these cases, however, the fault initiated overvoltages were dominant.

4.2.3 Cables Applied At Both Ends of An Overhead Line

Figure 13 summarizes the application of cables at both the sending and receiving terminals of the line. The results for the various length cables generally follow similar trends as the previous cases. The cables applied at the receiving terminal experienced the larger overvoltages then those applied at the sending terminal. In addition, the fault initiated overvoltages were again dominant in most of the cases with the remaining cases influenced by the contingency switching operations.

The cases involving longer cable lengths located at the line sending terminal required lower resistor sizes to limit the overvoltage to the required levels specified by the overhead insulation. This is attributed to the lower surge impedance presented by the cable which was being switched into.

The cases involving the 50 mile cables in conjunction with the 150 mile line again require shunt compensation to limit the Ferranti rise and again 20 miles of the cable was compensated to limit this rise to below 10%.

The maximum transient overvoltages recorded for this application was 1764 kV (1.8 p.u.) and was again produced by fault initiation and energizing into a single line to ground fault.

4.2.4 Summary of Results

In each of the systems studied, the maximum transient overvoltages fell within a range from 1470 kV to 2156 kV. These maximum values were generated from either fault initiation or contingency switching operations.

Although the overvoltage levels were within this narrow range, several trends are evident in the results. Cables which are located at the line receiving terminals were subjected to higher overvoltages than those applied at either the midpoint or sending terminal of the line. In general, the longer overhead systems produced the larger cable overvoltages.

MAXIMUM CABLE TRANSIENT OVERVOLTAGE

CABLE LENGTHS

OVERHEAD LINE LENGTH (MILES)	CABLE A: 10 MILES CABLE B: 600FT	CABLE A: 10 MILES CABLE B: 10 MILES	CABLE A: 50 MILES CABLE B: 600 FT	CABLE A: 50 MILES CABLE B: 50 MILES
50	< 1470 kV E - RC	1421 kV FI	< 1470 kV E - RC	1274 kV FI
	1470 kV RC-SLG	1519 kV FI	1470 kV E - RC	1470 kV, 1666 kV FI , E-SLG
100	< 1470 kV E - RC	1274 kV RC	< 1470 kV E - RC	1176 kV RC
	1470 kV FI , RC-SLG	1568 kV FI	1666 kV FI	1568 kV RC-SLG
150	< 1470 kV E - RC	1323 kV E-SLG	< 1470 kV E - RC	1470 kV RC
	1764 kV FI	1666 kV, 1764 kV FI , E-SLG	1666 kV FI	1764 kV RC-SLG

FIGURE 13

The requirements imposed by the overhead line insulation levels necessitated modification of the circuit breaker design. In addition to multistep resistor insertion which may be utilized, controlled contact closure may be included in the breaker control mechanism to further reduce the breaker generated overvoltages.[2]

Cases B-23 and B-24 located in the Appendix illustrate the effects of such additional breaker modifications. In general, the introduction of these additional breaker controls reduces the resulting overvoltages below the fault initiated levels. The fault initiated levels thus serve as a lower bound for the maximum cable transient overvoltages and further reduction in the breaker generated transients merely accentuates the importance of the fault initiated levels.

The above maximum stresses are considered typical for an UHV system and, in general, these values will vary with variations in the system parameters. If the specific system in which a CGIT cable may be applied has a lower short circuit capability than 40 GVA for instance, one would expect slightly higher overvoltages when the line is energized or reclosed with the converse also being true. The fault initiated overvoltages are dependent upon not only the ratio of positive and zero sequence surge impedances of the line in which the fault occurs, but also the impedances of the line terminations. In larger systems employing several UHV lines, faults occurring on neighboring lines located electrically close to the cable may, in addition, influence these overvoltage levels. Other investigations[4] have shown fault initiated overvoltages to occur with magnitudes as high as 2.0 p.u. under proper system conditions.

5. CABLE SWITCHING IMPULSE INSULATION LEVEL REQUIREMENTS

A summary of the maximum switching surge overvoltages for the four lengths of cable considered in the analysis is indicated in Table 1. The "normal" levels indicate the maximum stresses imposed by energizing and high speed reclosing operations. The contingency overvoltages are those produced by energizing or reclosing into single line to ground faults.

TABLE 1

MAXIMUM SWITCHING SURGE OVERVOLTAGES

Cable Length	Maximum Overvoltages	
	Normal	Contingency
600 ft	1574 kV	1968 kV
2 Miles	1574 kV	1968 kV
10 Miles	1574 kV	1764 kV
50 Miles	1574 kV	2165 kV

5.1 Criteria Used in Establishing Insulation Requirements

Two general philosophies may be used to establish the switching insulation level for non-self-restoring insulation. The first philosophy establishes the insulation levels on the basis the cable will be designed to withstand the maximum overvoltage levels the system will impose. The cable in this sense is self-protected with the insulation level set at some margin above the maximum switching surge overvoltages. The second philosophy sets the insulation level using the surge arrester to reduce the system imposed stresses. The insulation level in this case is established at some margin above the arrester protective characteristics.

Applying the philosophy that the cable will be self-protected sets the switching surge insulation requirements as indicated on Table 2. These requirements were established by setting the insulation levels 15% above the maximum overvoltage which the cable may experience.

TABLE 2

CABLE INSULATION REQUIREMENTS: SELF-PROTECTION

Cable Length	Maximum Overvoltage	Switching Insulation Level
600 FT	1968 kV	2263 kV
2 Miles	1968 kV	2263 kV
10 Miles	1764 kV	2029 kV
50 Miles	2165 kV	2490 kV

The surge arrester characteristics used to define the insulation requirements with the second philosophy are indicated in Table 3. The arrester rating considered was 864 kV, or 72% on a 1200 kV system. Two arrester designs, the conventional active gap, and the "Gapless" ceramic oxide arrester were considered. The maximum cable overvoltages were recorded at the cable terminals since switching surge wavefronts are typically much longer than that of a surge produced by a lightning stroke. The overvoltages at both the cable terminals in addition were approximately equal in magnitude. The cable length, therefore, does not dictate the location and number of arresters as may be the case for a lightning surge. The arrester protective characteristics therefore specify the insulation levels for each of the cable lengths considered. The resulting cable insulation requirements are shown on Table 4. These insulation levels resulted from adding a 15% margin to the arrester maximum switching impulse sparkover levels.

TABLE 3

- SURGE ARRESTER CHARACTERISTICS -

	Conventional	Ceramic Oxide
Arrester Rating	864 kV	864 kV
Switching Impulse Sparkover Voltage	1766 kV (1.45 pu)*	1570 kV
Switching Impulse Discharge Voltage	1766 kV (1.45 pu)	1570 kV

*(1 pu = 864kV x $\sqrt{2}$)

TABLE 4

- CABLE INSULATION REQUIREMENTS: SURGE ARRESTER PROTECTED -

	864 kV Arrester	
	Conventional	Ceramic Oxide
Cable Switching Impulse Insulation level	2031 kV	1806 kV

5.2 Recommendations

The maximum cable overvoltages were generated by either energizing or reclosing into single line to ground faults. Forty-seven systems were considered in the analysis. Of the overvoltages resulting from these systems, only nine produced magnitudes great enough to sparkover the conventional arrester. In addition, approximately twenty-four of the systems produced levels great enough to "sparkover" the zinc oxide arrester.

The contingency switching operations represent events which should occur rarely in the system. In addition, these maximum overvoltages were produced with optimum circuit breaker closing times and resistor insertion times. These closing times in practice occur randomly which further reduces the probability of these maximum switching levels to be reached. In view of the relatively small probability that these overvoltages will be attained in practice, adequate protection should be achieved by establishing the cables basic switching impulse insulation level with surge arrester protection. The cable insulation level established in this manner has the added advantage of being insensitive to system parameter changes as discussed in the previous section.

5.3 Surge Arrester Application Considerations

The available energy stored in a cable prior to arrester sparkover and the resulting discharge currents following sparkover may limit an arrester application.

The amount of energy the conventional arrester is required to dissipate is dependent not only upon its value block elements but also the performance of the active gaps. The gap performance is in turn sensitive to the initial discharge currents. These initial arrester discharge currents may become rather severe when discharging systems with inherently low surge impedances. These initial currents are limited primarily by the arrester valve block elements as well as the system equivalent surge impedance. Application guidelines established for the Westinghouse conventional arrester suggests that when this initial discharge current exceeds 3400 amperes, the active gap is prohibited from "valving off and

resealing" according to specifications. This condition may lead to overstressing thermally the valve block elements and increase the probability of subsequent arrester sparkovers at lower than specified levels. Application guidelines have not been published for the General Electric or Ohio Brass station class arresters, however, it is believed this "critical current" is somewhat lower, approximately 2000 amperes.

Figure 14 shows the valve block characteristics for these manufacturers. These characteristics which apply to the conventional arresters only were used to calculate the initial discharge current following sparkover in addition to establishing the crest valve of the current discharge neglecting gap activity. The method used was to graphically find the intersection of the block V-I curve with the system V-I curve ("load line"). Using the equivalent system surge impedance, the arrester sparkover voltage and the maximum overvoltage without the arrester applied at the cable terminal the initial and maximum discharge currents were found. Table 5 indicates these initial and maximum discharge current levels. This tabulation indicates both the Ohio Brass and General Electric arrester may be overdutied. The manufacturers should be consulted as to the adequacy of this arrester application for each of the cable lengths under consideration.

The "Gapless" arrester will in addition be required to discharge energy from the system. The electrical characteristics and application guidelines were not available for the ceramic oxide arrester. Manufacturers again should be required to verify this arrester application.

TABLE 5

DISCHARGE CURRENTS - CONVENTIONAL ARRESTER

Manufacturer	Arrester Rating	Critical Current	Initial Discharge Current	Maximum Discharge Current
Ohio Brass	864 kV	2 kA	2.81 kA	3.67 kA
Westinghouse	864 kV	3.4 kA	1.89 kA	2.5 kA
General Electric	864 kV	2 kA	3.26 kA	4.64 kA

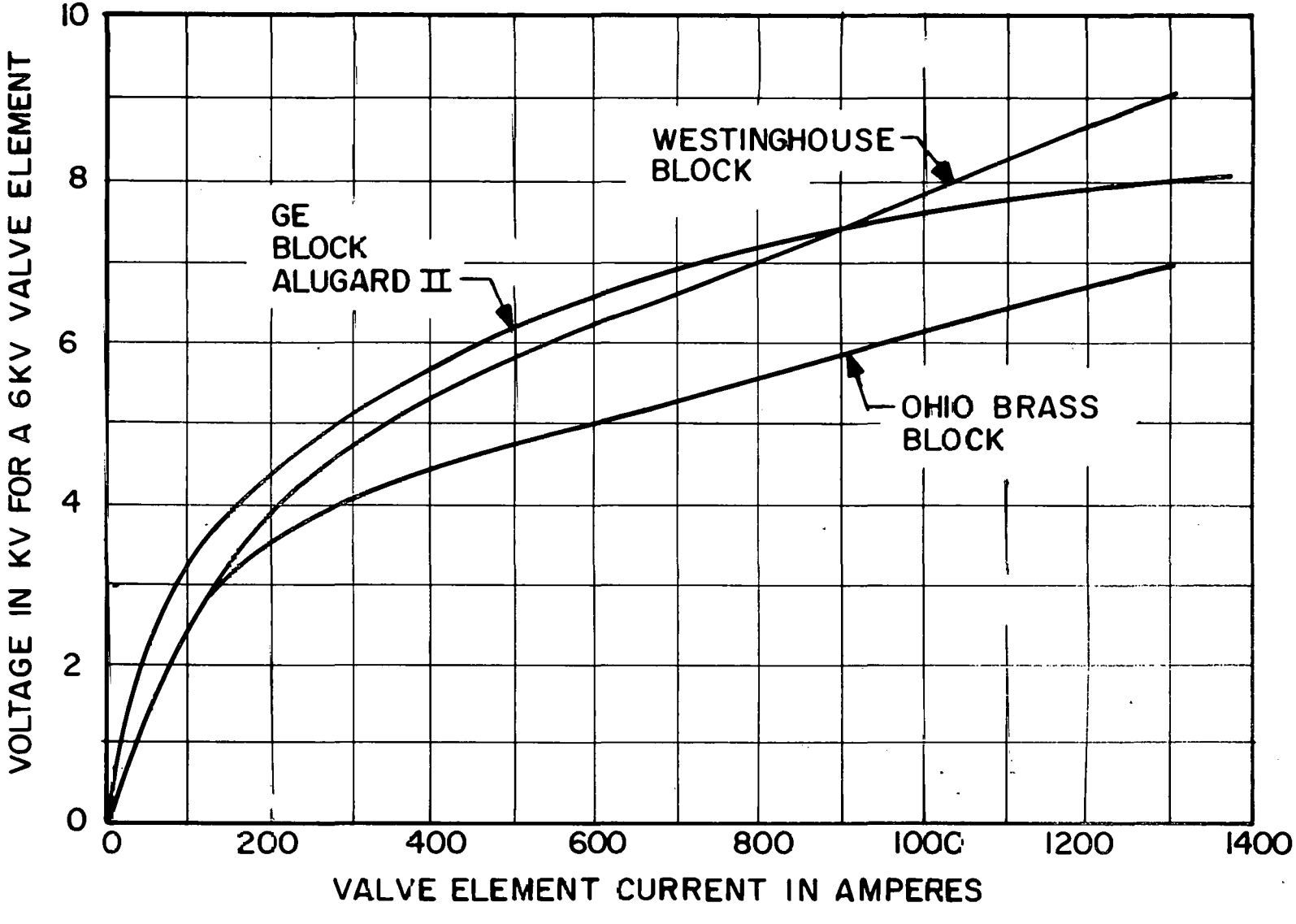


FIGURE 14 - Block Voltage and Current Relationship for a 6-kV Valve Element

6. COMPARISON OF RECOMMENDATIONS WITH PRELIMINARY REPORT

Insulation levels were established in the first quarterly report (October 15, 1975) associated with ERDA Contract E(49-18)-2061. These levels are indicated in Table 6.

TABLE 6

INSULATION LEVELS ESTABLISHED IN THE FIRST QUARTERLY REPORT

Switching Impulse Level BSL	Ceramic Oxide Arrester	Conventional Arrester 864 kV	Conventional Arrester 960 kV
Arrester Protected	1805 kV	2360 kV	2623 kV
Maximum Surge	1577 kV	1577 kV	1577 kV

The insulation levels based on the maximum surge are lower than the values indicated in this report. This is due to the fact that the maximum switching surge overvoltage was assumed to be 1372 kV (1.4 p.u.) which would be generated by normal reclosing operations. A 15% margin was added for safety. The insulation levels established in the arrester protected case using the conventional arrester are higher than those established in this report. This is primarily due to two aspects of the assumed arrester characteristics. Table 7 indicates the arrester characteristics used for the previous analysis. Although the arrester rating is the same, the protective levels expressed in per unit of crest arrester rating are higher than was assumed in this analysis (see Table 3). In addition, these characteristics assume the maximum switching impulse discharge voltage to be above the sparkover levels. This assumption required the use of the discharge voltage characteristics rather than the sparkover levels. For example, a 15% margin was applied to the 2052 kV discharge voltage to attain the 2360 kV insulation level. It is recommended that the manufacturers be asked to specify the maximum discharge voltage levels of this rating arrester to insure proper coordination with the arrester protective characteristics.

TABLE 7

ARRESTER PROTECTIVE CHARACTERISTICS USED IN THE FIRST QUARTERLY REPORT

	864 kV Arrester
Maximum Switching Impulse Sparkover	1894 kV (1.55 pu)*
Maximum Switching Impulse Discharge Voltage	2052 kV (1.68 pu)*

*(1 pu = 864 kV x $\sqrt{2}$)

7. AREAS FOR FURTHER INVESTIGATIONS

These investigations have concerned themselves with typical stresses which a CGIT cable will be expected to withstand. These stresses naturally being impressed across the phase conductor and the grounded sheath.

Cable systems employing such grounding schemes as cross bonding are in addition susceptible to voltages which may be developed across the joints which segregate the sheaths into each bonding segment. These overvoltages may be in the form of power frequency voltages which may result from line-to-ground faults both internal or external to the cable system or surge voltages developed across the joints as a result of faults, switching operations or lightning phenomena associated with the adjacent overhead system. Various techniques for protection of these systems have been suggested and include both the use of lightning arresters and bonding transformers.[5][6]

If the cross bonded grounding system is being considered for longer cable applications, consideration should be given to acquiring knowledge of the nature and magnitudes of these sheath overvoltages.

8. REFERENCES

1. Annestrand, S. A. and Parks, G. A. "Bonneville Power Administrations Prototype 1100/1200 kV Transmission Line Project", presented at IEEE 1976 Summer Power meeting.

2. Colclaser, D. G., Wagner, C. L. and Donohue, E. P. "Multistep Control of Switching Surges", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-89 No. 8, November/December pp. 1744-1756, 1970.

3. Kober, H Dictionary of Conformal Representation, TEXT, Dover Publications 1952.

4. E. W. Kimbark and A. C. Legate "Fault Surge Versus Switching Surge: A Study of Transient Overvoltages caused by line to ground faults", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-87, pp. 1762-1769, September 1968.

5. Watson, W. and Erven, C. C. "Surge Potentials on Underground Cable Sheath and Joint Insulation", IEEE Transactions on Power Apparatus and Systems, Vol. 88, June 1963.

6. Ball E. H., Occhini, E. and Luoni, G. "Sheath Overvoltages in High-Voltage Cables Resulting from Special Sheath Bonding Connections", IEEE Transactions on Power Apparatus and Systems, PAS-84 No. 10, October 1965.

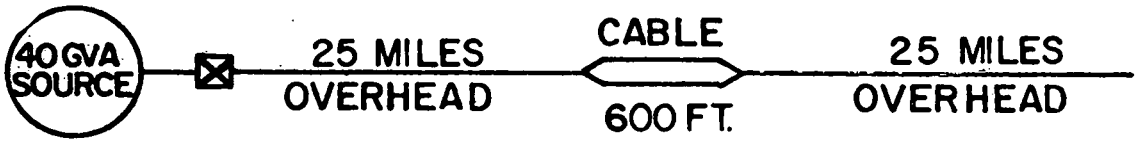
9. APPENDIX

This section of the report contains the individual cases comprising the analysis which was performed for the study. These cases are divided in four sections with each section containing the work which was performed for each of the four systems considered in the analysis. Each section begins with curves summarizing the maximum cable overvoltages followed by the oscillograms of the voltages measured in each case.

The following abbreviations are utilized on the curves summarizing the work for each system.

ABBREVIATIONS

E	- Energize Line
E-SLG	- Energize line with single line-to-ground fault
E-SLG-CC	- Energize line with single line-to-ground fault and controlled breaker contacts
RC	- High speed reclosing
RC-SLG	- High speed reclosing with single line-to-ground fault
RC-SLG-CC	- High speed reclosing with single line-to-ground fault and controlled breaker contacts
FI	- Fault initiated overvoltages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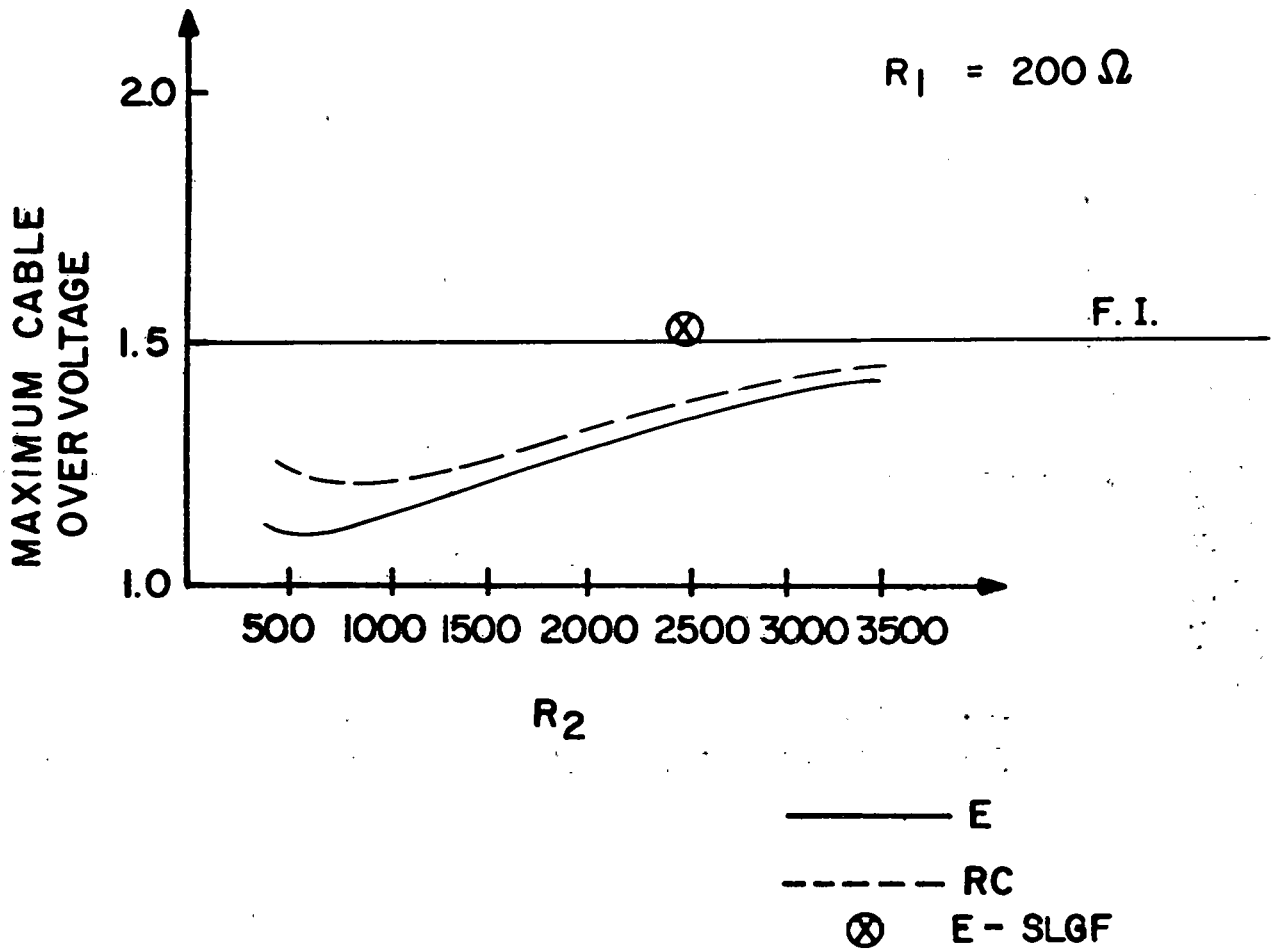
25 MILES OVERHEAD
CABLE
600 FT.
25 MILES OVERHEAD


R_1 = 200 Ω
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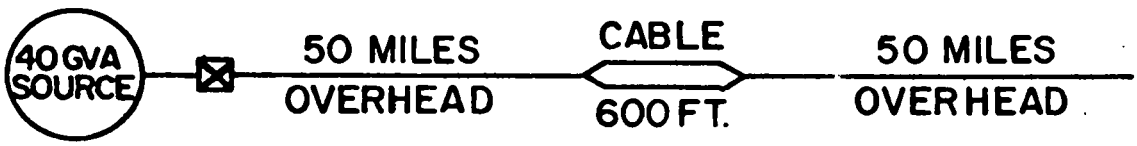
1.5
1.0
F. I.
500 1000 1500 2000 2500 3000 3500
R_2
E
RC
E - SLGF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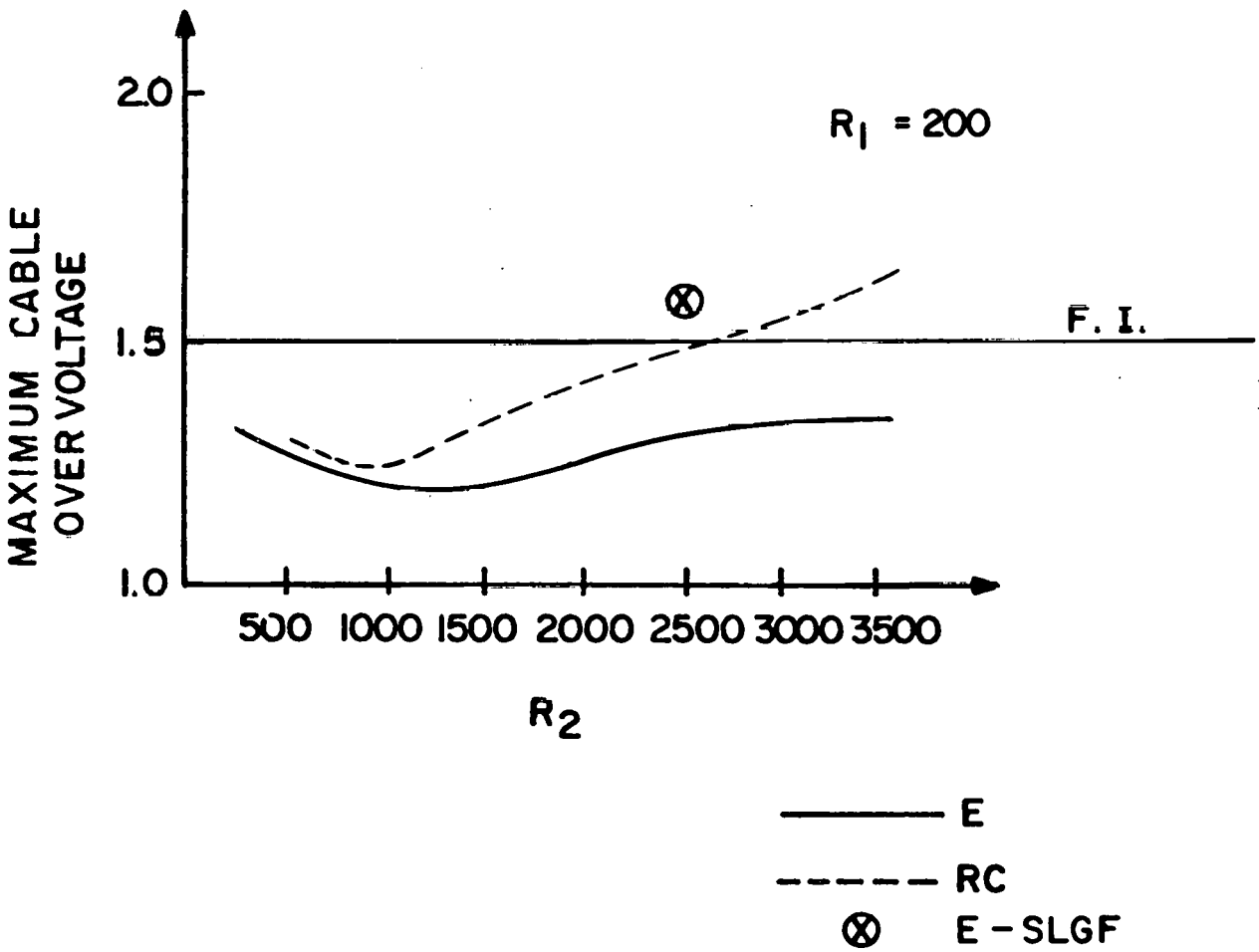
50 MILES OVERHEAD
CABLE
600 FT.
50 MILES OVERHEAD


MAXIMUM CABLE OVER VOLTAGE
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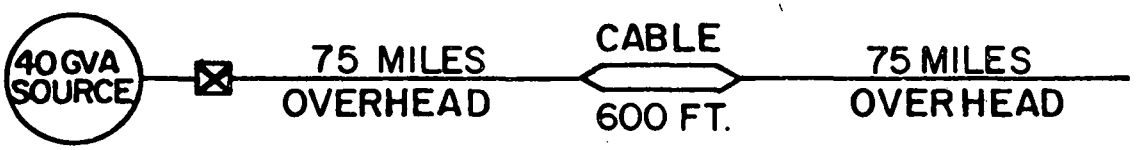
1.5
1.0
R_1 = 200
F. I.
500 1000 1500 2000 2500 3000 3500
R_2
E
RC
E - SLGF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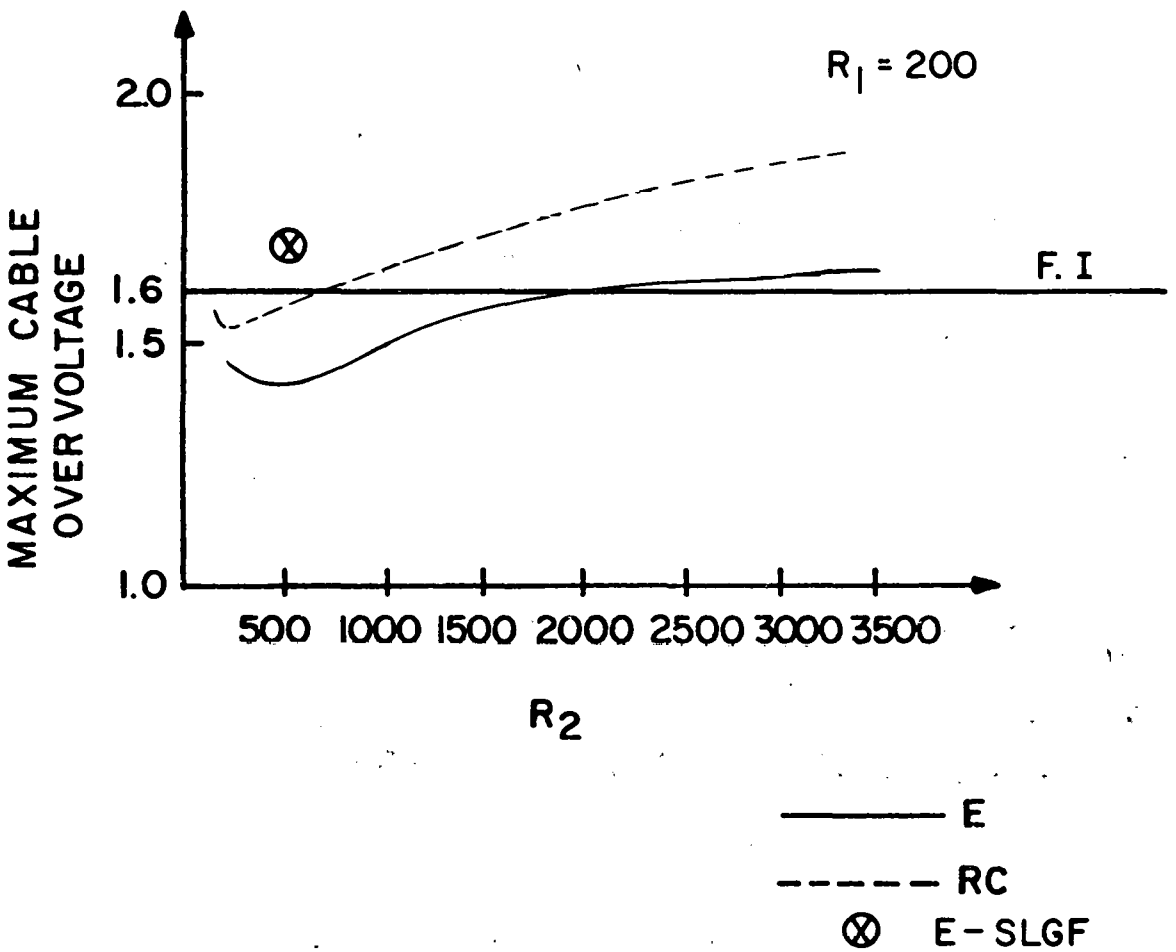
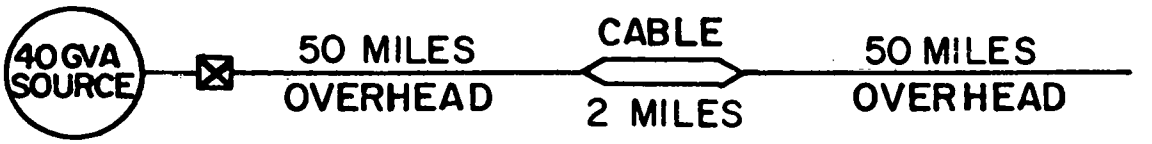
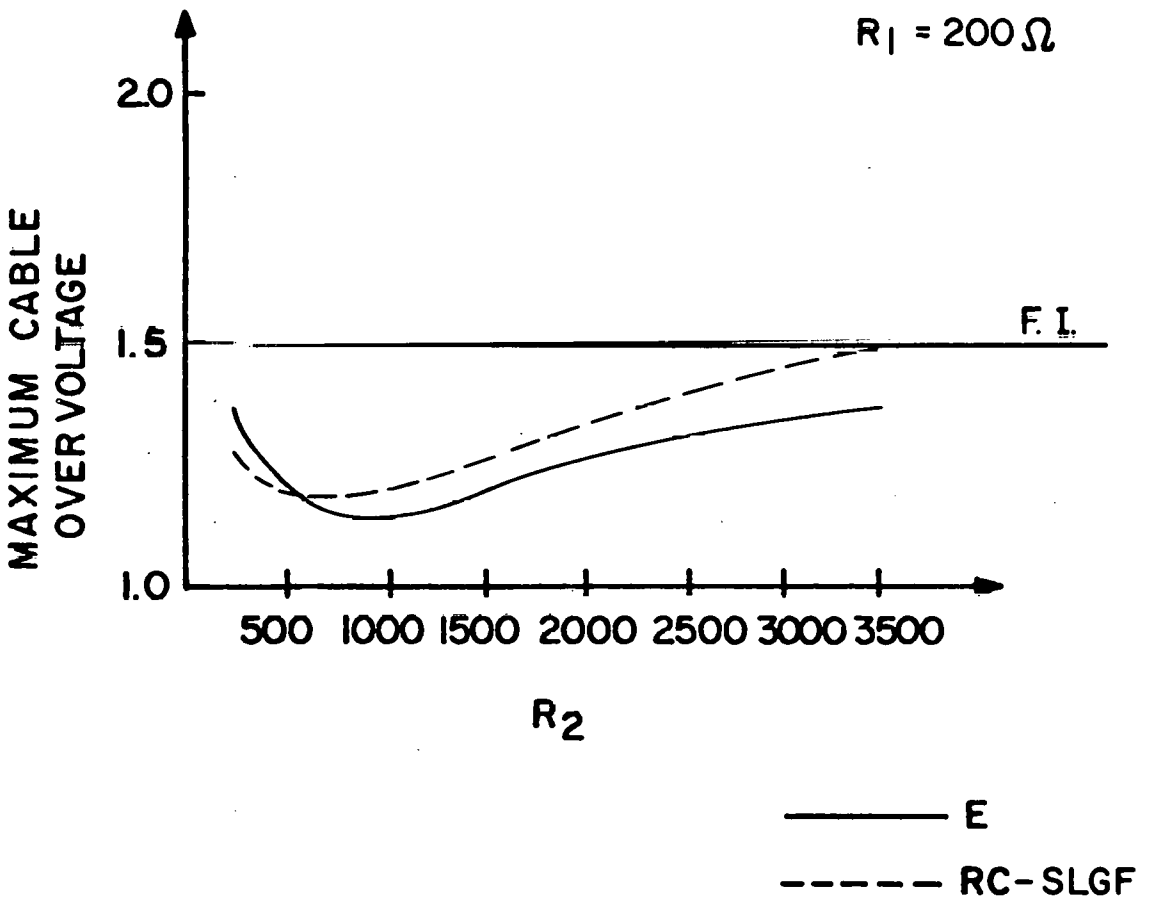
CABLE
600 FT.
75 MILES OVERHEAD


MAXIMUM CABLE OVER VOLTAGE
2.0
1.6
1.5
1.0
R_1 = 200
F. I
500 1000 1500 2000 2500 3000 3500
R_2
E
RC
E-SLGF


40 GVA SOURCE
50 MILES OVERHEAD
CABLE
2 MILES
50 MILES OVERHEAD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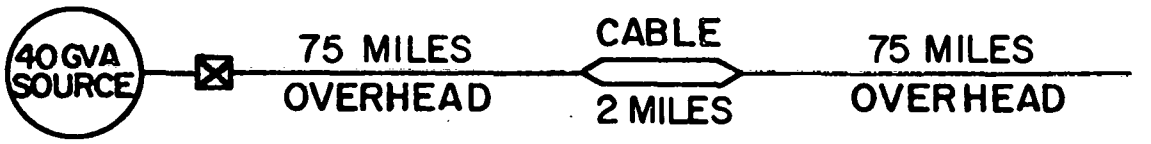
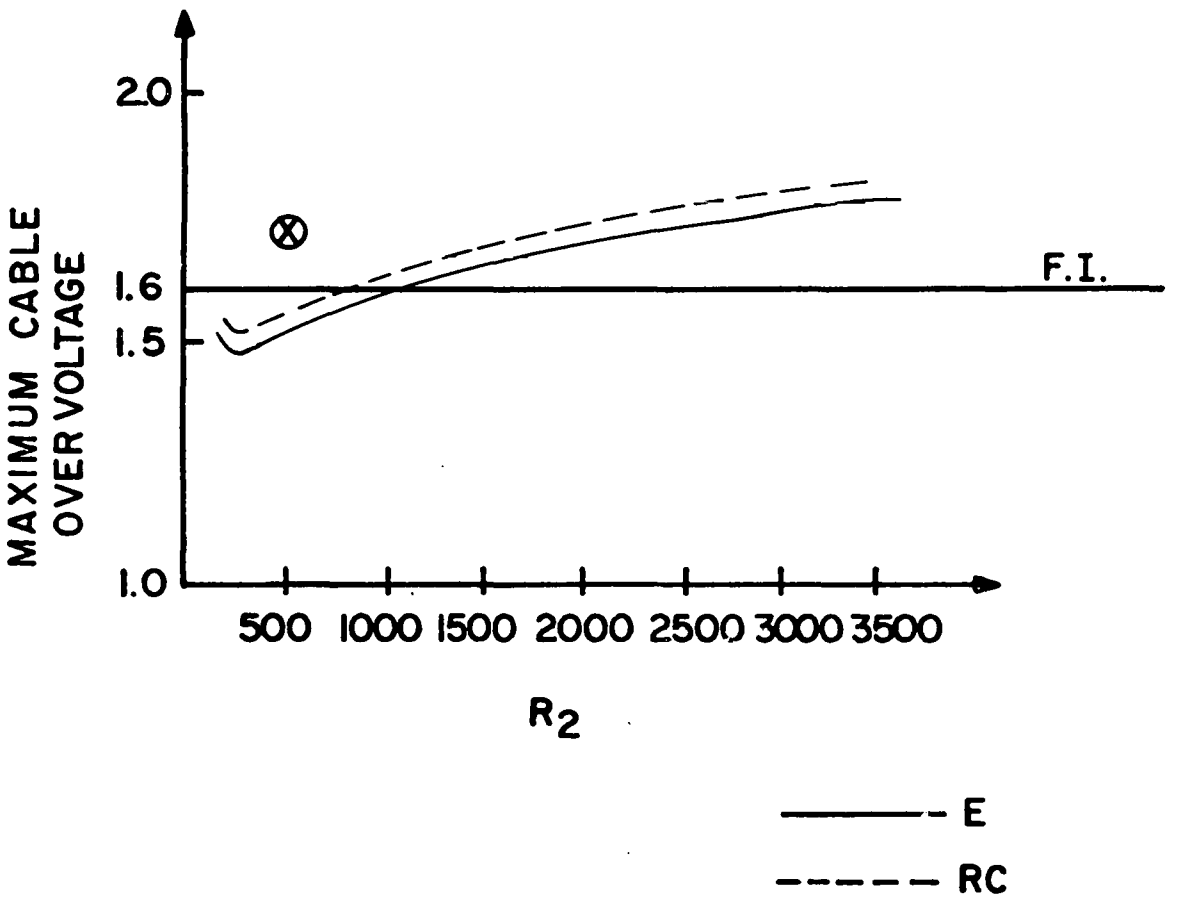
F. I.
MAXIMUM CABLE OVER VOLTAGE
500 1000 1500 2000 2500 3000 3500
R2
E
RC-SLGF


40 GVA SOURCE
75 MILES OVERHEAD
CABLE
2 MILES
75 MILES OVERHEAD


MAXIMUM CABLE OVER VOLTAGE
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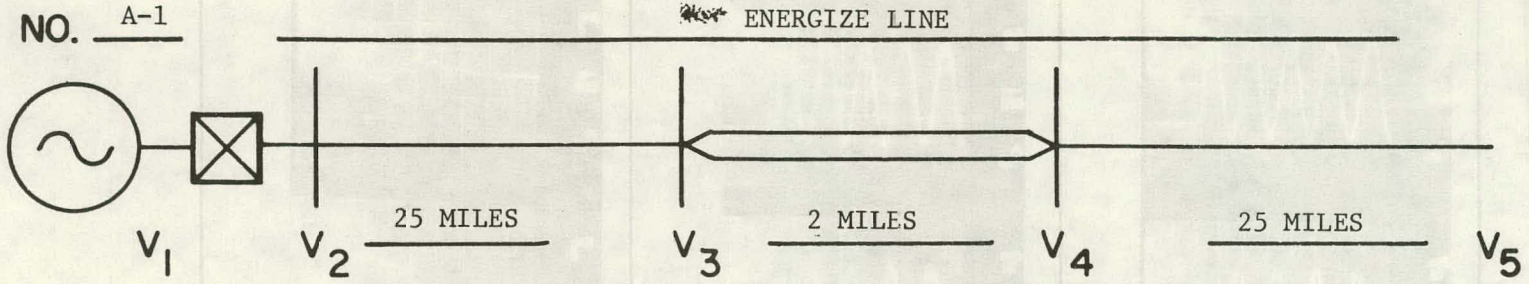
1.6
1.5
1.0
F.I.
500 1000 1500 2000 2500 3000 3500
R_2
E
RC

CASE NO. A-1



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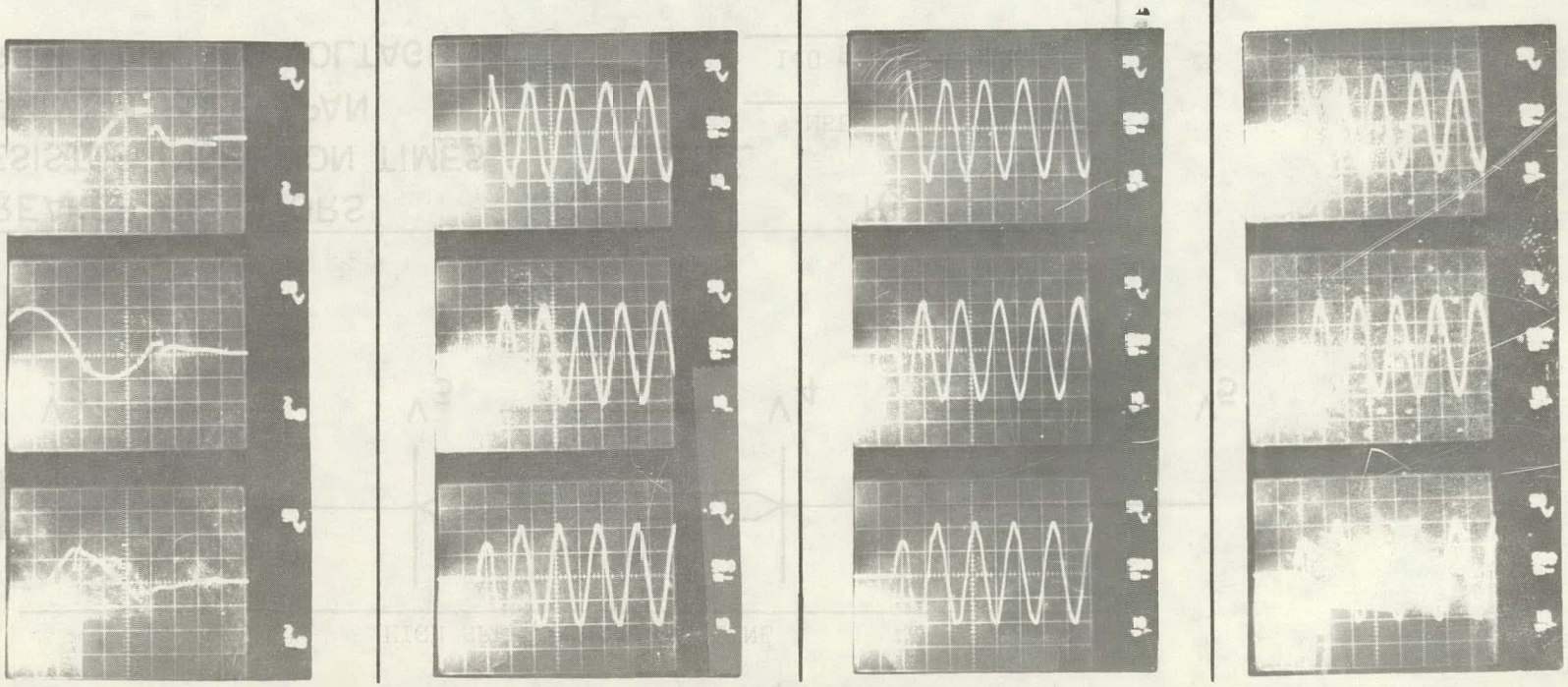
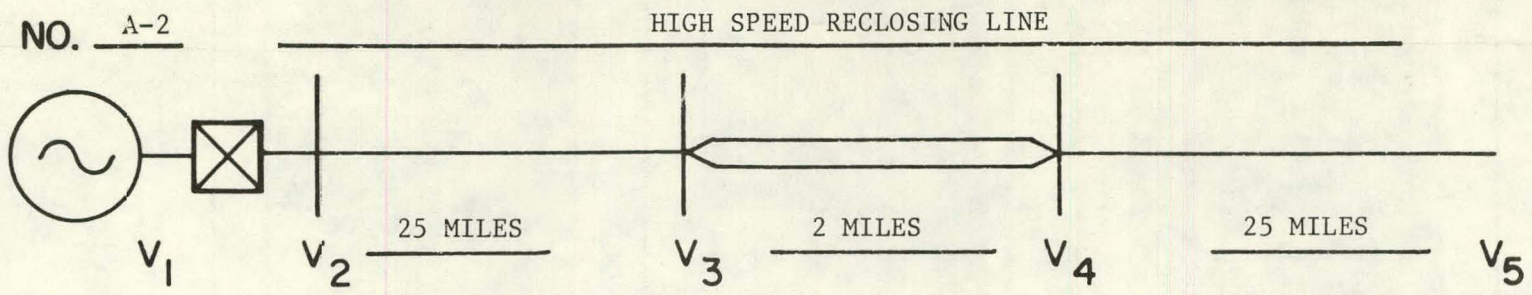
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU. OVERVOLTAGE	1.0 p.u.	1.3 p.u.	1.3 p.u.	1.3 p.u.
LOCATION	V_{1-2}	V_3	V_4	V_5

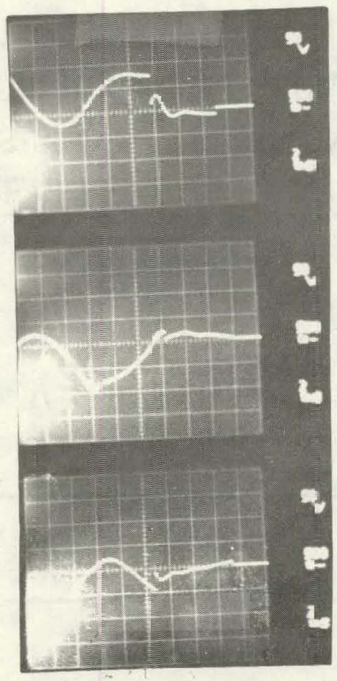


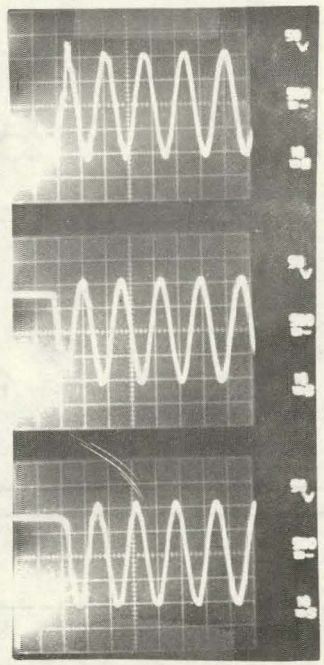
CASE NO. A-2

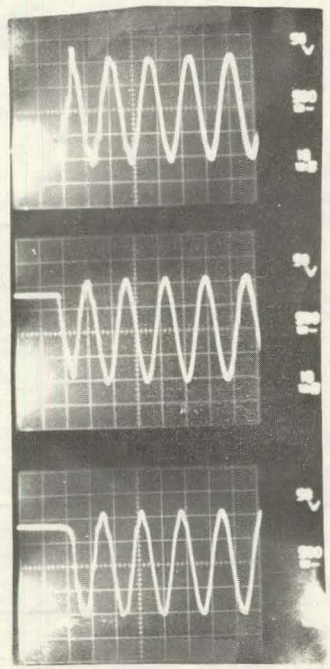


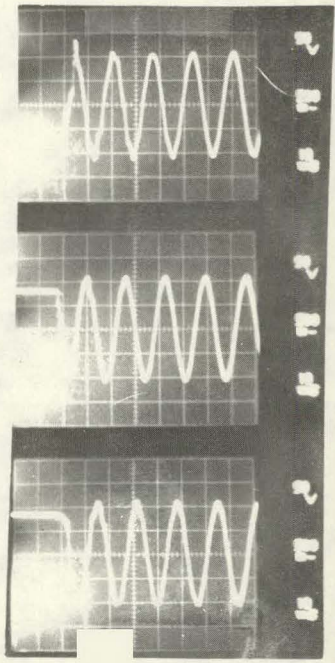
BREAKER RESISTORS	R_1 = 2000 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE— SWITCHED VOLTAGE	1.0 p.u.

MAX. PU. OVERVOLTAGE	1.3 p.u.	1.4 p.u.	1.4 p.u.	1.4 p.u.
LOCATION	V_{1-2}	V_3	V_4	V_5



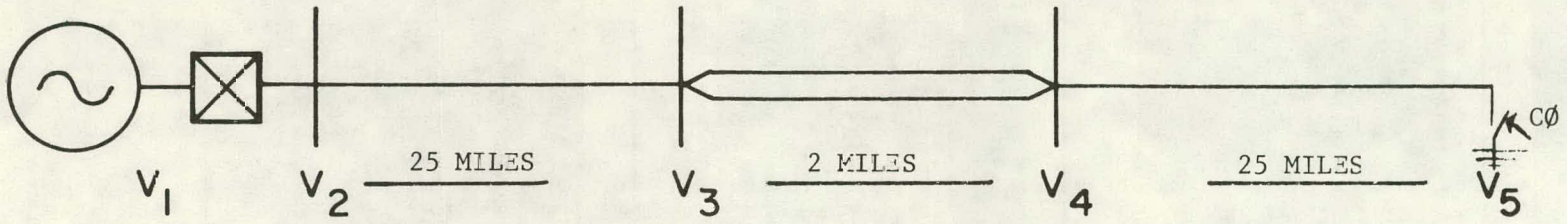






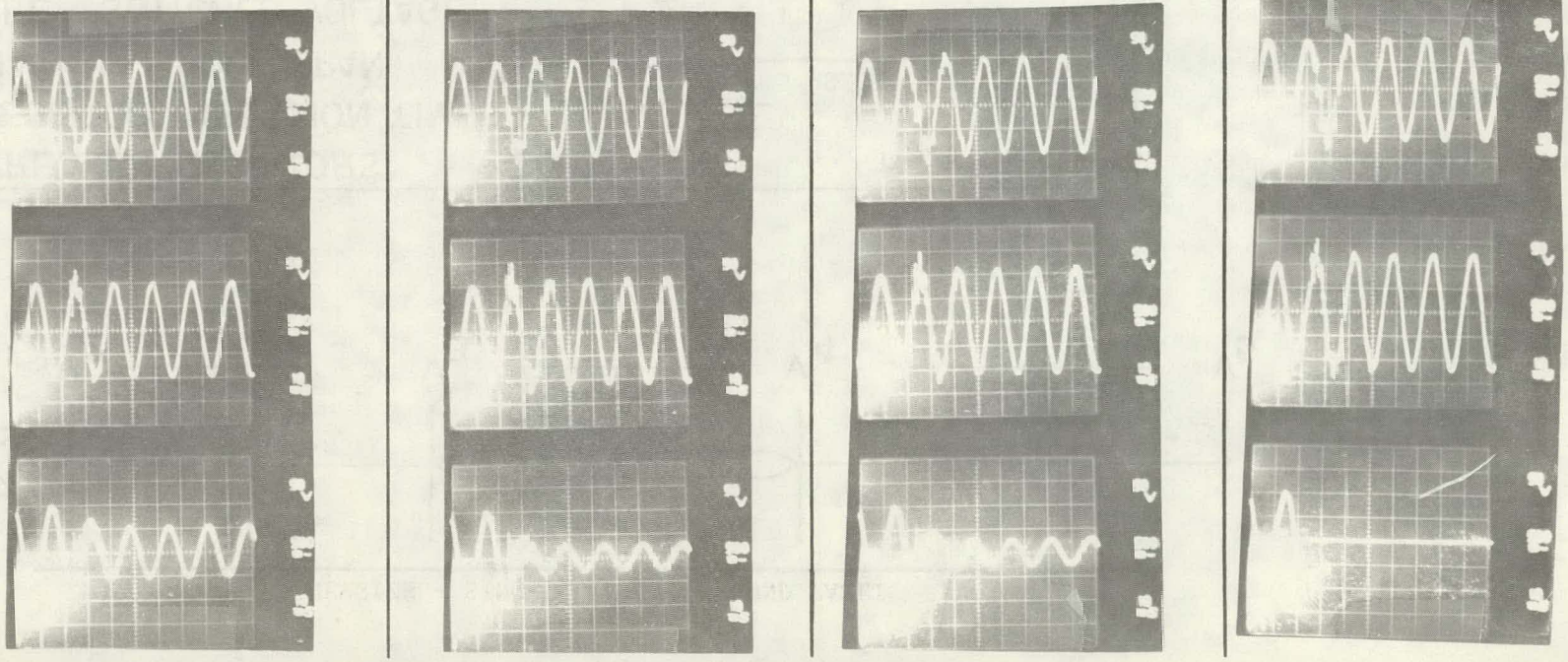
CASE NO. A-3

FAULT INITIATED OVERVOLTAGE - FAULT AT LINE END



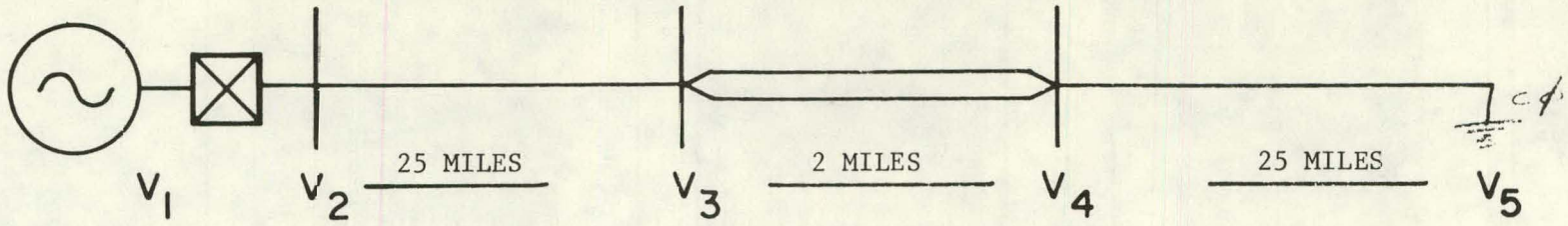
BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU. OVERVOLTAGE	1.3 p.u.	1.5 p.u.	1.5 p.u.	1.5 p.u.
LOCATION	V_{1-2}	V_3	V_4	V_5



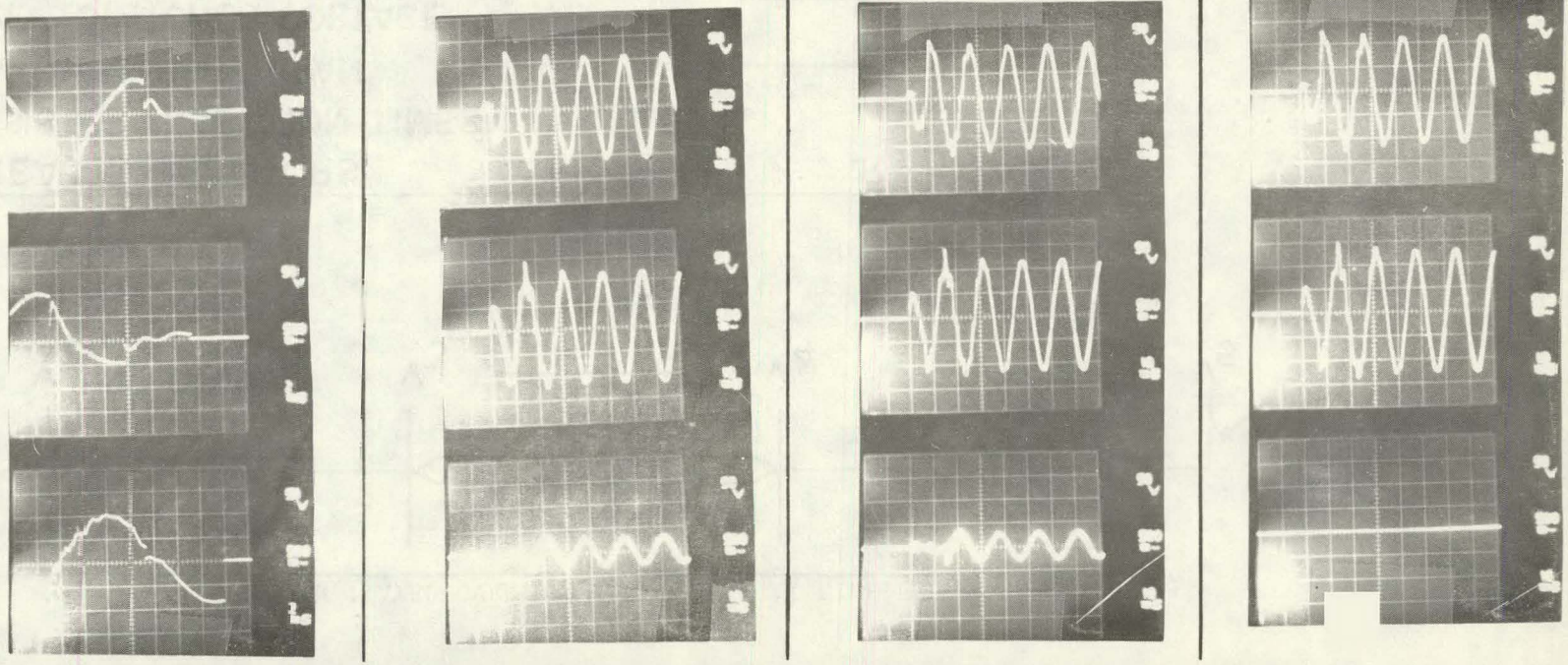
CASE NO. A-4

ENERGIZE - SINGLE LINE TO GROUND FAULT



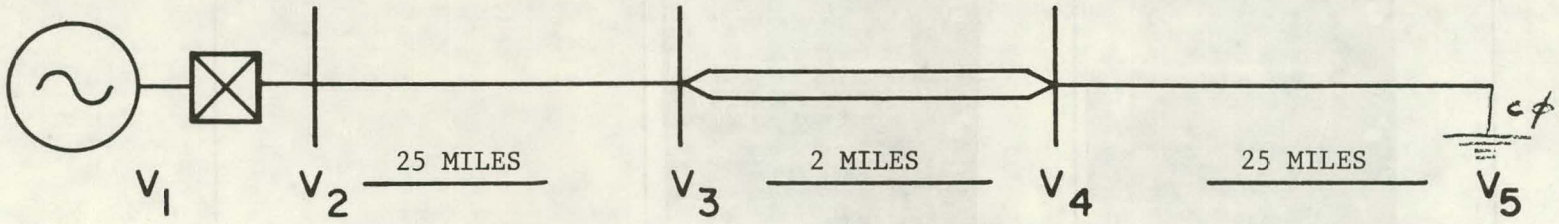
BREAKER RESISTORS	R_1 = 1500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU. OVERVOLTAGE	1.2 p.u.	1.4 p.u.	1.4 p.u.	1.5 p.u.
LOCATION	V_{1-2}	V_3	V_4	V_5



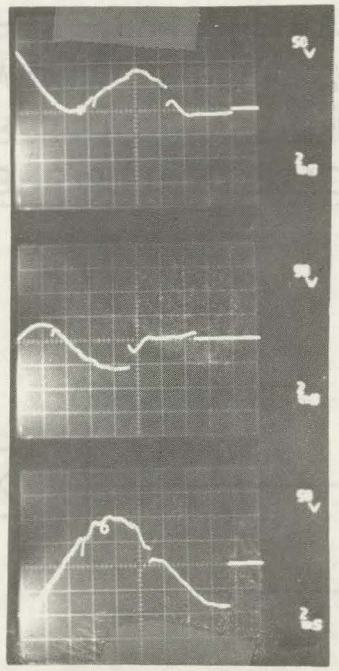
CASE NO. A-5

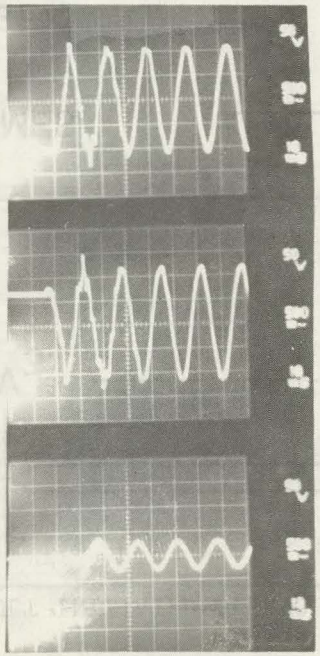
HIGH SPEED RECLOSING - SINGLE LINE TO GROUND FAULT

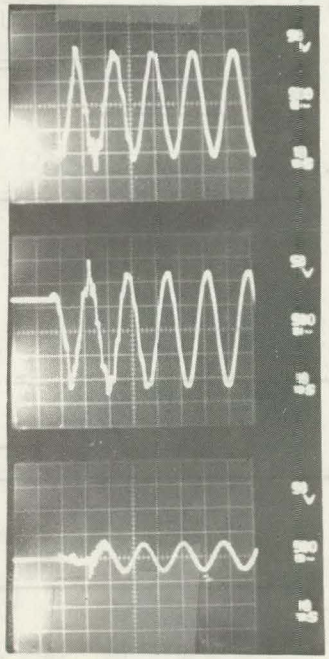


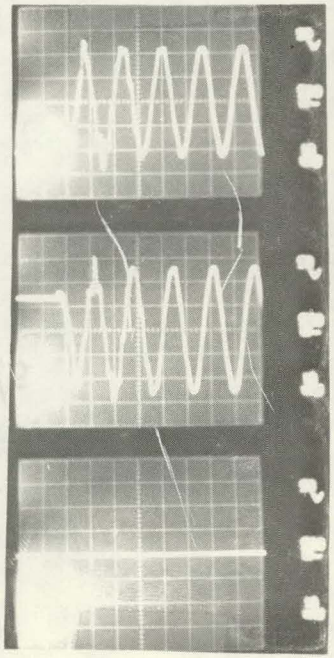
BREAKER RESISTORS	R_1 = 1500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. P.U. OVERVOLTAGE	1.0 p.u.	1.4 p.u.	1.5 p.u.	1.5 p.u.
LOCATION	V_{1-2}	V_3	V_4	V_5



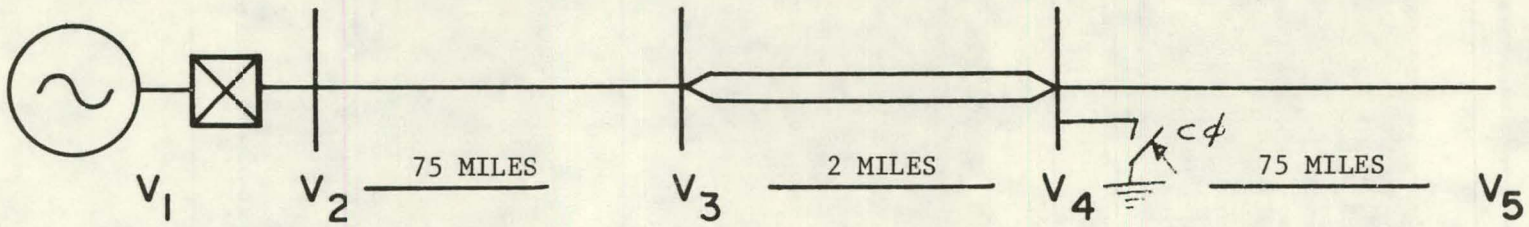






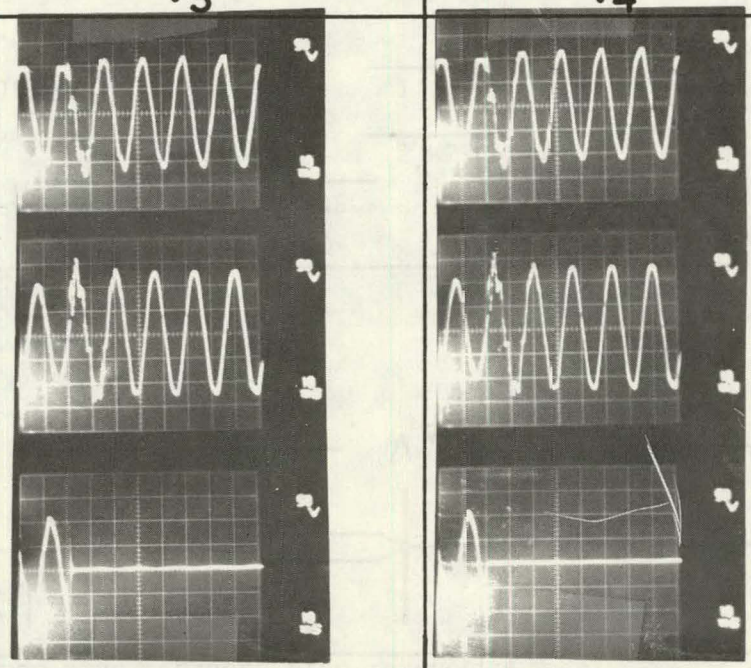
CASE NO. A-6

FAULT INITIATED OVERVOLTAGE

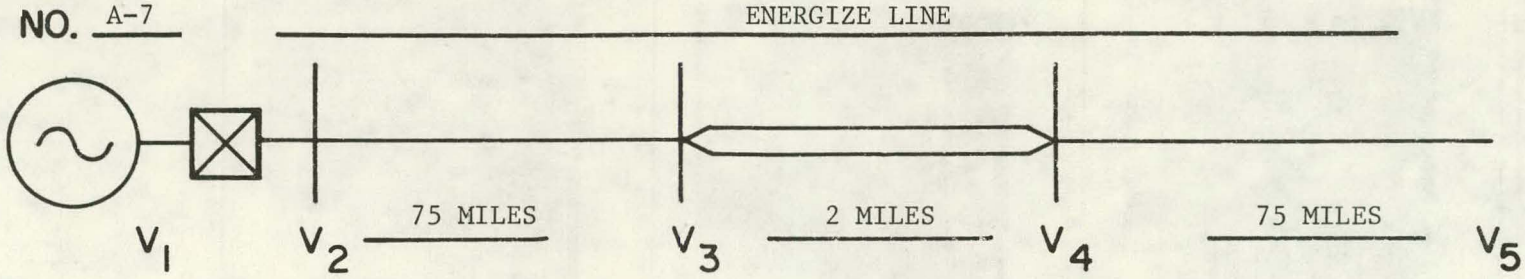


BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU. OVERVOLTAGE	-	1.6 p.u.	1.6 p.u.	-
LOCATION	V_{1-2}	V_3	V_4	V_5

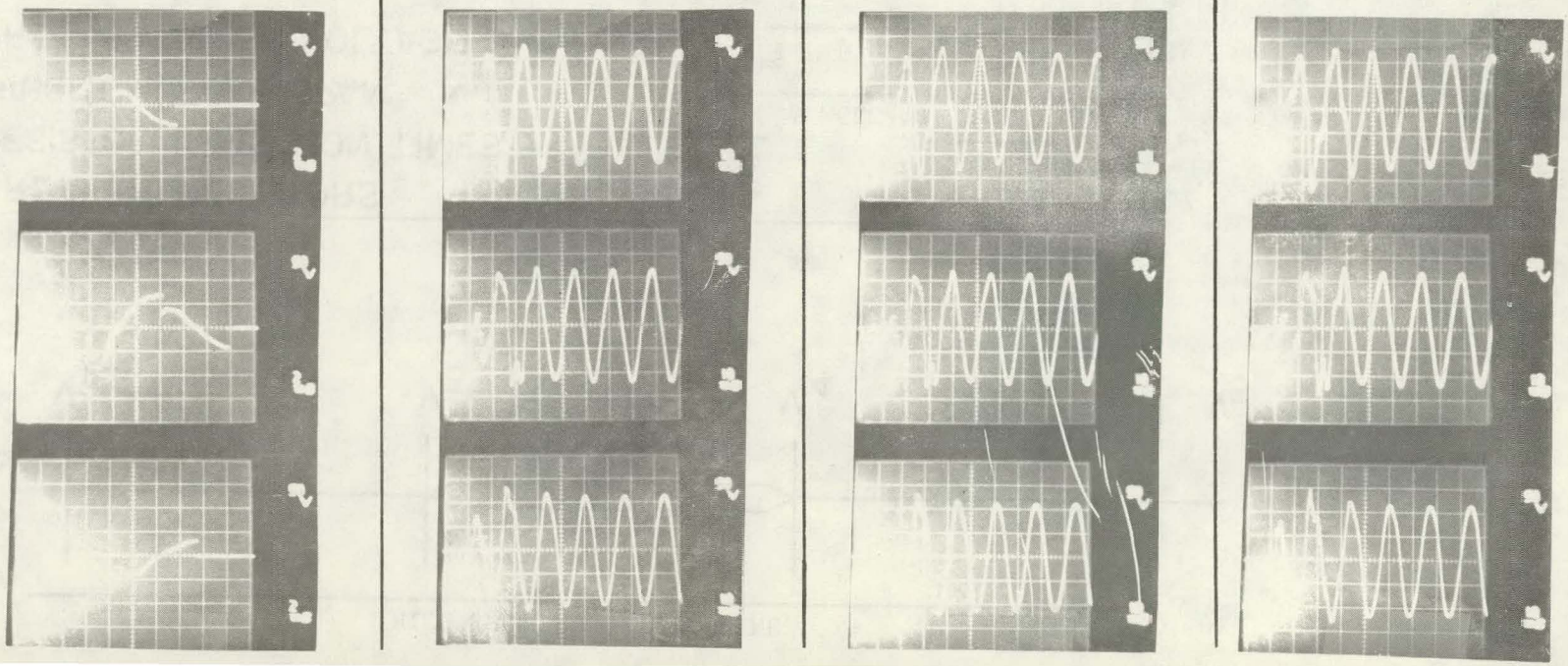


CASE NO. A-7



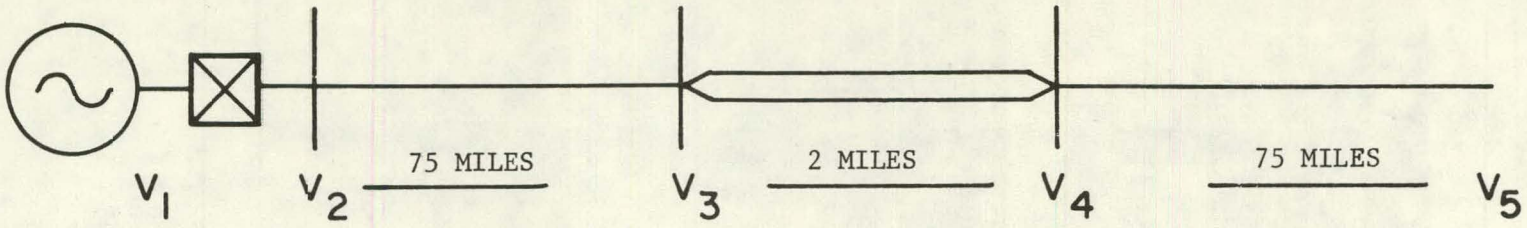
BREAKER RESISTORS	R_1 = 500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU. OVERVOLTAGE	1.3 p.u.	1.55 p.u.	1.55 p.u.	1.68 p.u.
LOCATION	V_{1-2}	V_3	V_4	V_5



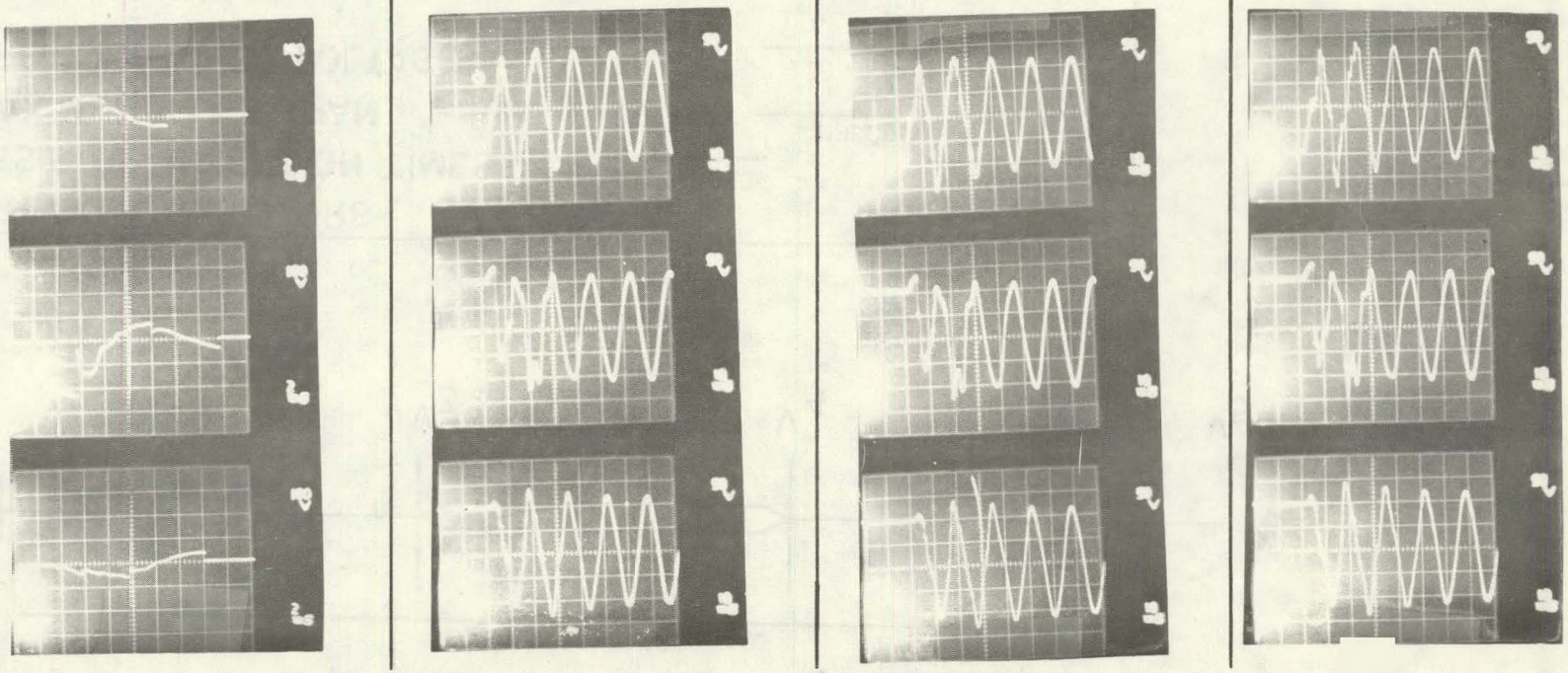
CASE NO. A-8

HIGH SPEED RECLOSING LINE

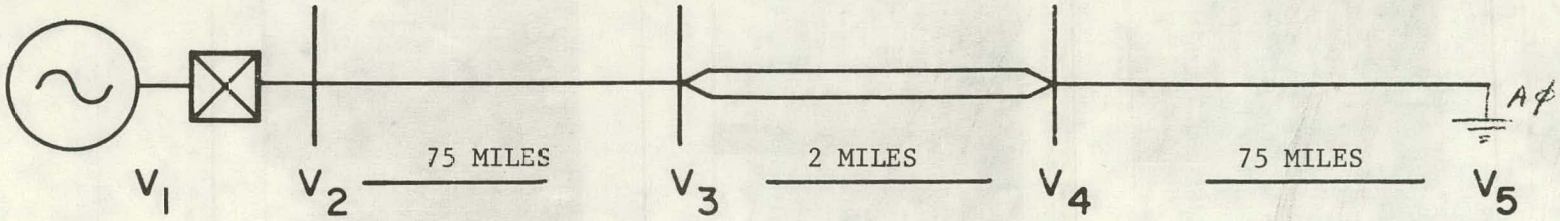


BREAKER RESISTORS	R_1 = 500 (6 MSEC) R_2 = 200 (6 MSEC)
RESISTOR INSERTION TIMES	5 MSEC
MAXIMUM POLE SPAN	1.0 p.u.
PRE-SWITCHED VOLTAGE	

MAX. P.U. OVERVOLTAGE	1.2 p.u.	1.5 p.u.	1.55 p.u.	1.7 p.u.
LOCATION	V_{1-2}	V_3	V_4	V_5

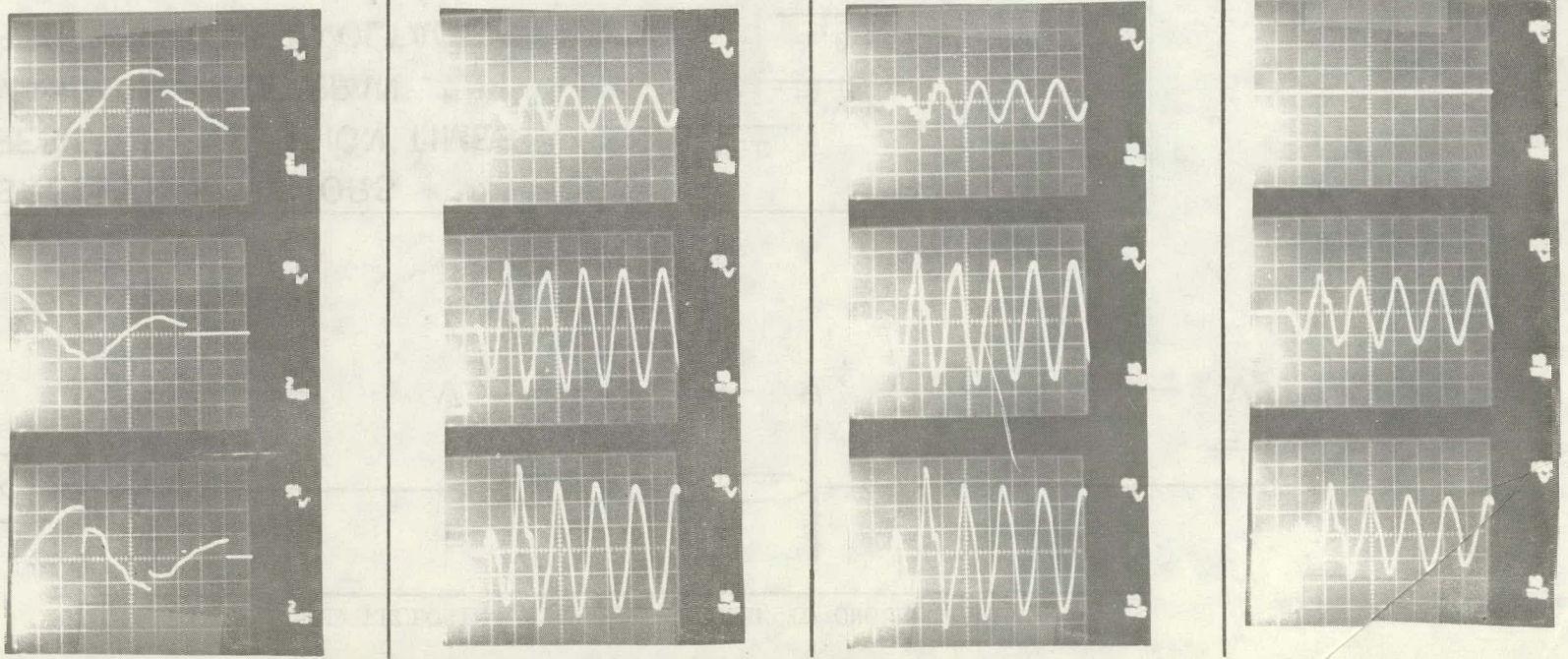


CASE NO. A-9 ENERGIZE - SINGLE LINE TO GROUND FAULT

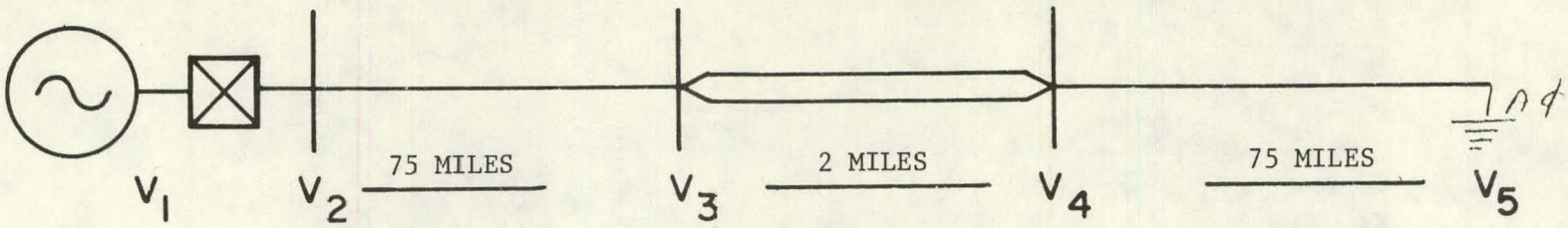


BREAKER RESISTORS	R_1 = 500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE— SWITCHED VOLTAGE	1.0 p.u.

MAX. PU. OVERVOLTAGE	1.2 p.u.	1.7 p.u.	1.75 p.u.	2.1 p.u.
LOCATION	V_{1-2}	V_3	V_4	V_5

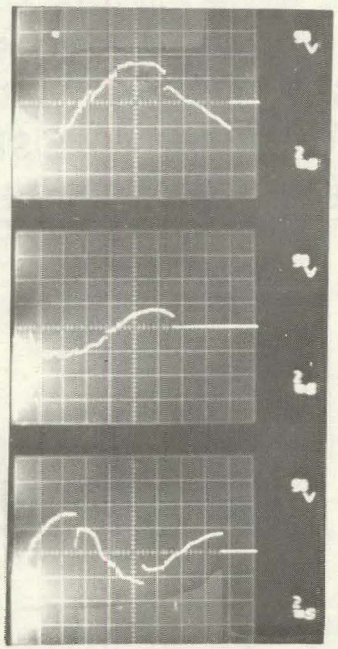


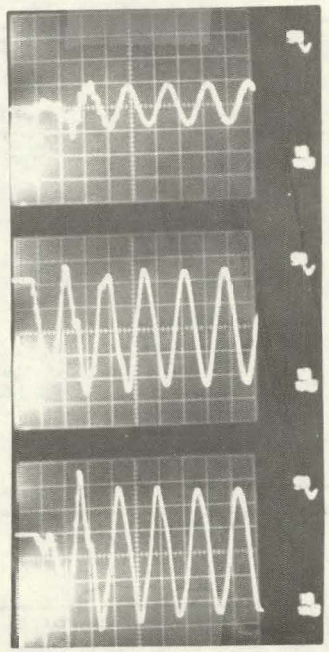
CASE NO. A-10 HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT

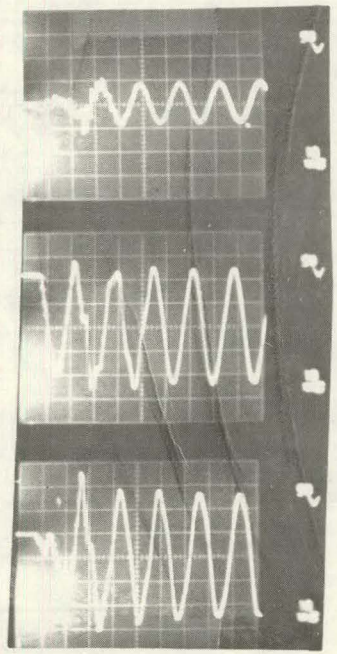


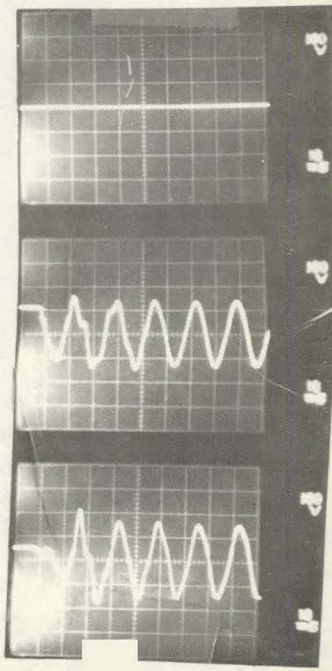
BREAKER RESISTORS	R_1 = 500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU. OVERVOLTAGE	2.0 p.u.	1.7 p.u.	1.75 p.u.	2.1 p.u.
LOCATION	V_{1-2}	V_3	V_4	V_5

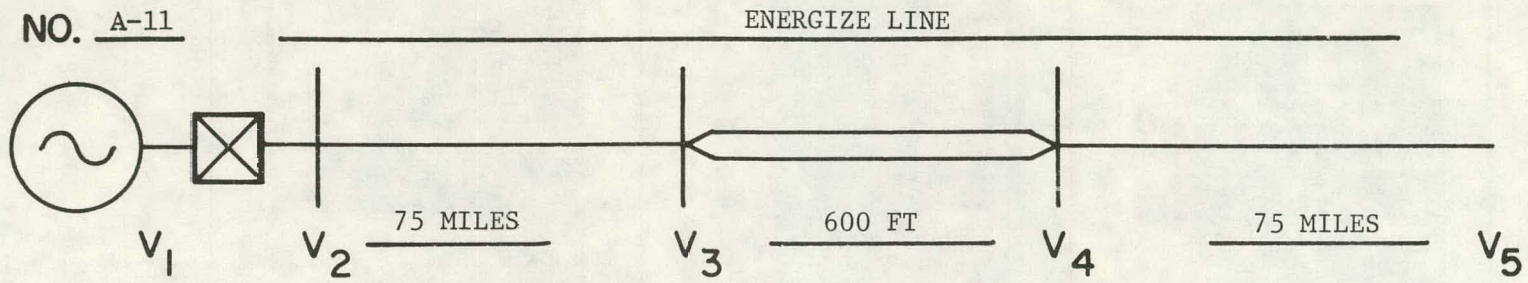




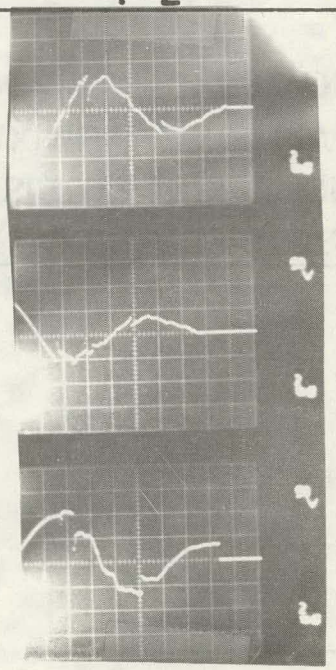
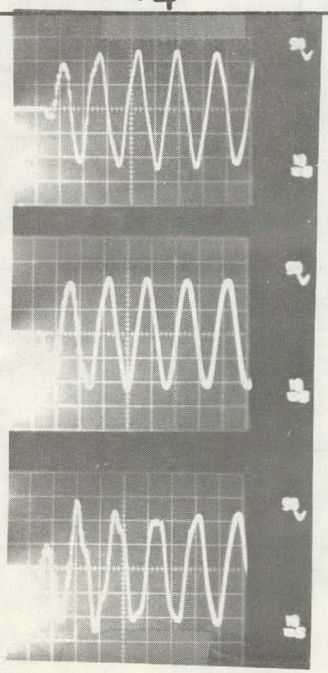
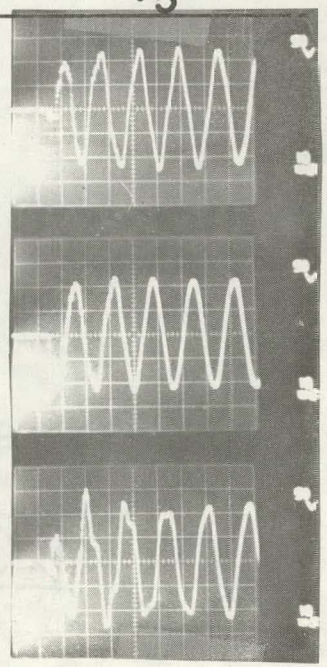




CASE NO. A-11

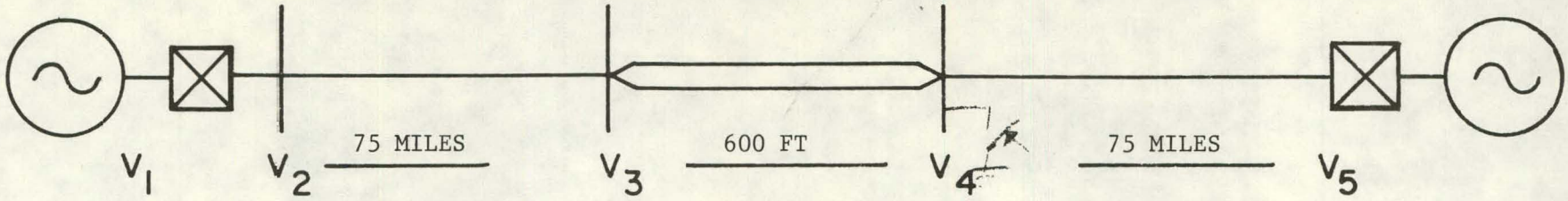


BREAKER RESISTORS	R_1 = 500 Ω 6 MSEC, R_2 = 200 Ω 6 MSEC
RESISTOR INSERTION TIMES	5 MSEC
MAXIMUM POLE SPAN	1.0 p.u.
PRE-SWITCHED VOLTAGE	

MAX. P.U. OVERVOLTAGE	1.0 p.u.	SAME AS V_4	1.45 p.u.	1.6 p.u.
LOCATION	V_{1-2}	V_3	V_4	V_5
				

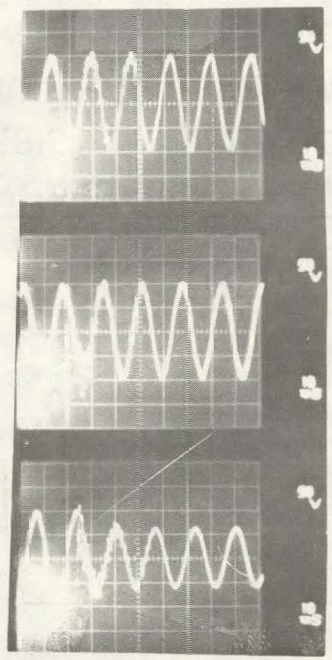
CASE NO. A-12

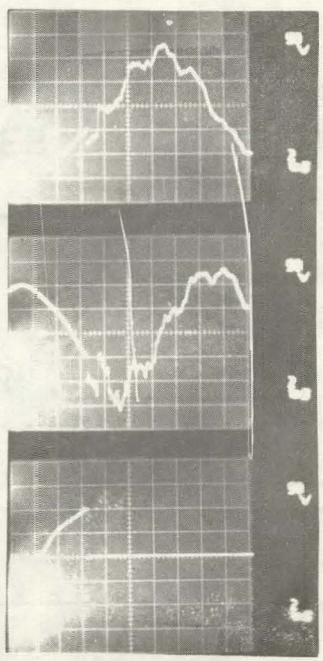
FAULT INITIATED OVERVOLTAGE

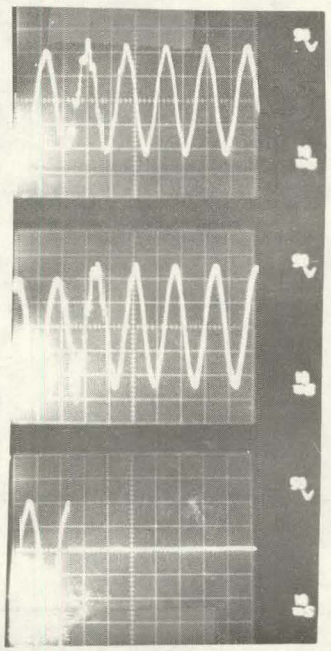


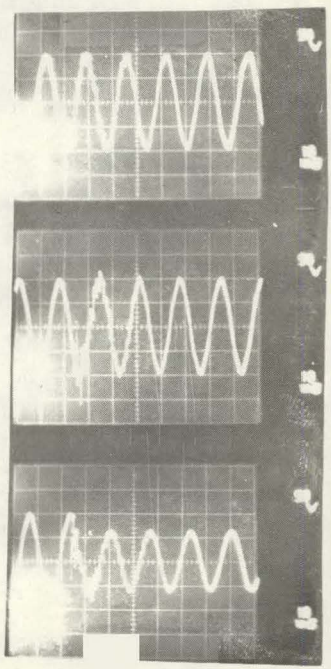
BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU. OVERVOLTAGE	1.3 p.u.	1.6 p.u.	1.6 p.u.	1.6 p.u.
LOCATION	V_2	V_4 EXPANDED SCALE	V_4	V_5



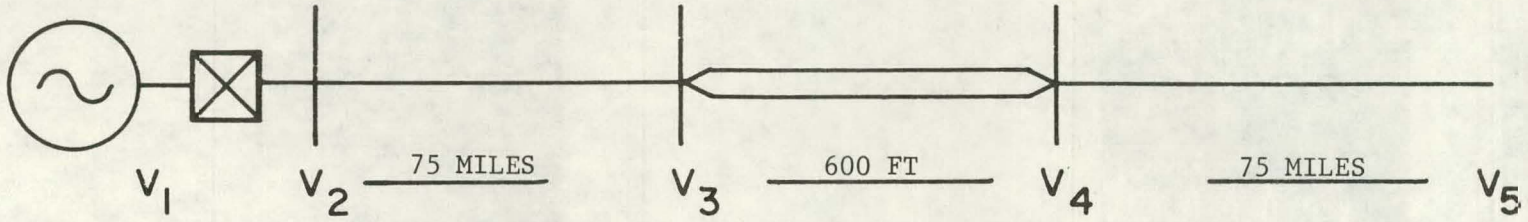






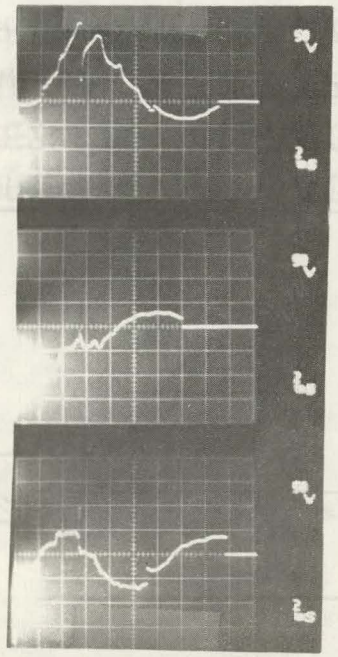
CASE NO. A-13

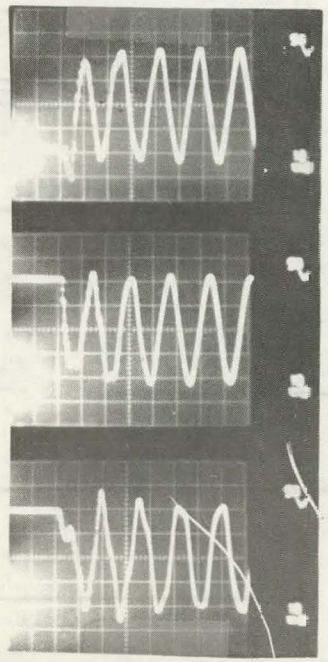
HIGH SPEED RECLOSING LINE

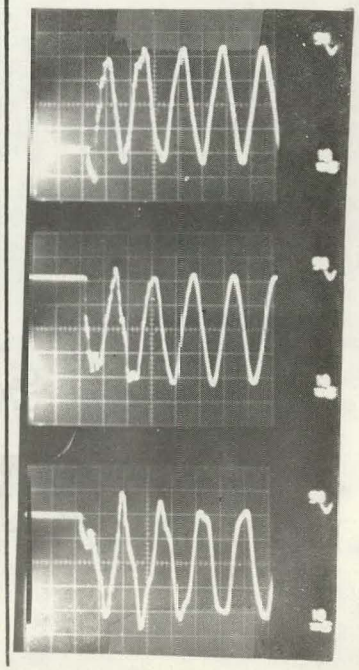


BREAKER RESISTORS	R_1 = 500	R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC	6 MSEC
MAXIMUM POLE SPAN	5 MSEC	
PRE—SWITCHED VOLTAGE	1.0 p.u.	

MAX. P.U. OVERVOLTAGE	1.5 p.u.	SAME AS V_4	1.6 p.u.	1.6 p.u.
LOCATION	V_{1-2}	V_3	V_4	V_5

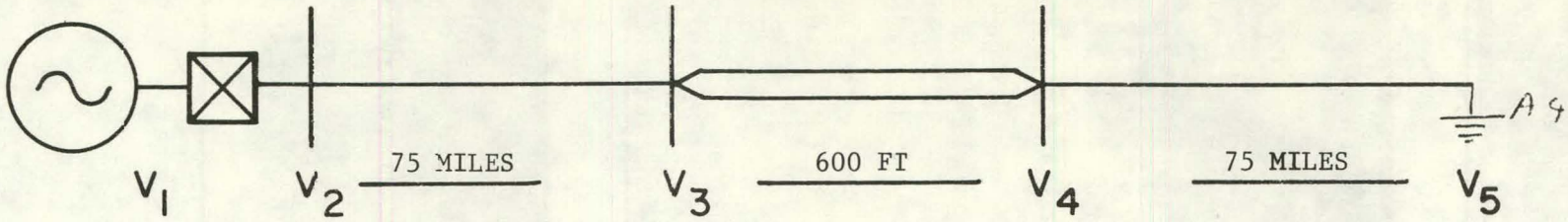






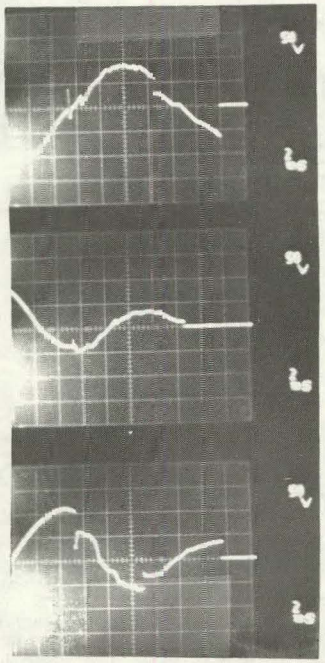
CASE NO. A-14

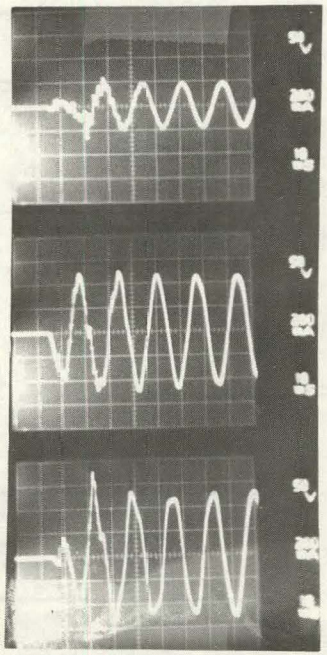
ENERGIZING INTO SINGLE LINE TO GROUND FAULT

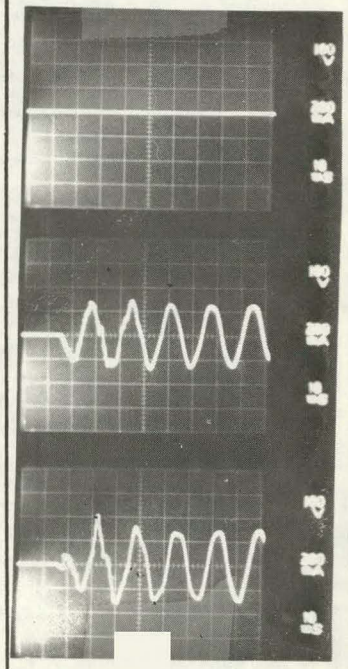


BREAKER RESISTORS	R_1 = 500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE—SWITCHED VOLTAGE	1.0 p.u.

MAX. PU. OVERVOLTAGE	1.0 p.u.	SAME AS V_4	1.7 p.u.	2.0 p.u.
LOCATION	V_{1-2}	V_3	V_4	V_5

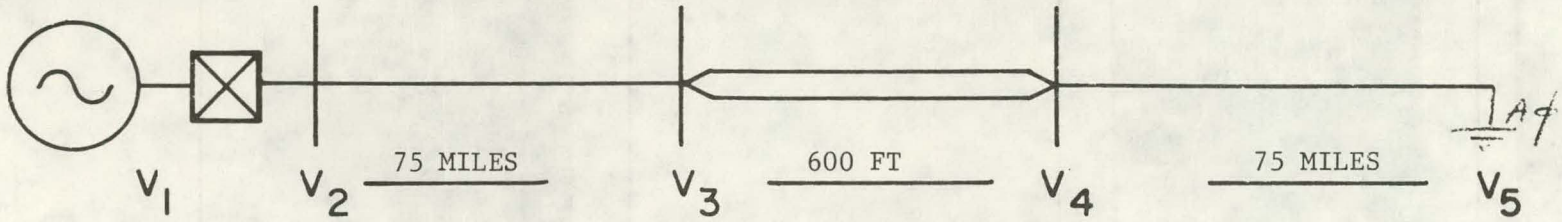




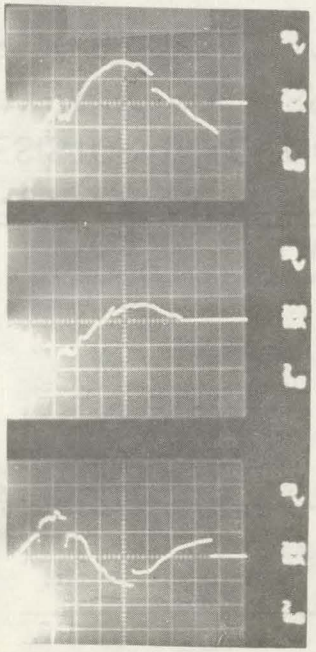
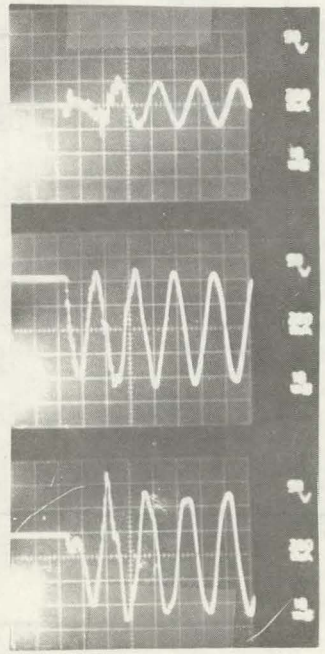
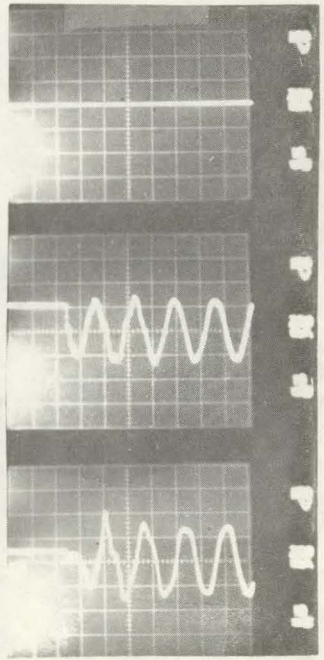


CASE NO. A-15

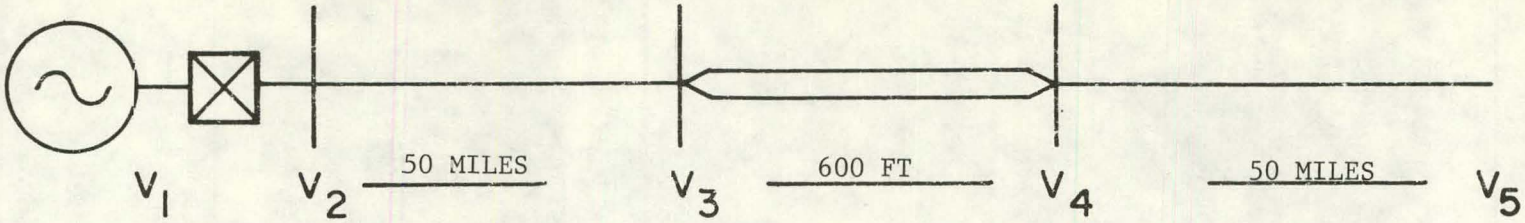
RECLOSING INTO SINGLE LINE TO GROUND FAULT



BREAKER RESISTORS	R_1 = 500Ω, 6 MSEC; R_2 = 200Ω, 6 MSEC
RESISTOR INSERTION TIMES	5 MSEC
MAXIMUM POLE SPAN	1.0 p.u.
PRE-SWITCHED VOLTAGE	

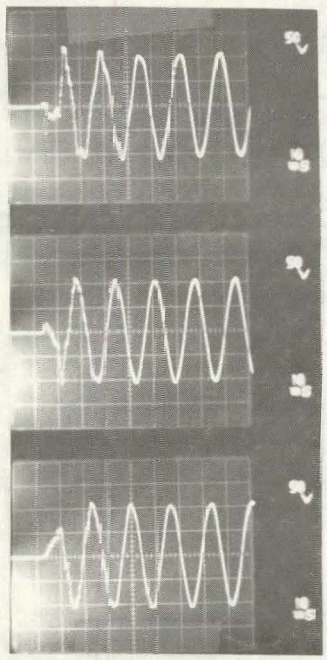
MAX. P.U. OVERVOLTAGE	1.0 p.u.	SAME AS V_4	1.75 p.u.	2.0 p.u.
LOCATION	V_{1-2}	V_3	V_4	V_5
				

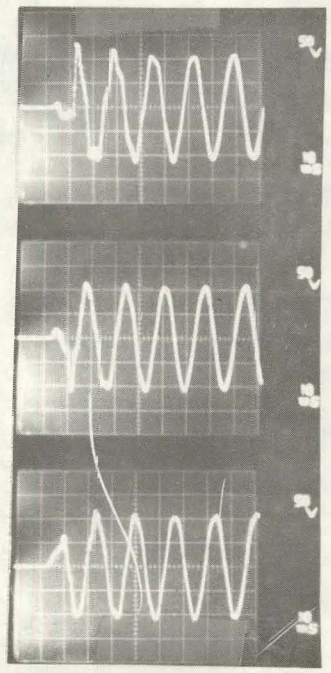
CASE NO. A-16

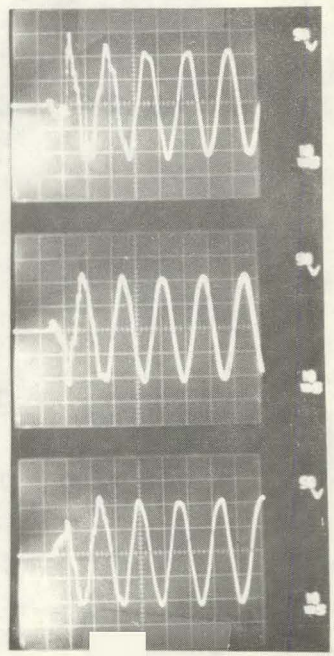


BREAKER RESISTORS	R_1 = 500	R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC	6 MSEC
MAXIMUM POLE SPAN	5 MSEC	
PRE-SWITCHED VOLTAGE	1.0 p.u.	

MAX. P.U. OVERVOLTAGE	1.25 p.u.	SAME AS V_4	1.3 p.u.	1.5 p.u.
LOCATION	V_2	V_3	V_4	V_5

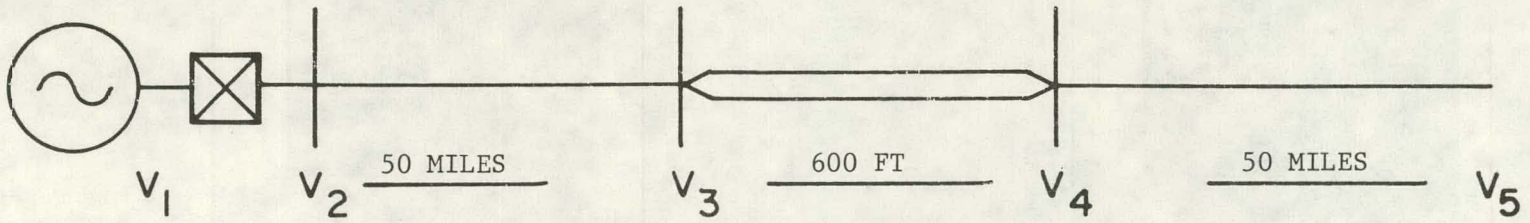






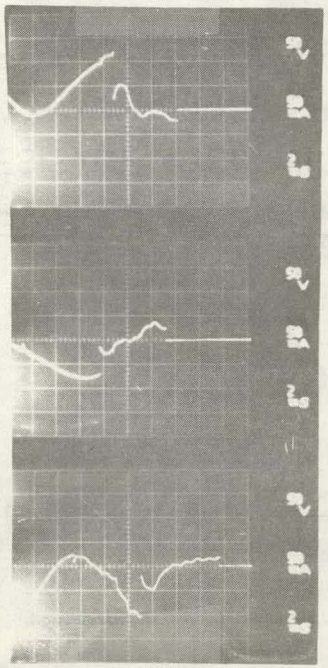
CASE NO. A-17

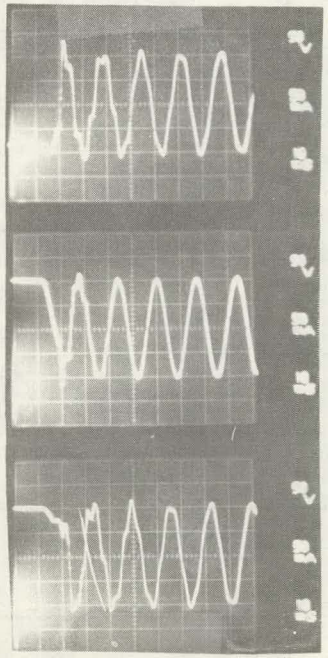
HIGH SPEED RECLOSING LINE

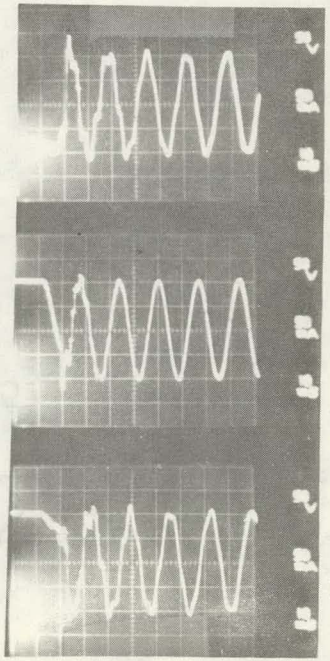


BREAKER RESISTORS	R_1 = 1500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. P.U. OVERVOLTAGE	1.5 p.u.	SAME AS V_4	1.32 p.u.	1.45 p.u.
LOCATION	V_{1-2}	V_3	V_4	V_5

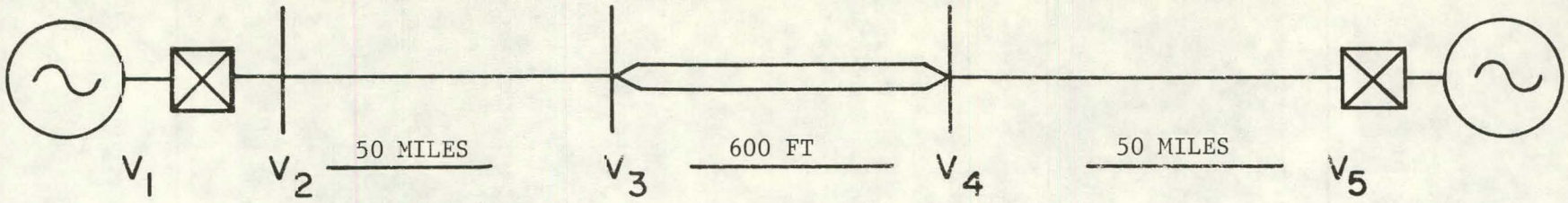






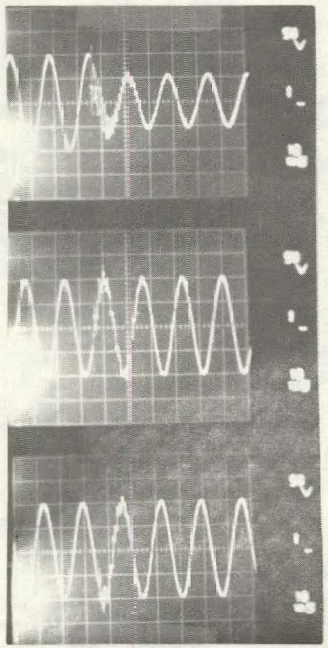
CASE NO. A-18

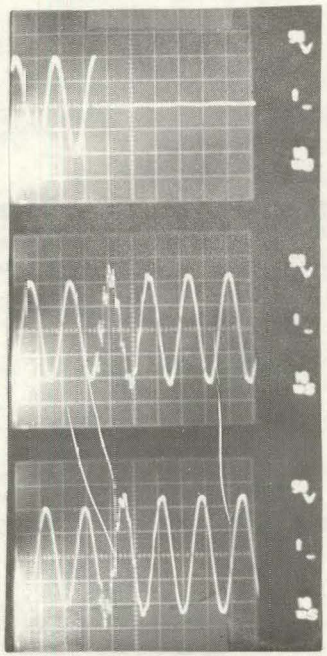
FAULT INITIATED OVERVOLTAGE

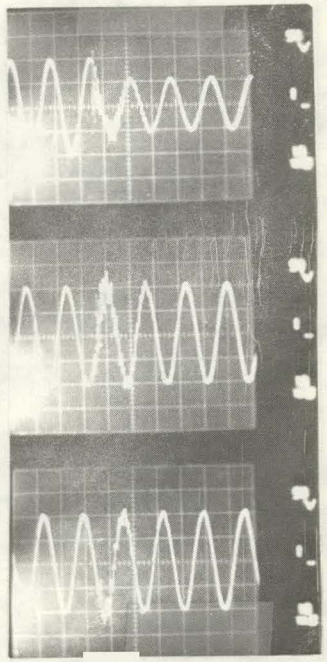


BREAKER RESISTORS	R_1 = — R_2 = —
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE—SWITCHED VOLTAGE	1.0 p.u.

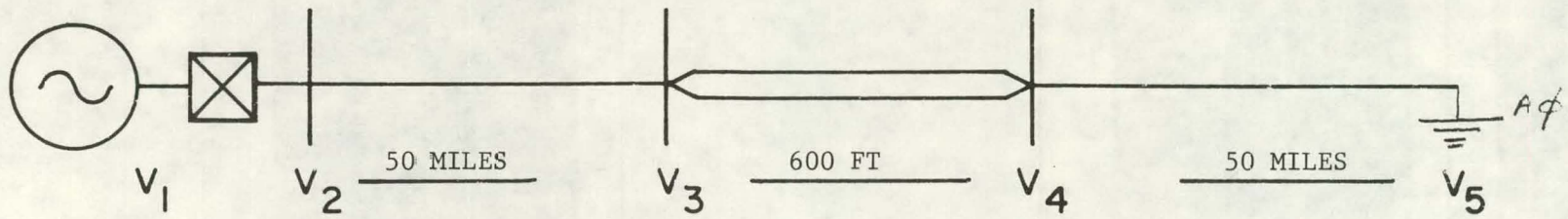
MAX. P.U. OVERVOLTAGE	1.3 p.u.	SAME AS V_4	1.5 p.u.	1.7 p.u.
LOCATION	V_2	V_3	V_4	V_5





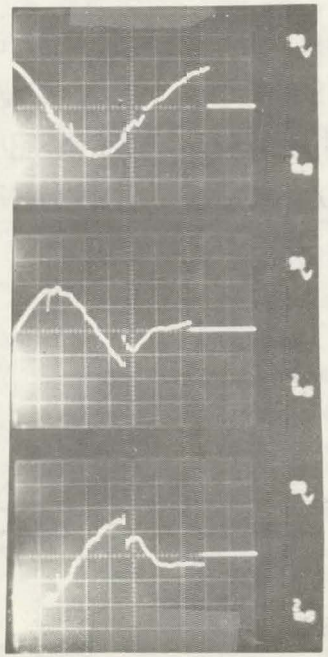


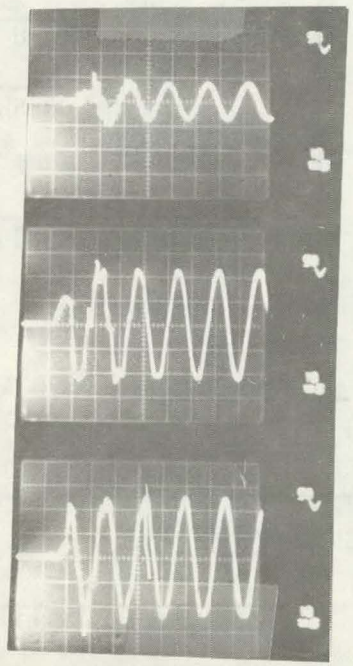
CASE NO. A-19 — ENERGIZING INTO SINGLE LINE TO GROUND FAULT

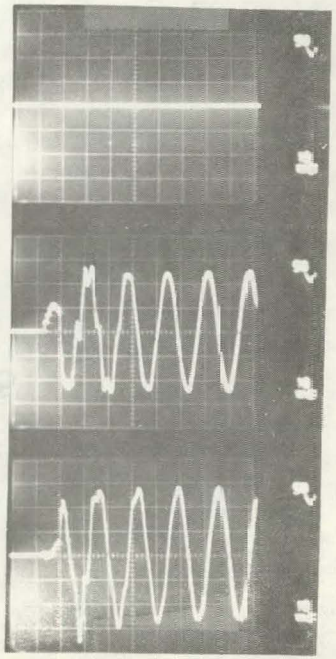


BREAKER RESISTORS	R_1 = 2500	R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC	6 MSEC
MAXIMUM POLE SPAN	5 MSEC	
PRE-SWITCHED VOLTAGE	1.0 p.u.	

MAX. PU. OVERVOLTAGE	1.0 p.u.	SAME AS V_4	1.6 p.u.	1.8 p.u.
LOCATION	V_{1-2}	V_3	V_4	V_5

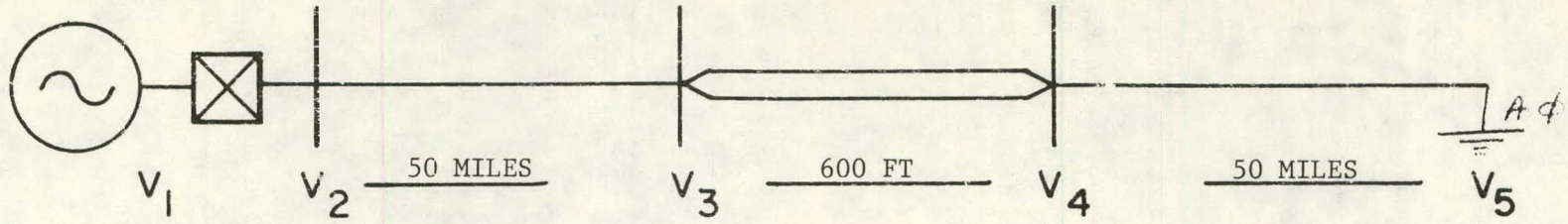




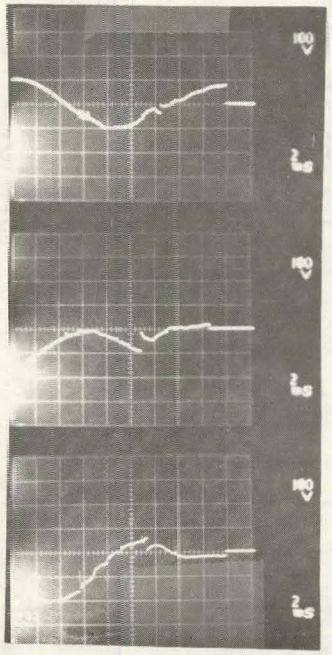
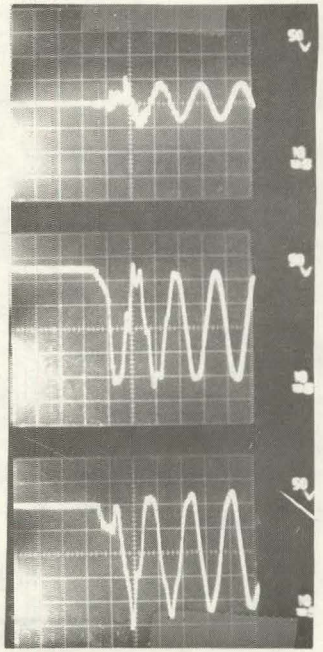
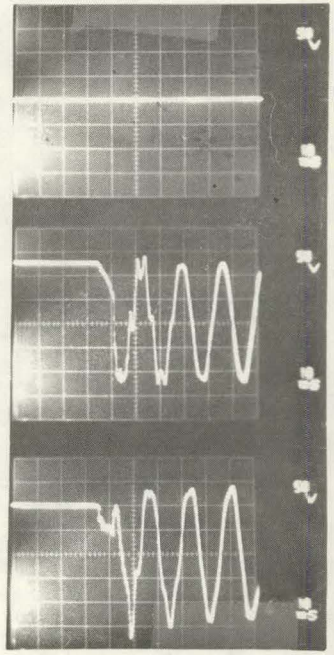


CASE NO. A-20

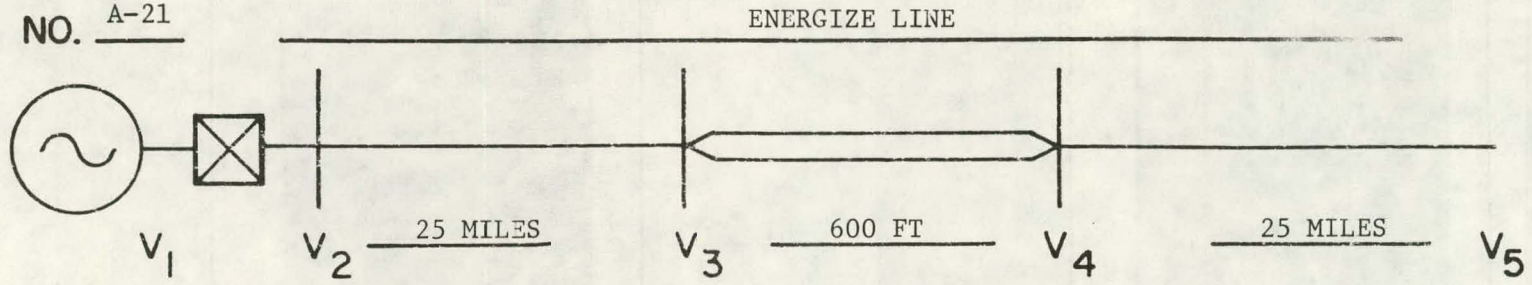
HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT



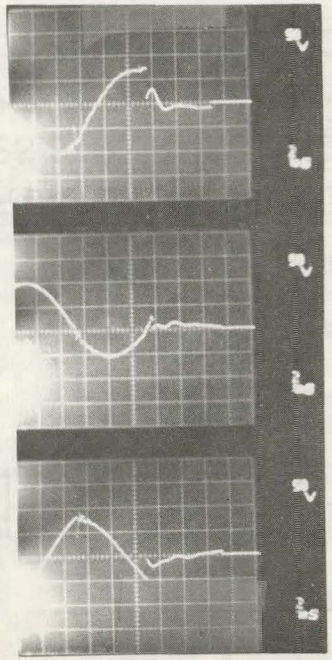
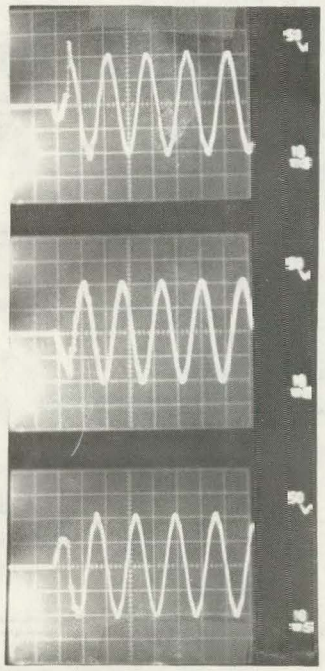
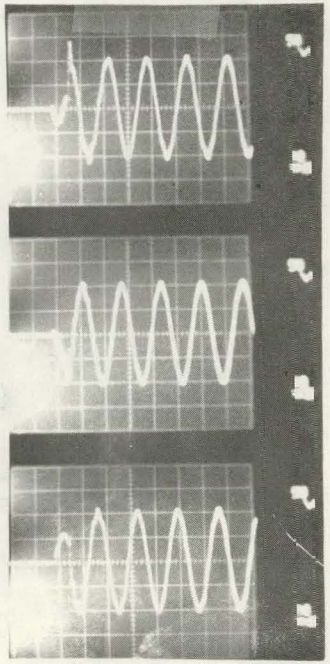
BREAKER RESISTORS	R_1 =		R_2 =
RESISTOR INSERTION TIMES	6 MSEC		6 MSEC
MAXIMUM POLE SPAN		5 MSEC	
PRE-SWITCHED VOLTAGE		1.0 p.u.	

MAX. PU. OVERVOLTAGE	2.0 p.u.	SAME AS V_4	1.6 p.u.	1.8 p.u.
LOCATION	V_{1-2}	V_3	V_4	V_5
		SAME AS V_4		

CASE NO. A-21

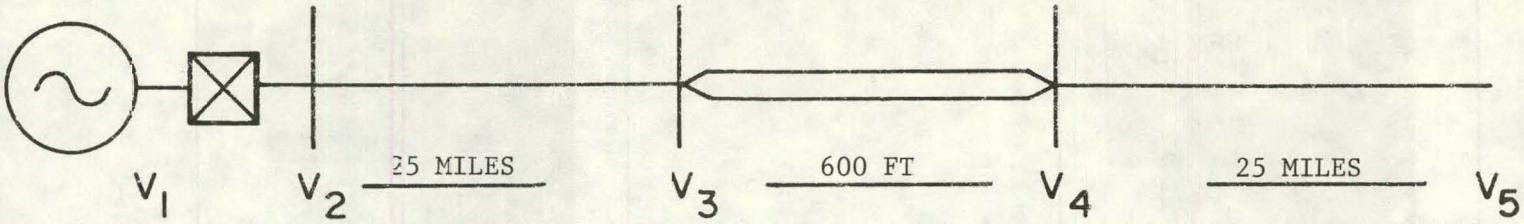


BREAKER RESISTORS	R_1 = 2500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU. OVERVOLTAGE	1.0 p.u.	SAME AS V_4	1.4 p.u.	1.4 p.u.
LOCATION	V_{1-2}	V_3	V_4	V_5
		SAME AS V_4		

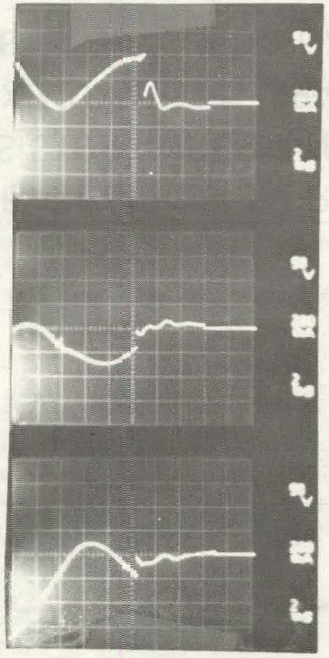
CASE NO. A-22

HIGH SPEED RECLOSING OF LINE

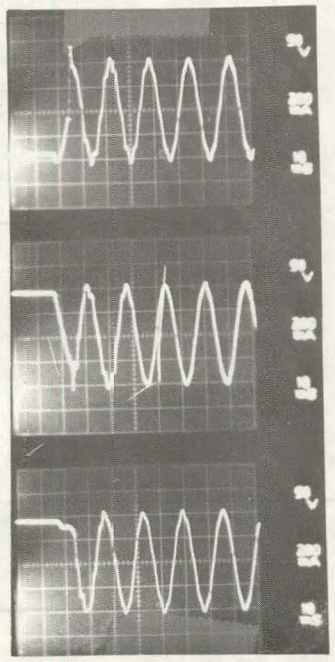


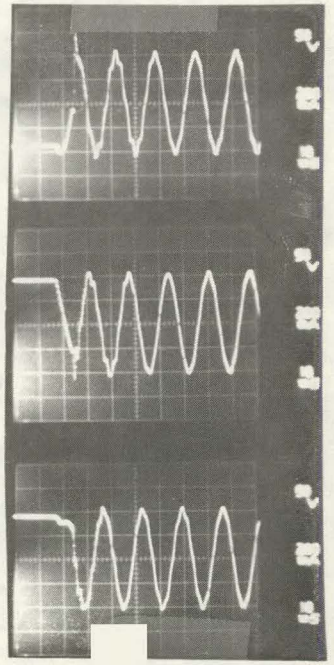
BREAKER RESISTORS	R_1 = 2500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. P.U. OVERVOLTAGE	2.[illegible] p.u.	SAME AS V_4	1.35 p.u.	1.48 p.u.
LOCATION	V_{1-2}	V_3	V_4	V_5



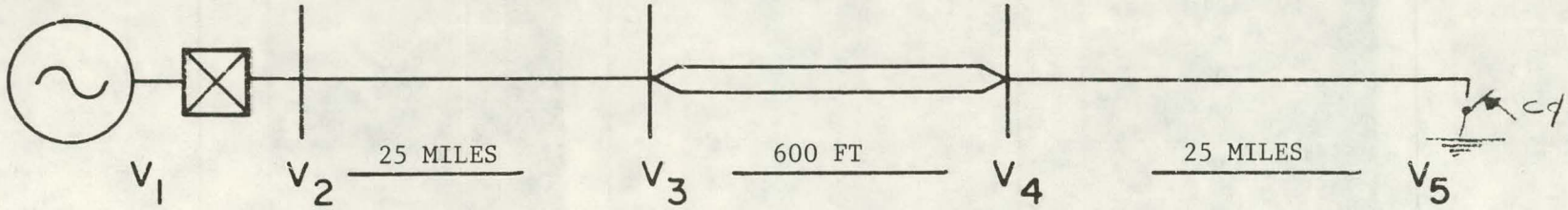
SAME AS V_4





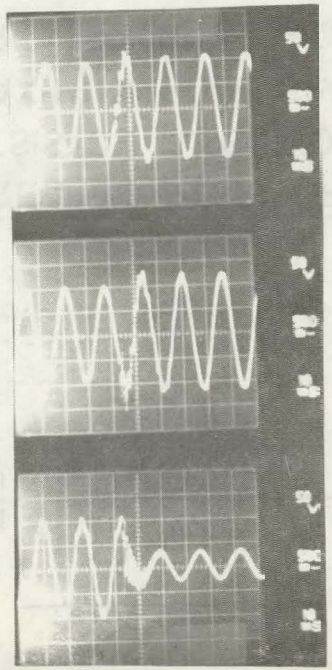
CASE NO. A-23

FAULT INITIATED OVERVOLTAGES - ONE SOURCE

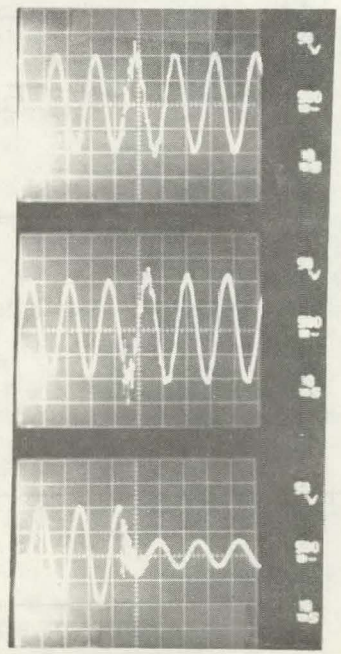


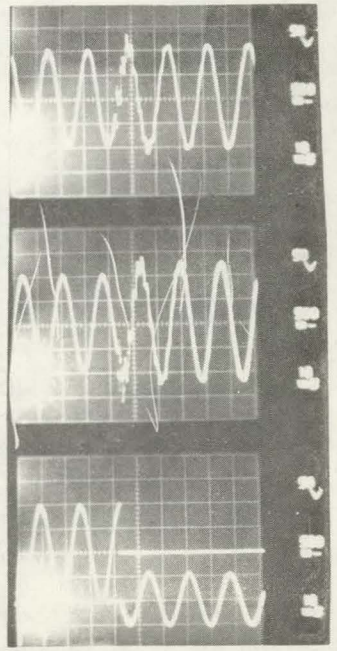
BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE— SWITCHED VOLTAGE	1.0 p.u.

MAX. P.U. OVERVOLTAGE	1.55 p.u.	SAME AS V_4	1.55 p.u.	1.6 p.u.
LOCATION	V_2	V_3	V_4	V_5



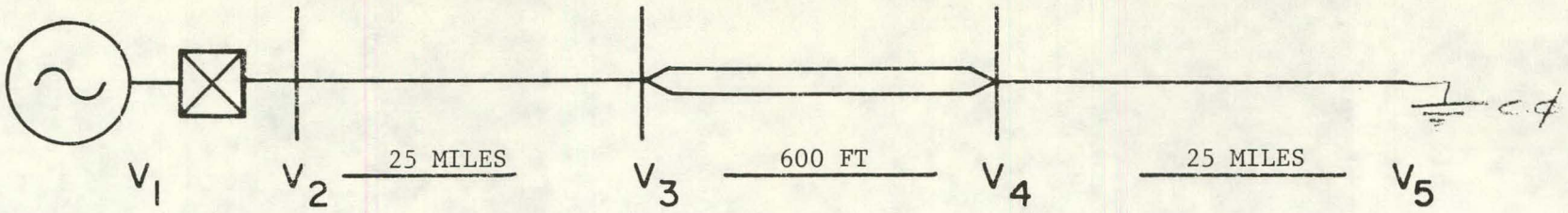
SAME AS V_4



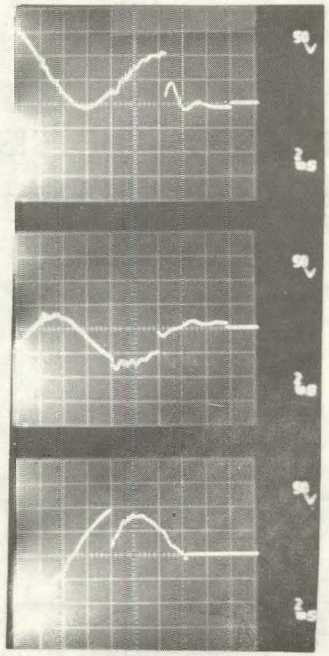
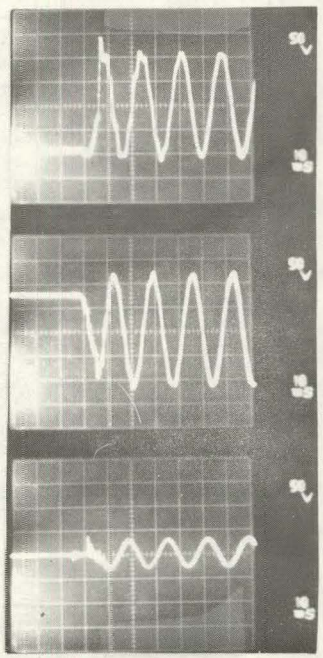
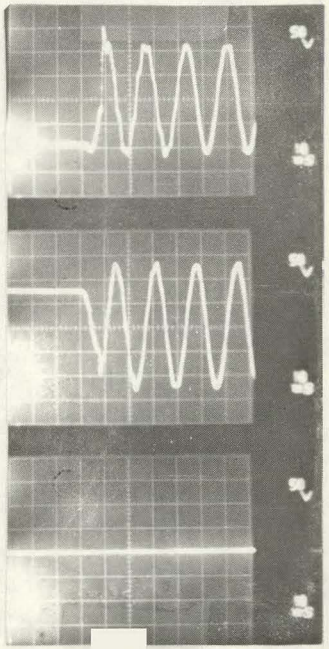


CASE NO. A-24

HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT

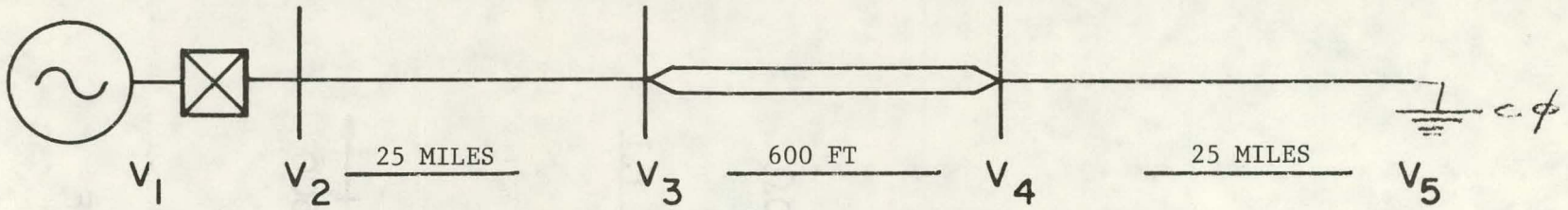


BREAKER RESISTORS	R_1 = 2500	R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC	6 MSEC
MAXIMUM POLE SPAN	5 MSEC	
PRE-SWITCHED VOLTAGE	1.0 p.u.	

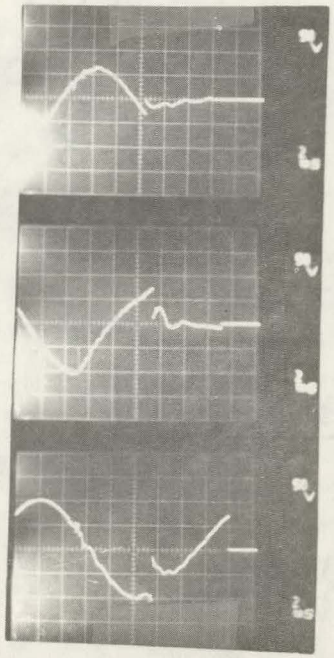
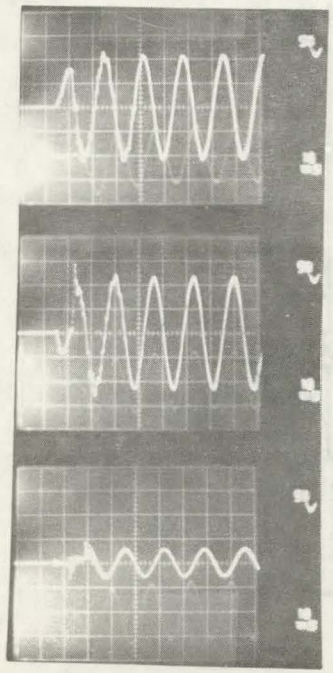
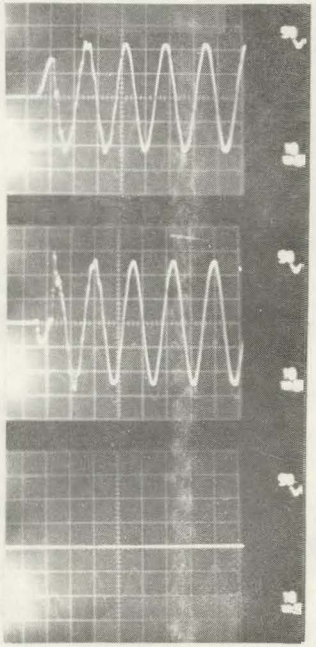
MAX. PU. OVERVOLTAGE	2.0 p.u.	SAME AS V_4	1.45 p.u.	1.5 p.u.
LOCATION	V_{1-2}	V_3	V_4	V_5
		SAME AS V_4		

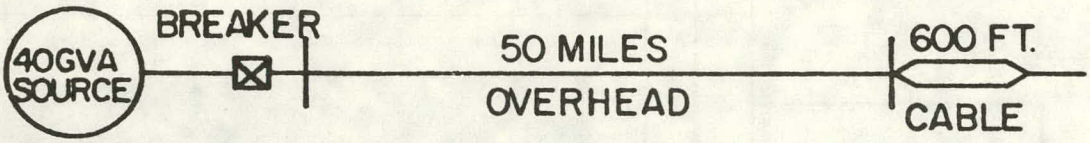
CASE NO. A-25

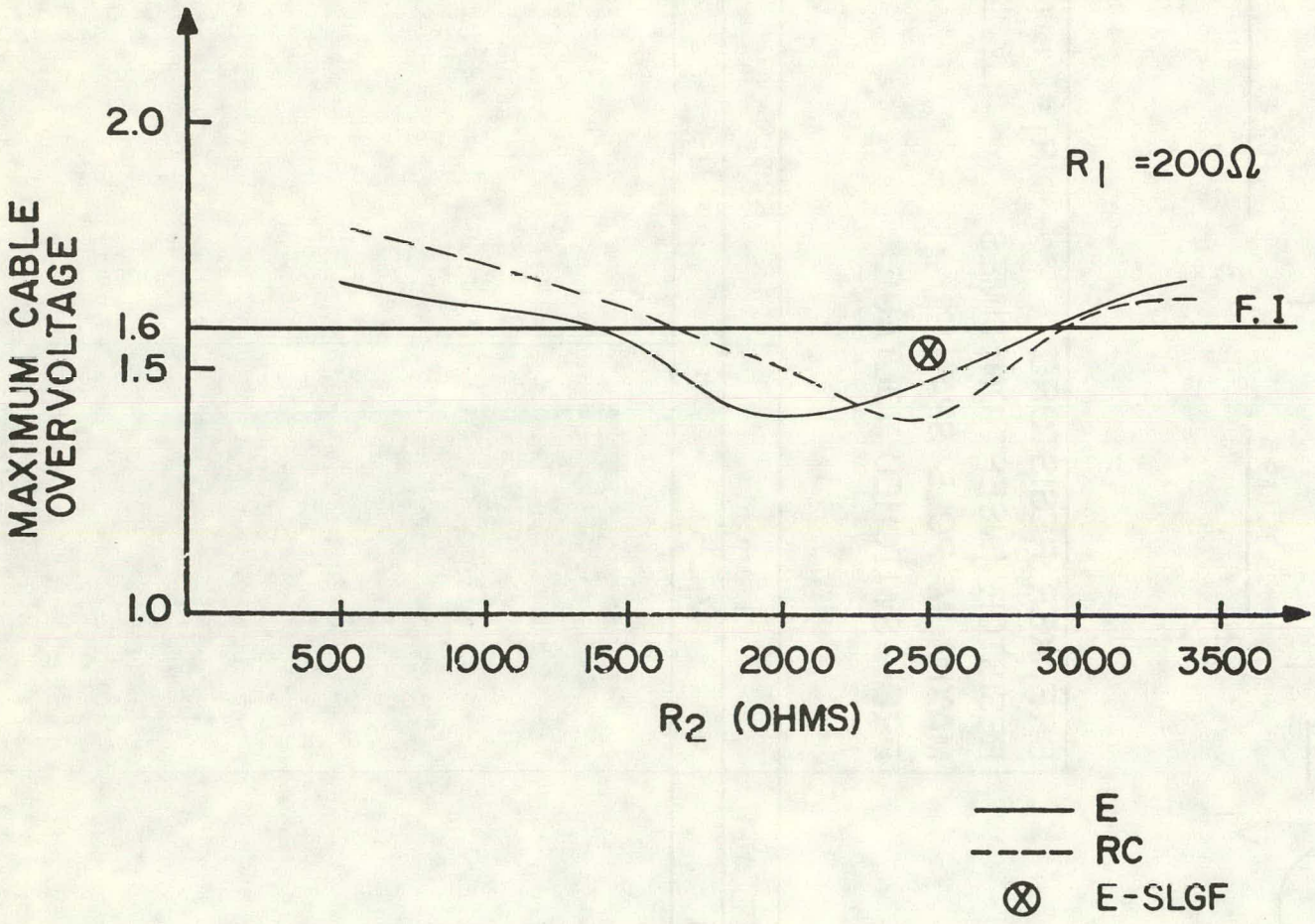
ENERGIZING INTO SINGLE LINE TO GROUND FAULT

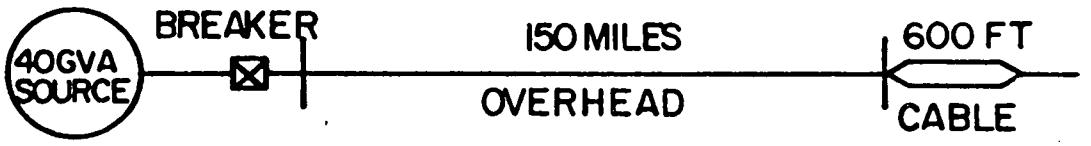


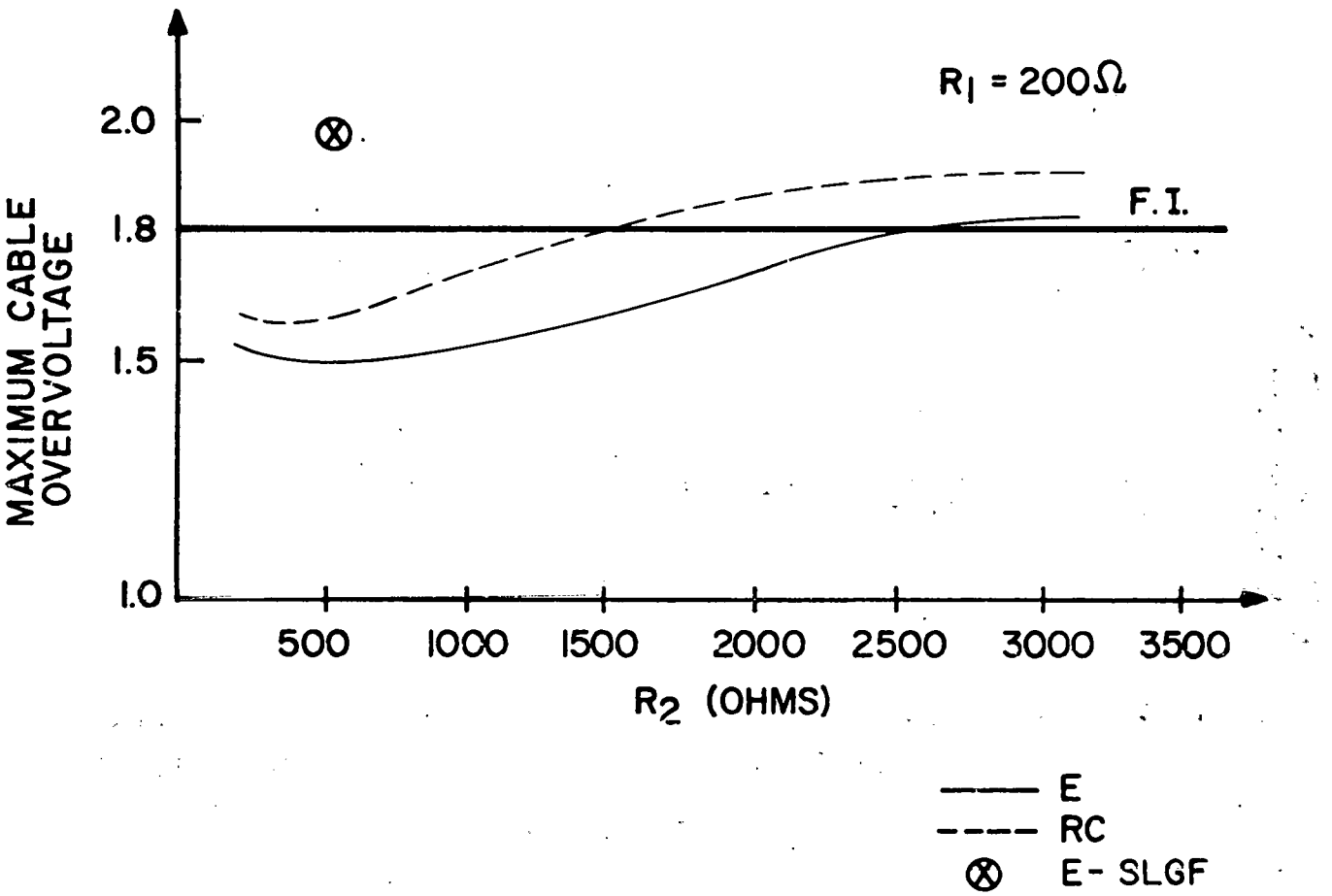
BREAKER RESISTORS	R_1 = 2500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU. OVERVOLTAGE	1.0 p.u.	SAME AS V_4	1.45 p.u.	1.5 p.u.
LOCATION	V_{1-2}	V_3	V_4	V_5
		SAME AS V_4		

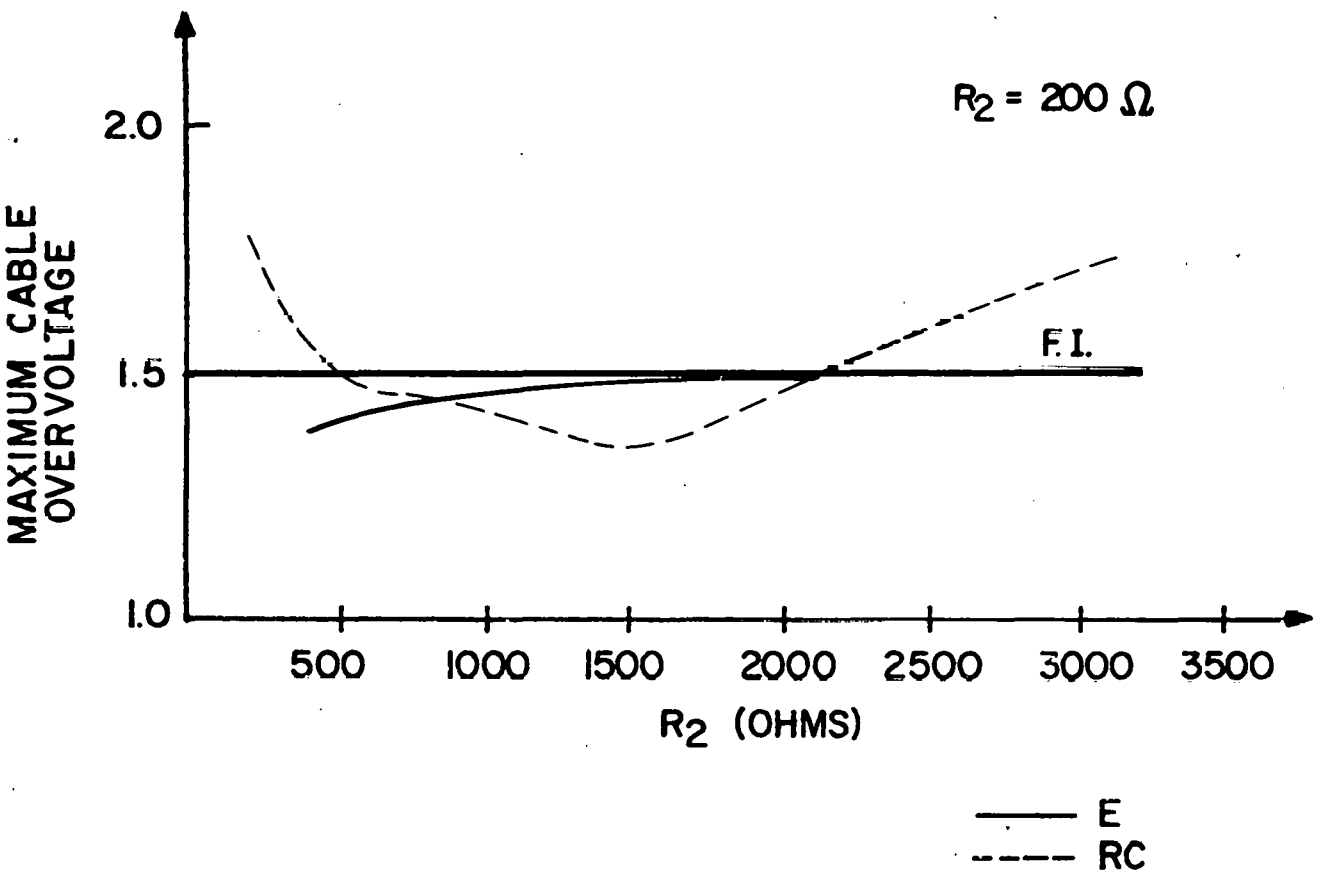

40GVA
SOURCE
BREAKER
50 MILES
OVERHEAD
600 FT.
CABLE


MAXIMUM CABLE
OVERVOLTAGE
2.0
1.6
1.5
1.0
R_1 =200Ω
F. I
500
1000
1500
2000
2500
3000
3500
R_2 (OHMS)
E
RC
E-SLGF

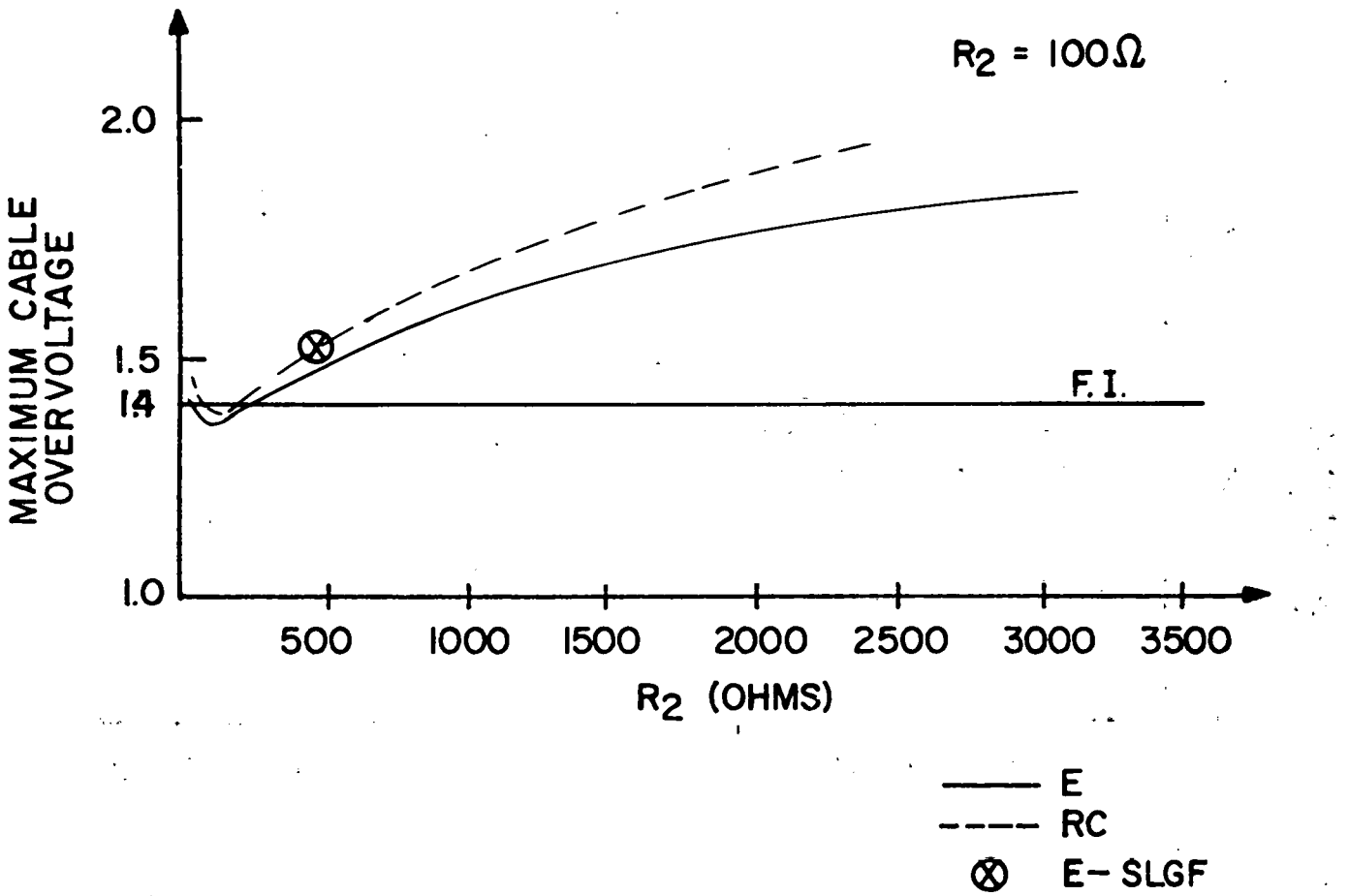

40GVA
SOURCE
BREAKER
150 MILES
OVERHEAD
600 FT
CABLE


$R_1 = 200\Omega$
F.I.
MAXIMUM CABLE OVERVOLTAGE
2.0
1.8
1.5
1.0
500
1000
1500
2000
2500
3000
3500
R_2 (OHMS)
E
RC
E- SLGF

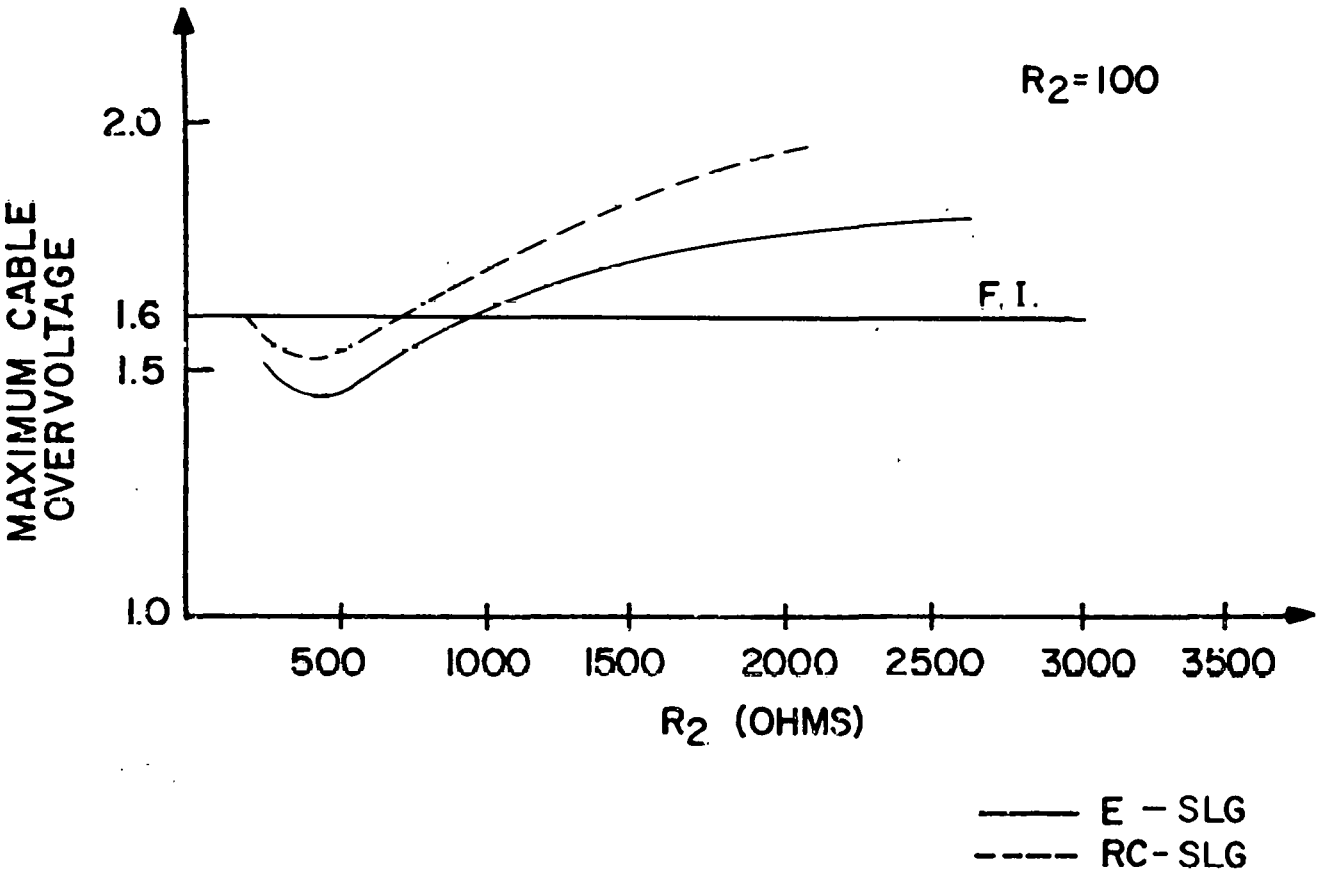

40GVA
SOURCE
BREAKER
50 MILES
OVERHEAD
2 MILES
CABLE

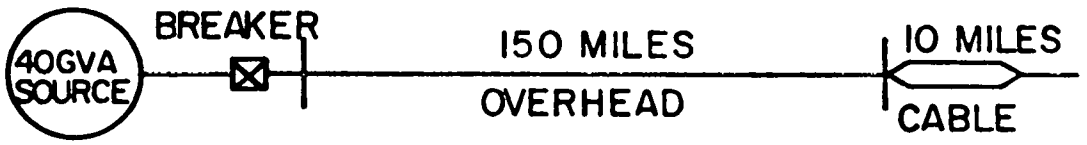

R_2 = 200 Ω
MAXIMUM CABLE OVERVOLTAGE
2.0
1.5
1.0
F.I.
500
1000
1500
2000
2500
3000
3500
R_2 (OHMS)
E
RC

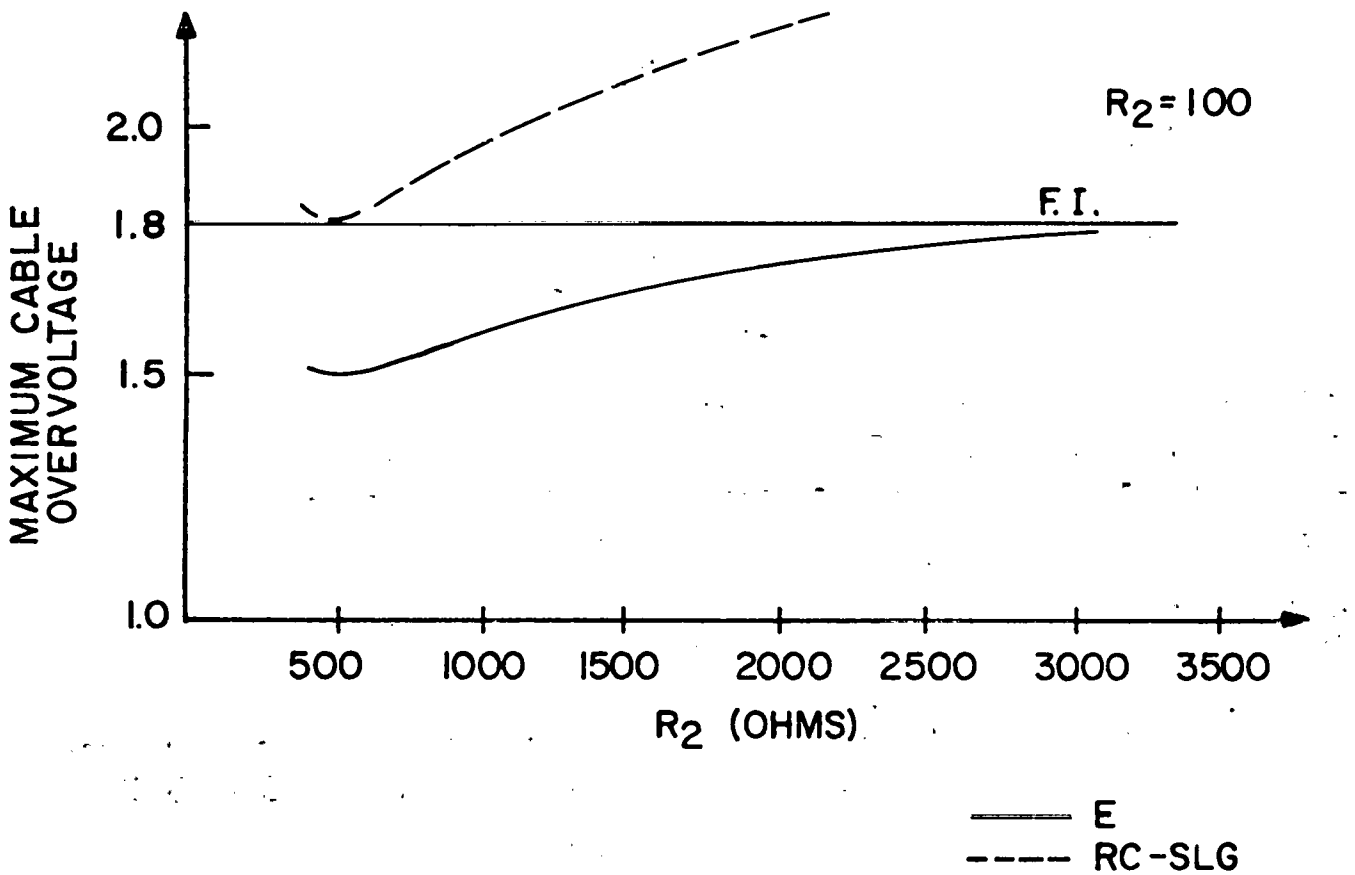

40GVA
SOURCE
BREAKER
50 MILES
OVERHEAD
10 MILES
CABLE

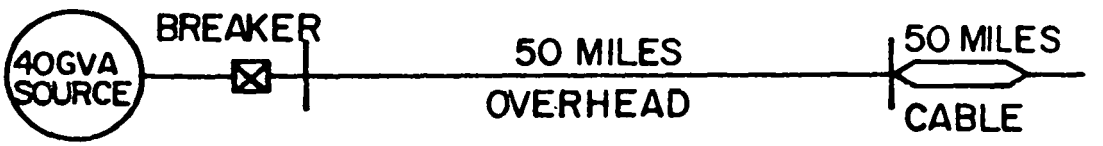

R_2 = 100Ω
2.0
1.5
1.4
1.0
MAXIMUM CABLE OVERVOLTAGE
F.I.
500
1000
1500
2000
2500
3000
3500
R_2 (OHMS)
E
RC
E- SLGF


40GVA
SOURCE
BREAKER
100 MILES
OVERHEAD
10 MILES
CABLE

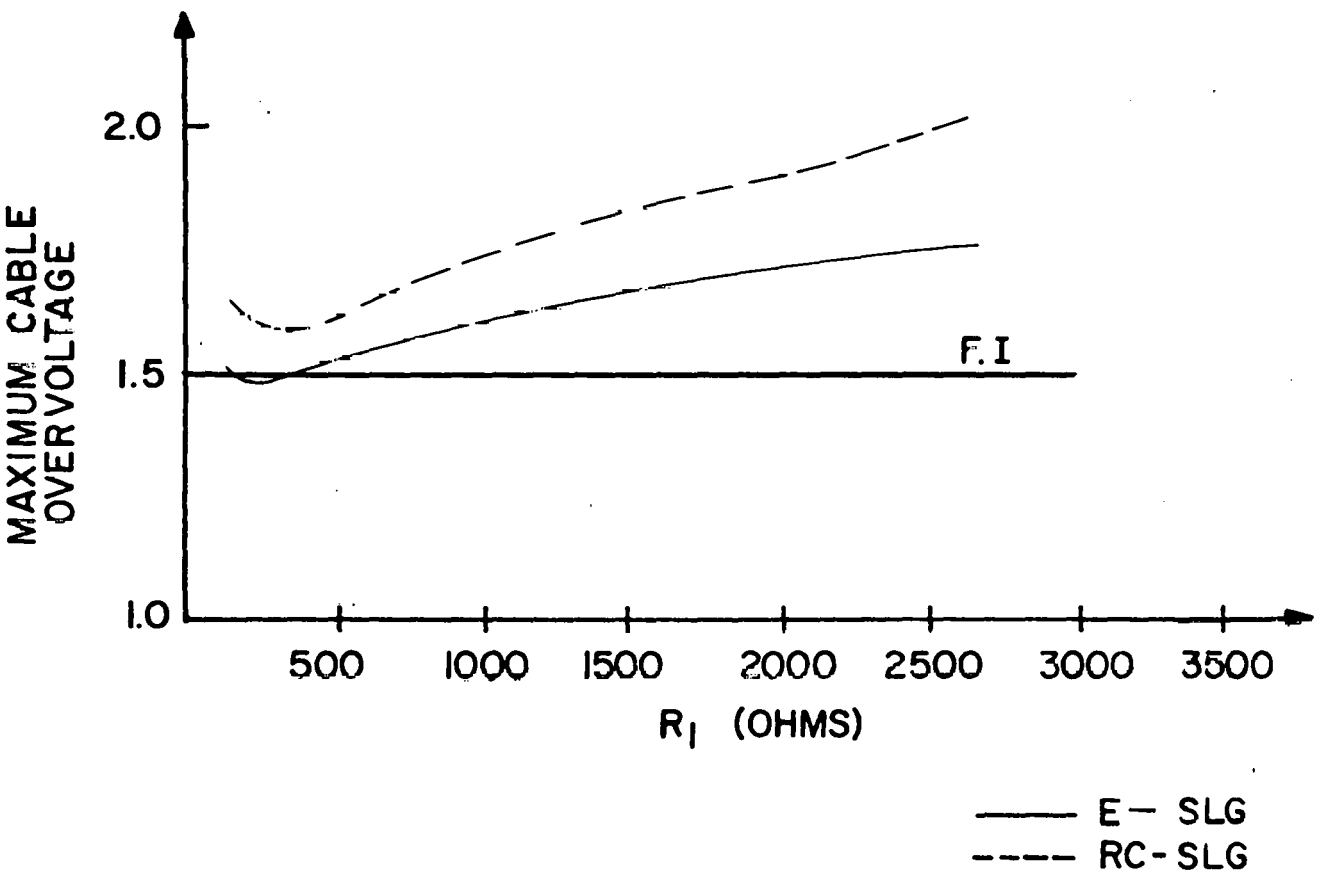

R_2=100
2.0
1.6
1.5
1.0
F. I.
MAXIMUM CABLE
OVERVOLTAGE
500
1000
1500
2000
2500
3000
3500
R_2 (OHMS)
E – SLG
RC – SLG


40GVA SOURCE
BREAKER
150 MILES
OVERHEAD
10 MILES
CABLE

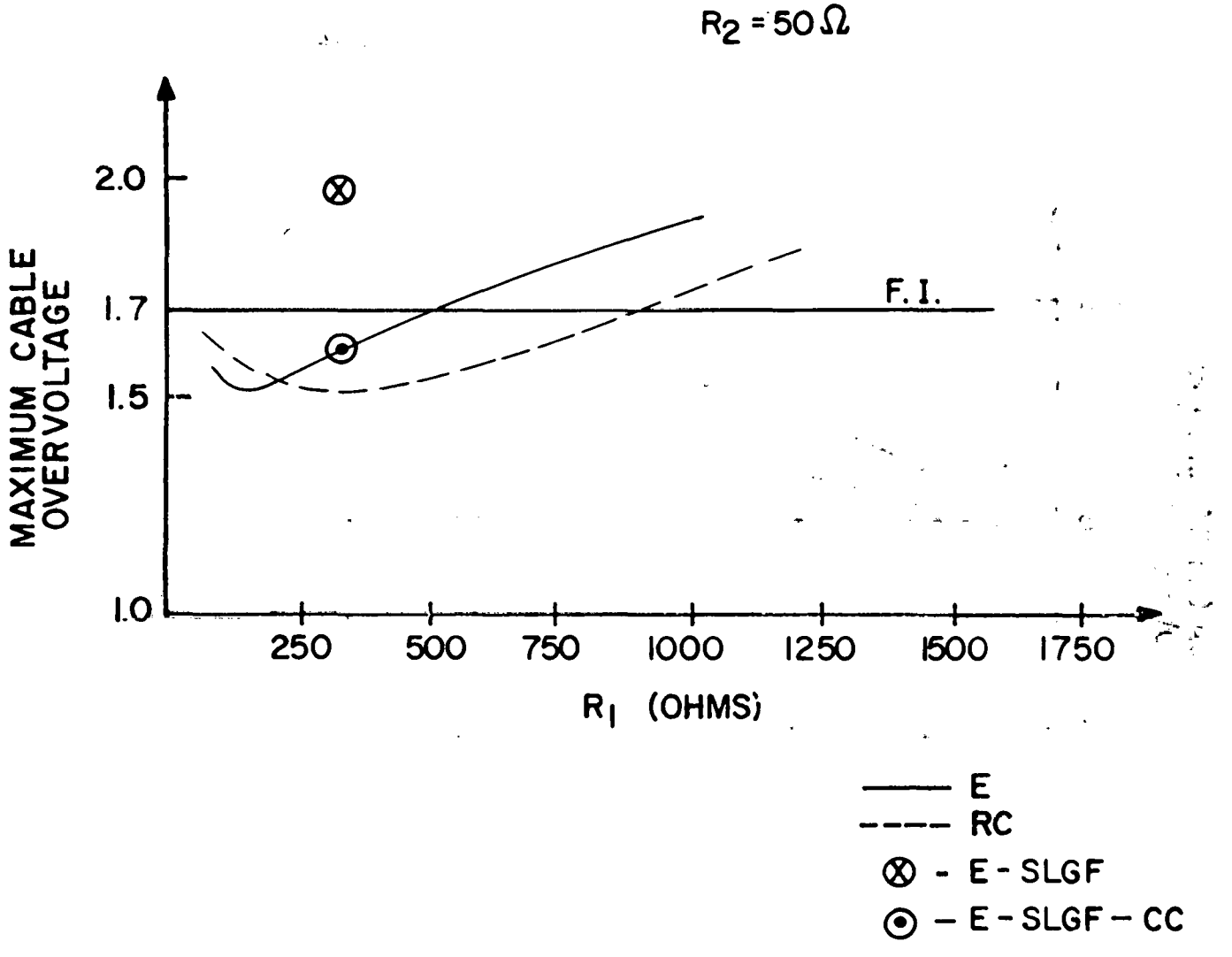

MAXIMUM CABLE OVERVOLTAGE
2.0
1.8
1.5
1.0
500
1000
1500
2000
2500
3000
3500
R2 (OHMS)
R2=100
F.I.
E
RC-SLG

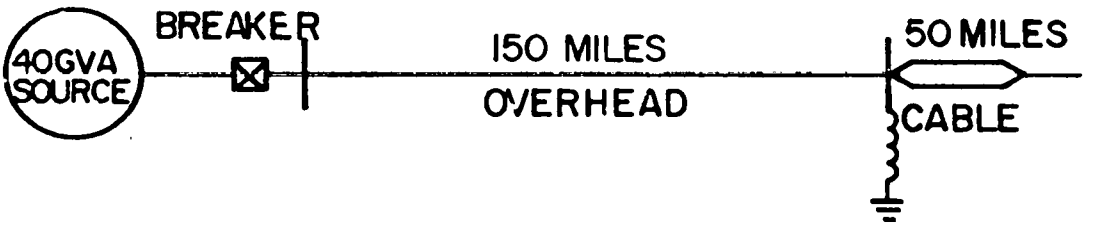

40GVA
SOURCE
BREAKER
50 MILES
OVERHEAD
50 MILES
CABLE

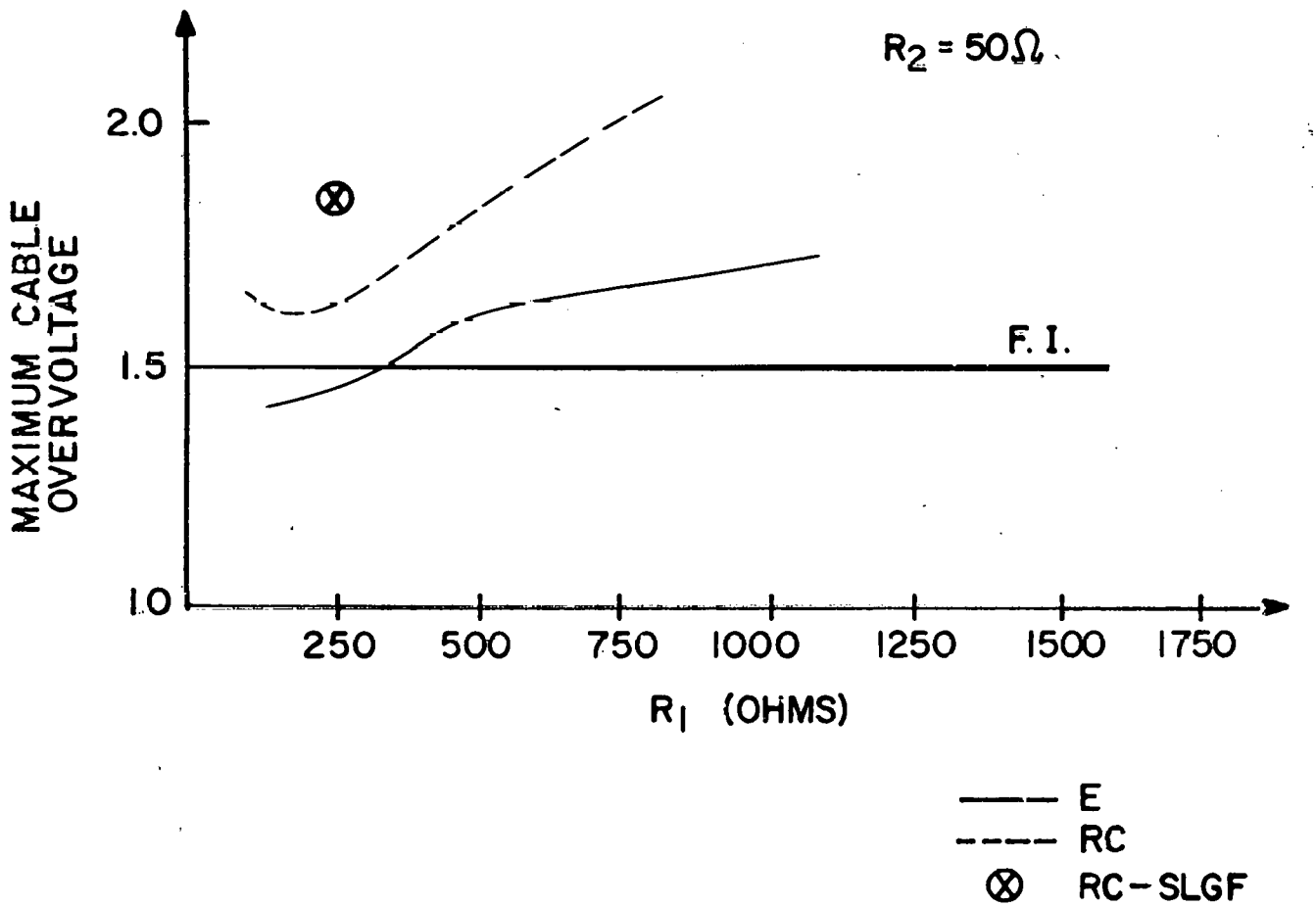
$R_2 = 50\Omega$


MAXIMUM CABLE
OVERVOLTAGE
2.0
1.5
1.0
F.I
500
1000
1500
2000
2500
3000
3500
R_1 (OHMS)
E— SLG
RC-SLG

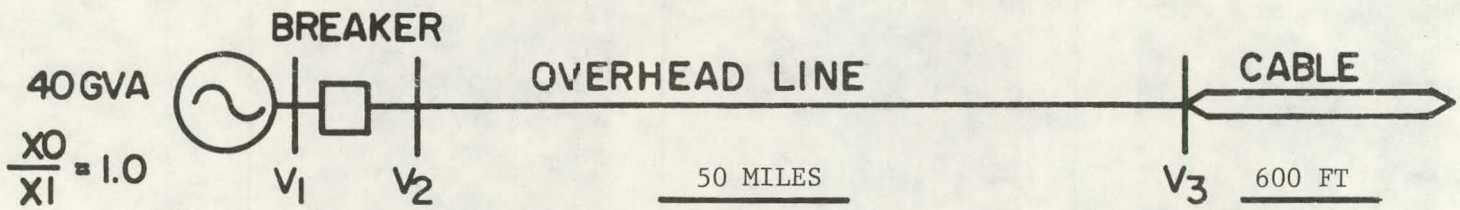

40GVA SOURCE
BREAKER
100 MILES
OVERHEAD
50 MILES
CABLE


$R_2 = 50\,\Omega$
MAXIMUM CABLE OVERVOLTAGE
2.0
1.7
1.5
1.0
F. I.
250
500
750
1000
1250
1500
1750
R_1 (OHMS)
E
RC
⊗ - E - SLGF
⊙ - E - SLGF - CC


40GVA
SOURCE
BREAKER
150 MILES
OVERHEAD
50 MILES
CABLE

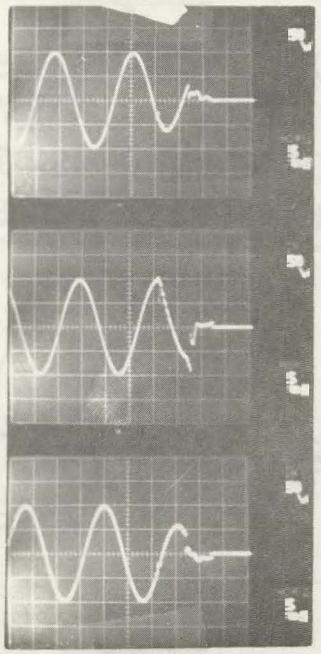

$R_2 = 50\Omega$
MAXIMUM CABLE OVERVOLTAGE
2.0
1.5
1.0
F. I.
250
500
750
1000
1250
1500
1750
R_1 (OHMS)
E
RC
RC-SLGF

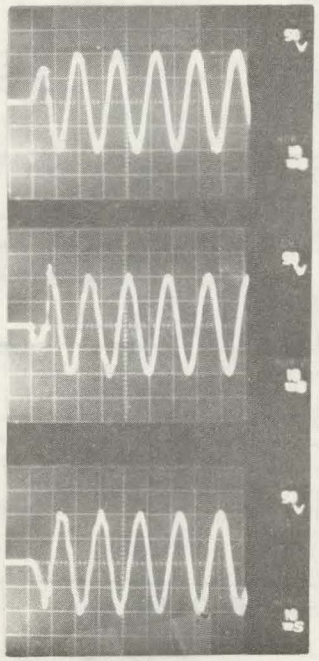
CASE NO. B-1 ENERGIZE LINE

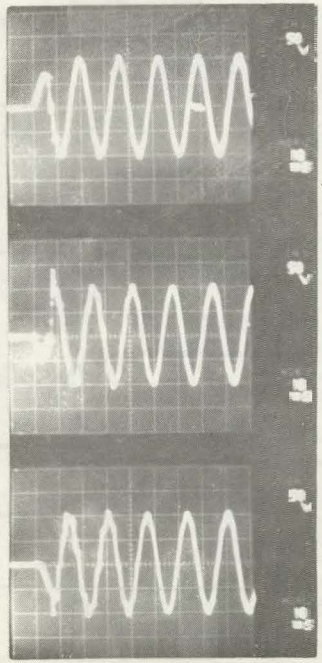


BREAKER RESISTORS	R_1 = 2500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE	1.0 p.u.	1.3 p.u.	1.4 p.u.	
LOCATION	V_1 -2	V_2	V_3	



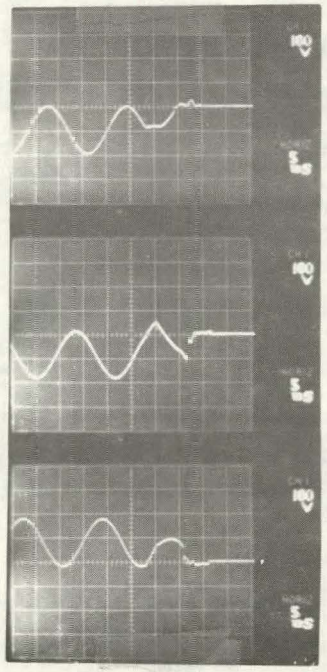


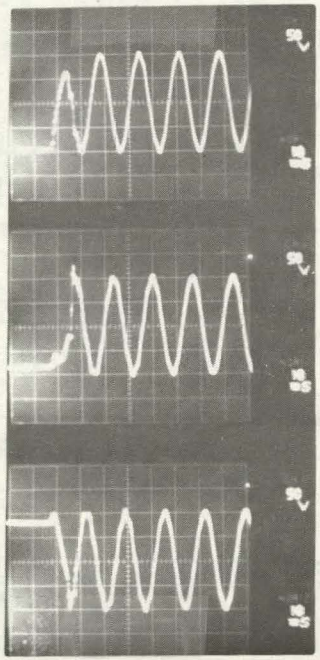


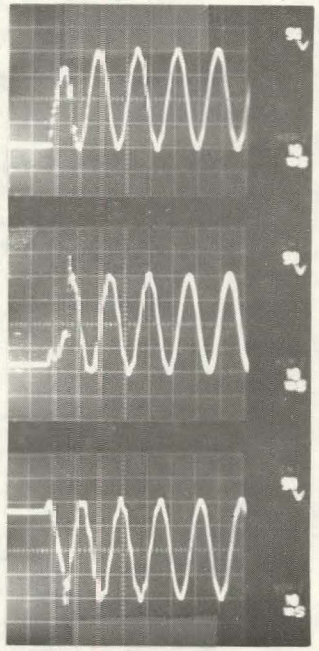
CASE NO. B-2 — HIGH SPEED RECLOSING OF LINE

BREAKER RESISTORS	R_1 = 2500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

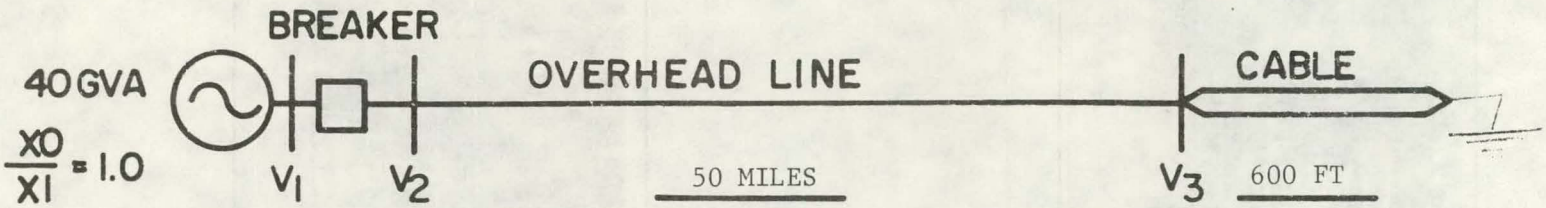
MAX. PU OVERVOLTAGE	2.0 p.u.	1.3 p.u.	1.4 p.u.	
LOCATION	V_1 -2	V_2	V_3	



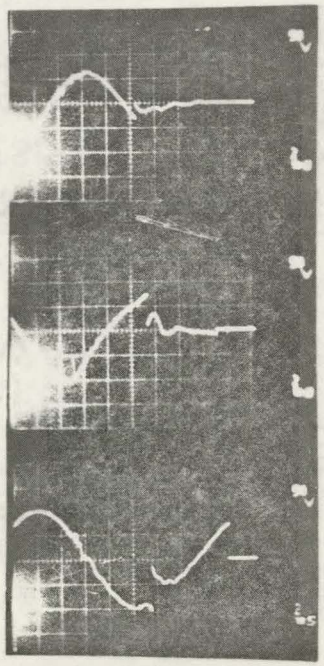
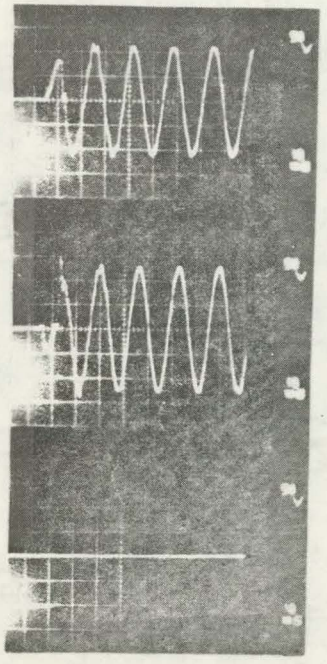




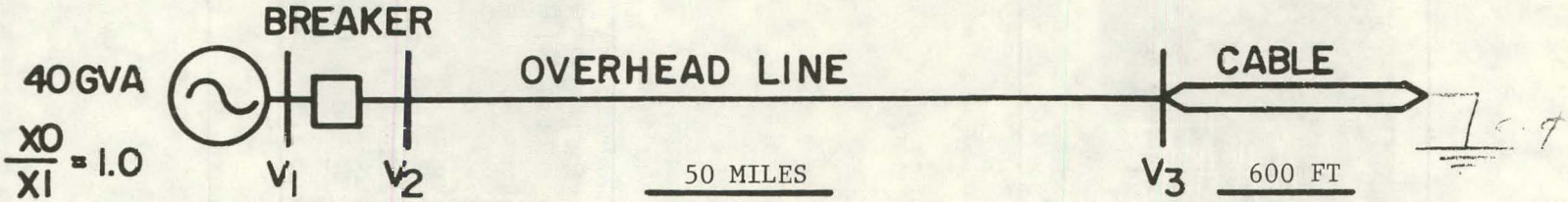
CASE NO. B-3 ENERGIZE INTO SINGLE LINE TO GROUND FAULT



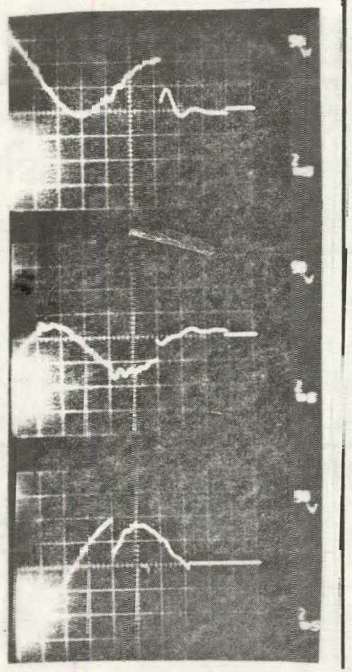
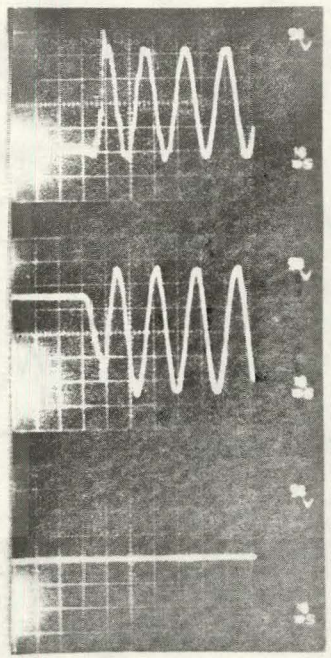
BREAKER RESISTORS	R_1 = 2500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE	1.2 p.u.		1.5 p.u.	SAME AS V_3
LOCATION	V_1 -2	V_2	V_3	V_4
				SAME AS V_3

CASE NO. B-4 HIGH SPEED RECLOSE INTO SINGLE LINE TO GROUND FAULT

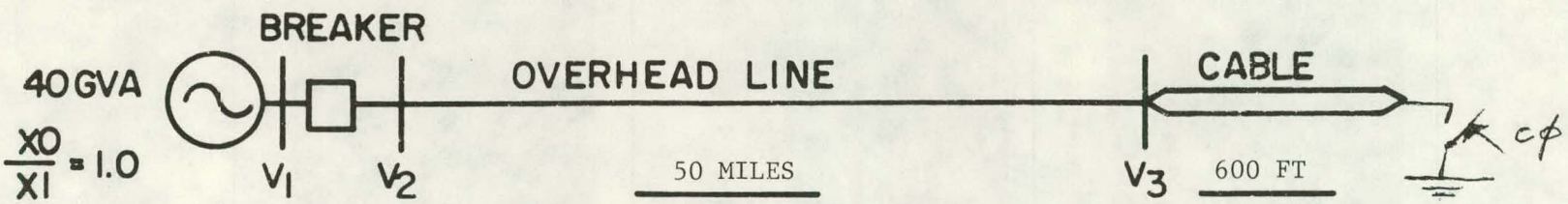


BREAKER RESISTORS	R_1 = 2500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE	2.0 p.u.		1.5 p.u.	SAME AS V_3
LOCATION	V_1 -2	V_2	V_3	V_4
				SAME AS V_3

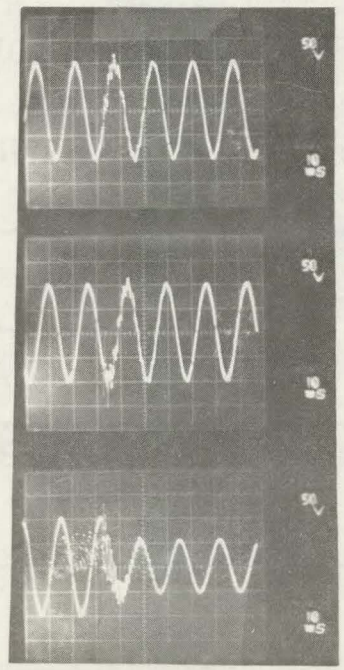
CASE NO. B-5

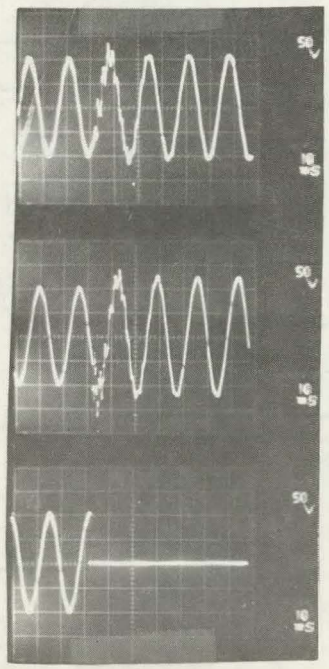
FAULT INITIATED OVERVOLTAGES



BREAKER RESISTORS	R_1 = , R_2 =
RESISTOR INSERTION TIMES	6 MSEC, 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE		1.5 p.u.	1.6 p.u.	
LOCATION		V2	V3	

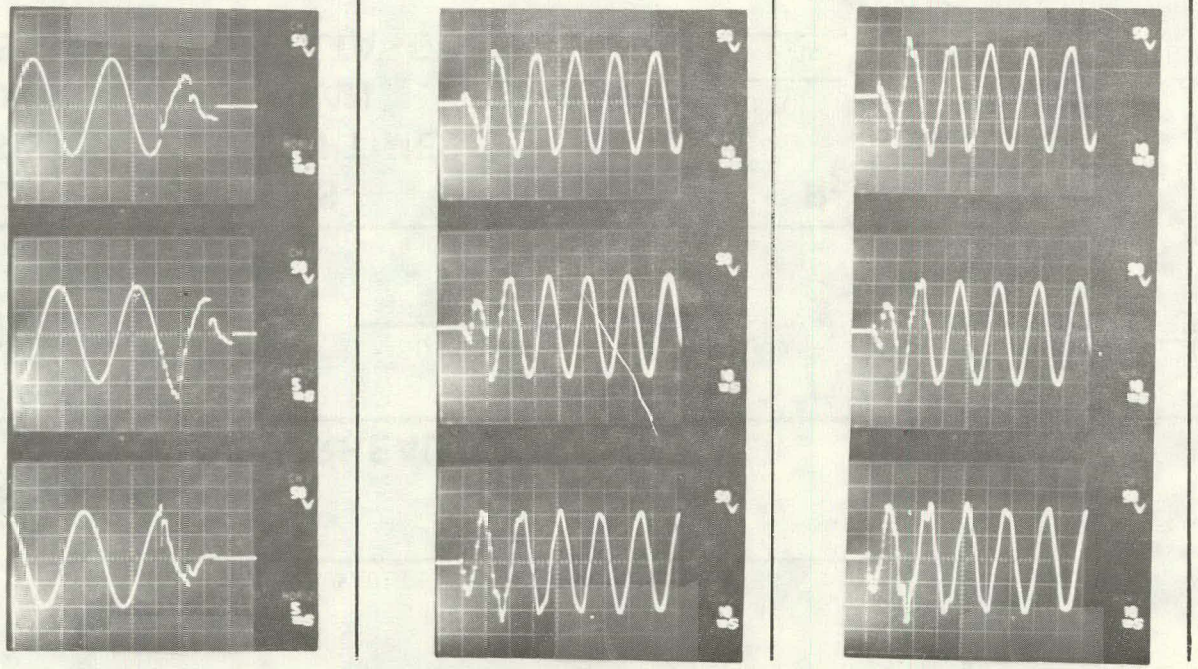




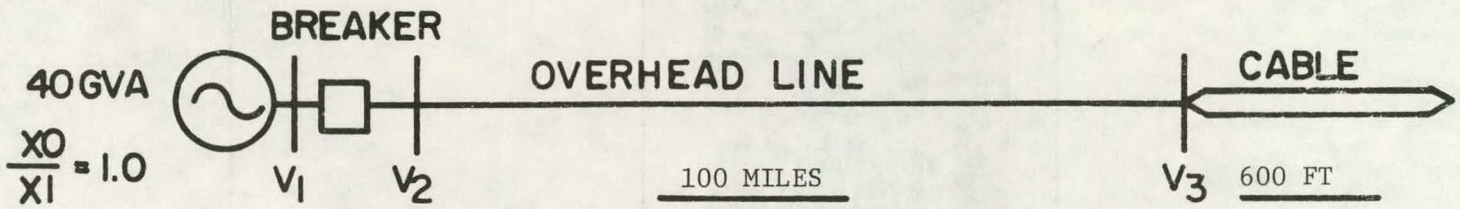
CASE NO. B-6 ENERGIZE LINE

BREAKER RESISTORS	R_1 = 1000 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE	1.00 p.u.	1.2 p.u.	1.35 p.u.	
LOCATION	V_1 -2	V_2	V_3	

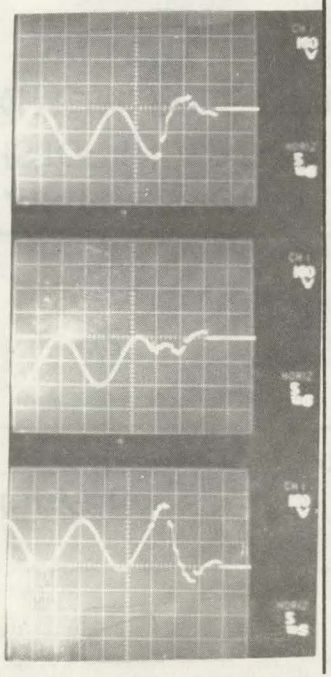


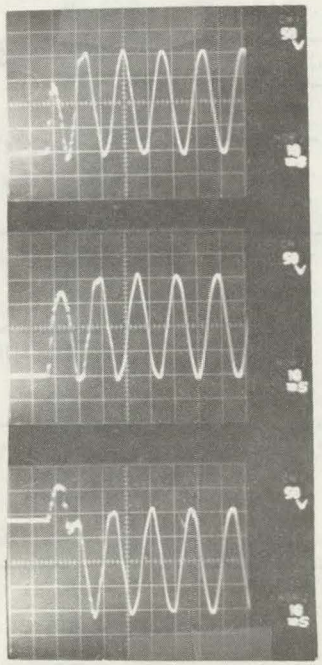
CASE NO. B-7 HIGH SPEED RECLOSING LINE

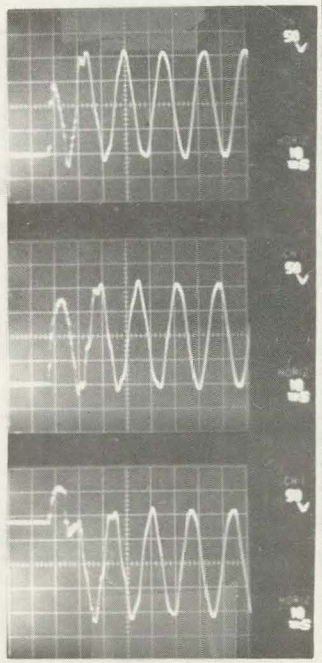


BREAKER RESISTORS	R_1 = 1000 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

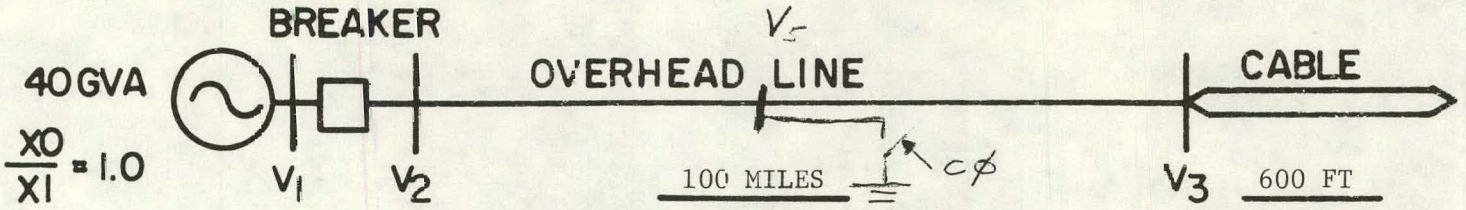
MAX. PU OVERVOLTAGE	2.5 p.u.	1.6 p.u.	1.6 p.u.	
LOCATION	$V_1 - 2$	V_2	V_3	V_4



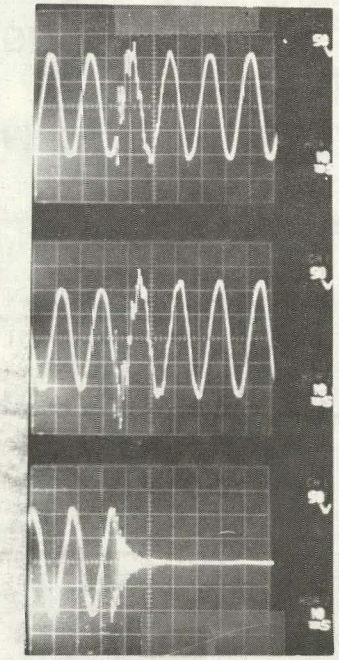
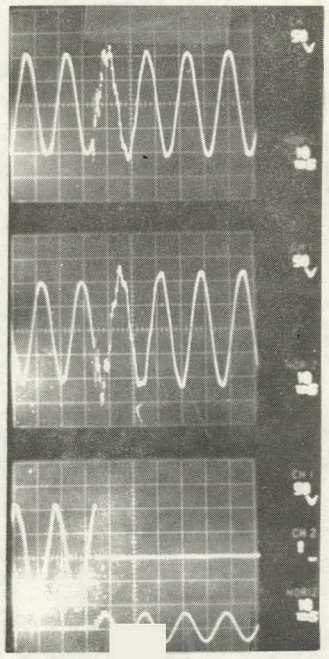




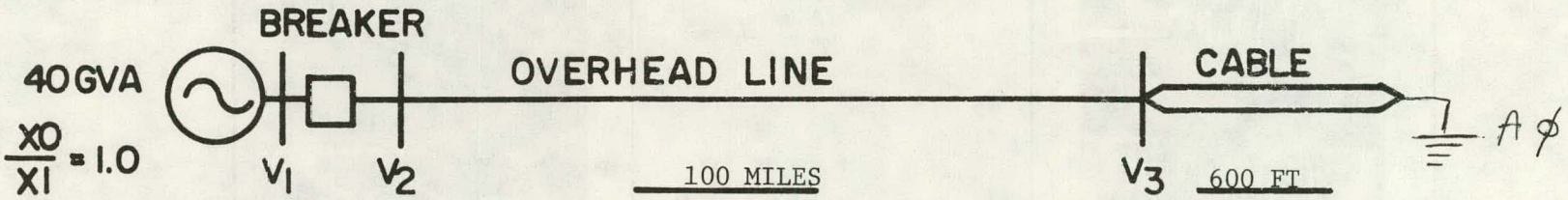
CASE NO. B-8 FAULT INITIATED OVERVOLTAGES



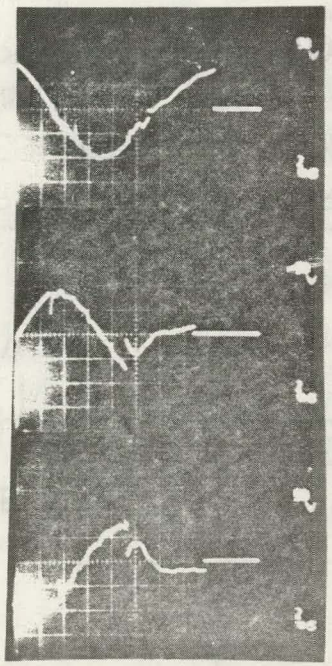
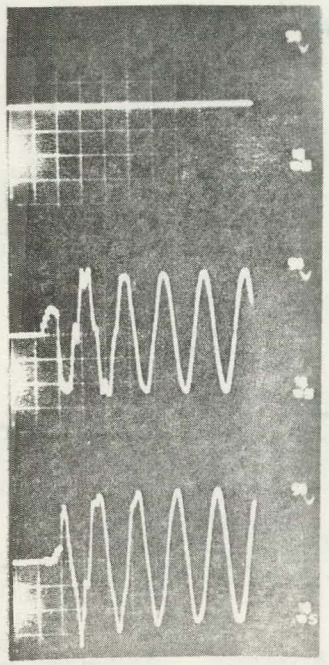
BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE		1.8 p.u.	1.8 p.u.	1.55 p.u.
LOCATION	V_2	V_3	V_4	V_5
				

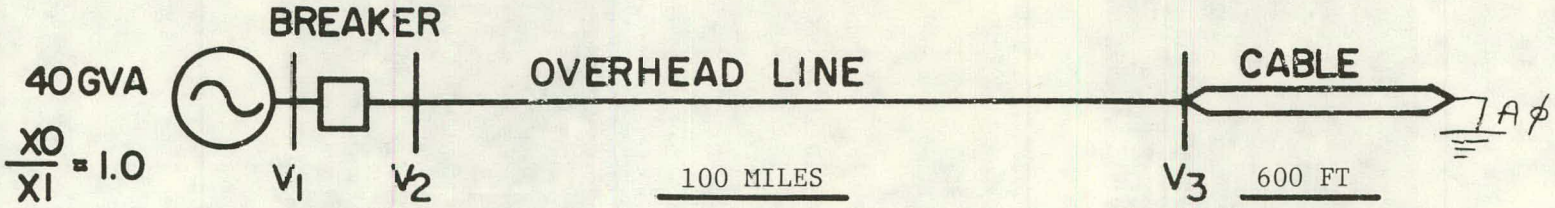
CASE NO. B-9 ENERGIZE LINE INTO SINGLE LINE TO GROUND FAULT



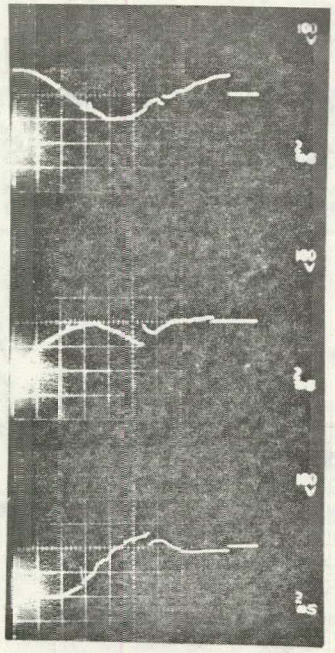
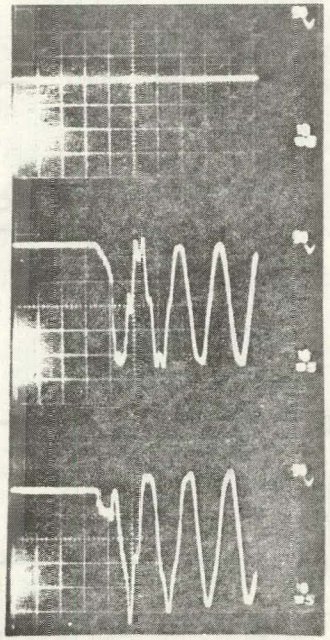
BREAKER RESISTORS	R_1 = 2500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE	1.0 p.u.		1.8 p.u.	SAME AS V_3
LOCATION	$V_1 - 2$	V_2	V_3	V_4
				SAME AS V_3

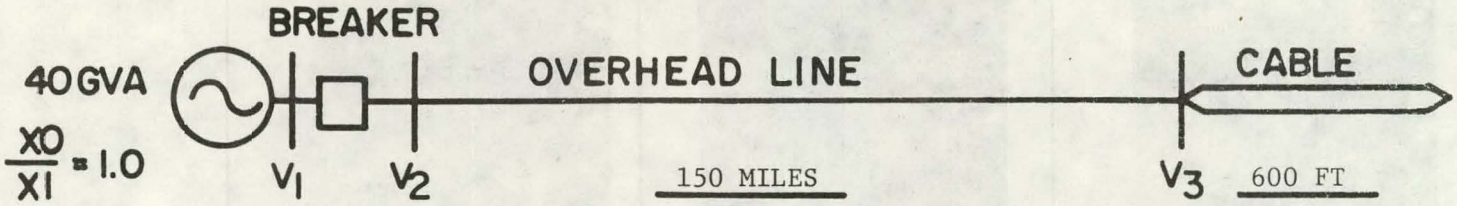
CASE NO. B-10 HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT



BREAKER RESISTORS	R_1 = 2000 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

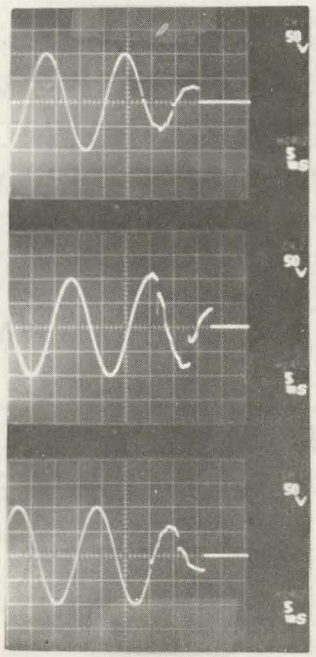
MAX. PU OVERVOLTAGE	2.0 p.u.		1.8 p.u.	SAME AS V_3
LOCATION	V_1 -2	V_2	V_3	V_4
				SAME AS V_3

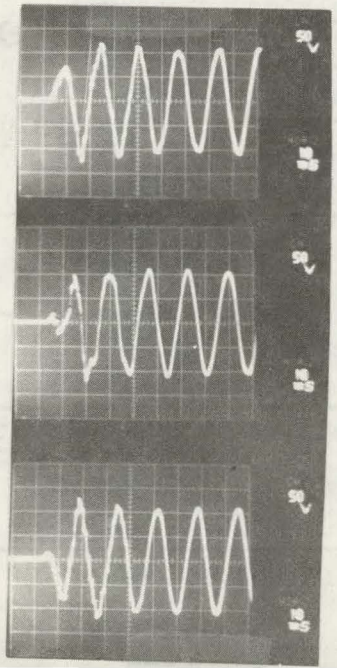
CASE NO. B-11 ENERGIZE LINE

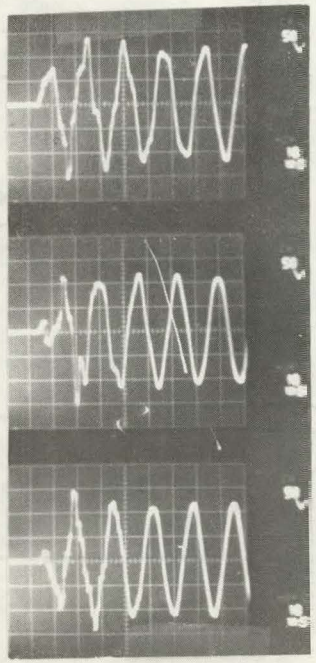


BREAKER RESISTORS	R_1 = 1000 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE	1.00 p.u.	1.3 p.u.	1.5 p.u.	
LOCATION	V_1 -2	V_2	V_3	



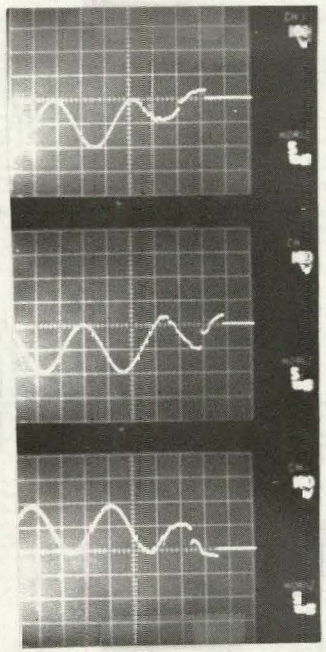


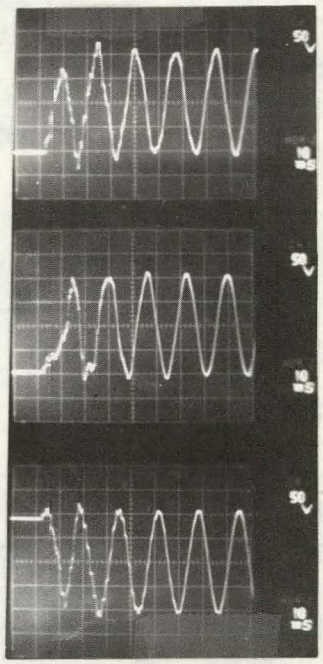


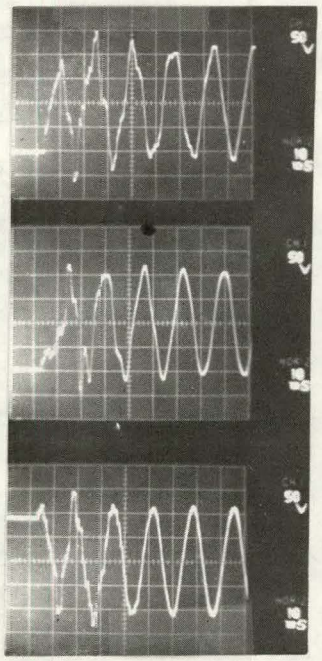
CASE NO. B-12 HIGH SPEED RECLOSING

BREAKER RESISTORS	R_1 = 1000 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

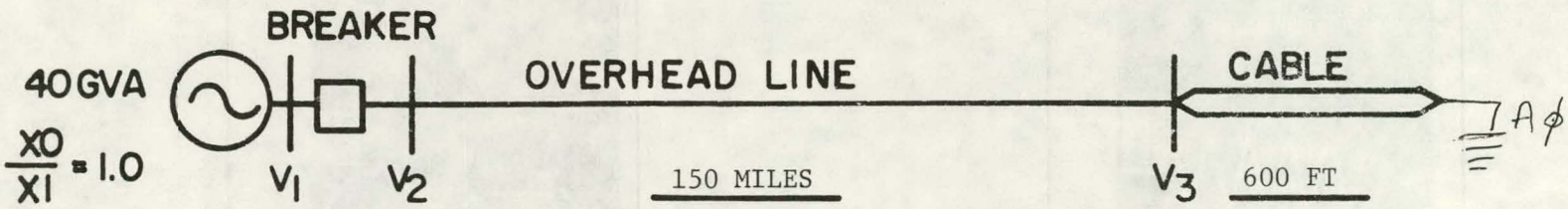
MAX. PU OVERVOLTAGE	2.0 p.u.	1.4 p.u.	1.6 p.u.
LOCATION	V_1 -2	V_2	V_3



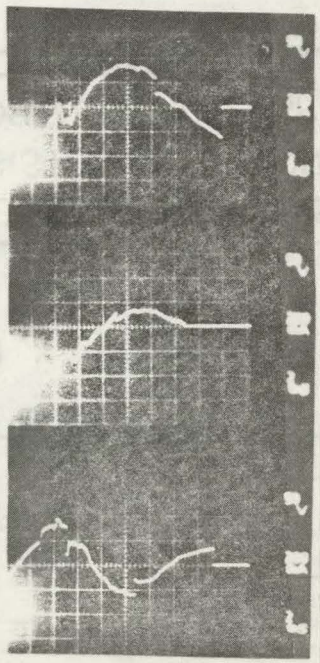
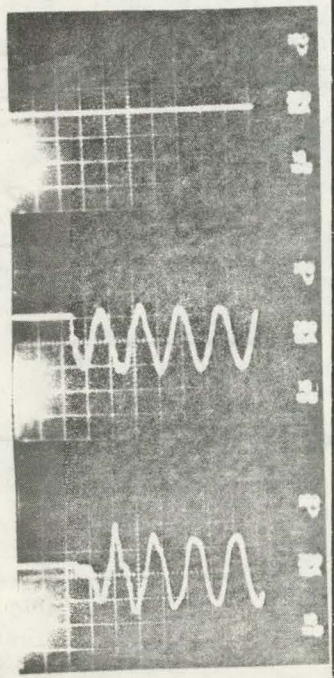




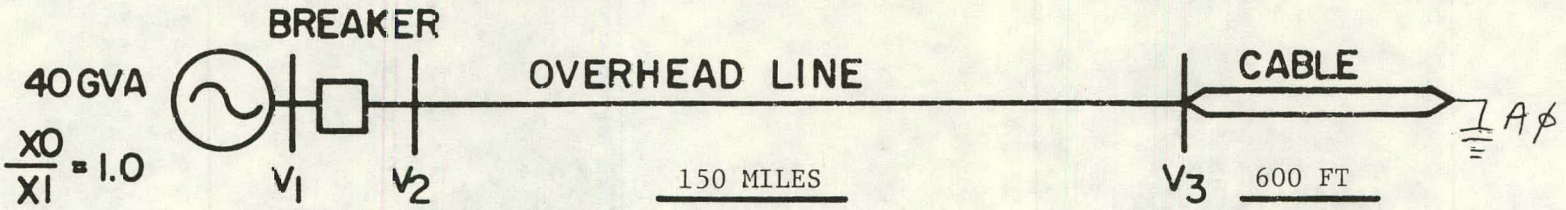
CASE NO. B-13 HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT



BREAKER RESISTORS	R_1 = 500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

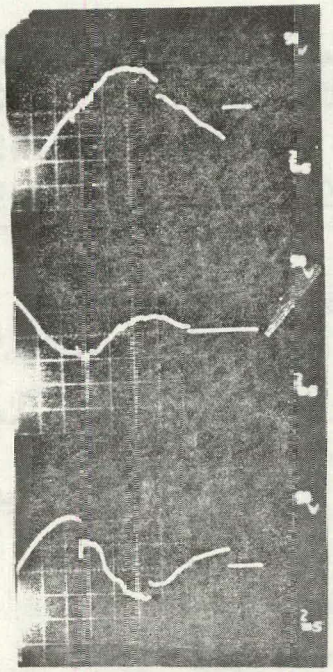
MAX. PU OVERVOLTAGE	2.0 p.u.		2.0 p.u.	SAME AS V_3
LOCATION	V_1 -2	V_2	V_3	V_4
				SAME AS V_3

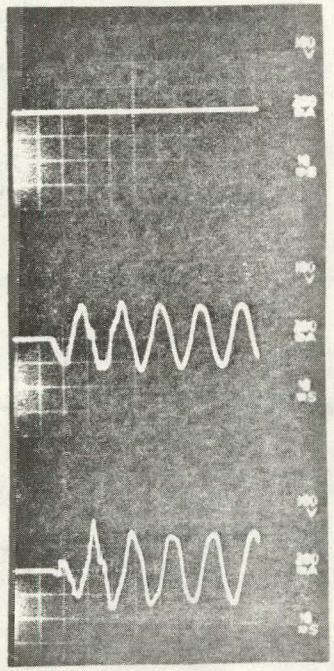
CASE NO. B-14 ENERGIZING INTO SINGLE LINE TO GROUND FAULT



BREAKER RESISTORS	R_1 = 500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE	1.0 p.u.		2.0 p.u.	SAME AS V_3
LOCATION	V_1 -2	V_2	V_3	V_4

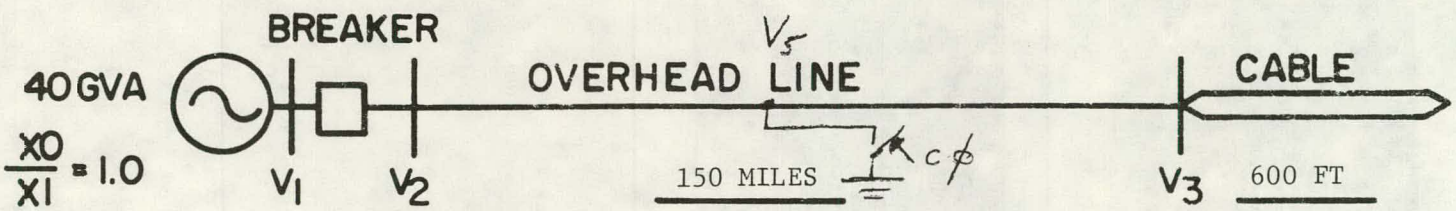




SAME AS V_3

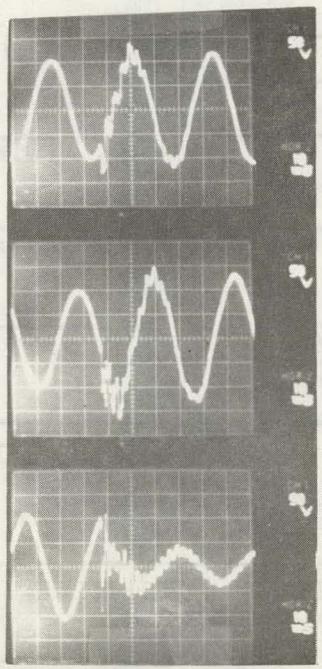
CASE NO. B-15

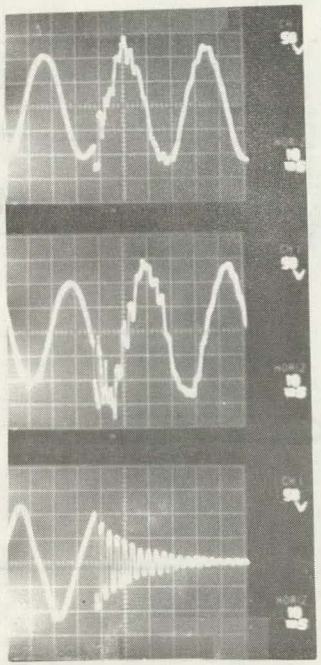
FAULT INITIATED OVERVOLTAGES

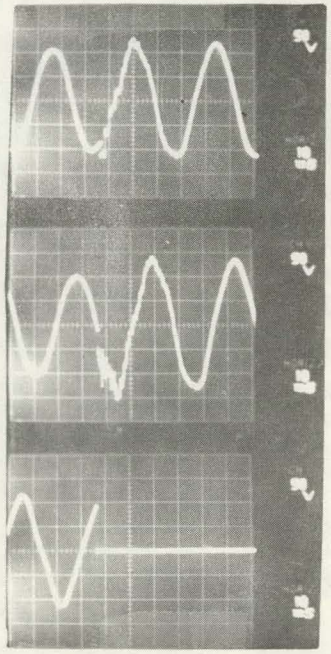


BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE		1.7 p.u.	1.8 p.u.	1.5 p.u.
LOCATION	$V_1 - 2$	V_2	V_3	V_4





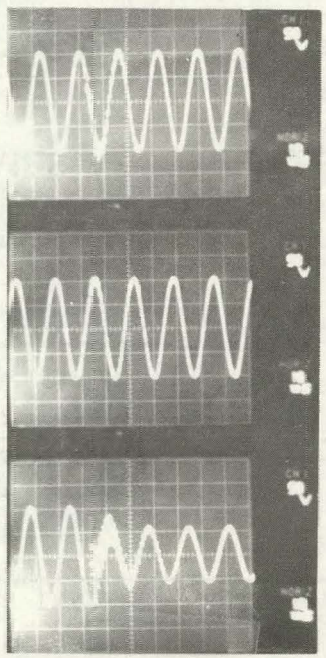


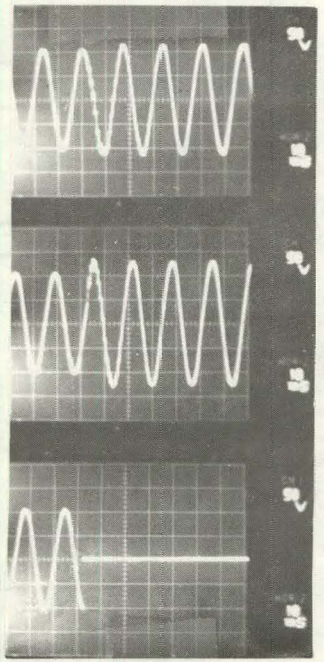
CASE NO. B-16

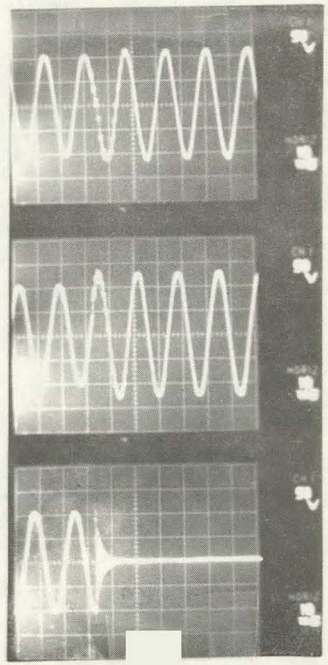
FAULT INITIATED OVERVOLTAGE

BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

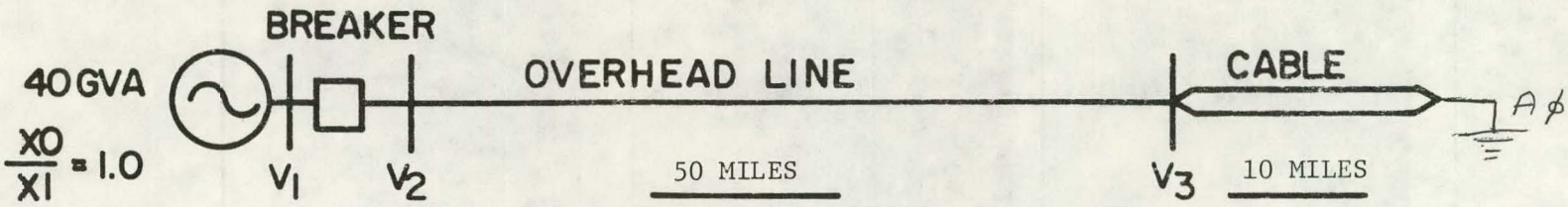
MAX. PU OVERVOLTAGE		1.2 p.u.	1.4 p.u.	1.4 p.u.
LOCATION	$V_1 - 2$	V_2	V_3	V_4





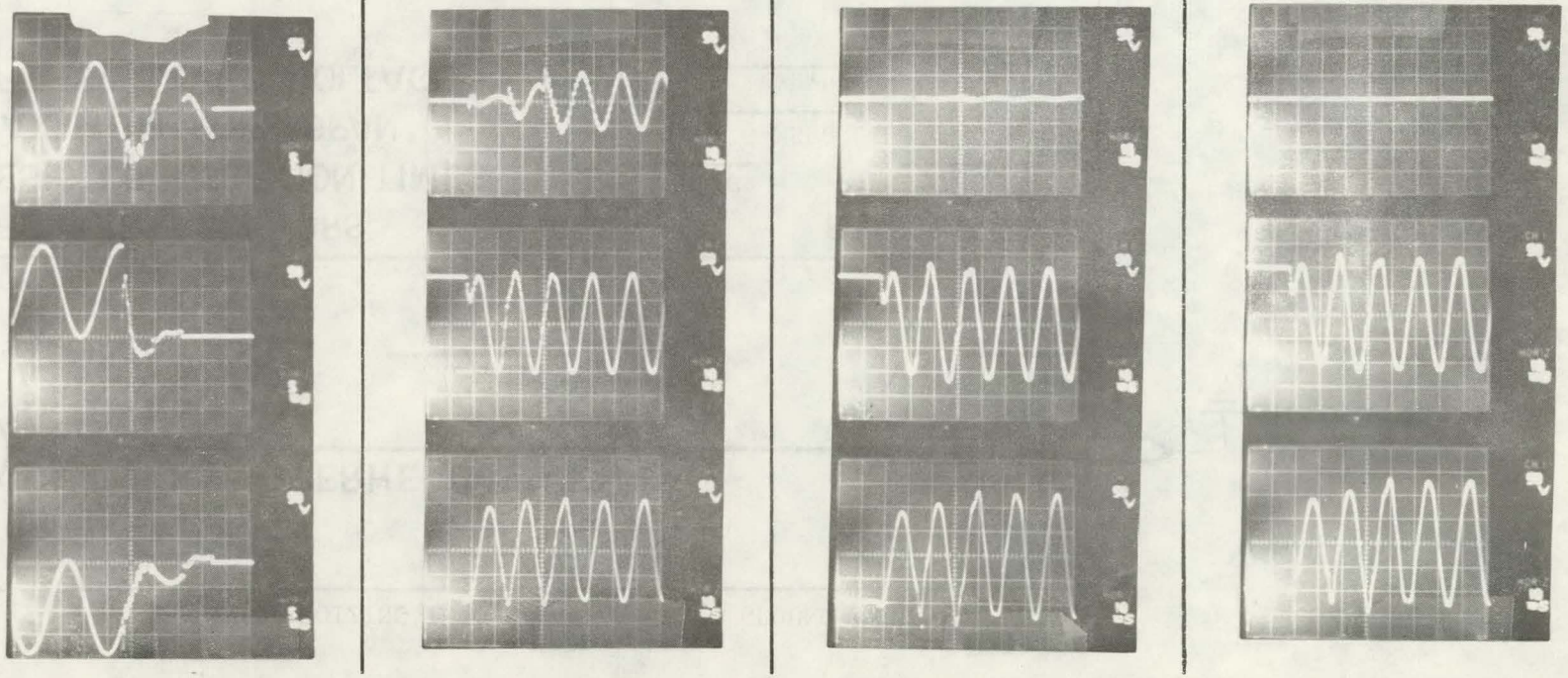


CASE NO. B-17 HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT

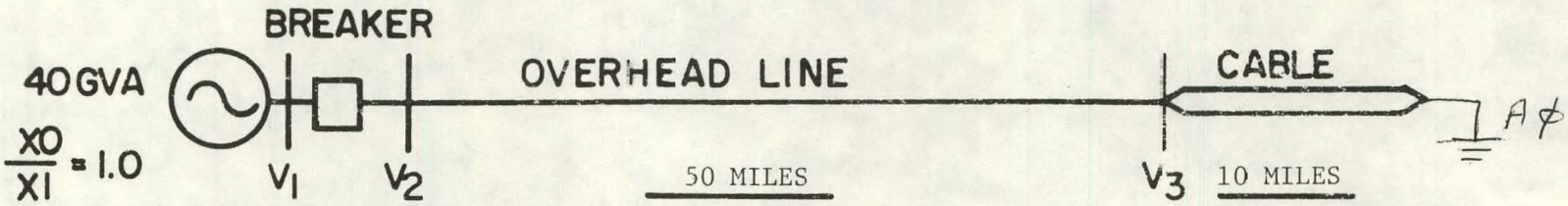


BREAKER RESISTORS	R_1 = 500 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE	2.0 p.u.	1.1 p.u.	1.45 p.u.	1.45 p.u.
LOCATION	V_1 -2	V_2	V_3	V_4

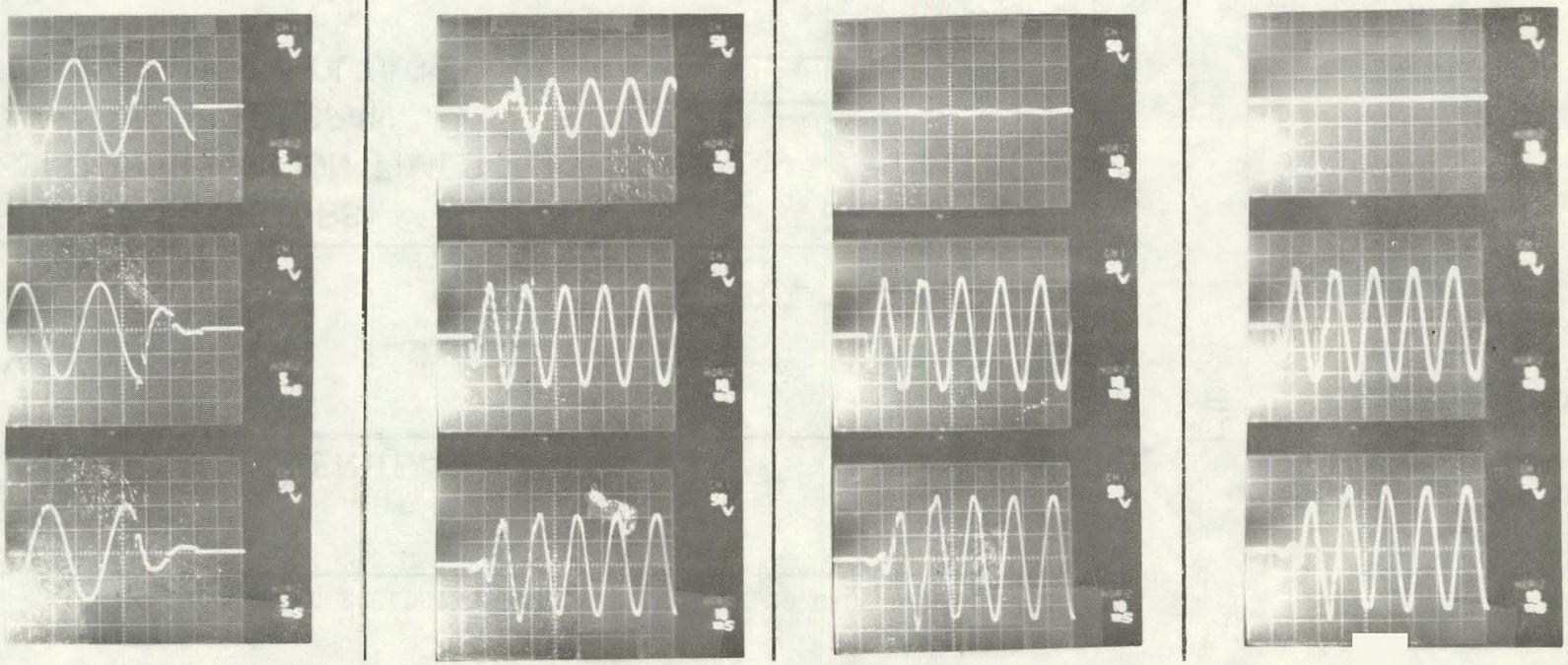


CASE NO. B-18 ENERGIZING INTO SINGLE LINE TO GROUND FAULT

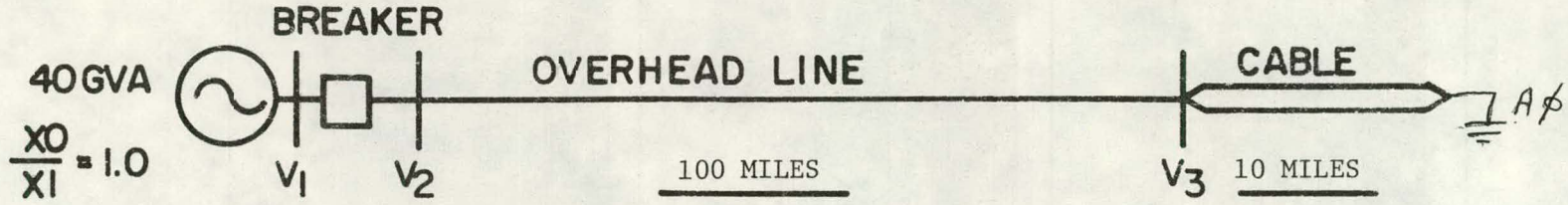


BREAKER RESISTORS	R_1 = 500 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE	1.0 p.u.	1.2 p.u.	1.5 p.u.	1.5 p.u.
LOCATION	V_1 -2	V_2	V_3	V_4

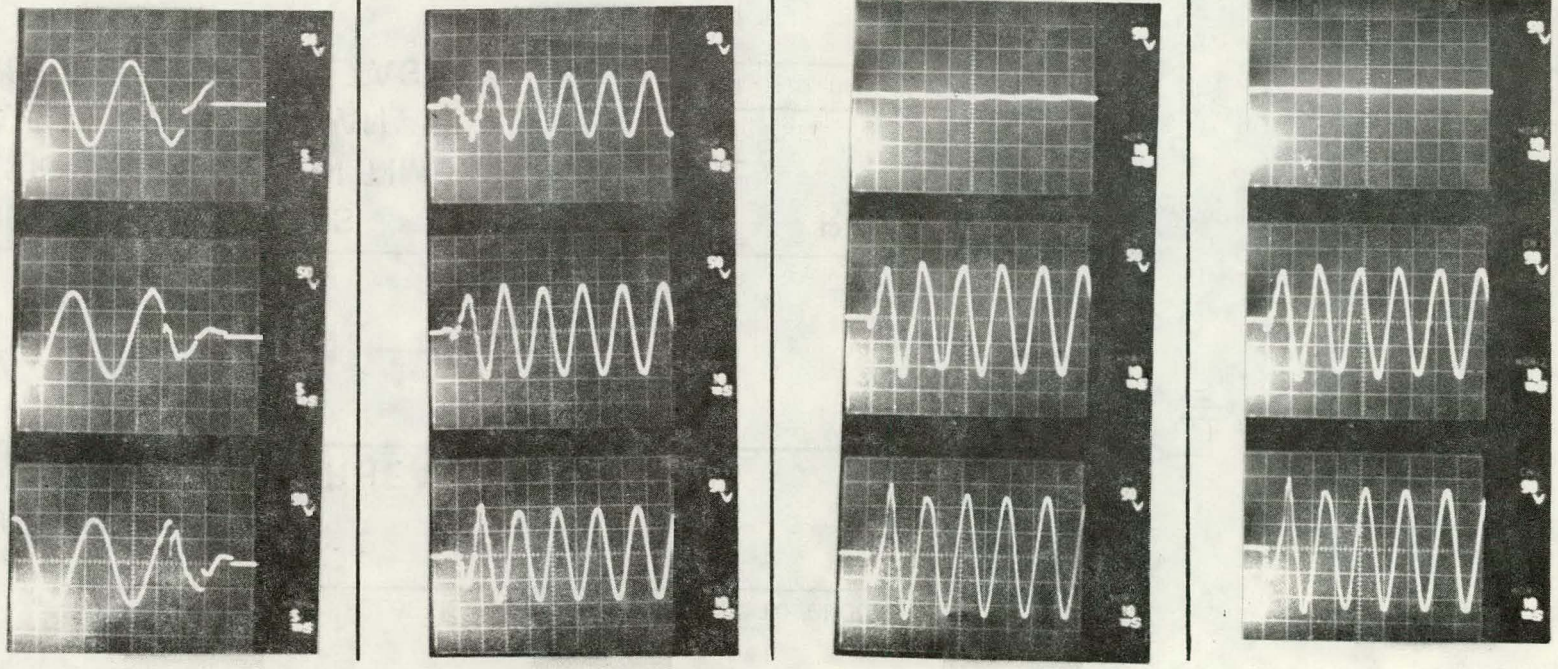


CASE NO. B-19 ENERGIZING INTO SINGLE LINE TO GROUND FAULT

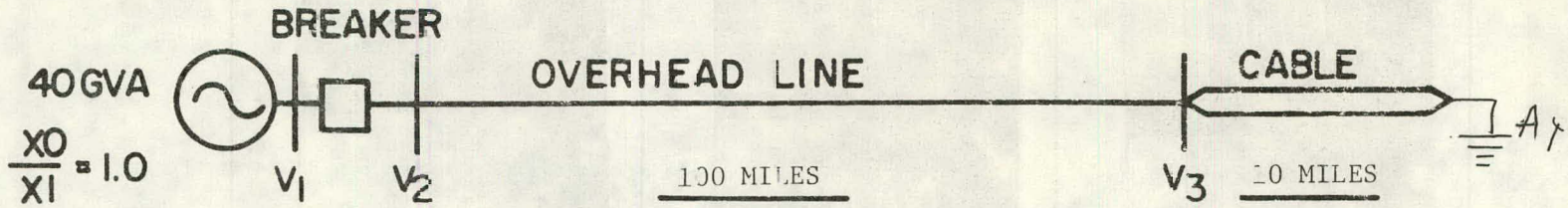


BREAKER RESISTORS	R_1 = 500 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE	1.0 p.u.	1.1 p.u.	1.45 p.u.	1.45 p.u.
LOCATION	V_1 -2	V_2	V_3	V_4

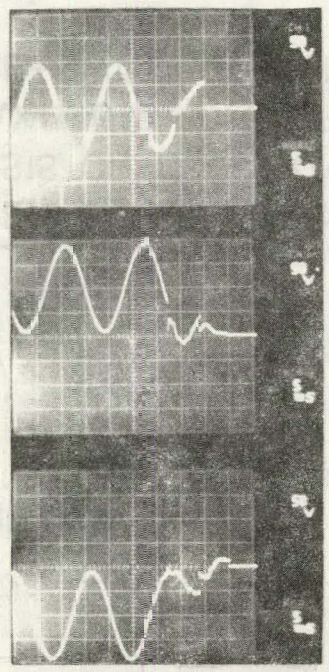


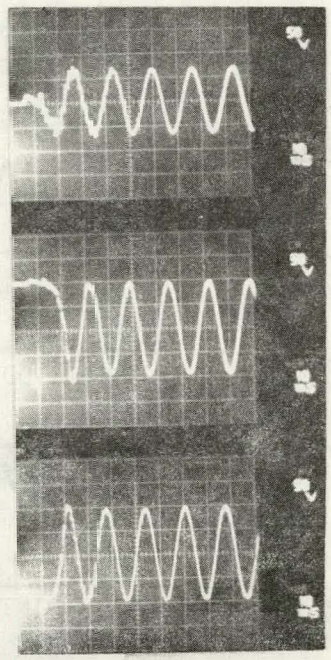
CASE NO. B-20 HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT

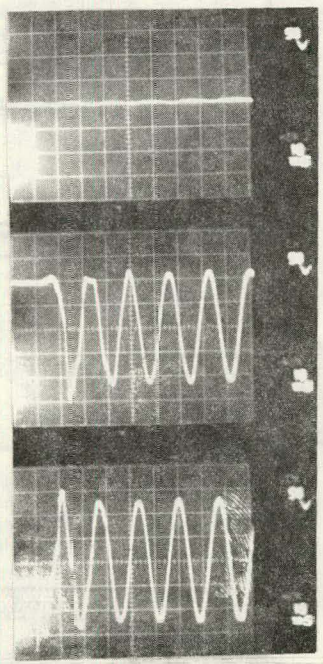


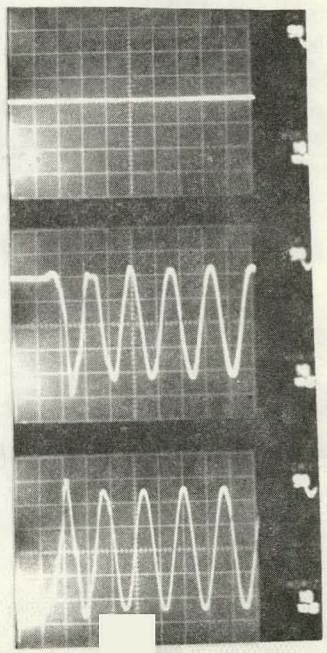
BREAKER RESISTORS	R_1 = 500 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE	2.0 p.u.	1.1 p.u.	1.5 p.u.	1.5 p.u.
LOCATION	V_1 -2	V_2	V_3	V_4

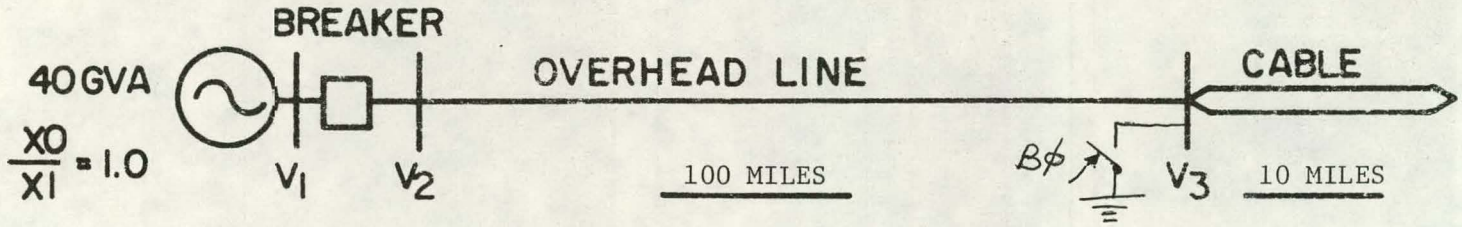






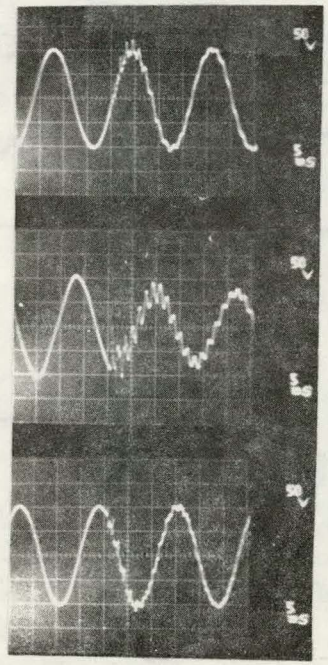


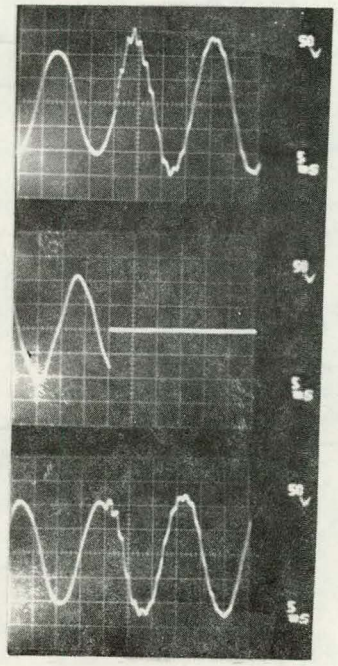
CASE NO. 3-21 FAULT INITIATED OVERVOLTAGES

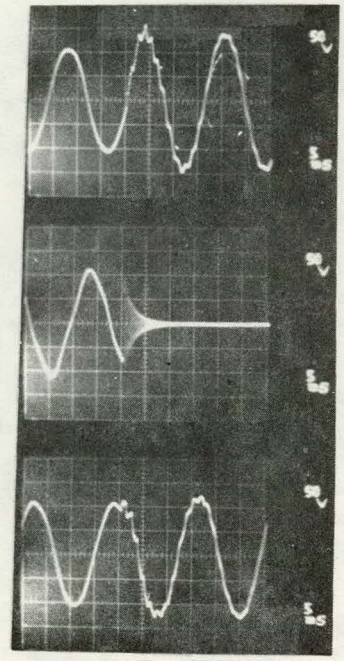


BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE		1.2 p.u.	1.6 p.u.	1.6 p.u.
LOCATION	$V_1 - 2$	V_2	V_3	V_4

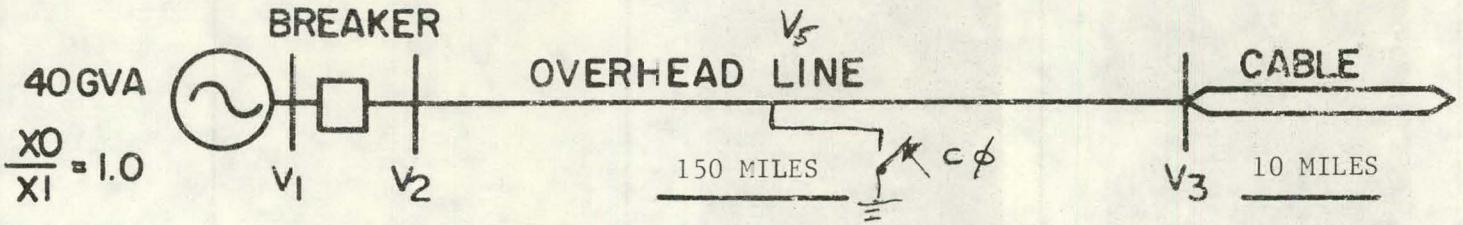






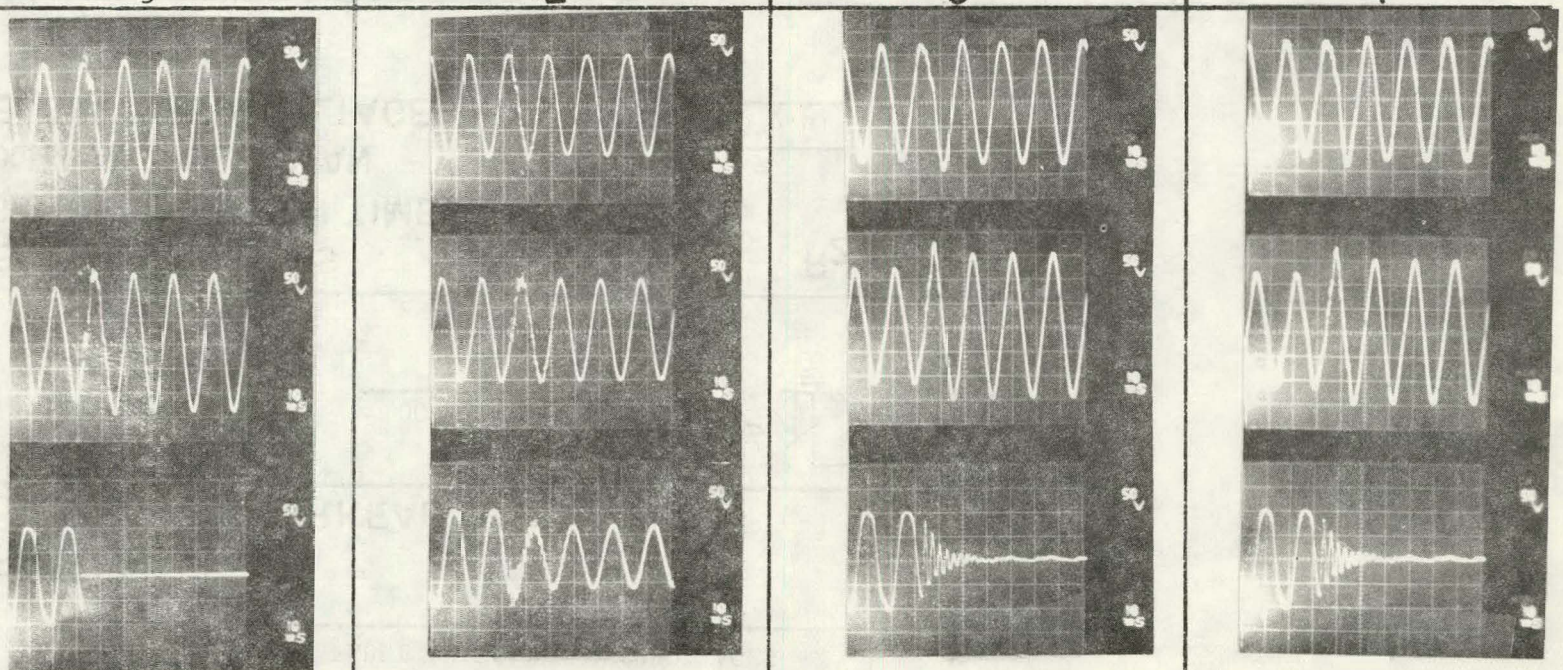
CASE NO. B-22

FAULT INITIATED OVERVOLTAGES

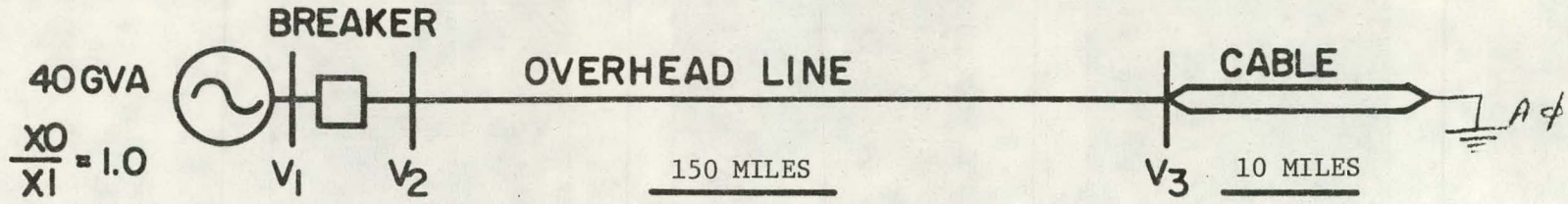


BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE	1.6 p.u.	1.2 p.u.	1.8 p.u.	1.8 p.u.
LOCATION	V_5	V_2	V_3	V_4

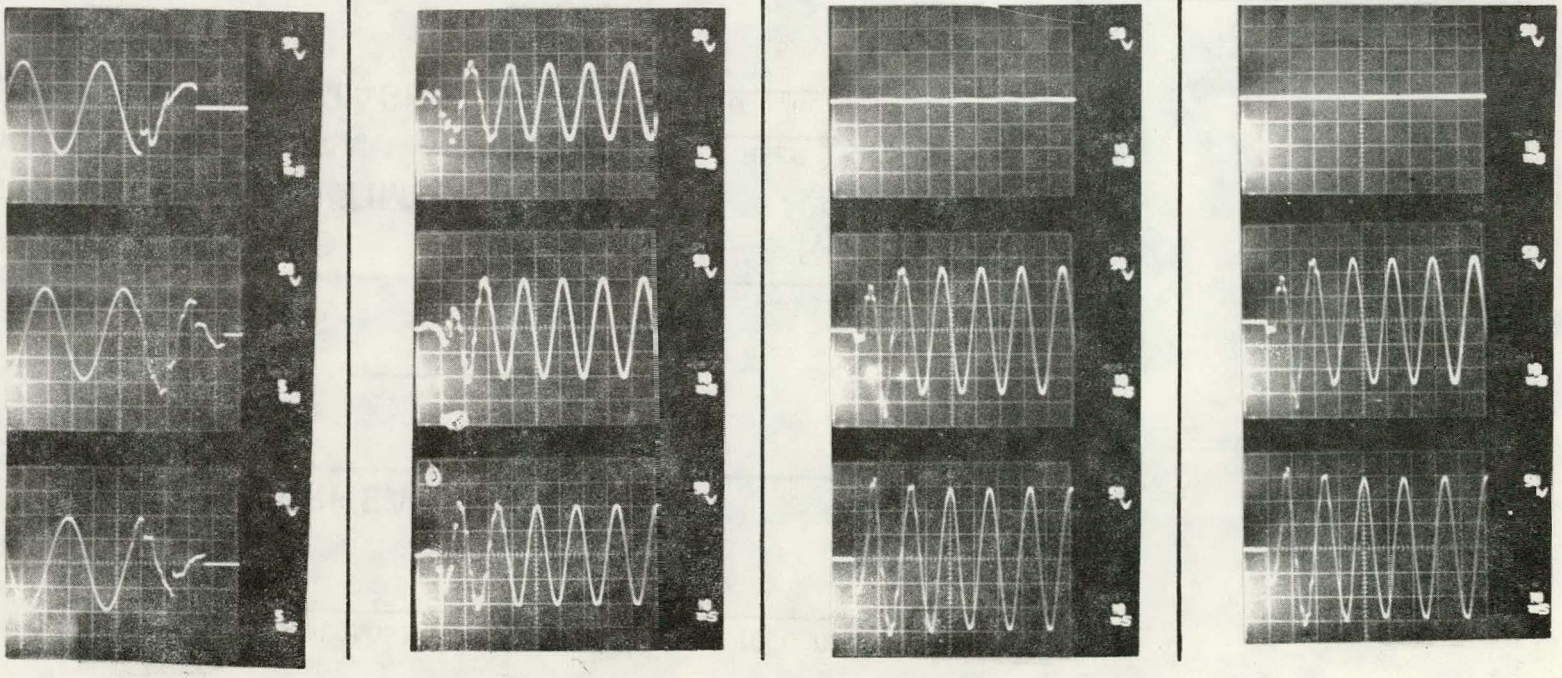


CASE NO. B-23 ENERGIZING INTO SINGLE LINE TO GROUND FAULT

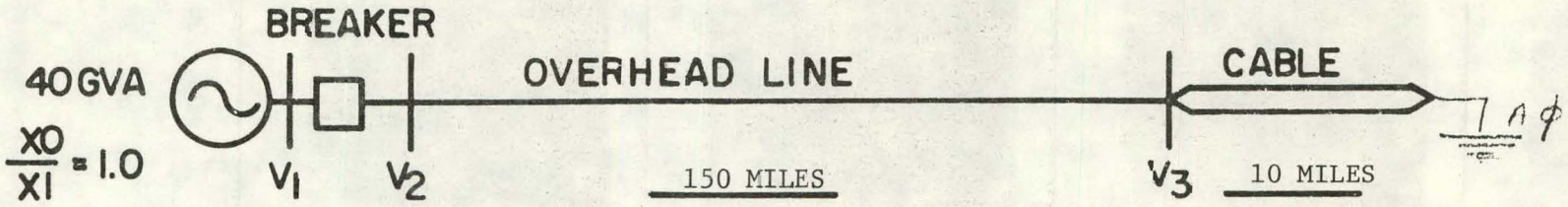


BREAKER RESISTORS	R_1 = 500 Ω, R_2 = 100 Ω
RESISTOR INSERTION TIMES	6 MSEC, 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE	1.0 p.u.	1.1 p.u.	1.8 p.u.	1.8 p.u.
LOCATION	V_1 -2	V_2	V_3	V_4

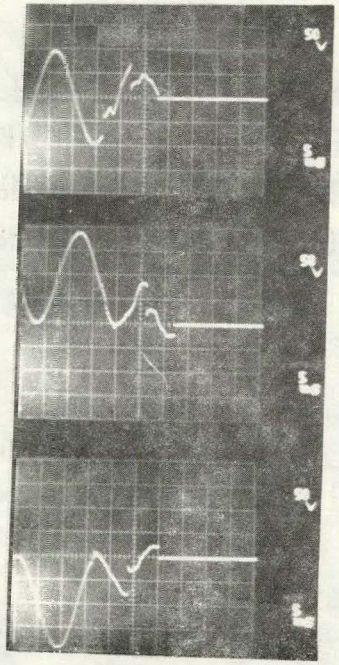


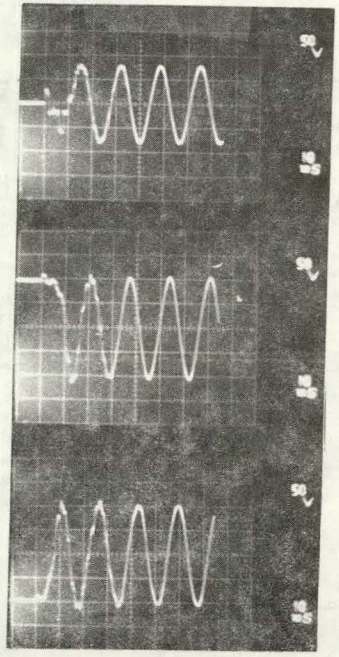
CASE NO. B-24 HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT

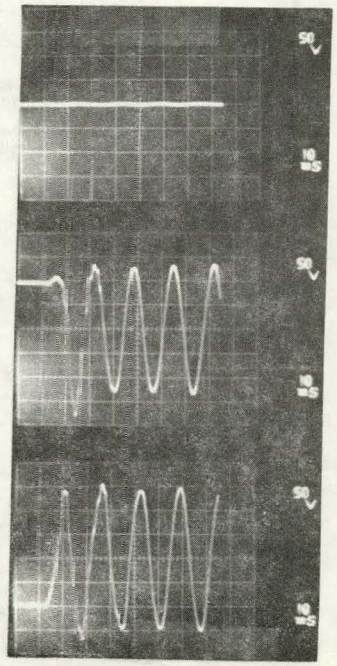


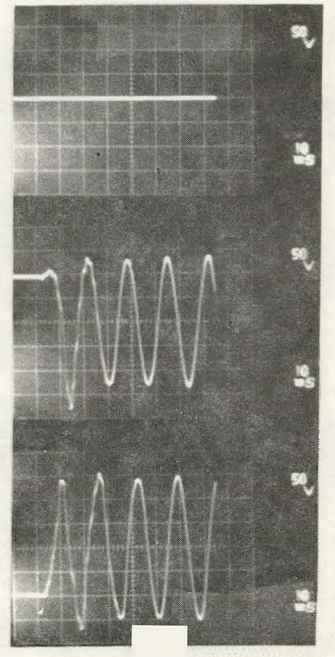
BREAKER RESISTORS	R_1 = 500 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE	2.0 p.u.	1.1 p.u.	1.8 p.u.	1.8 p.u.
LOCATION	V_1 -2	V_2	V_3	V_4

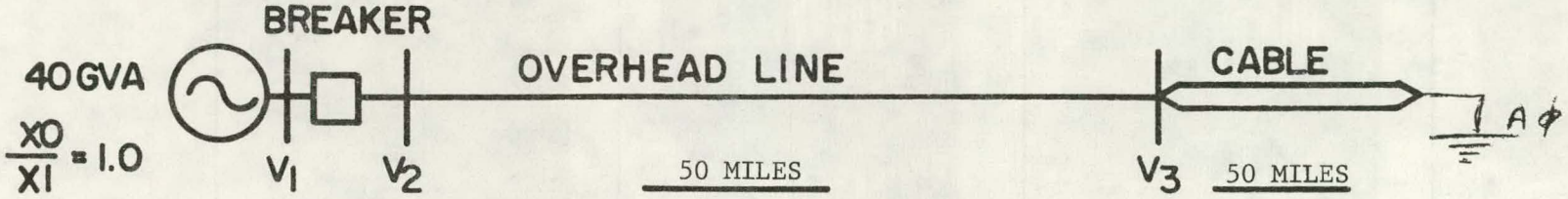




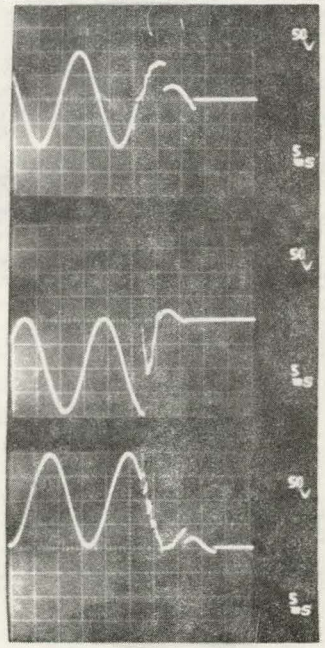
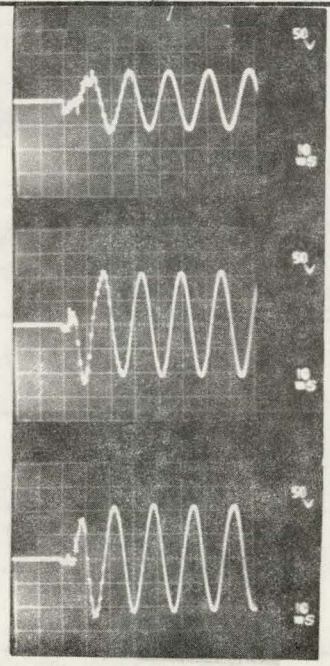
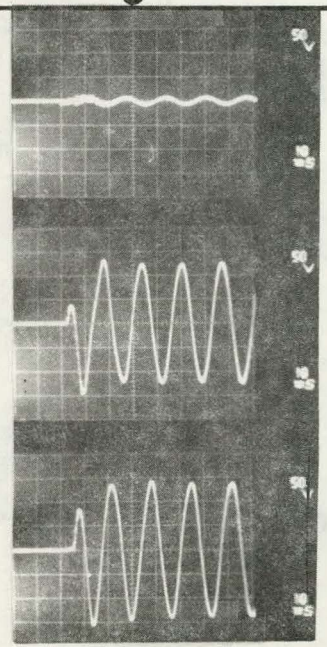
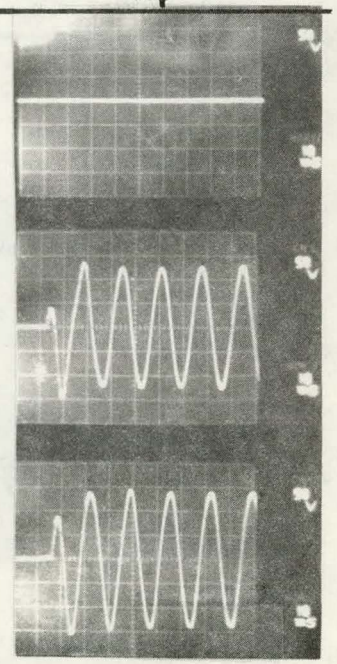




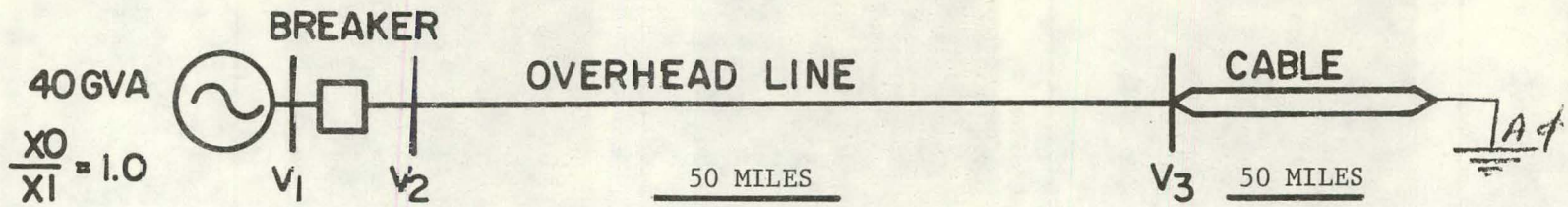
CASE NO. B-25 ENERGIZING INTO SINGLE LINE TO GROUND FAULT



BREAKER RESISTORS	R_1 = 200 R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

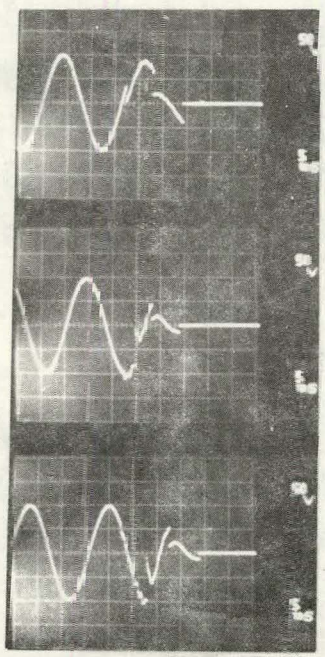
MAX. PU OVERVOLTAGE	2.0 p.u.	1.2 p.u.	1.55 p.u.	1.55 p.u.
LOCATION	V_1 -2	V_2	V_3	V_4
				

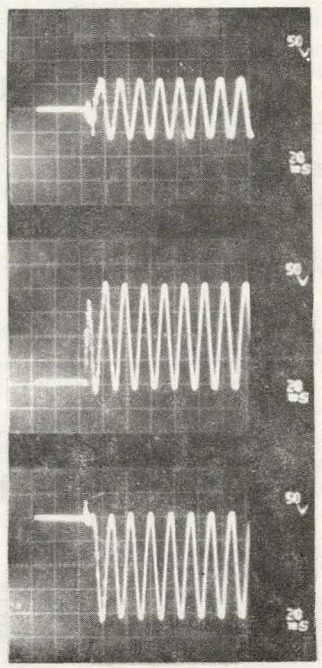
CASE NO. B-26 HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT

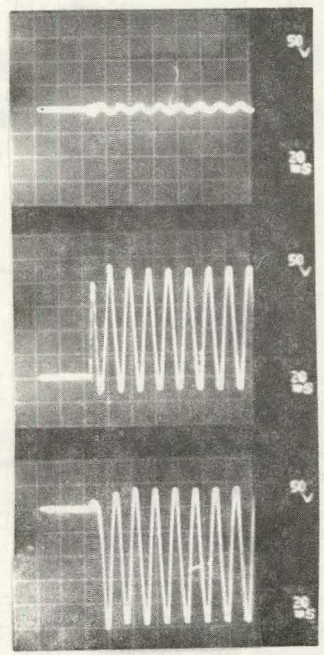


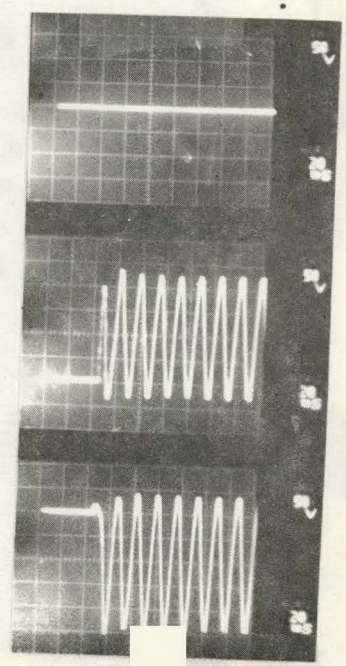
BREAKER RESISTORS	R_1 = 200 R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE	1.0 p.u.	1.3 p.u.	1.5 p.u.	1.5 p.u.
LOCATION	V_1 -2	V_2	V_3	V_4



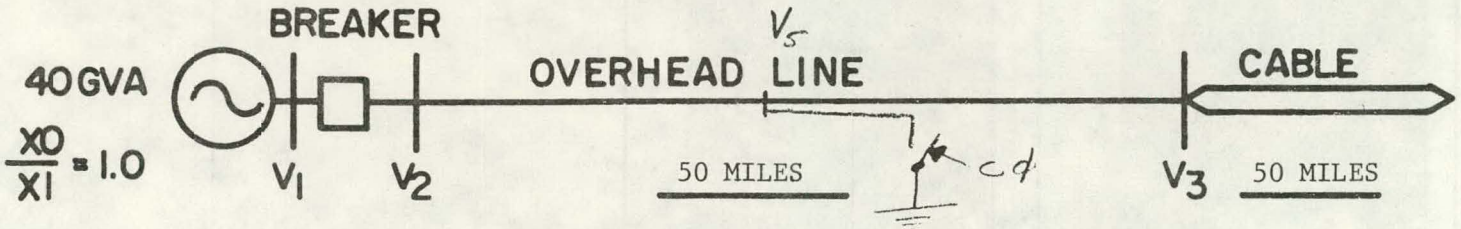






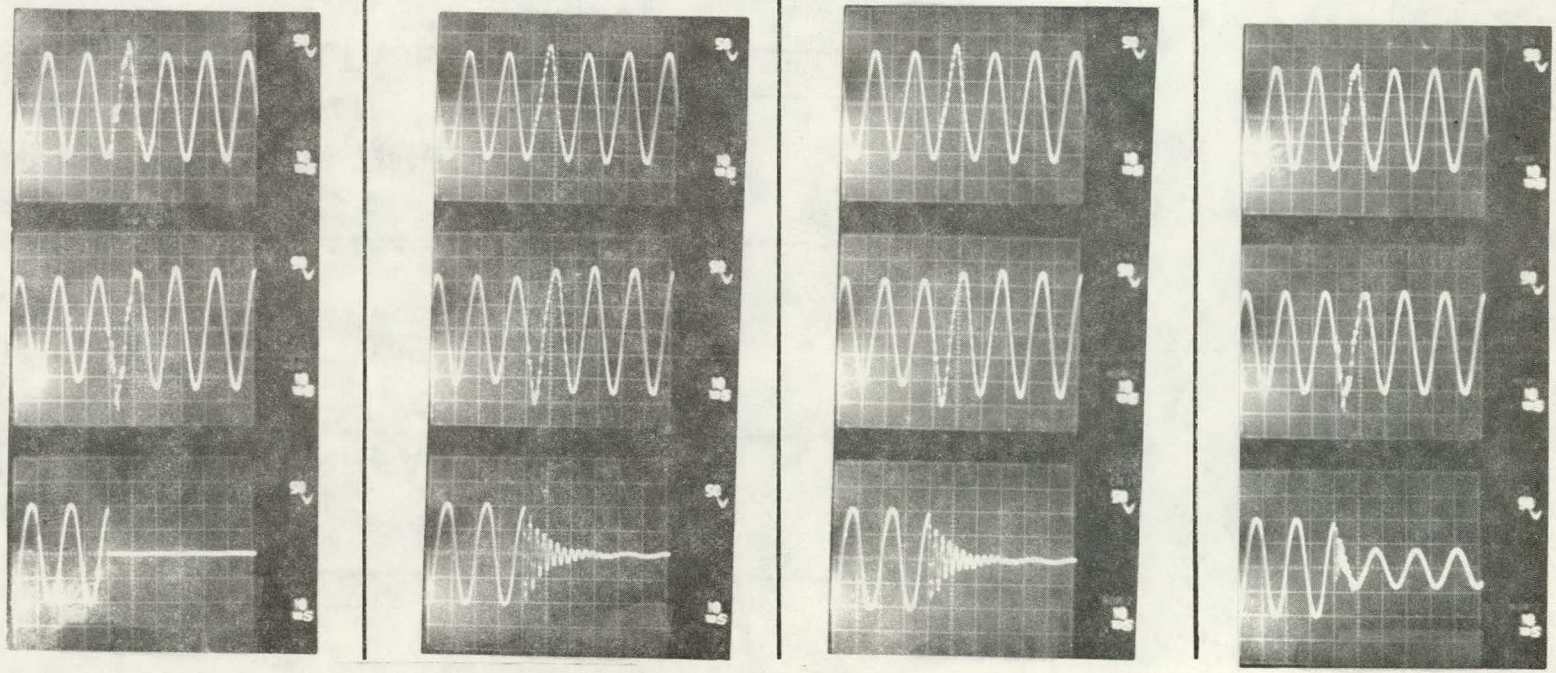
CASE NO. B-27

FAULT INITIATED OVERVOLTAGES

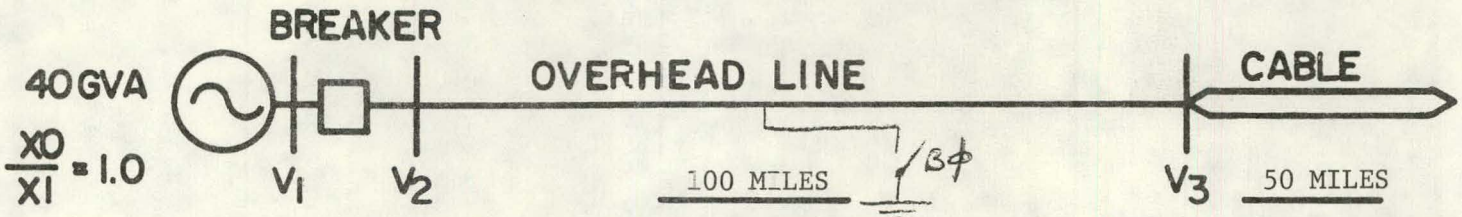


BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE	1.7 p.u.	1.5 p.u.	1.5 p.u.	1.5 p.u.
LOCATION	V_5	V_2	V_3	V_4

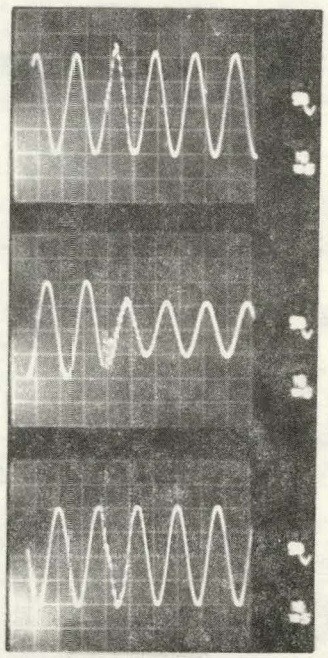


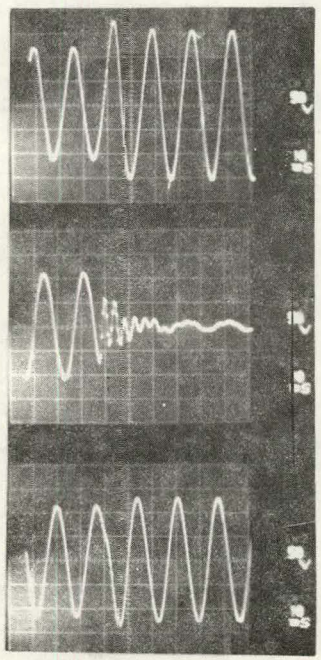
CASE NO. B-28 FAULT INITIATED OVERVOLTAGES

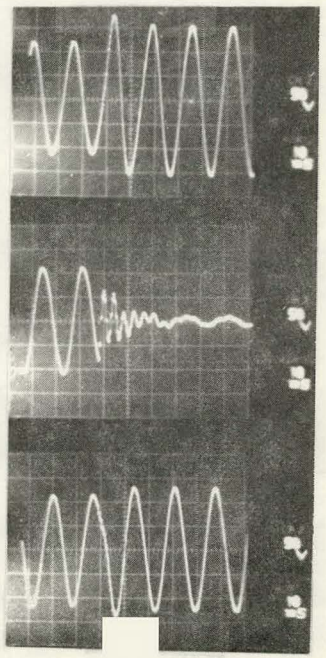


BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

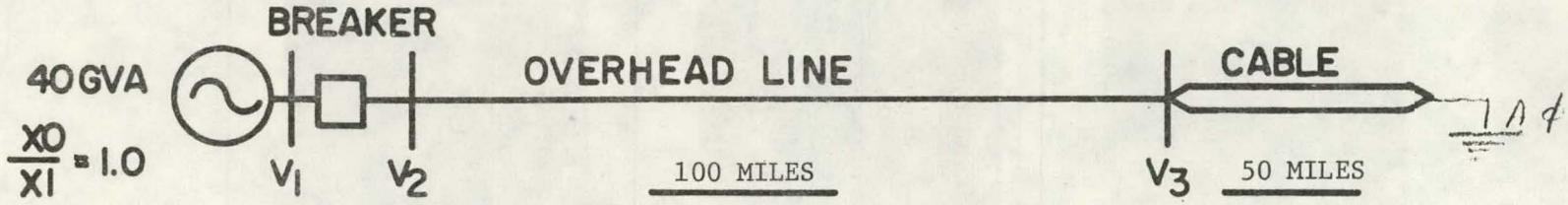
MAX. PU OVERVOLTAGE		1.3 p.u.	1.8 p.u.	1.8 p.u.
LOCATION	V_1 -2	V_2	V_3	V_4





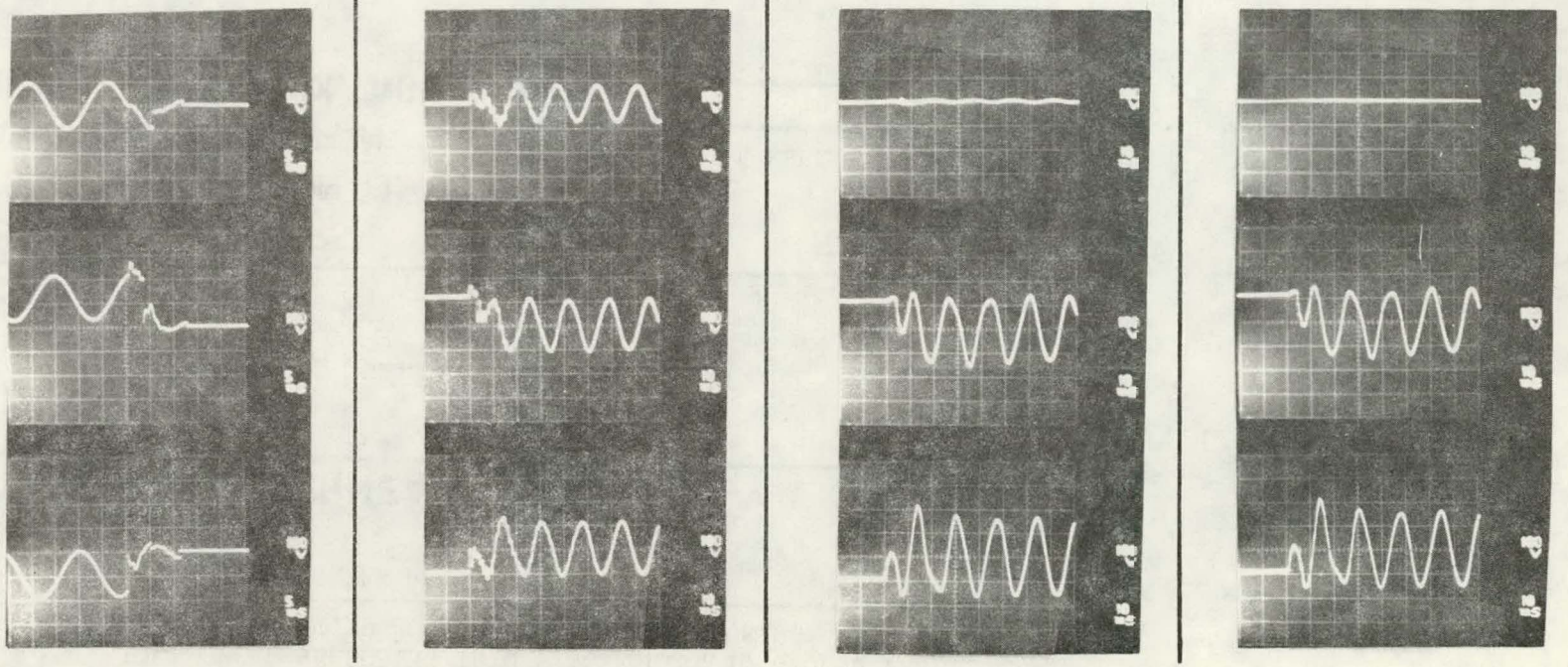


CASE NO. B-29 HIGH SPEED RECLOSING IN SINGLE LINE TO GROUND FAULT



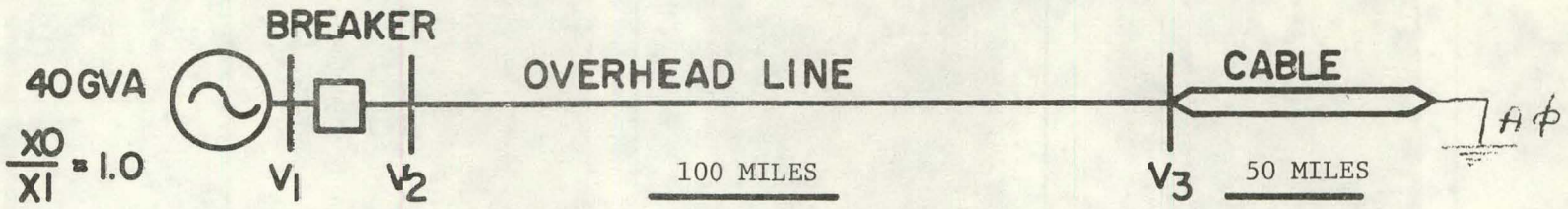
BREAKER RESISTORS	R_1 = 200 R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE	2.0 p.u.	1.4 p.u.	2.2 p.u.	2.2 p.u.
LOCATION	V_1 -2	V_2	V_3	V_4



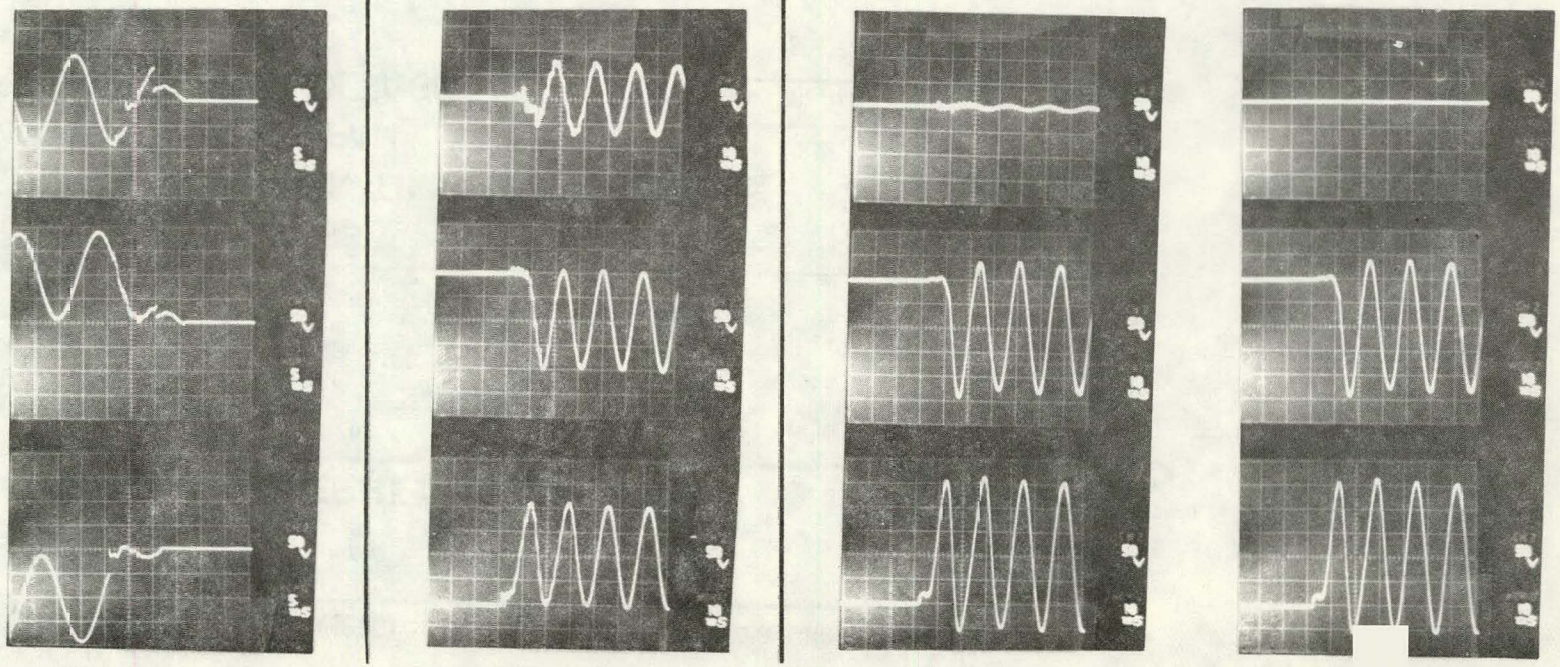
CASE NO. B-30

HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT
WITH CONTROLLED BREAKER CLOSING



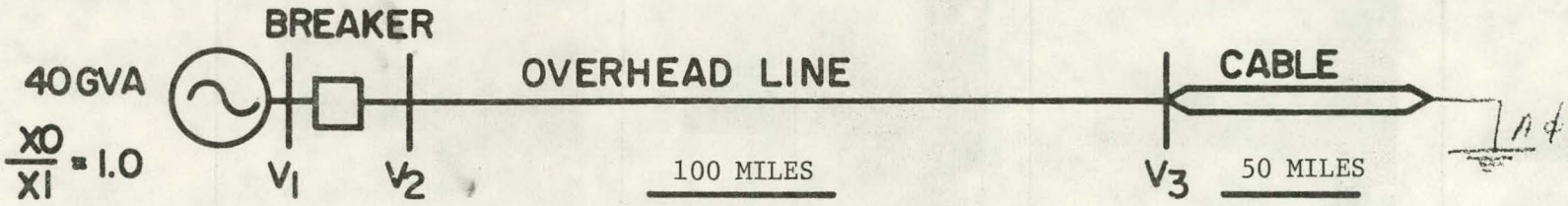
BREAKER RESISTORS	R_1 = 200 R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE	2.0 p.u.	1.1 p.u.	1.6 p.u.	1.6 p.u.
LOCATION	V_1 -2	V_2	V_3	V_4



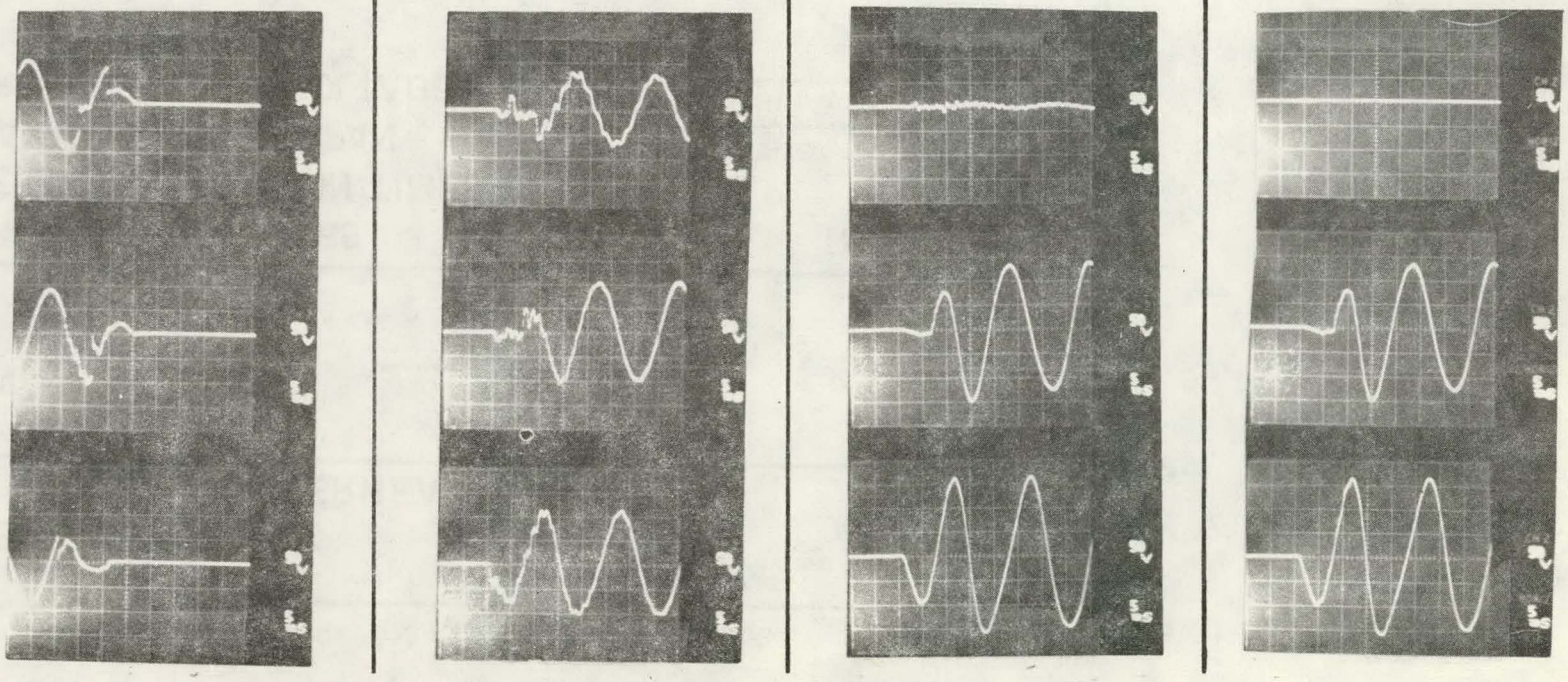
CASE NO. B-31

ENERGIZING INTO SINGLE LINE TO GROUND FAULT
WITH CONTROLLED BREAKER CLOSING



BREAKER RESISTORS	R_1 = 200	R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC	6 MSEC
MAXIMUM POLE SPAN	5 MSEC	
PRE-SWITCHED VOLTAGE	1.0 p.u.	

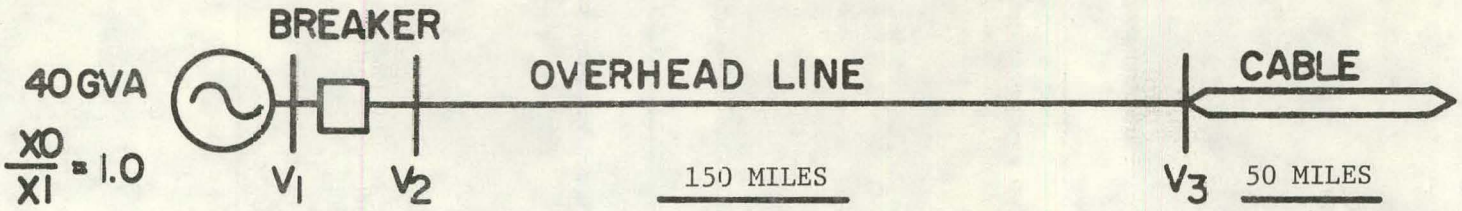
MAX. PU OVERVOLTAGE	1.0 p.u.	1.1 p.u.	1.6 p.u.	1.6 p.u.
LOCATION	V_1 -2	V_2	V_3	V_4



CASE NO. B-32

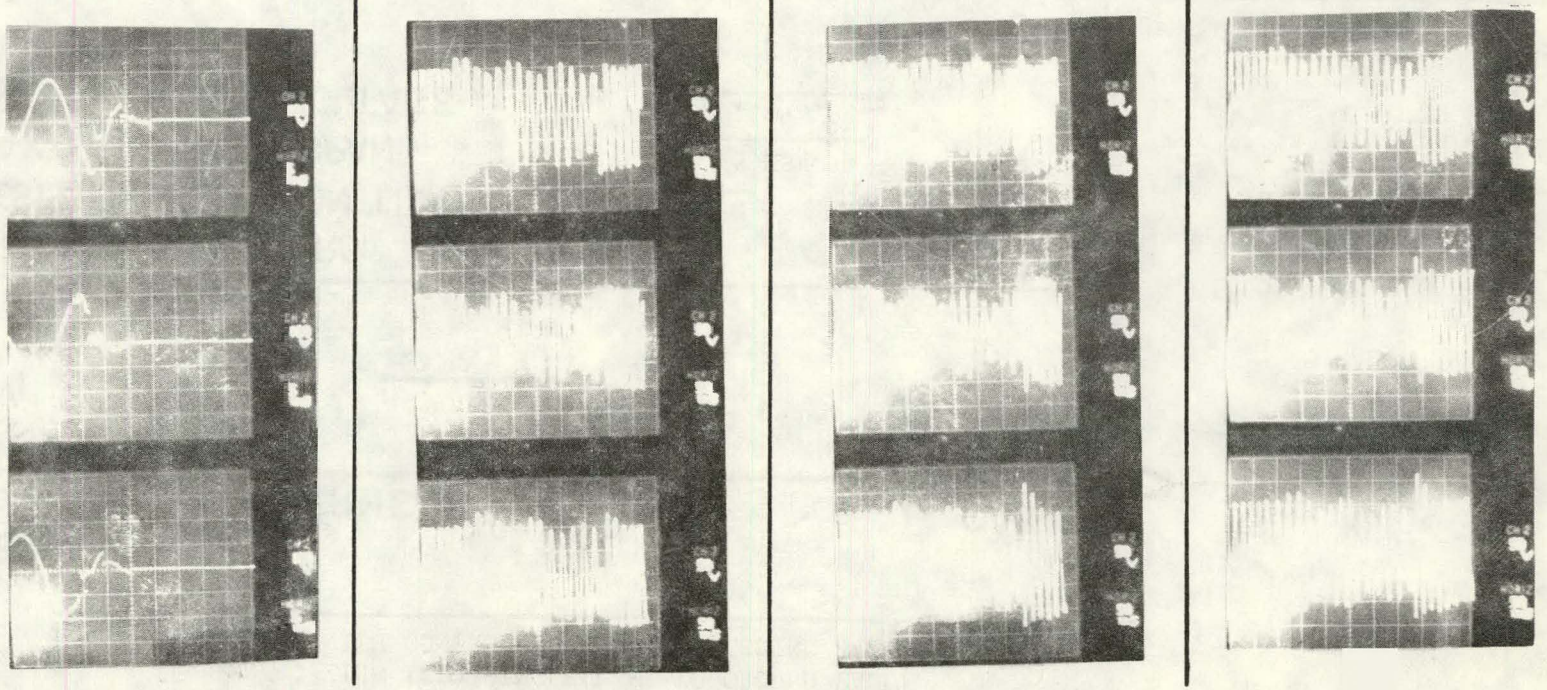
HIGH SPEED RECLOSING LINE

(19 Hz DEAD TIME)



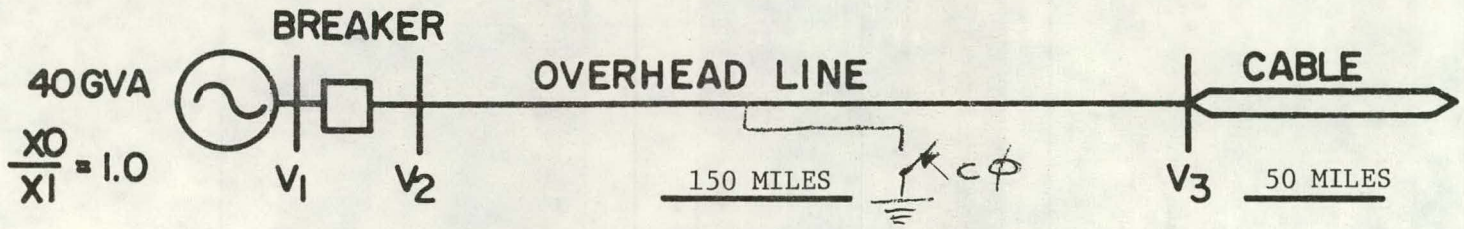
BREAKER RESISTORS	R_1 = 200 R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE	1.0 p.u.	1.3 p.u.	1.6 p.u.	1.6 p.u.
LOCATION	V_1 -2	V_2	V_3	V_4

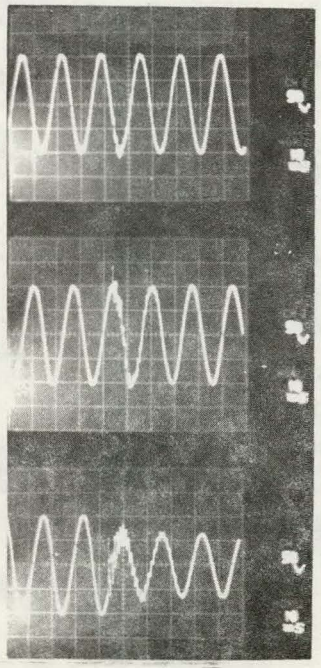
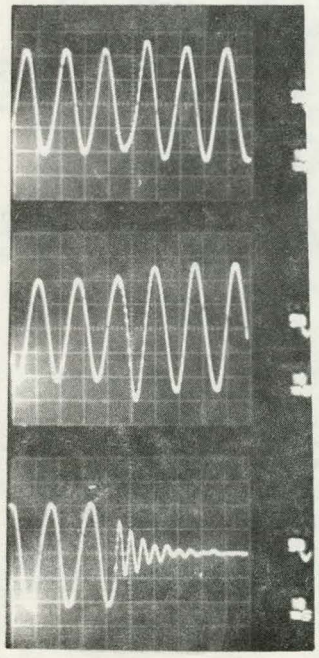
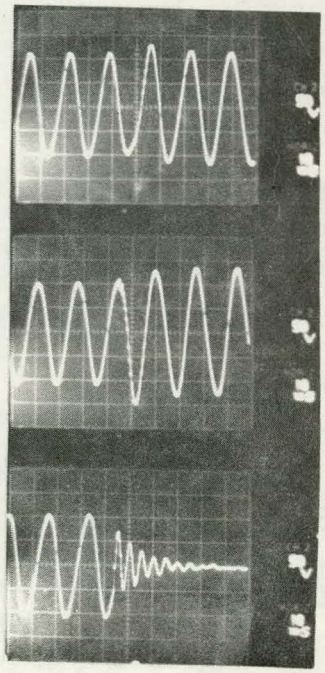


CASE NO. B-33

FAULT INITIATED OVERVOLTAGES



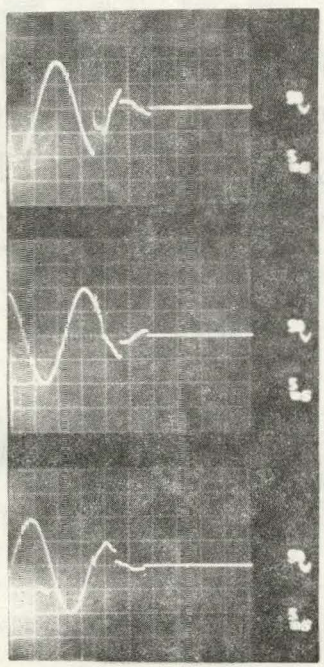
BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

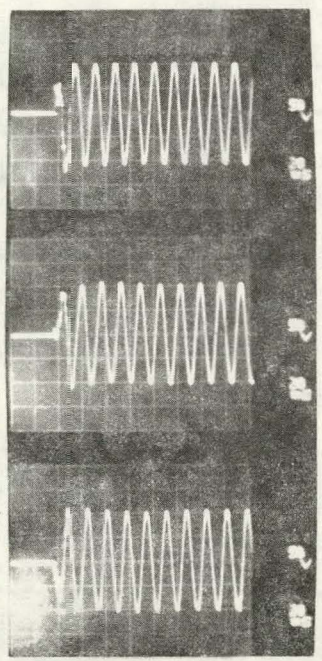
MAX. PU OVERVOLTAGE		1.2 p.u.	1.5 p.u.	1.5 p.u.
LOCATION	V_1 -2	V_2	V_3	V_4
				

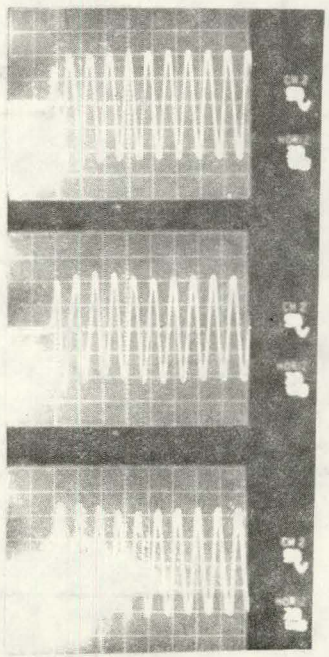
CASE NO. B-34 ENERGIZING LINE

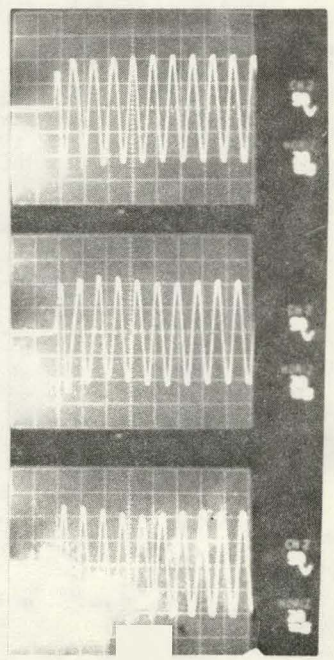
BREAKER RESISTORS	R_1 = 200	R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC	6 MSEC
MAXIMUM POLE SPAN	5 MSEC	
PRE-SWITCHED VOLTAGE	1.0 p.u.	

MAX. PU OVERVOLTAGE	1.0 p.u.	1.2 p.u.	1.4 p.u.	1.4 p.u.
LOCATION	V_1 -2	V_2	V_3	V_4

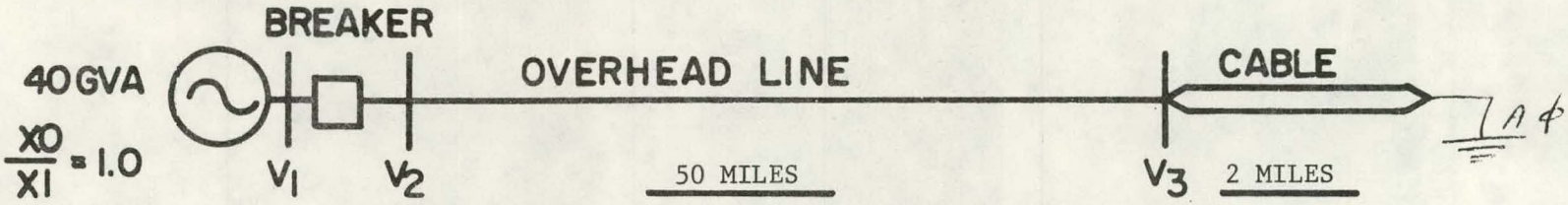






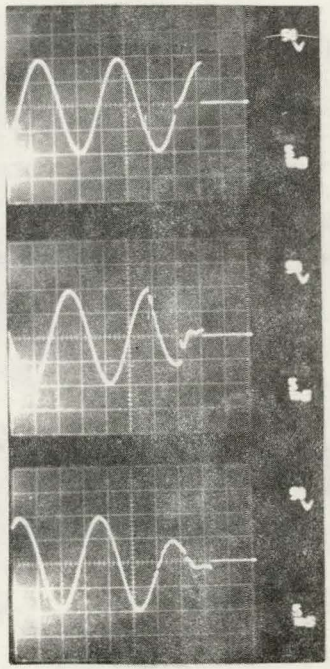


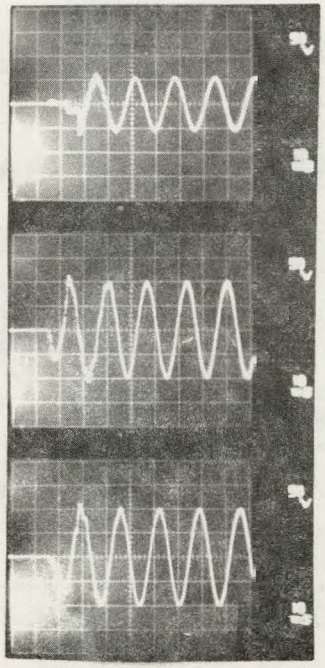
CASE NO. B-35 ENERGIZING INTO SINGLE LINE TO GROUND FAULT

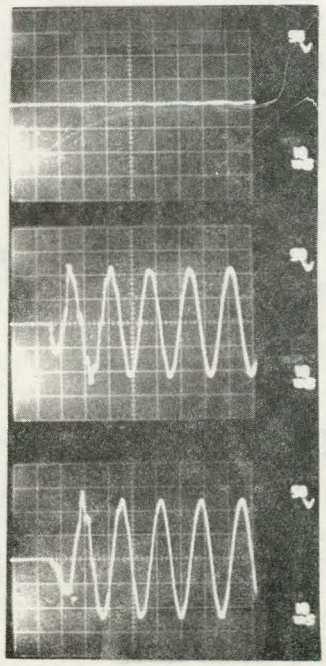


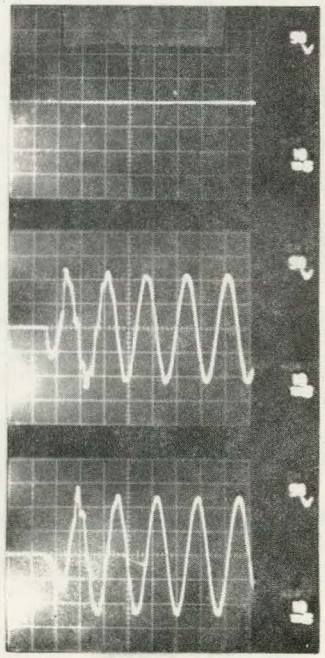
BREAKER RESISTORS	R_1 = 1500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE	1.0 p.u.	1.1 p.u.	1.4 p.u.	1.4 p.u.
LOCATION	V_1 -2	V_2	V_3	V_4

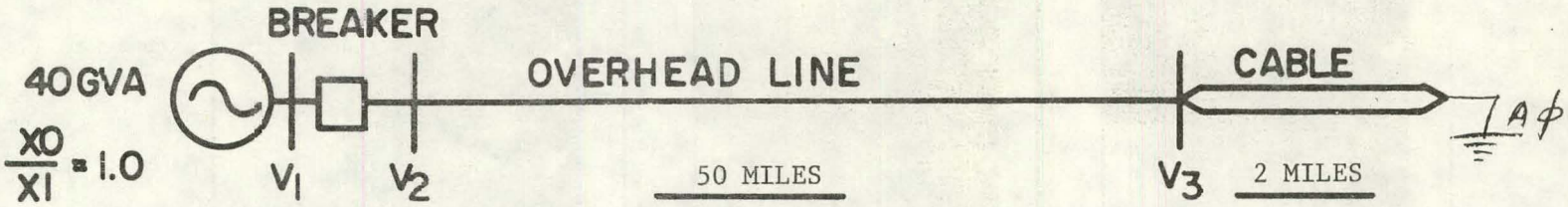






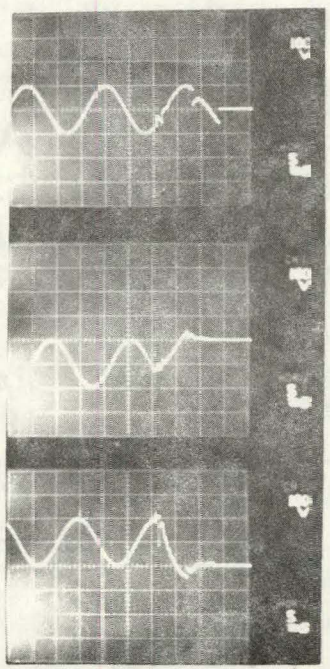


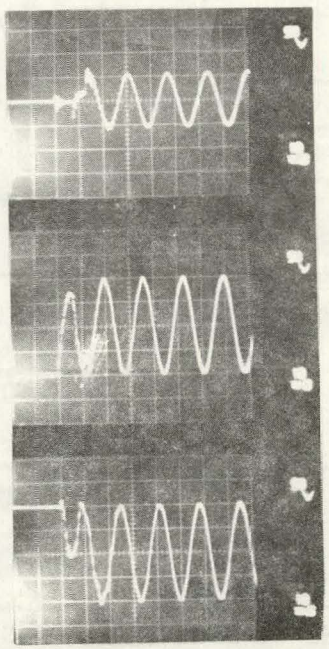
CASE NO. B-36 HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT

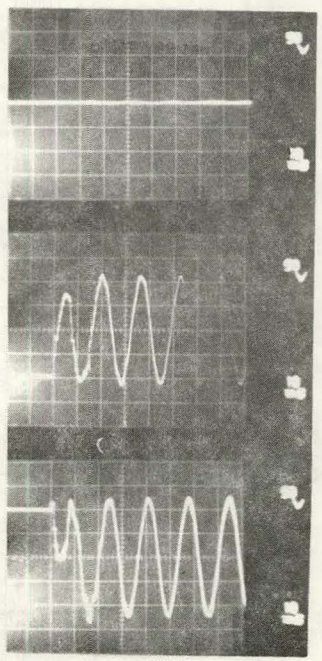


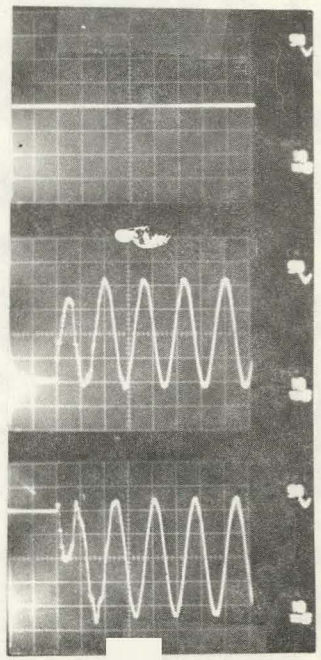
BREAKER RESISTORS	R_1 = 1500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE	2.0 p.u.	1.0 p.u.	1.4 p.u.	1.4 p.u.
LOCATION	$V_1 - 2$	V_2	V_3	V_4

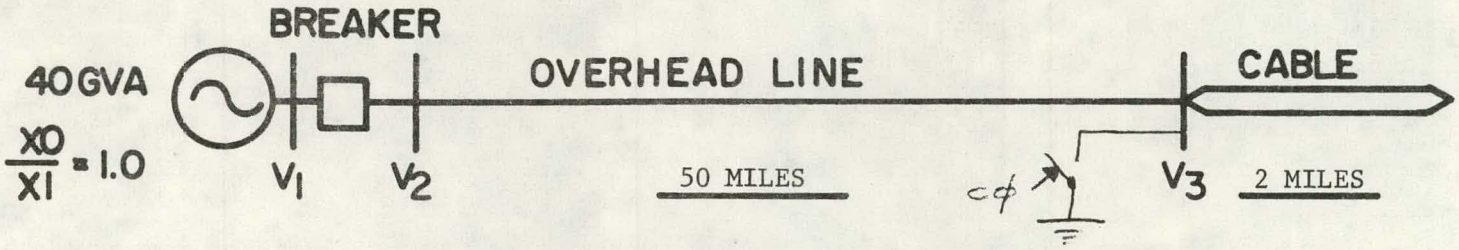






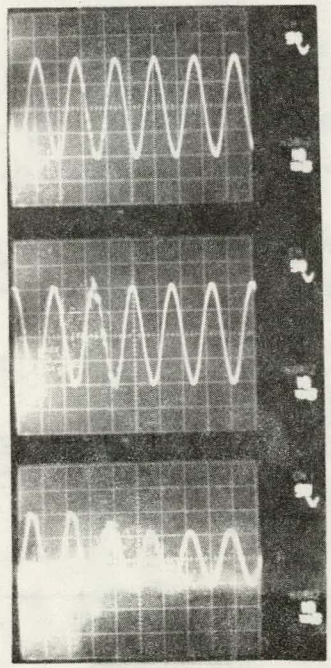


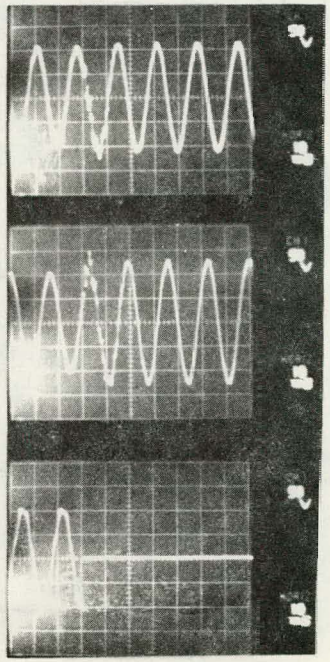
CASE NO. B-37 FAULT INITIATED OVERVOLTAGES

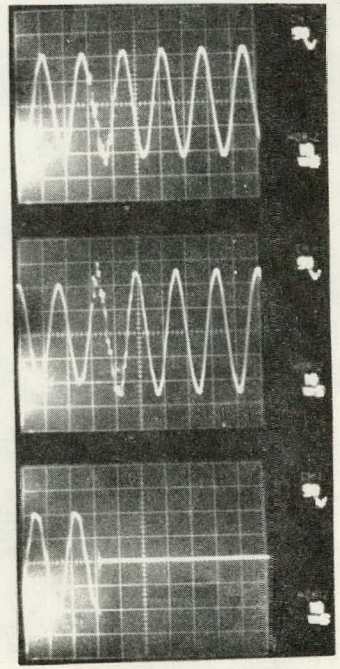


BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. PU OVERVOLTAGE		1.2 p.u.	1.5 p.u.	1.5 p.u.
LOCATION	V_1 -2	V_2	V_3	V_4



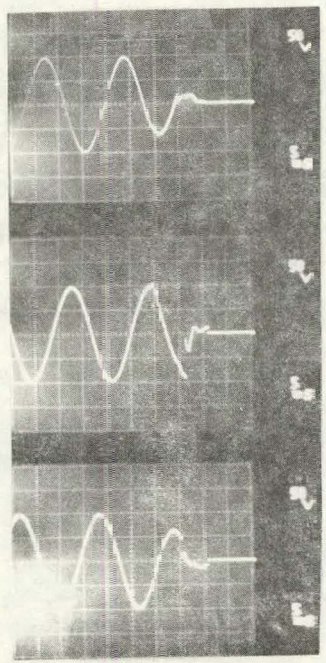


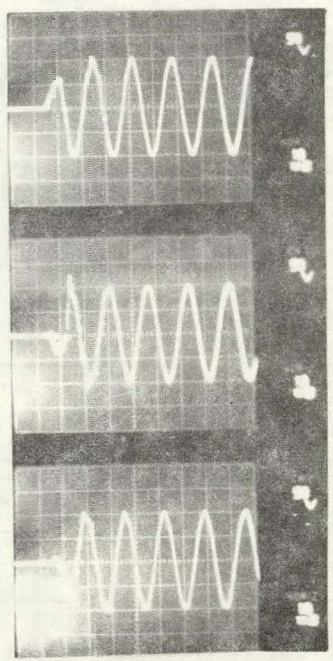


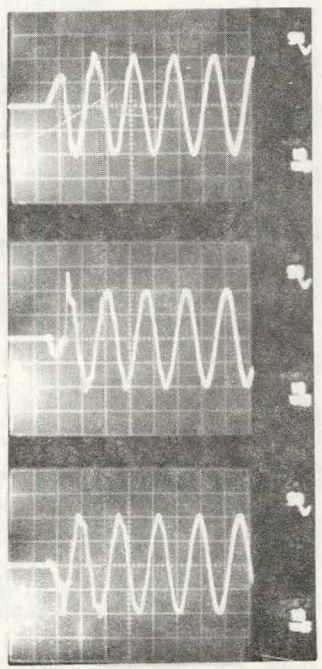
CASE NO. B-38 ENERGIZE LINE

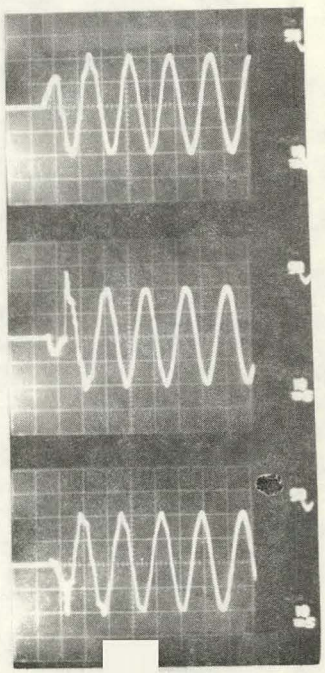
BREAKER RESISTORS	R_1 = 2500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

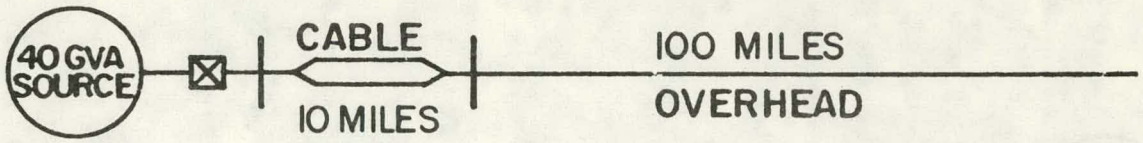
MAX. PU OVERVOLTAGE	1.0 p.u.	1.3 p.u.	1.4 p.u.	1.4 p.u.
LOCATION	V_1 -2	V_2	V_3	V_4

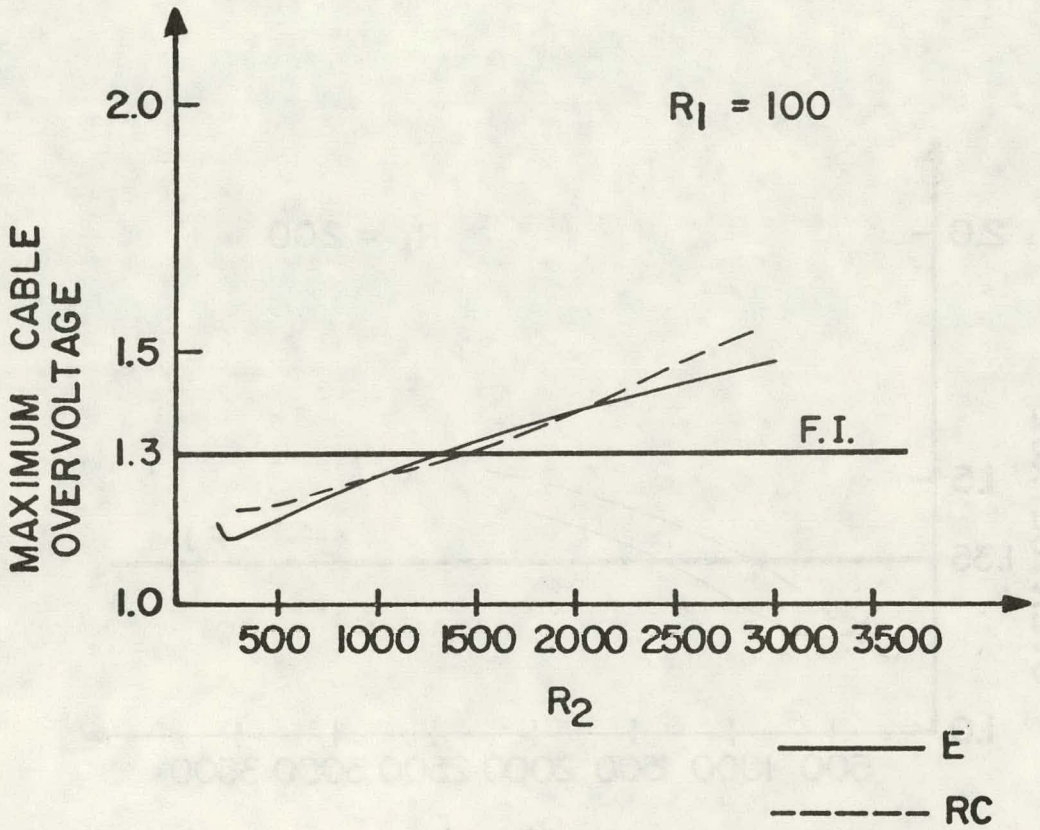


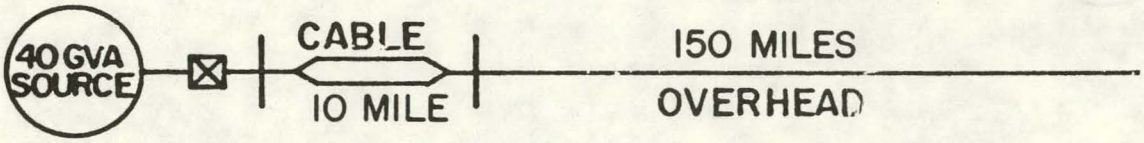


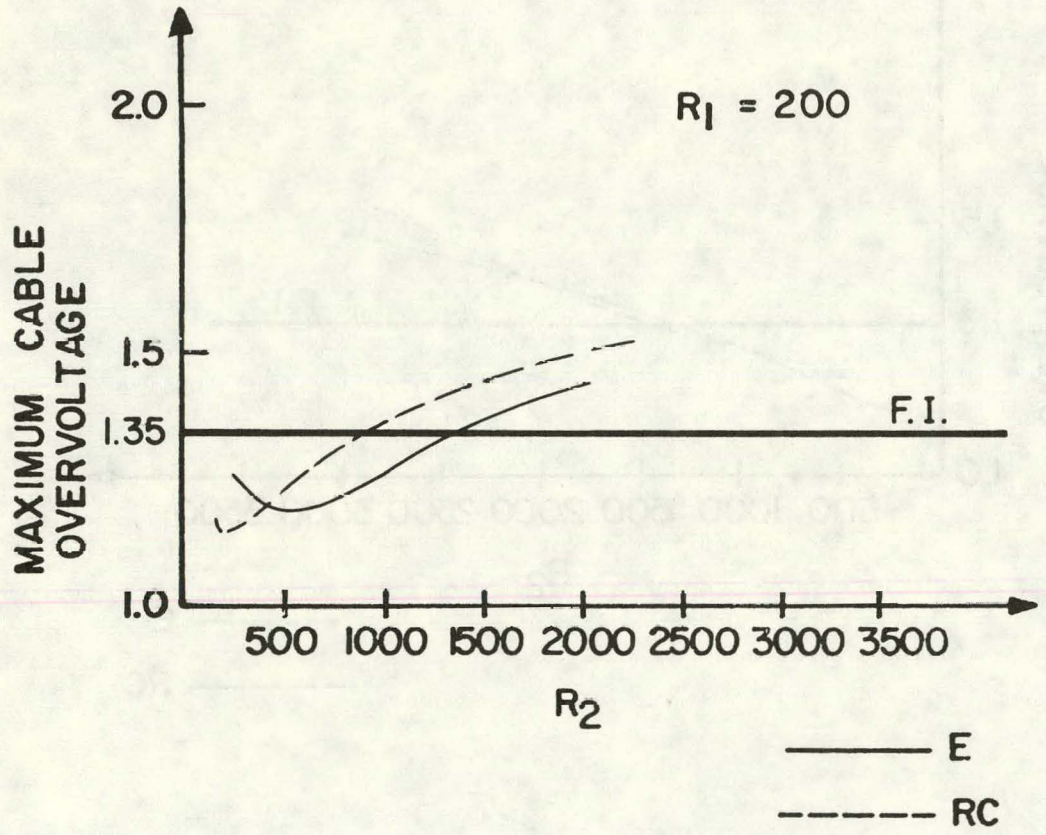


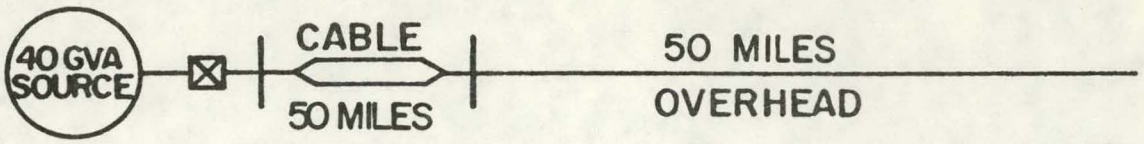


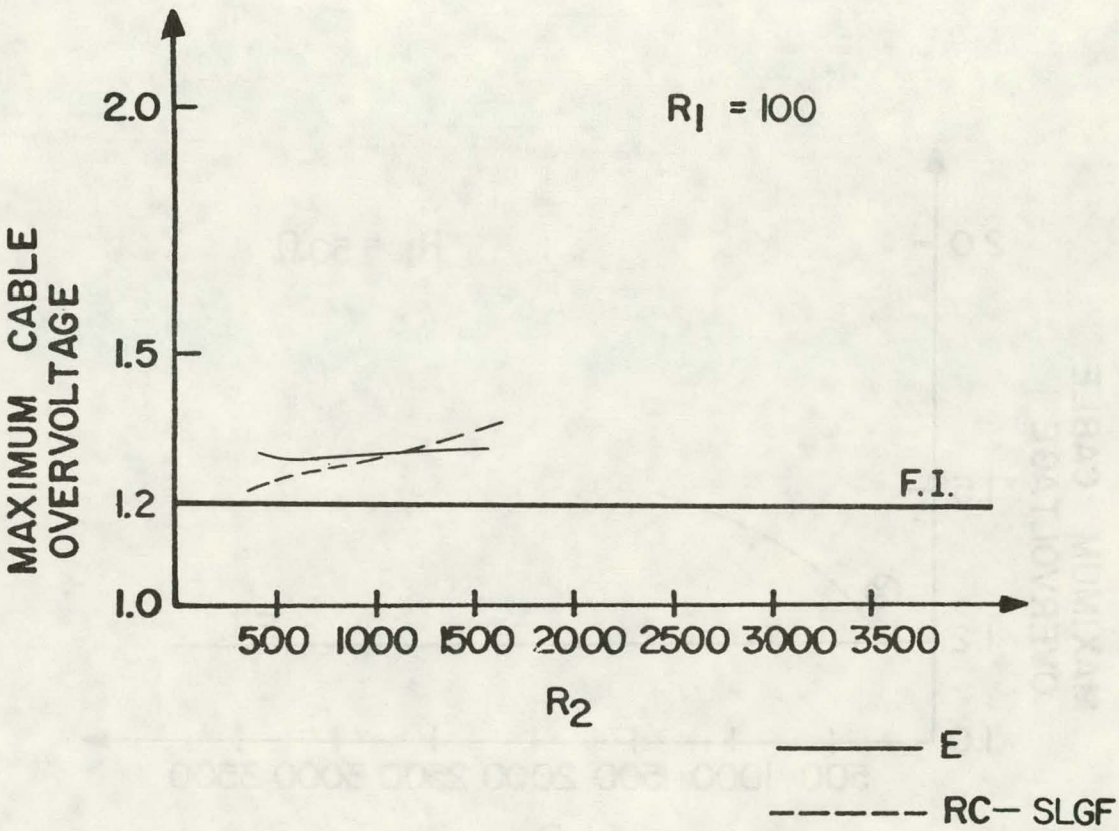

40 GVA SOURCE
CABLE
10 MILES
100 MILES
OVERHEAD

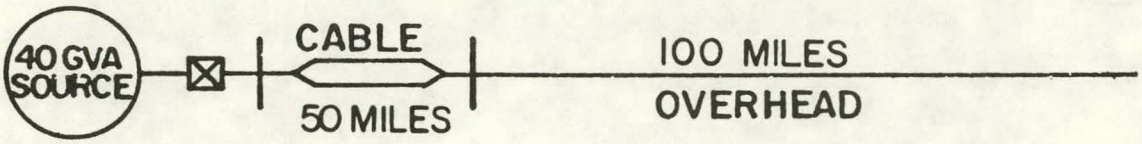

2.0
1.5
1.3
1.0
MAXIMUM CABLE OVERVOLTAGE
R1 = 100
F.I.
500 1000 1500 2000 2500 3000 3500
R2
E
RC

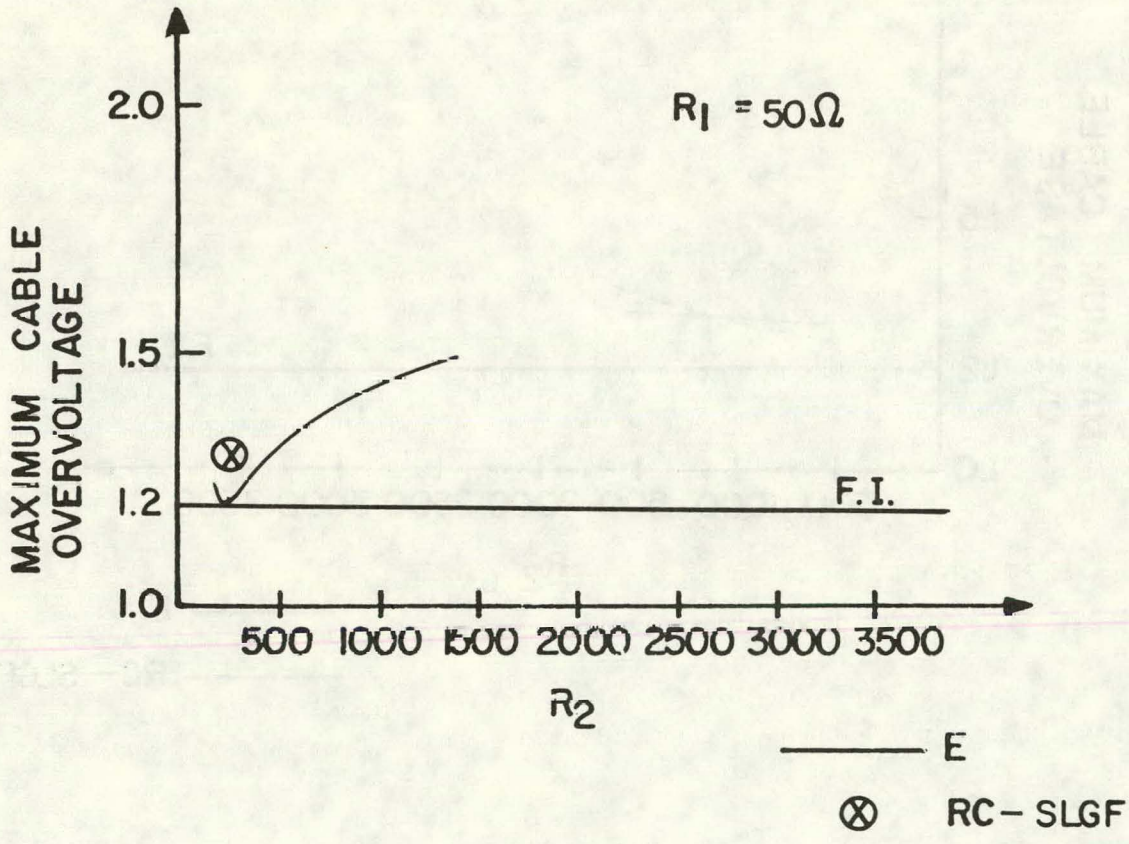

40 GVA SOURCE
CABLE
10 MILE
150 MILES
OVERHEAD

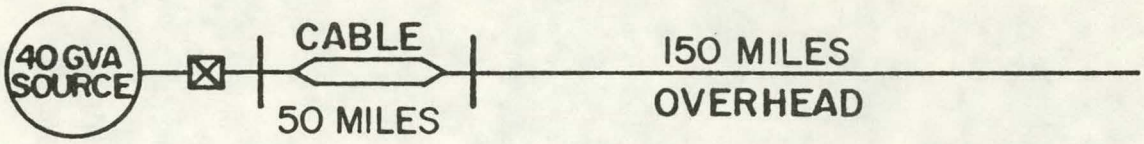

MAXIMUM CABLE OVERVOLTAGE
2.0
1.5
1.35
1.0
R_1 = 200
F.I.
500 1000 1500 2000 2500 3000 3500
R_2
E
RC

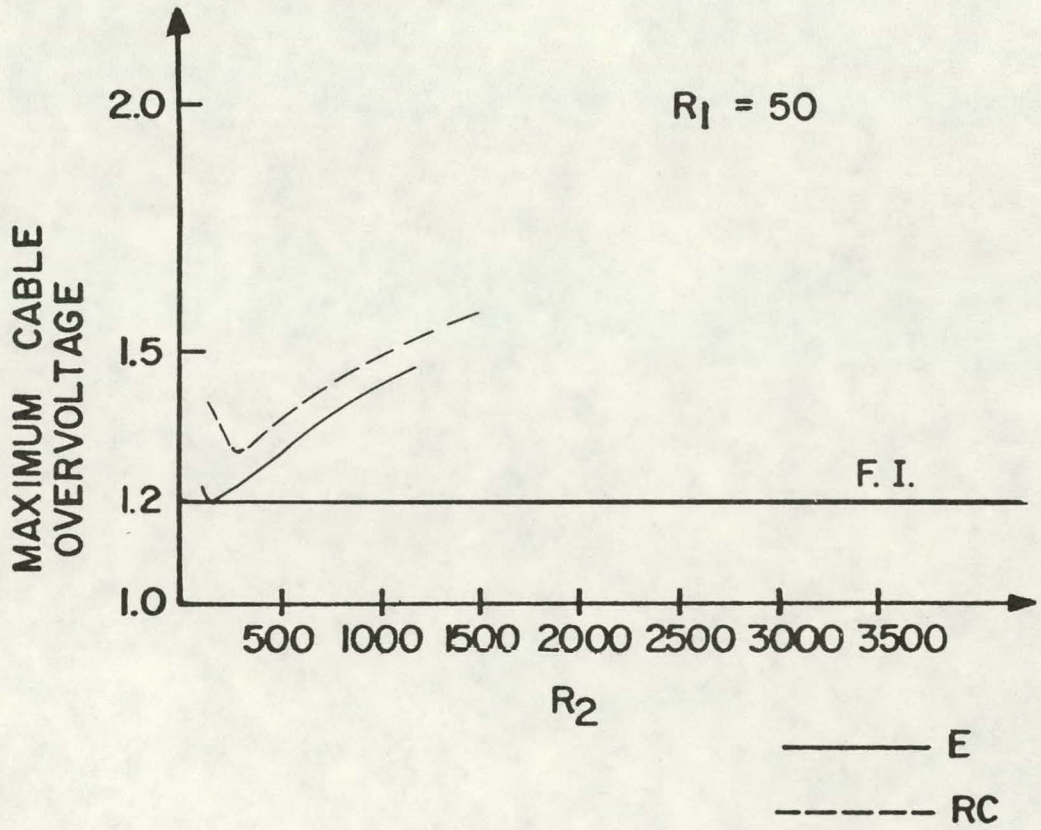

40 GVA SOURCE
CABLE
50 MILES
50 MILES
OVERHEAD


MAXIMUM CABLE OVERVOLTAGE
2.0
1.5
1.2
1.0
R1 = 100
F.I.
500 1000 1500 2000 2500 3000 3500
R2
E
RC– SLGF

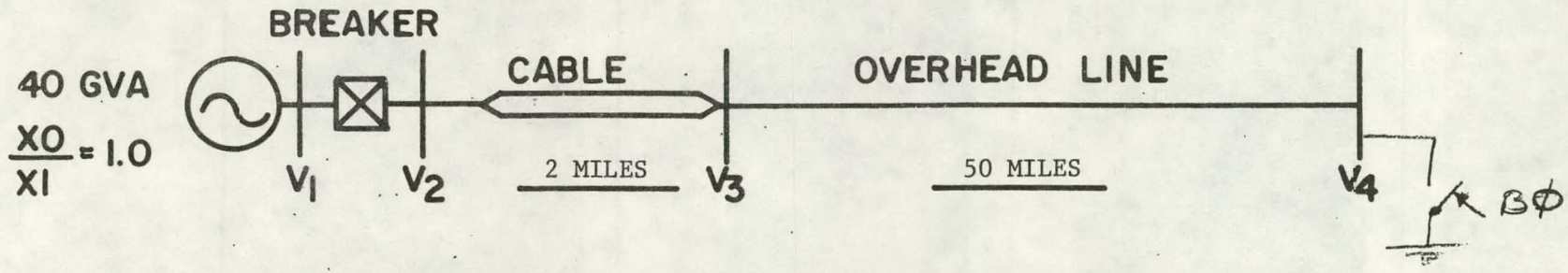

40 GVA
SOURCE
CABLE
50 MILES
100 MILES
OVERHEAD


MAXIMUM CABLE
OVERVOLTAGE
2.0
1.5
1.2
1.0
$R_1 = 50\Omega$
F.I.
500 1000 1500 2000 2500 3000 3500
R_2
E
RC – SLGF

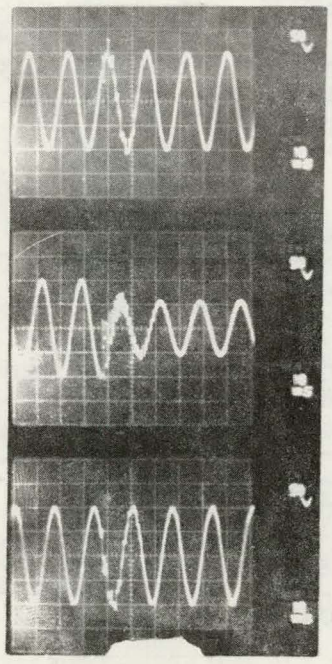
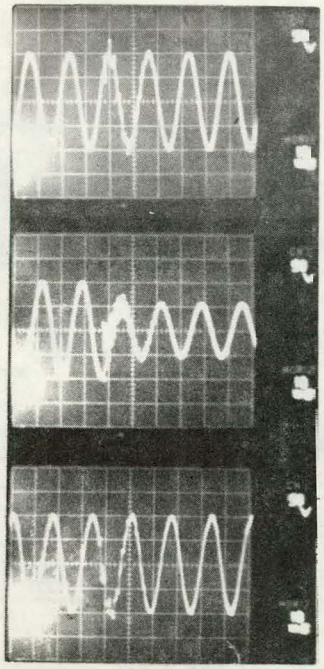
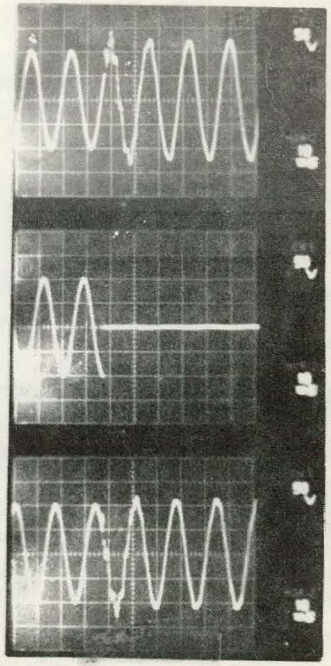

40 GVA
SOURCE
CABLE
50 MILES
150 MILES
OVERHEAD


MAXIMUM CABLE
OVERVOLTAGE
2.0
1.5
1.2
1.0
R_1 = 50
F. I.
500 1000 1500 2000 2500 3000 3500
R_2
E
RC

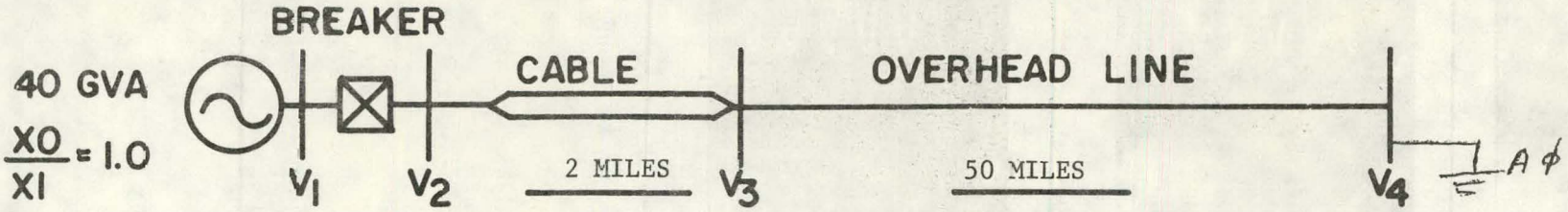
CASE NO. C-1 FAULT INITIATED OVERVOLTAGES



BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

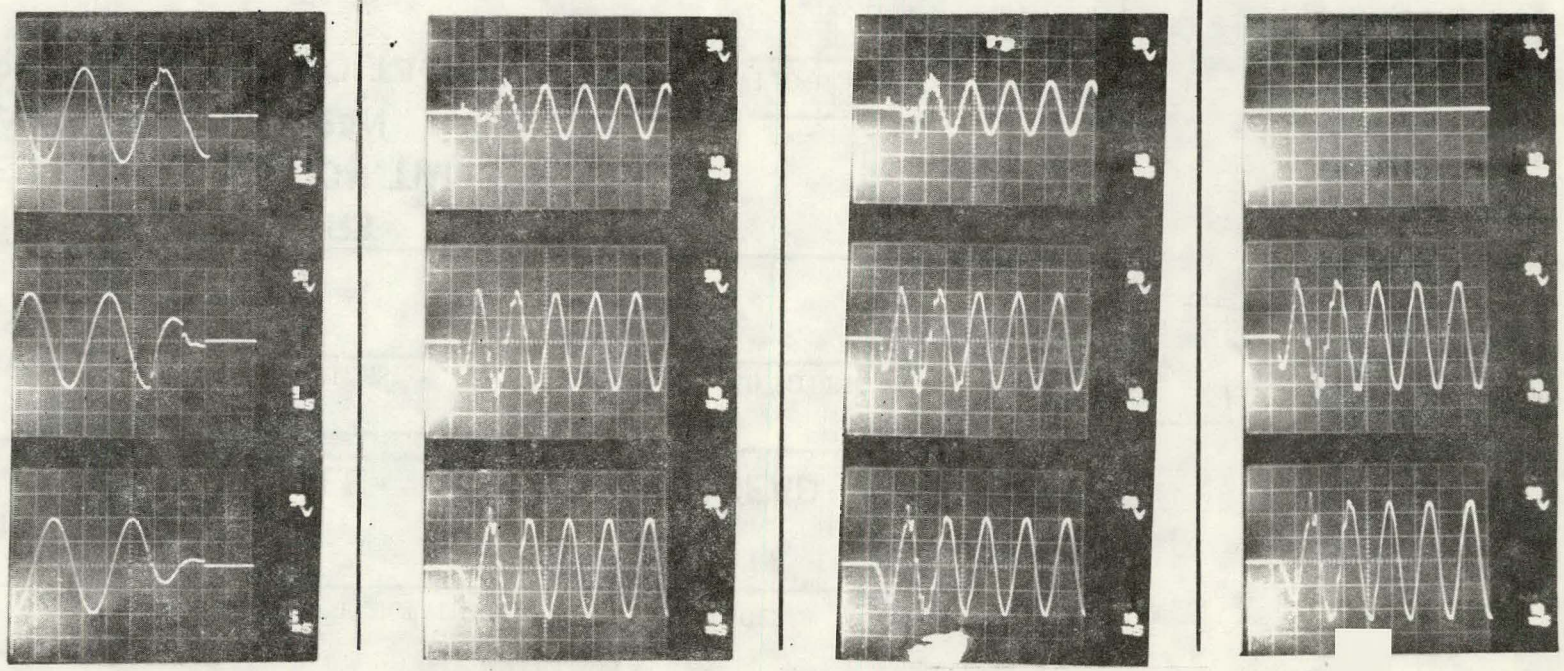
MAX. P.U. OVERVOLTAGE		1.3 p.u.	1.3 p.u.	1.4 p.u.
LOCATION	V_{1-2}	V_2	V_3	V_4
				

CASE NO. C-2 ENERGIZING INTO SINGLE LINE TO GROUND FAULT

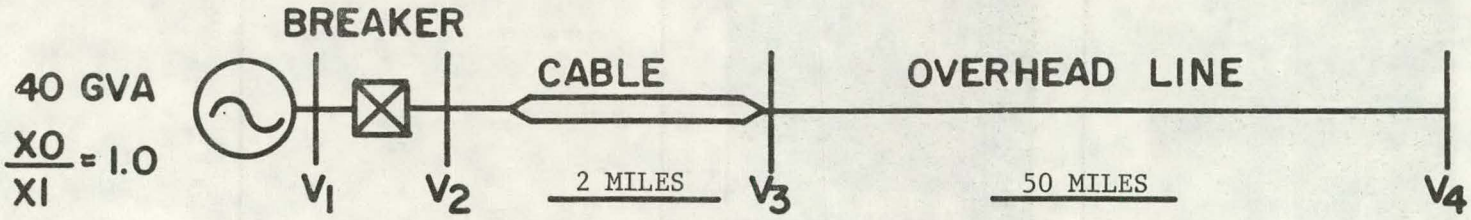


BREAKER RESISTORS	R_1 = 1000 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. P.U. OVERVOLTAGE	1.0 p.u.	1.3 p.u.	1.3 p.u.	1.4 p.u.
LOCATION	V_{1-2}	V_2	V_3	V_4

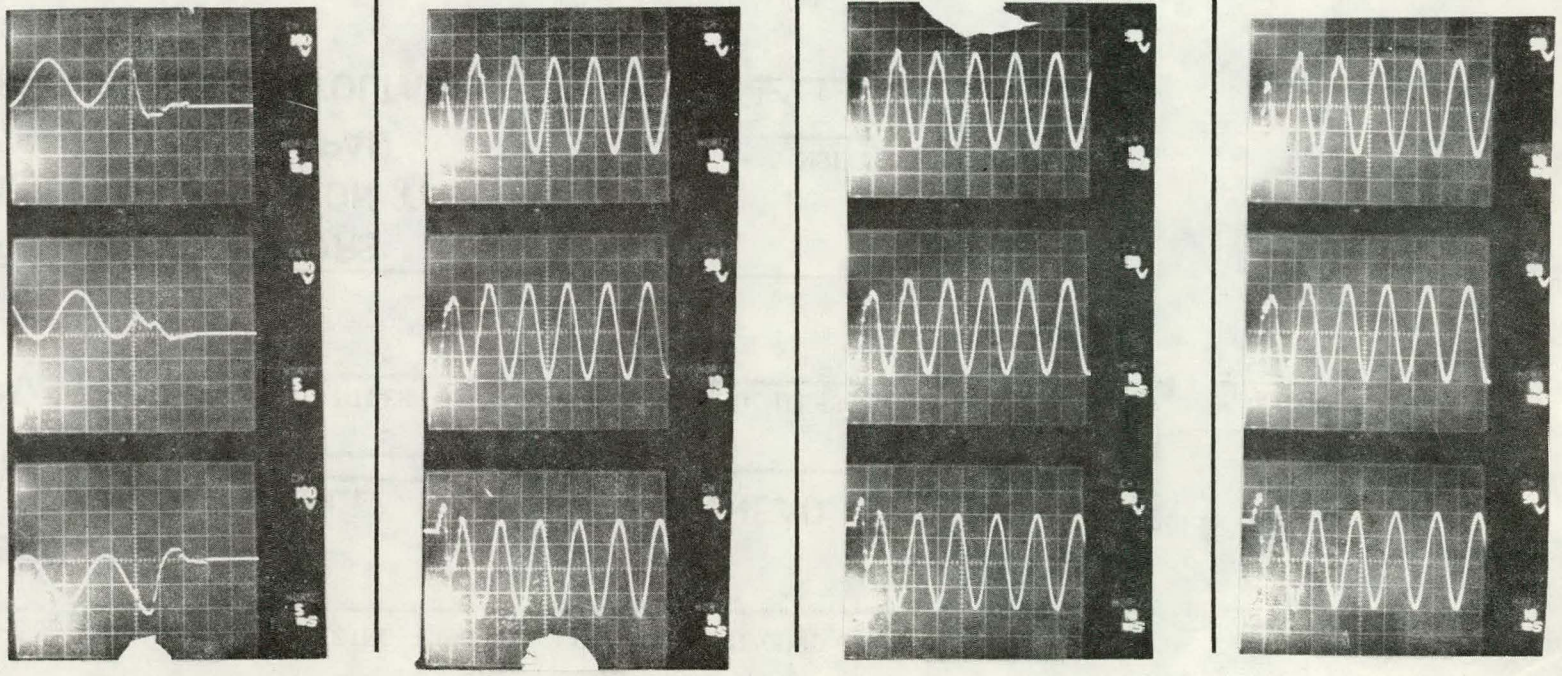


CASE NO. C-3 HIGH SPEED RECLOSING OF LINE

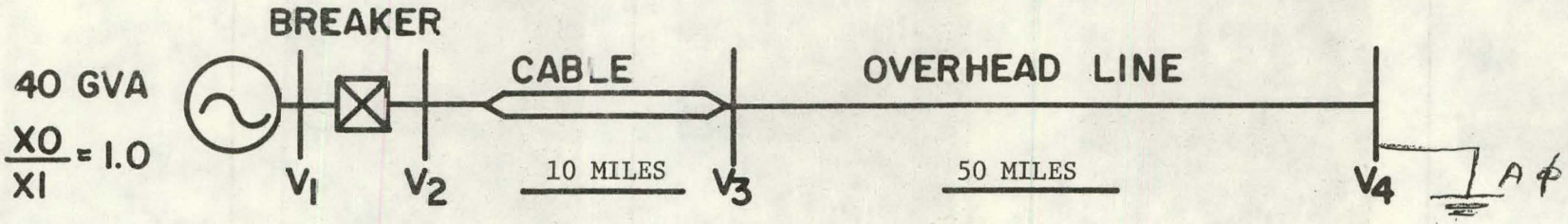


BREAKER RESISTORS	R_1 = 1000 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

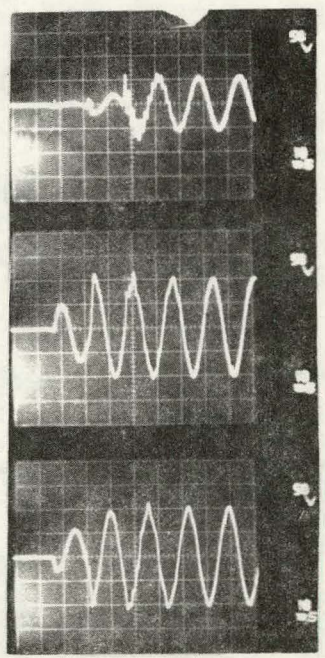
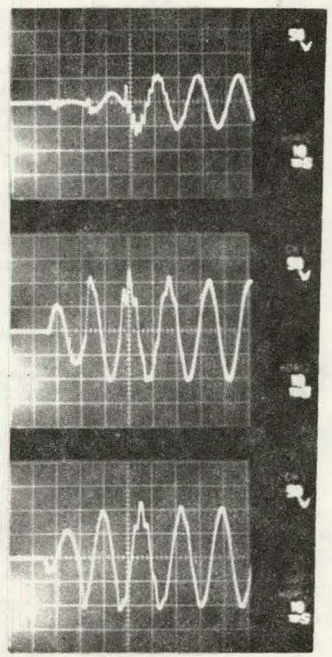
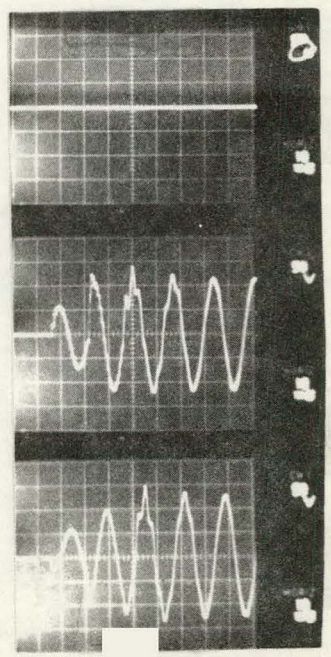
MAX. P.U. OVERVOLTAGE	2.0 p.u.	1.3 p.u.	1.3 p.u.	1.3 p.u.
LOCATION	V_{1-2}	V_2	V_3	V_4



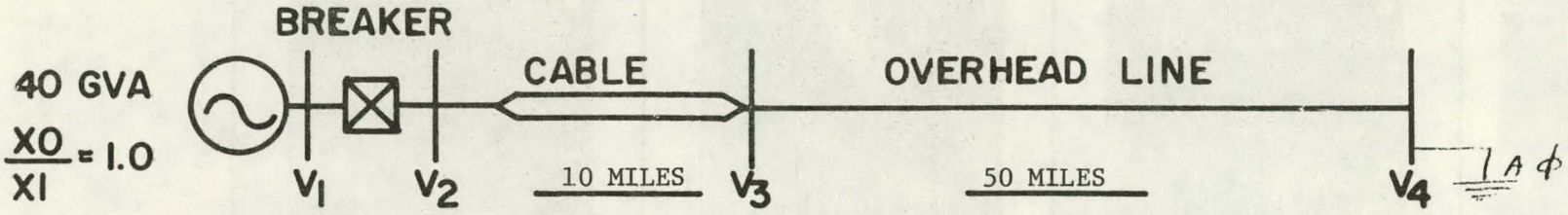
CASE NO. C-4 ENERGIZING INTO SINGLE LINE TO GROUND FAULT



BREAKER RESISTORS	R_1 = 1500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

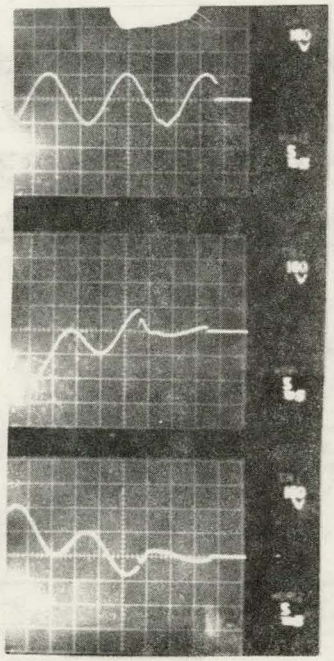
MAX. P.U. OVERVOLTAGE		1.2 p.u.	1.3 p.u.	1.5 p.u.
LOCATION	V_{1-2}	V_2	V_3	V_4
				

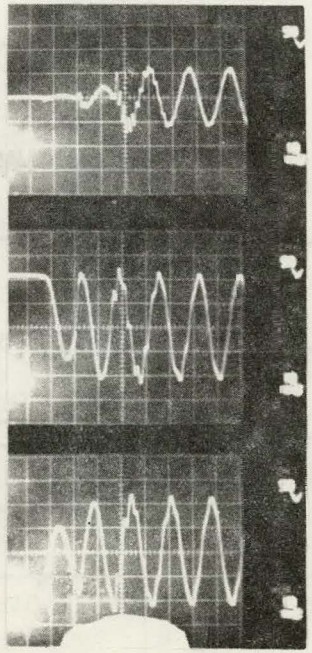
CASE NO. C-5 HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT

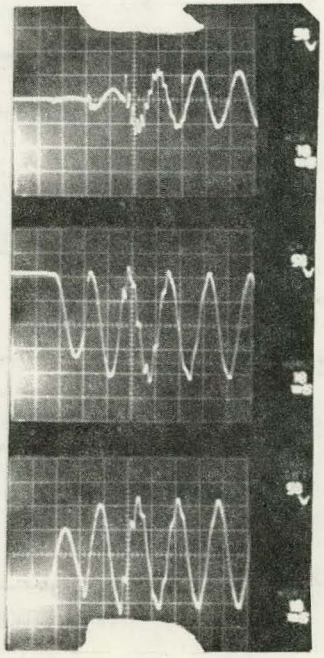


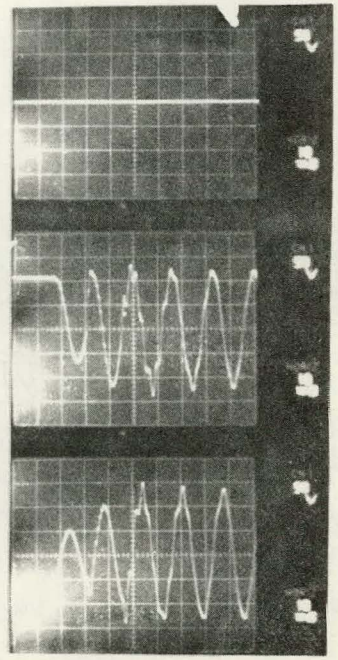
BREAKER RESISTORS	R_1 = 1500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. P.U. OVERVOLTAGE	2.0 p.u.	1.2 p.u.	1.2 p.u.	1.5 p.u.
LOCATION	V_{1-2}	V_2	V_3	V_4

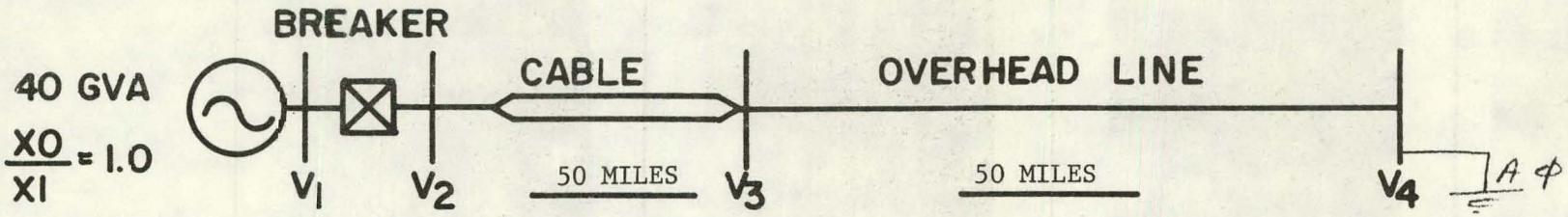






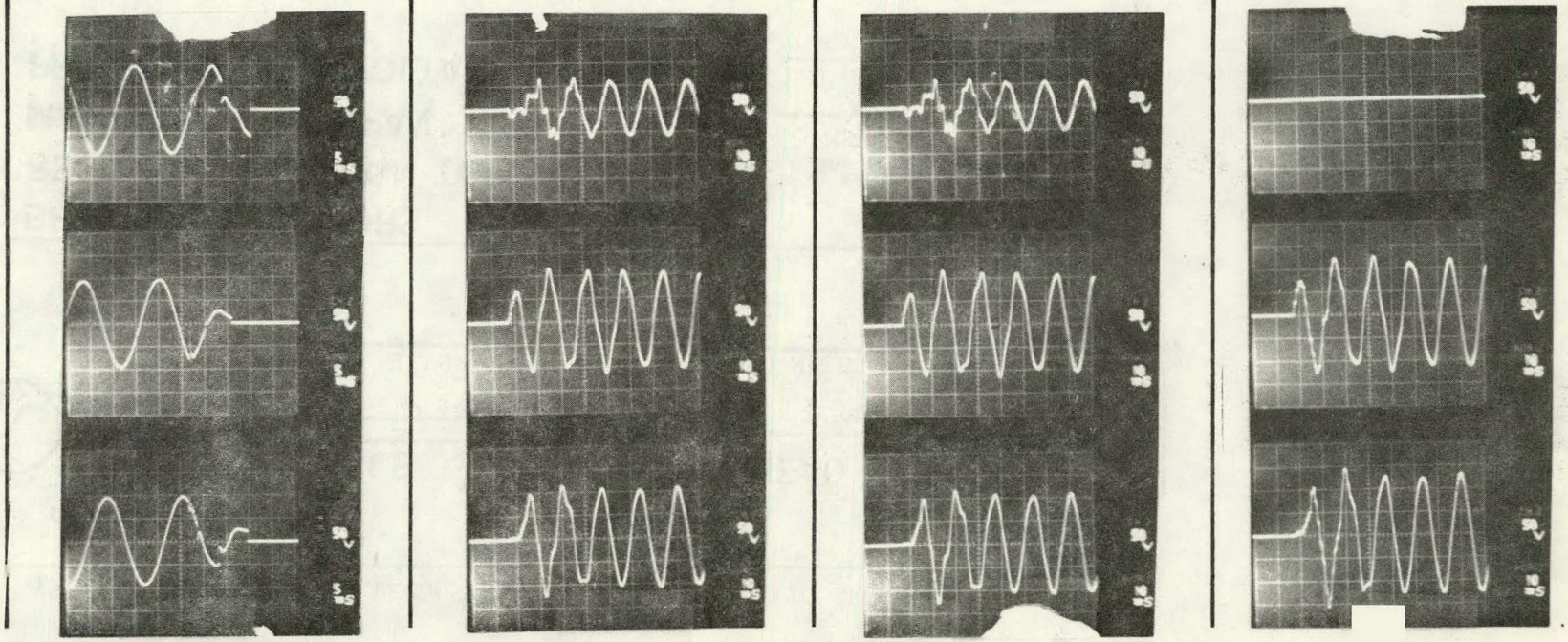


CASE NO. C-6 ENERGIZING INTO SINGLE LINE TO GROUND FAULT

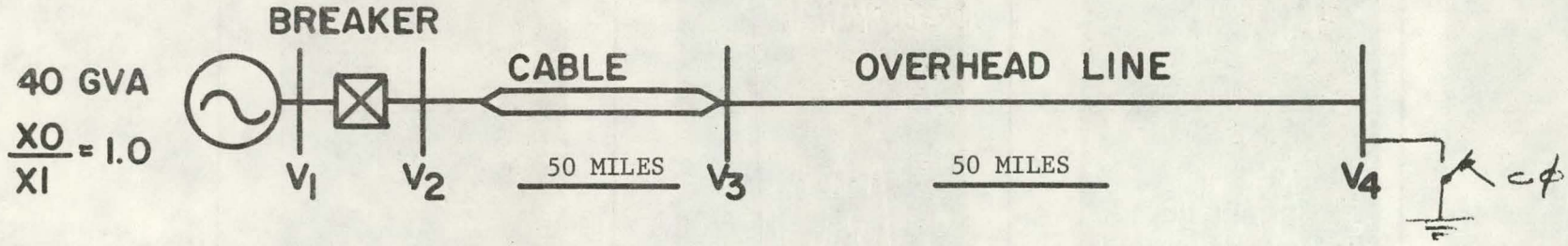


BREAKER RESISTORS	R_1 = 500 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. P.U. OVERVOLTAGE	1.0 p.u.	1.3 p.u.	1.3 p.u.	1.6 p.u.
LOCATION	V_{1-2}	V_2	V_3	V_4

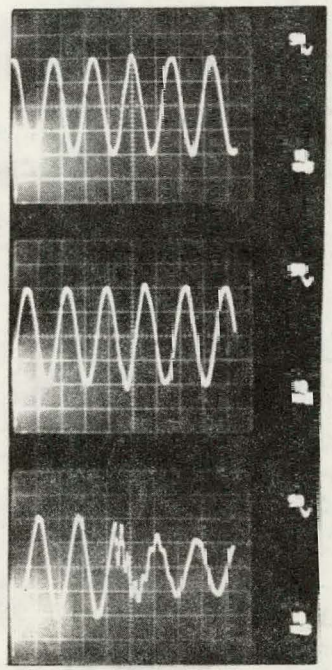


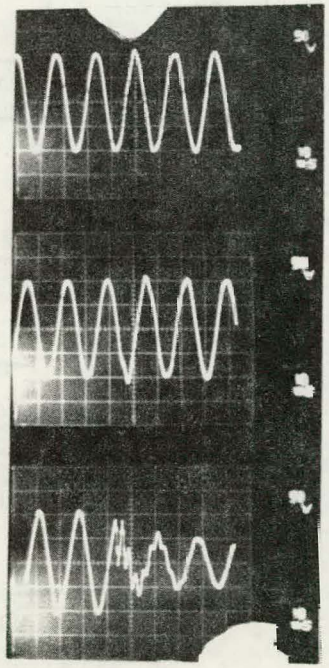
CASE NO. C-7 FAULT INITIATED OVERVOLTAGES

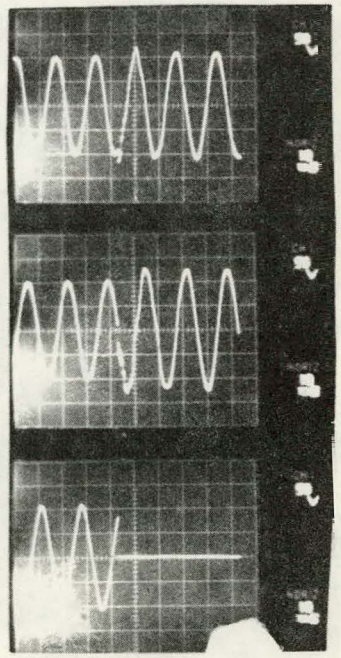


BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

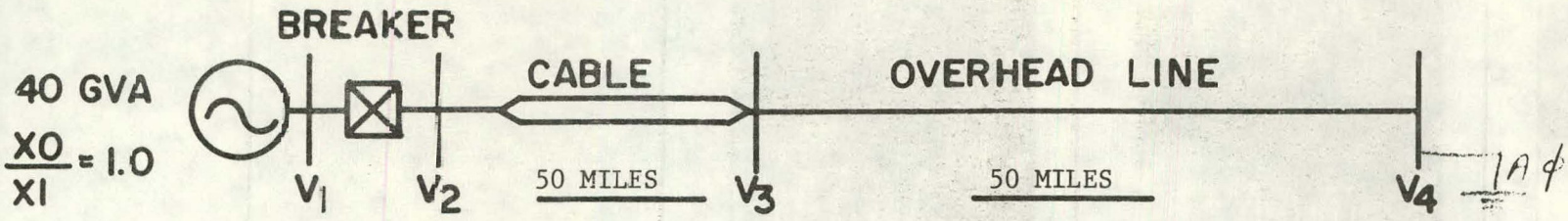
MAX. P.U. OVERVOLTAGE		1.15 p.u.	1.15 p.u.	1.3 p.u.
LOCATION	V_{1-2}	V_2	V_3	V_4





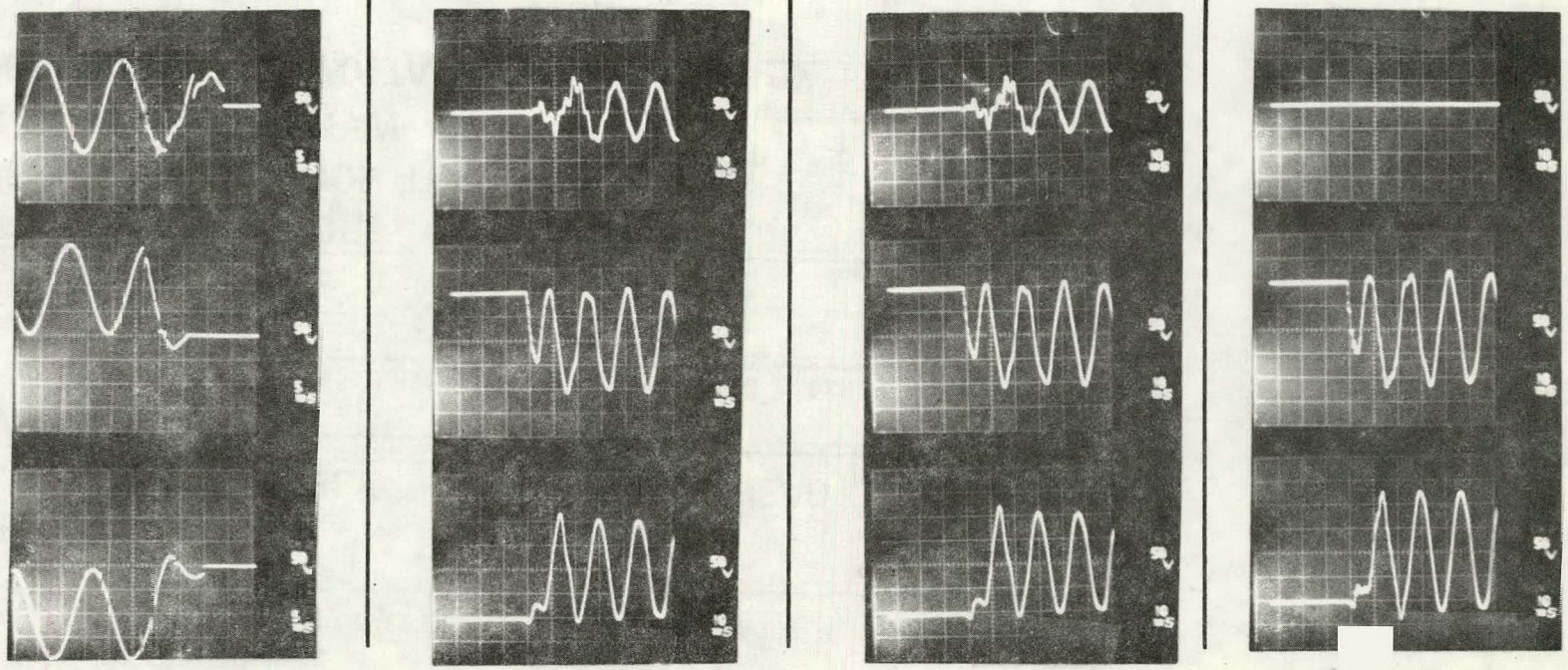


CASE NO. C-8 HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT

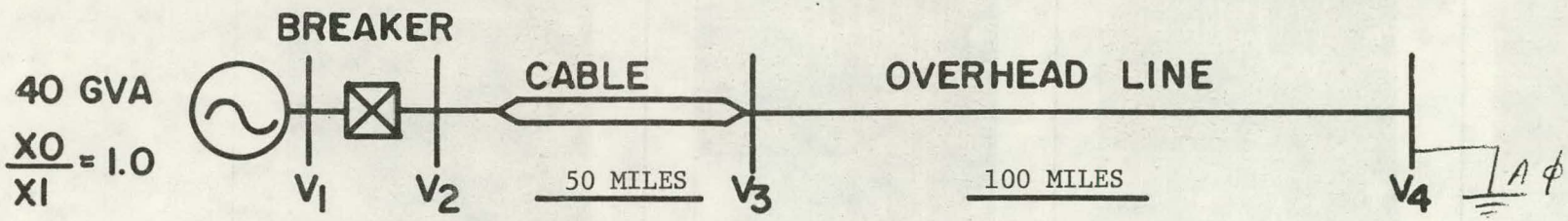


BREAKER RESISTORS	R_1 = 500 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. P.U. OVERVOLTAGE	2.0 p.u.	1.2 p.u.	1.2 p.u.	1.3 p.u.
LOCATION	V_{1-2}	V_2	V_3	V_4

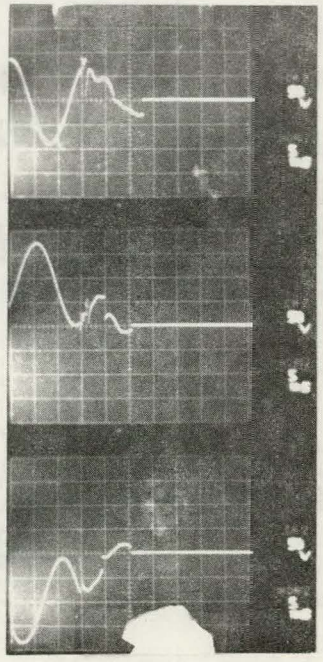


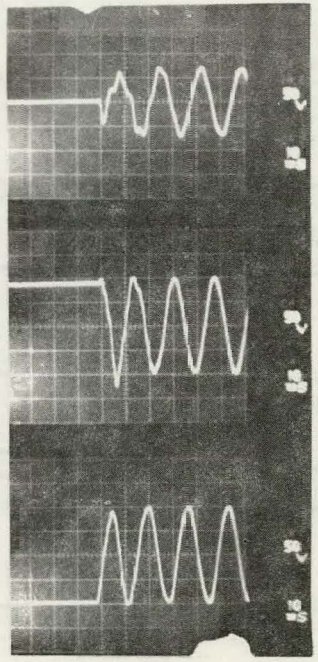
CASE NO. C-9 HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULTS

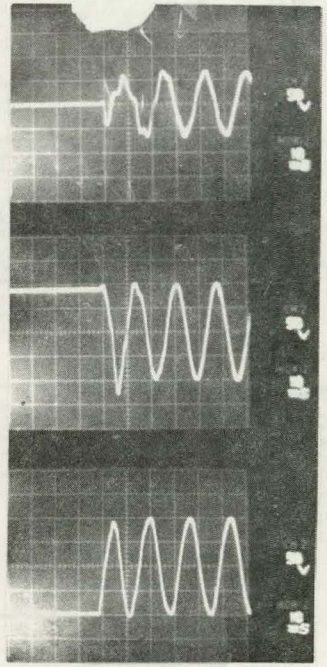


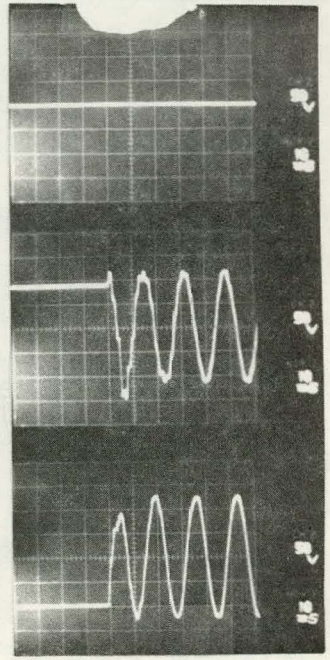
BREAKER RESISTORS	R_1 = 200 R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. P.U. OVERVOLTAGE	2.0 p.u.	1.3 p.u.	1.3 p.u.	1.5 p.u.
LOCATION	V_{1-2}	V_2	V_3	V_4

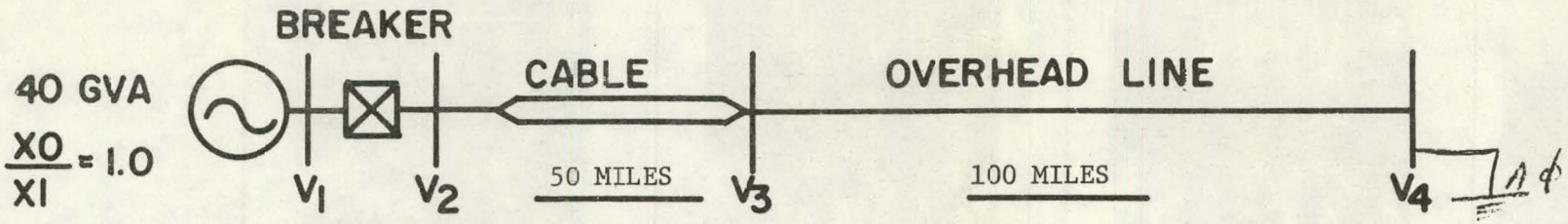






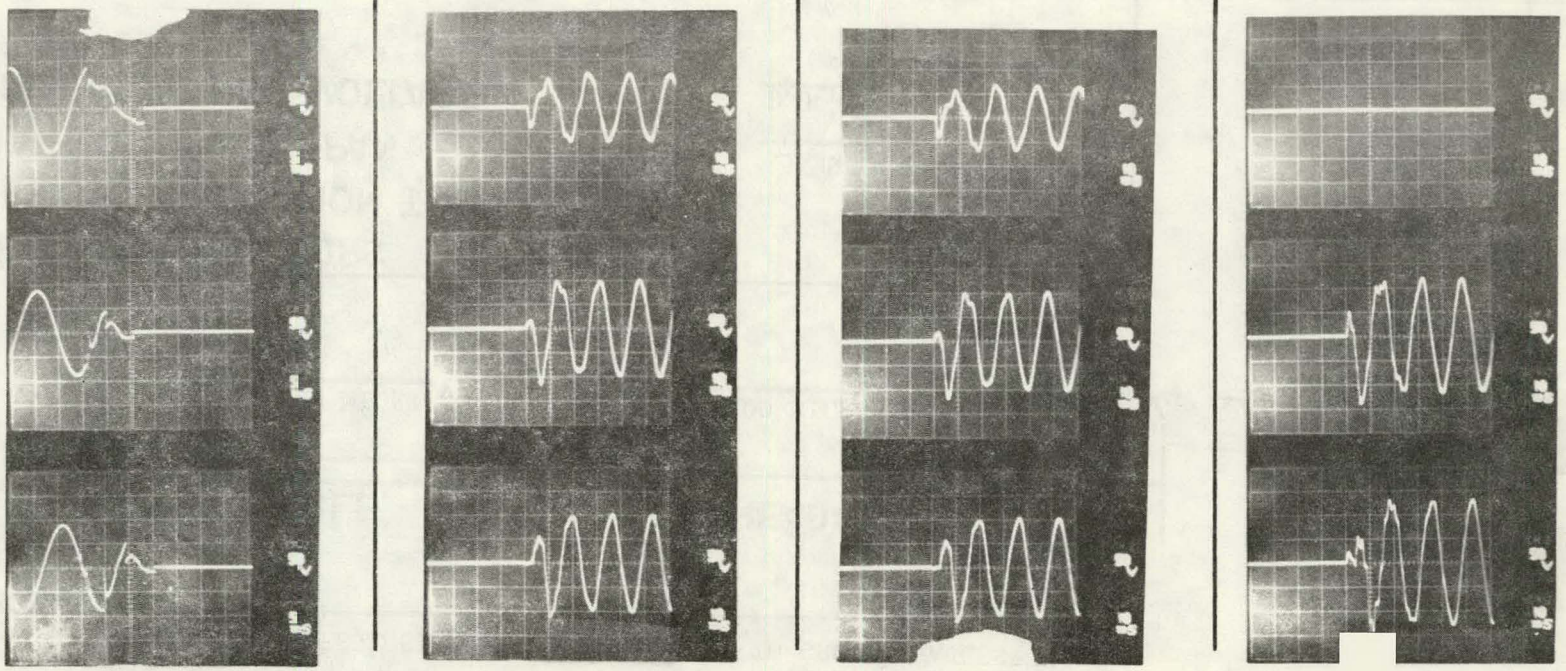


CASE NO. C-10 ENERGIZING INTO SINGLE LINE TO GROUND FAULT

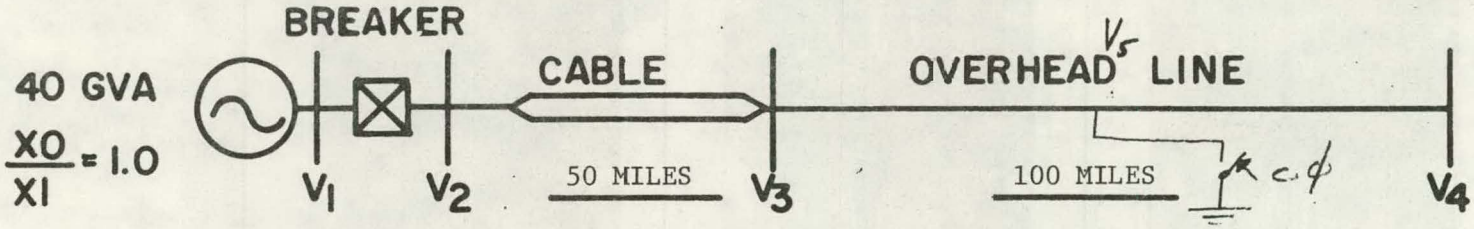


BREAKER RESISTORS	R_1 = 200 R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. P.U. OVERVOLTAGE	1.0 p.u.	1.2 p.u.	1.2 p.u.	1.4 p.u.
LOCATION	V_{1-2}	V_2	V_3	V_4

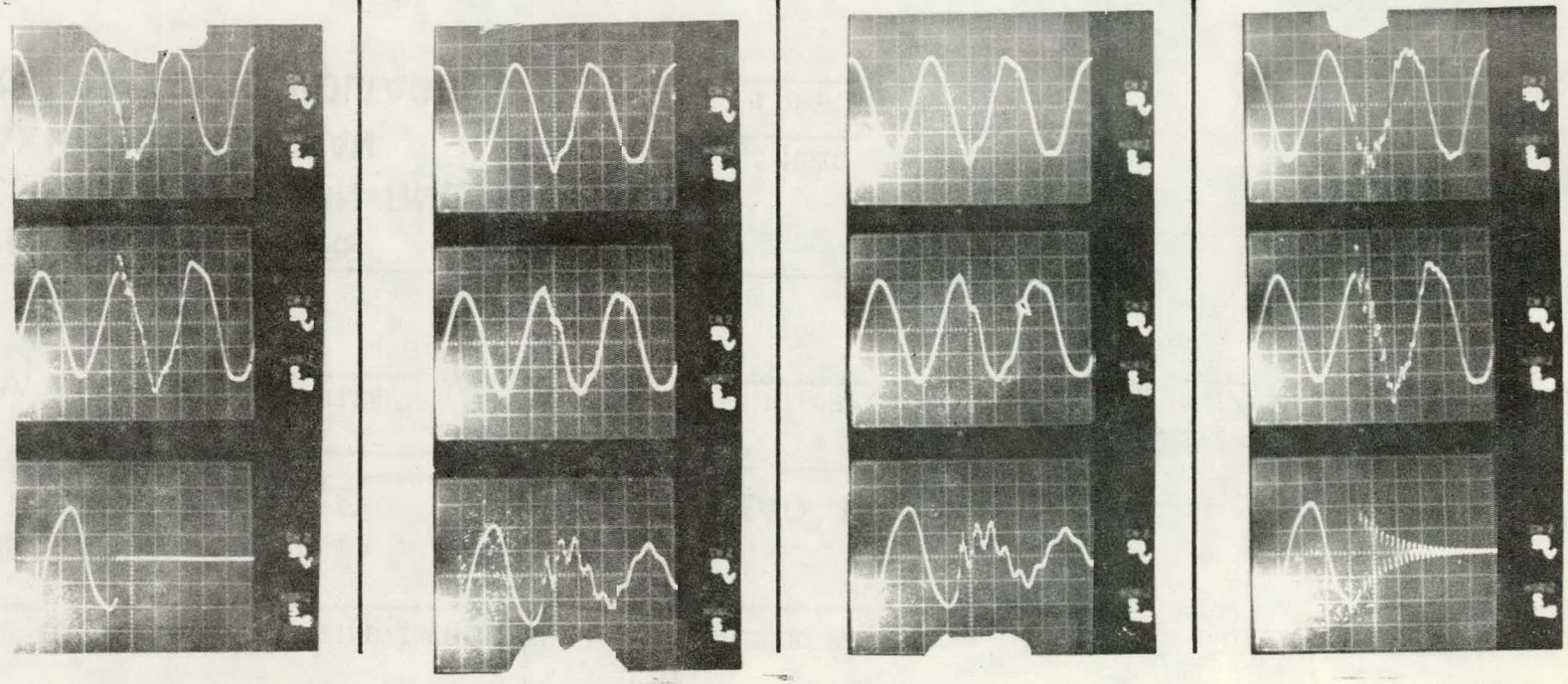


CASE NO. C-11 FAULT INITIATED OVERVOLTAGES

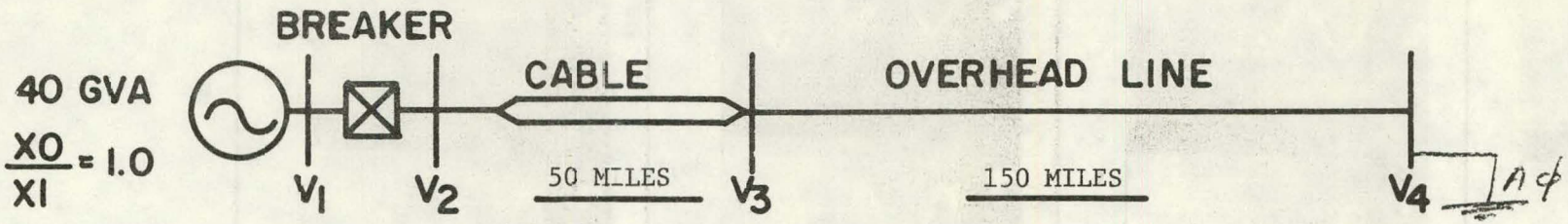


BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. P.U. OVERVOLTAGE	1.4 p.u.	1.2 p.u.	1.2 p.u.	1.7 p.u.
LOCATION	V_5	V_2	V_3	V_4

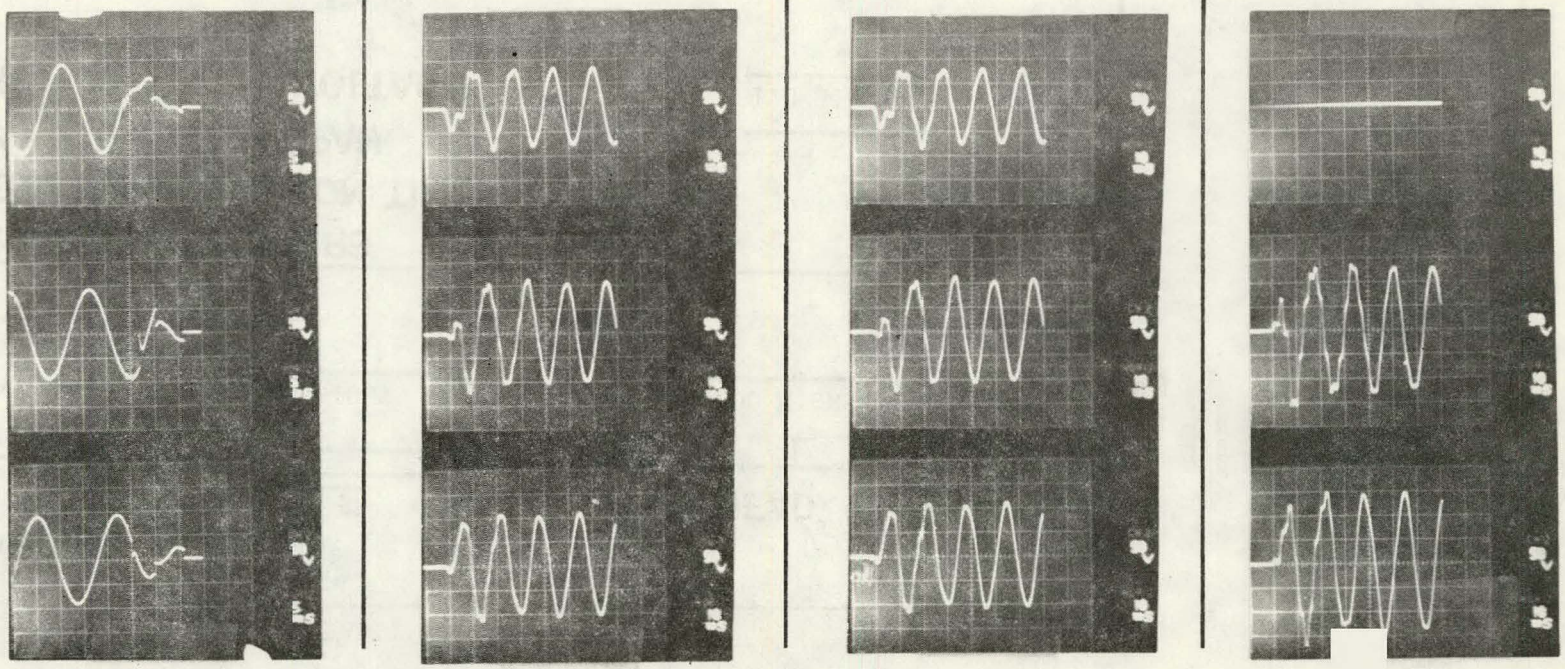


CASE NO. C-12 ENEERGIZING INTO SINGLE LINE TO GROUND FAULT

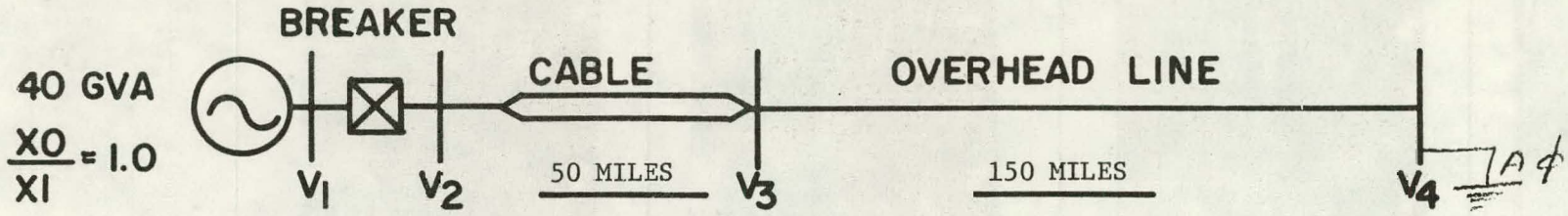


BREAKER RESISTORS	R_1 = 200 R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. P.U. OVERVOLTAGE	1.0 p.u.	1.2 p.u.	1.2 p.u.	1.7 p.u.
LOCATION	V_{1-2}	V_2	V_3	V_4

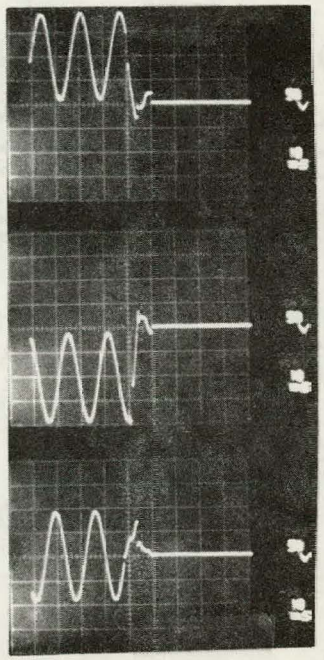


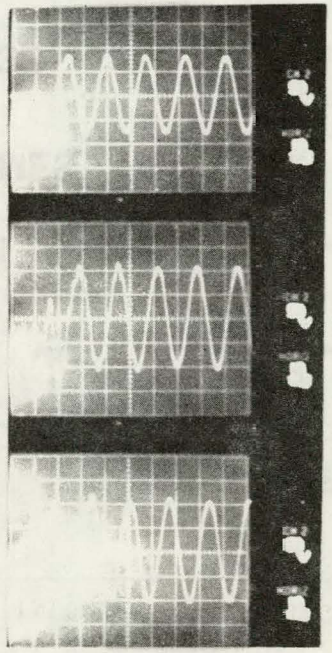
CASE NO. C-13 HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT

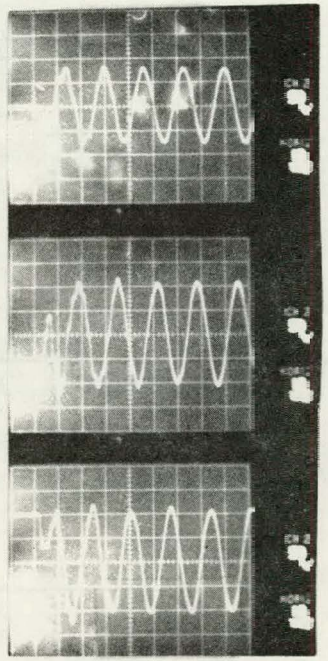


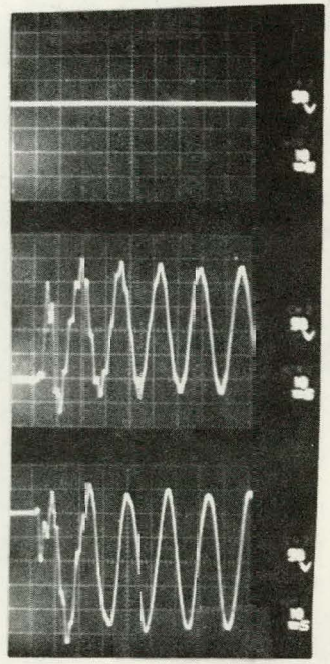
BREAKER RESISTORS	R_1 = 200 Ω, R_2 = 50 Ω
RESISTOR INSERTION TIMES	6 MSEC, 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. P.U. OVERVOLTAGE	2.0 p.u.	1.3 p.u.	1.3 p.u.	1.7 p.u.
LOCATION	V_{1-2}	V_2	V_3	V_4



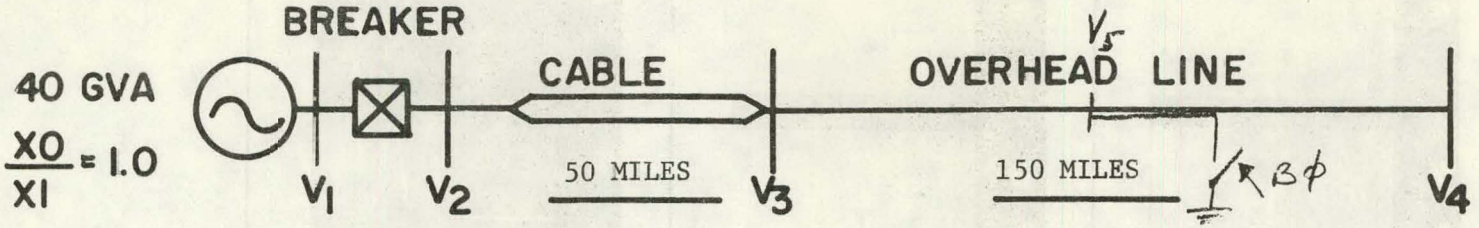






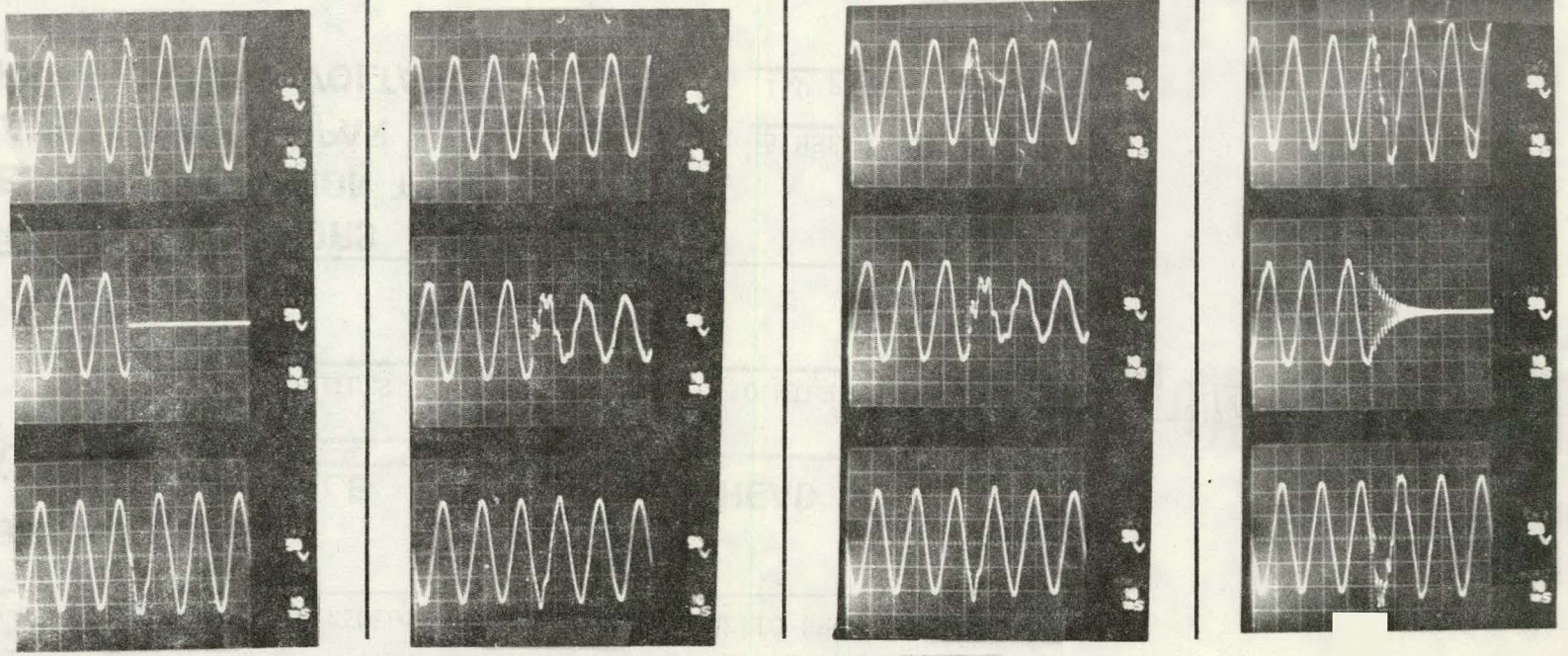
CASE NO. C-14

FAULT INITIATED OVERVOLTAGES

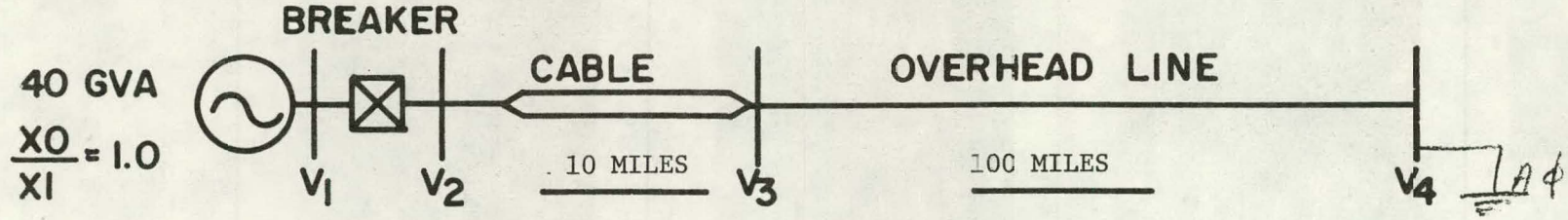


BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. P.U. OVERVOLTAGE	1.4 p.u.	1.2 p.u.	1.2 p.u.	1.7 p.u.
LOCATION	V_5	V_2	V_3	V_4

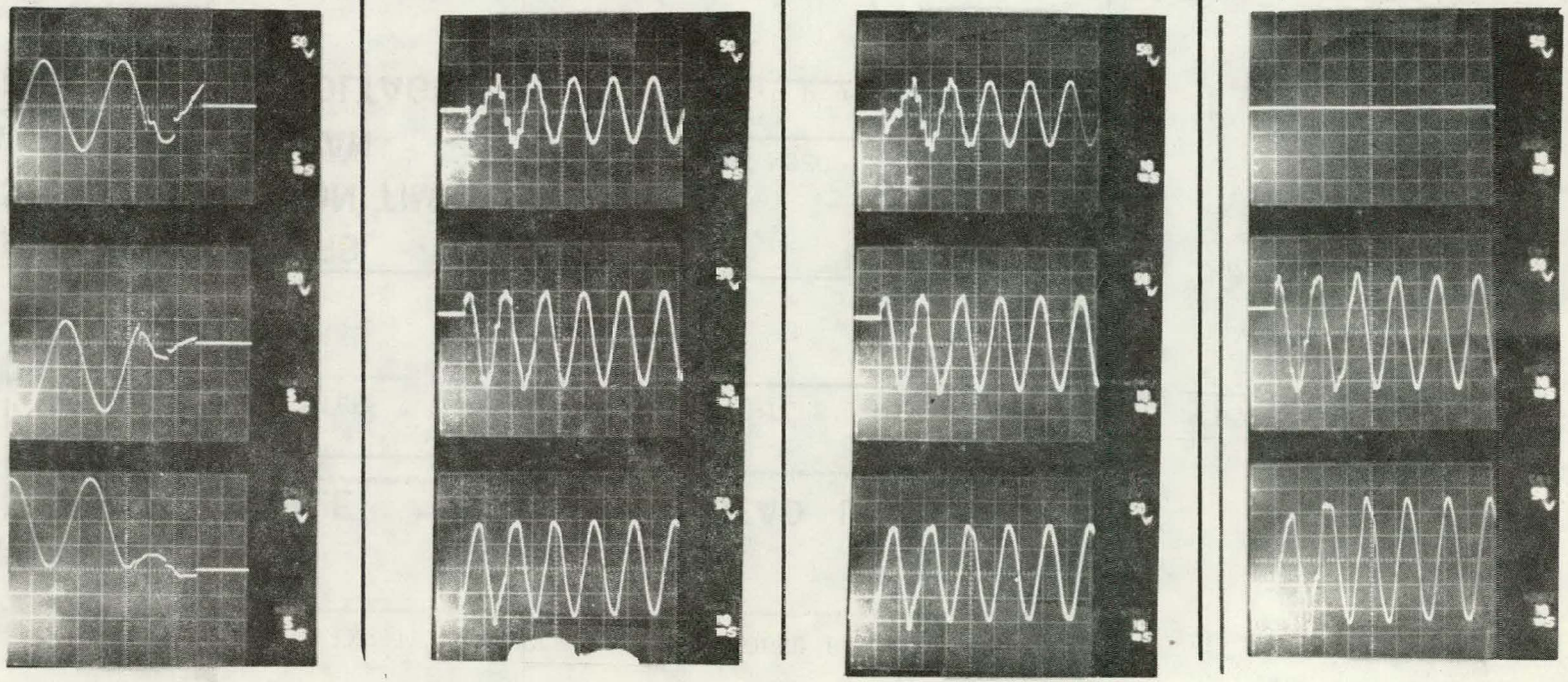


CASE NO. C-15 HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT

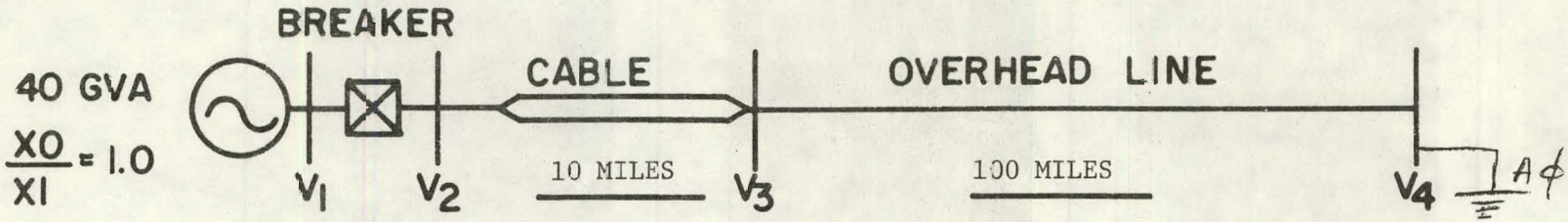


BREAKER RESISTORS	R_1 = 250 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. P.U. OVERVOLTAGE	2.0 p.u.	1.2 p.u.	1.2 p.u.	1.5 p.u.
LOCATION	V_{1-2}	V_2	V_3	V_4

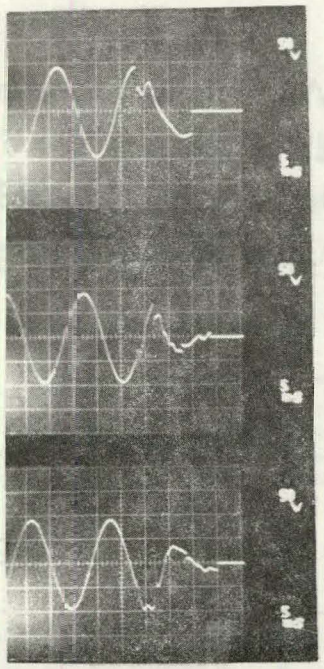


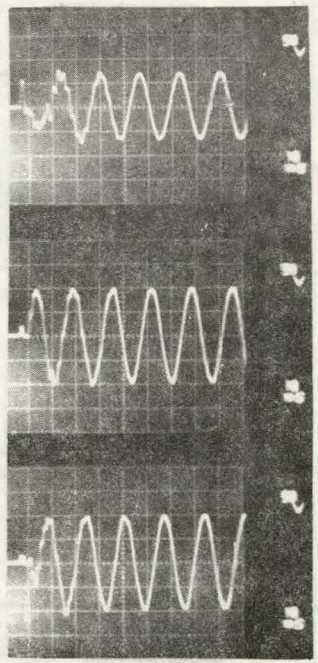
CASE NO. C-16 ENERGIZING INTO SINGLE LINE TO GROUND FAULT

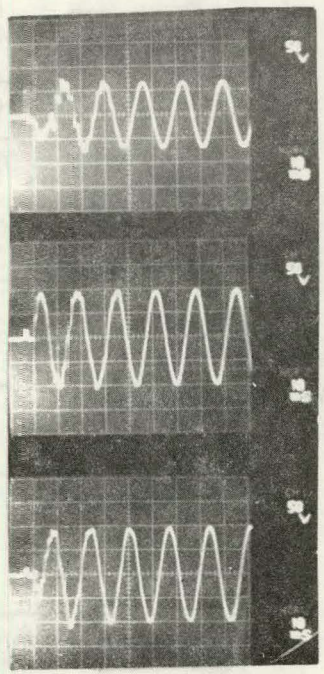


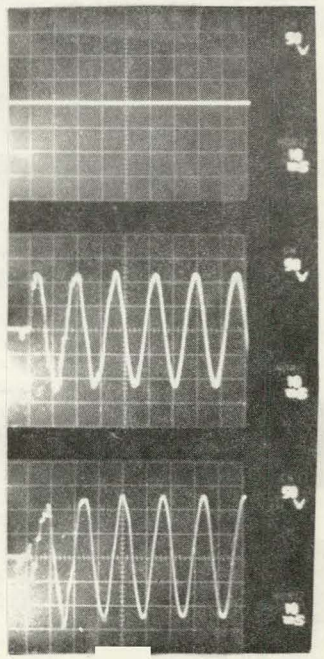
BREAKER RESISTORS	R_1 = 250 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. P.U. OVERVOLTAGE	1.0 p.u.	1.1 p.u.	1.1 p.u.	1.5 p.u.
LOCATION	V_{1-2}	V_2	V_3	V_4



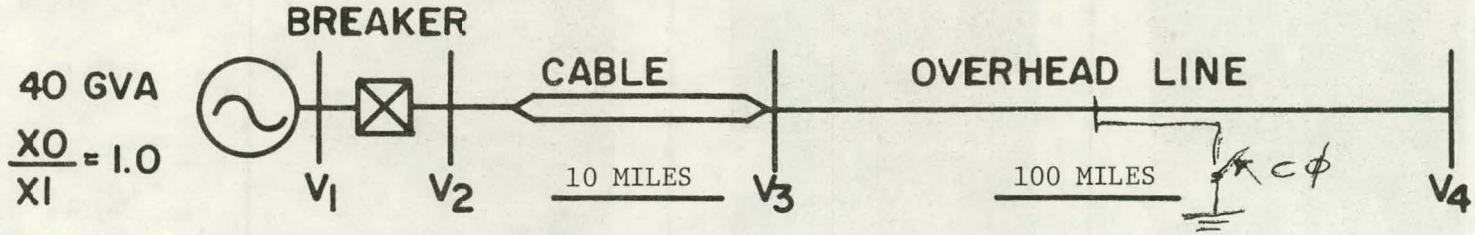




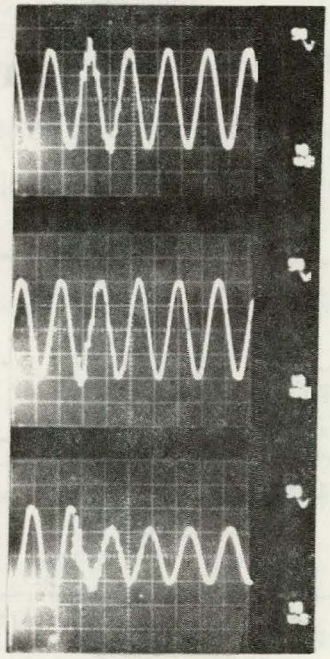
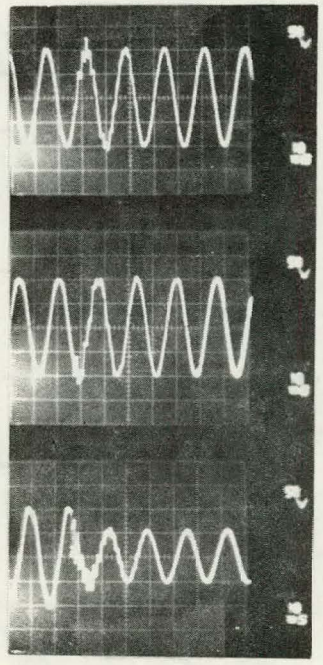
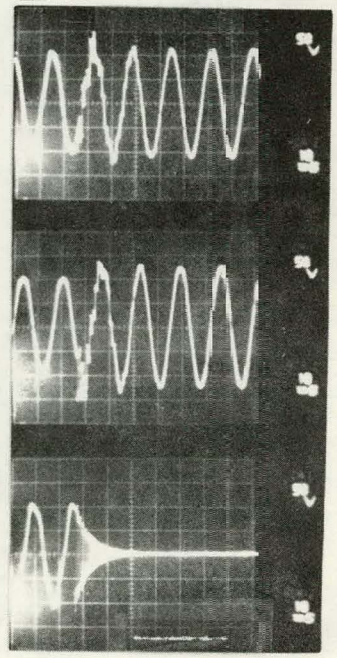


CASE NO. C-17

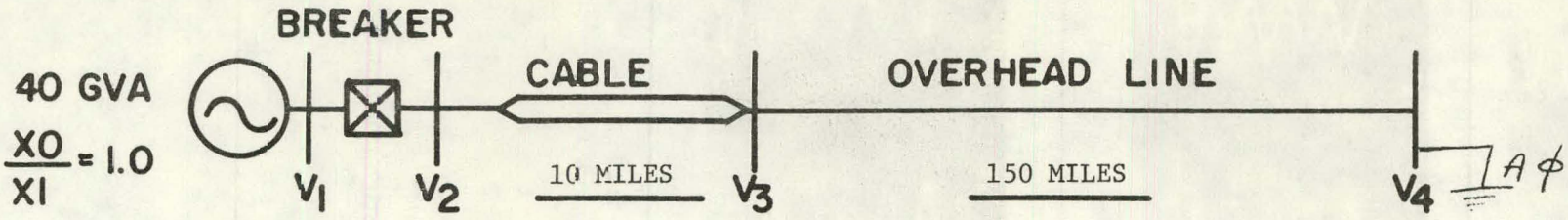
FAULT INITIATED OVERVOLTAGES



BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

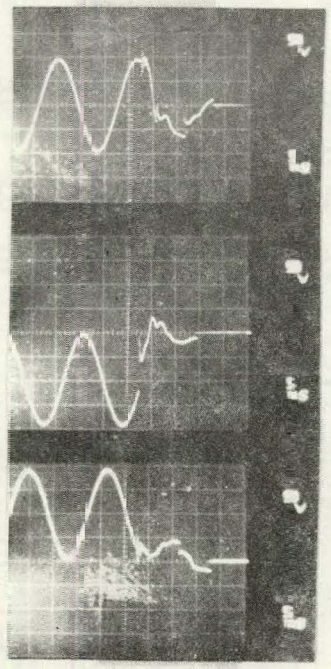
MAX. P.U. OVERVOLTAGE		1.3 p.u.	1.3 p.u.	1.5 p.u.
LOCATION	V_{1-2}	V_2	V_3	V_4
				

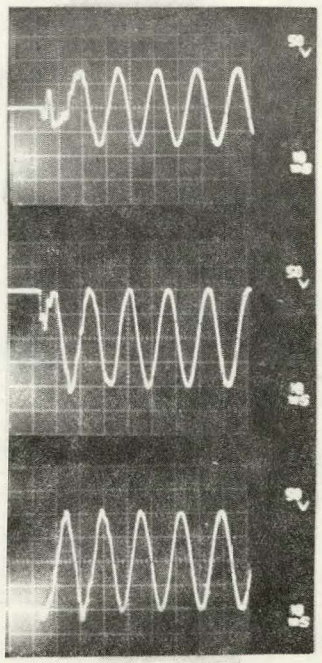
CASE NO. C-18 HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT

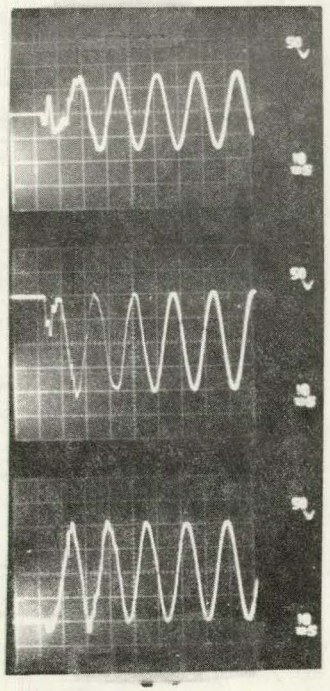


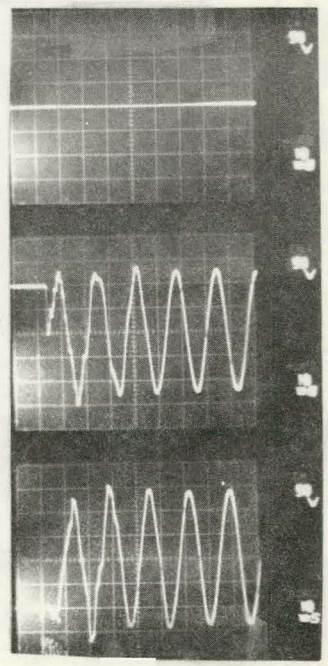
BREAKER RESISTORS	R_1 = 500 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. P.U. OVERVOLTAGE	2.0 p.u.	1.2 p.u.	1.2 p.u.	1.7 p.u.
LOCATION	V_{1-2}	V_2	V_3	V_4

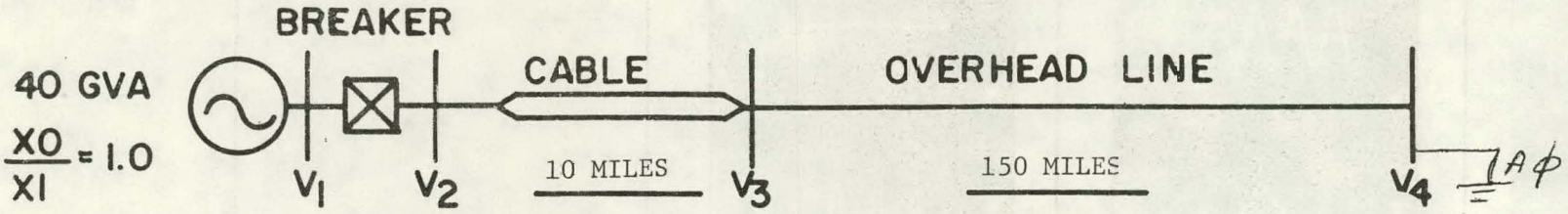






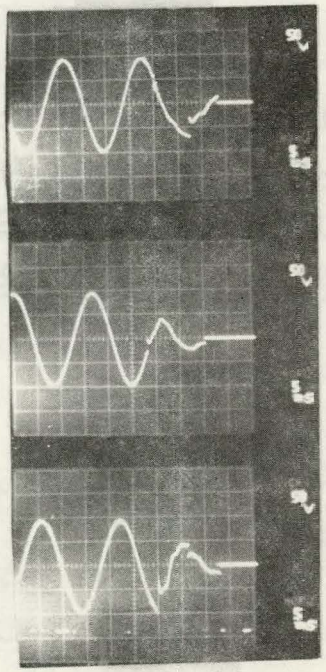


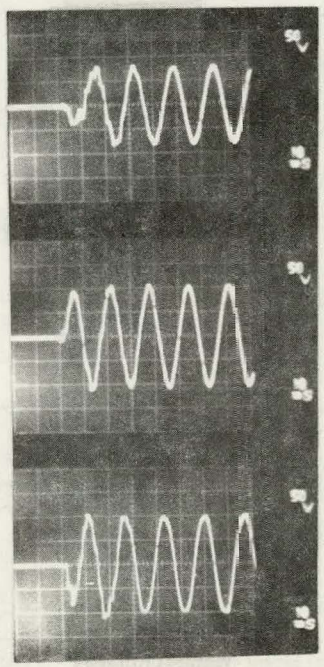
CASE NO. C-19 ENERGIZING INTO SINGLE LINE TO GROUND FAULT

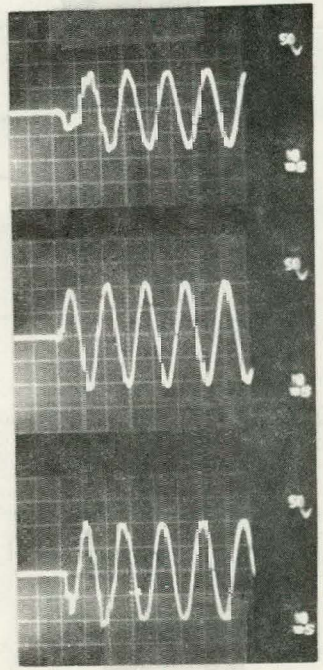


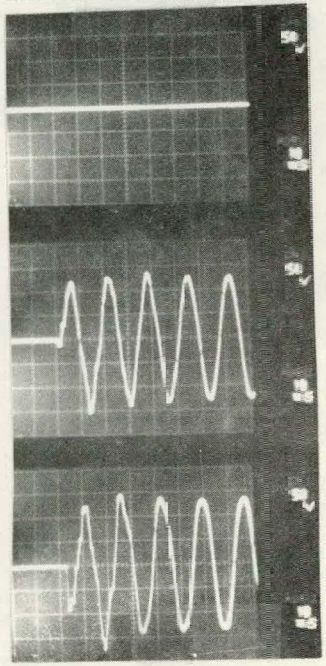
BREAKER RESISTORS	R_1 = 500 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. P.U. OVERVOLTAGE	1.0 p.u.	1.2 p.u.	1.2 p.u.	1.8 p.u.
LOCATION	V_{1-2}	V_2	V_3	V_4

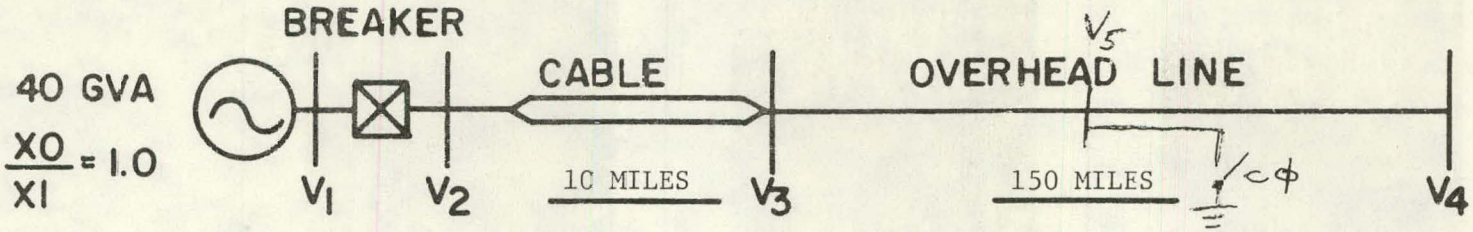




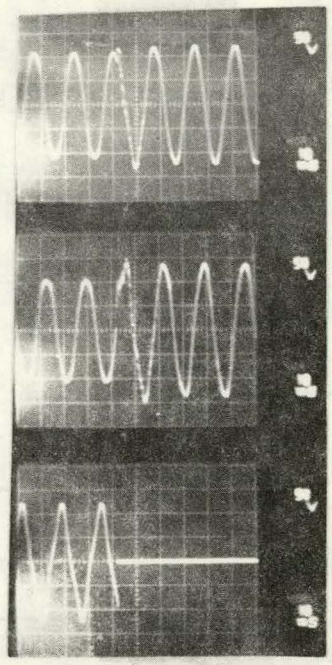
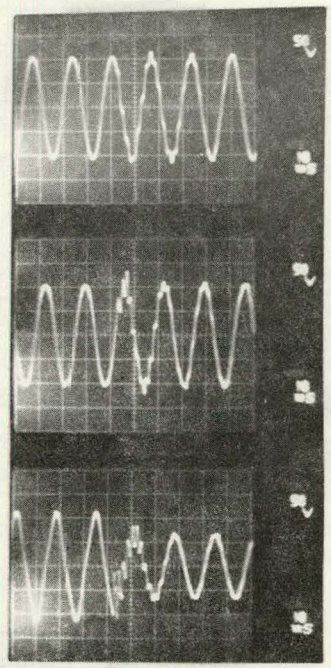
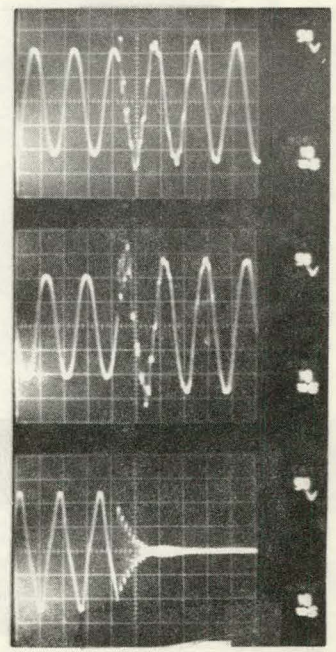




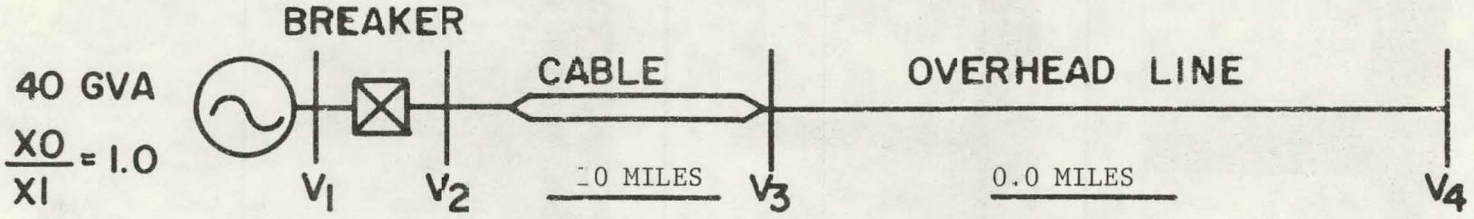
CASE NO. C-20 FAULT INITIATED OVERVOLTAGES



BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

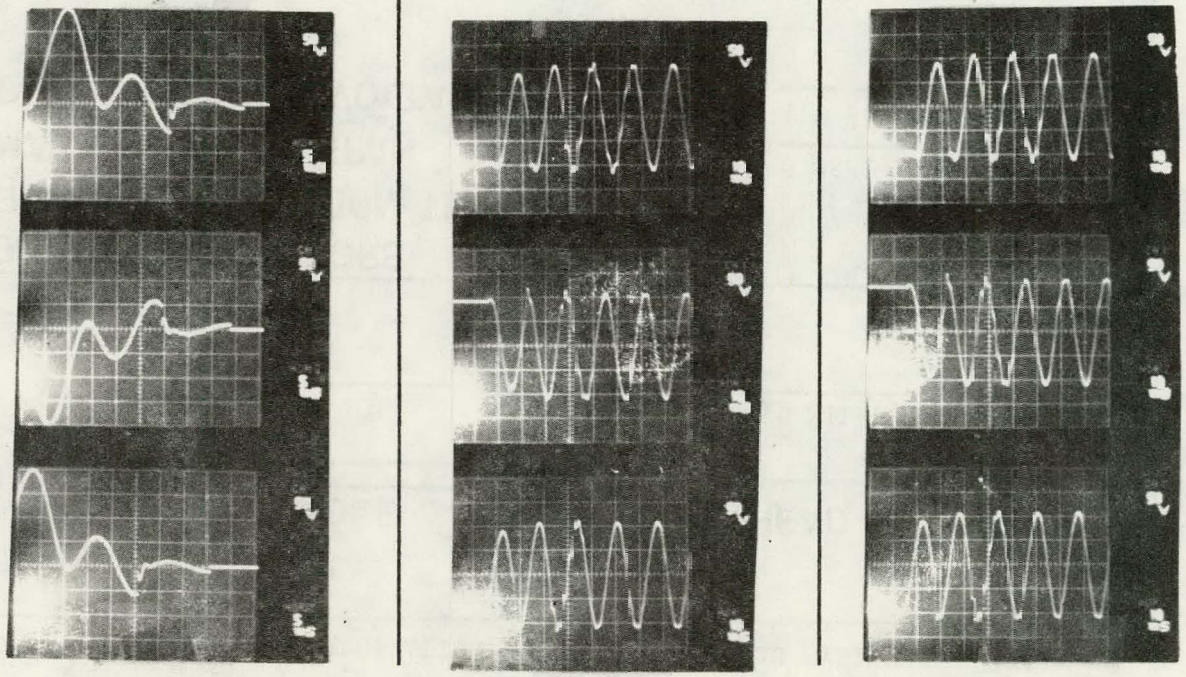
MAX. P.U. OVERVOLTAGE		1.5 p.u.	1.35 p.u.	1.8 p.u.
LOCATION	V_{1-2}	V_5	V_3	V_4
				

CASE NO. C-21 HIGH SPEED RECLOSING

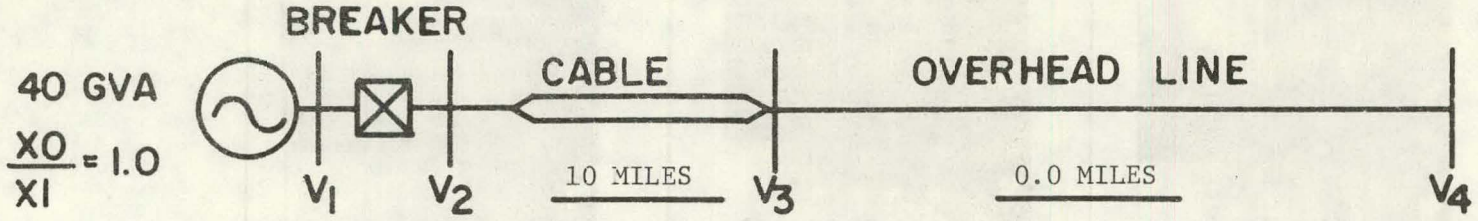


BREAKER RESISTORS	R_1 = 1500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 5 MSEC
MAXIMUM POLE SPAN	1.0 p.u.
PRE-SWITCHED VOLTAGE	

MAX. P.U. OVERVOLTAGE	2.0 p.u.	1.2 p.u.	1.2 p.u.	
LOCATION	V_{1-2}	V_2	V_3	V_4

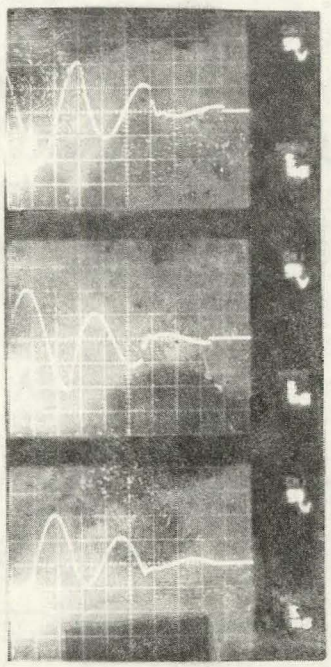


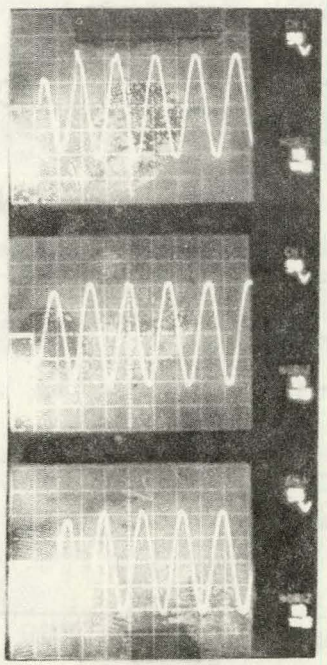
CASE NO. C-22 ENERGIZATION - WITH NO OVERHEAD SYSTEM

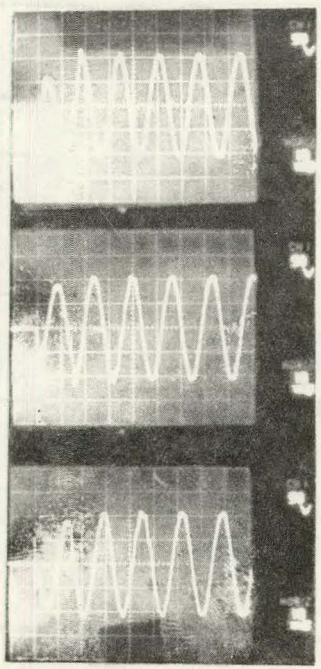


BREAKER RESISTORS	R_1 = 1500 R_2 = 200
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

MAX. P.U. OVERVOLTAGE	1.0 p.u.	1.2 p.u.	1.2 p.u.	
LOCATION	V_{1-2}	V_2	V_3	V_4

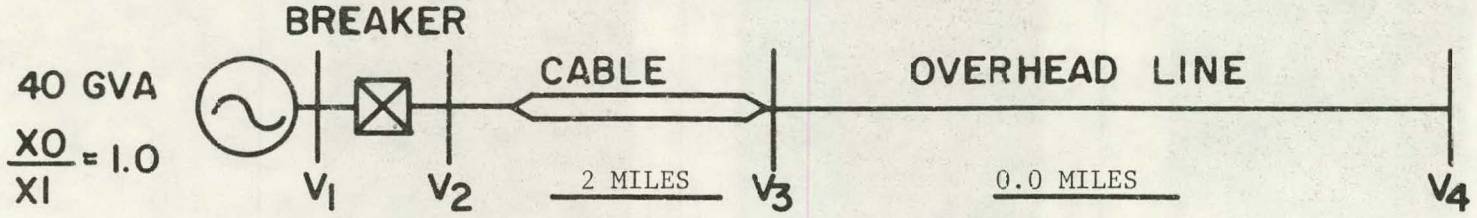






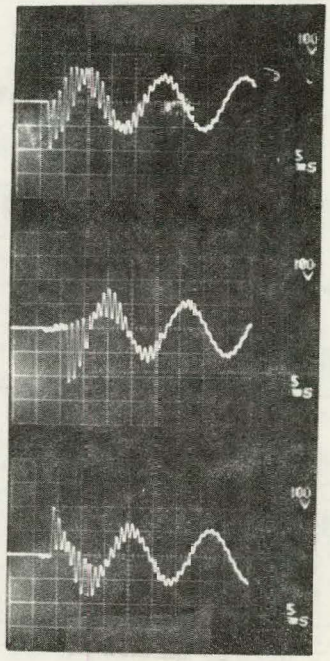
CASE NO. C-23 — ENERGIZATION - NO BREAKER RESISTORS

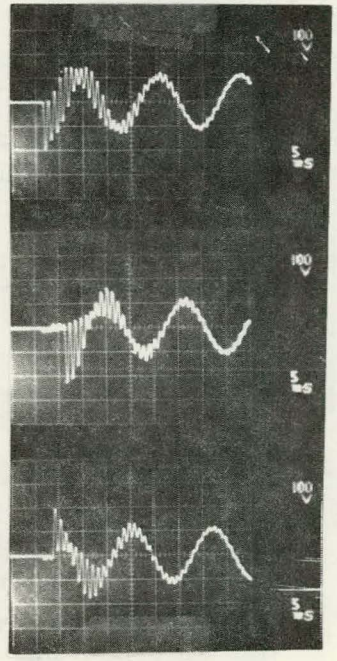
NO OVERHEAD LINE



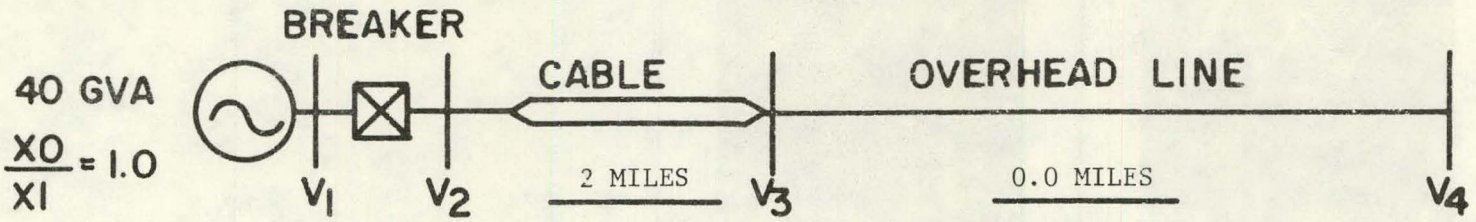
BREAKER RESISTORS	R_1 = 0.0 — R_2 = 0.0 —
RESISTOR INSERTION TIMES	5 MSEC
MAXIMUM POLE SPAN	1.0 p.u.
PRE-SWITCHED VOLTAGE	

MAX. P.U. OVERVOLTAGE		2.2 p.u.	2.2 p.u.	
LOCATION	V_{1-2}	V_2	V_3	V_4



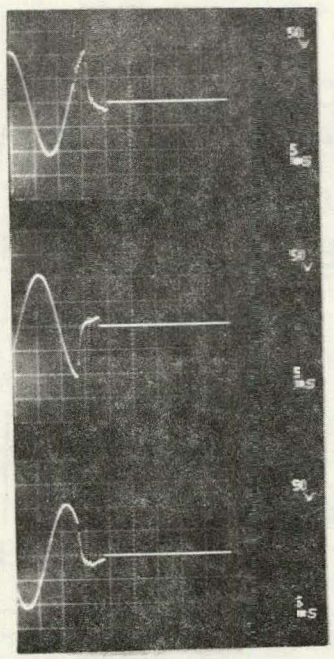


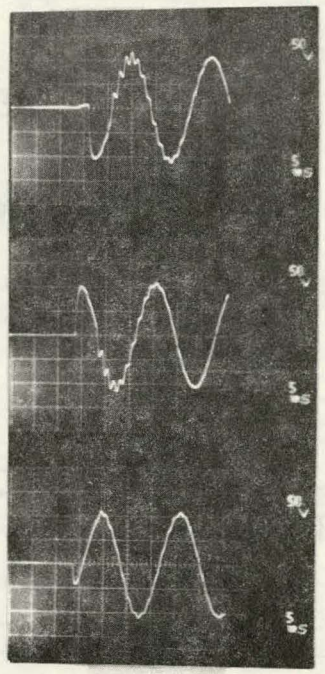
CASE NO. C-24 ENERGIZATION - ONE STEP RESISTOR - NO OVERHEAD

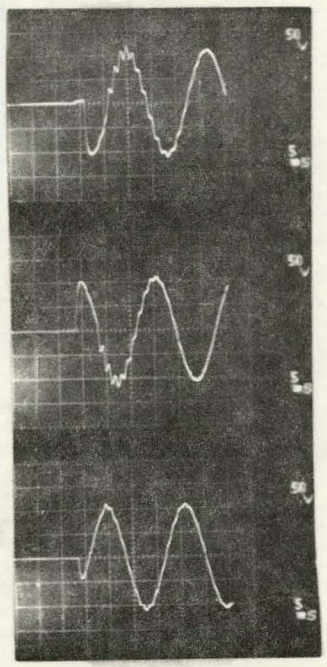


BREAKER RESISTORS	R_1 = 1000Ω, R_2 = 0.0
RESISTOR INSERTION TIMES	6 MSEC, -
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

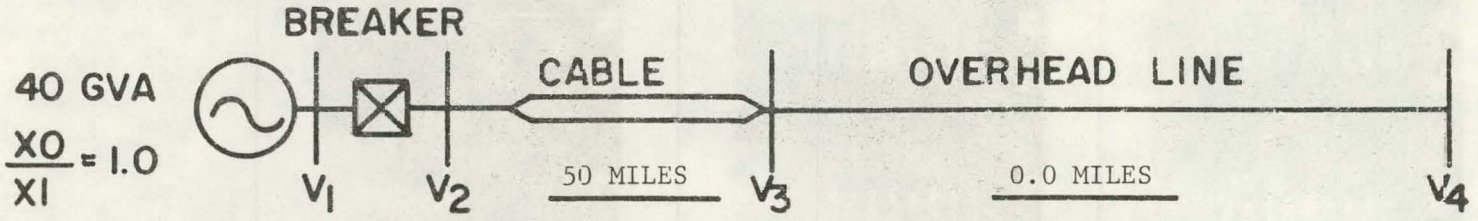
MAX. P.U. OVERVOLTAGE	1.0 p.u.	1.2 p.u.	1.2 p.u.	
LOCATION	V_{1-2}	V_2	V_3	V_4





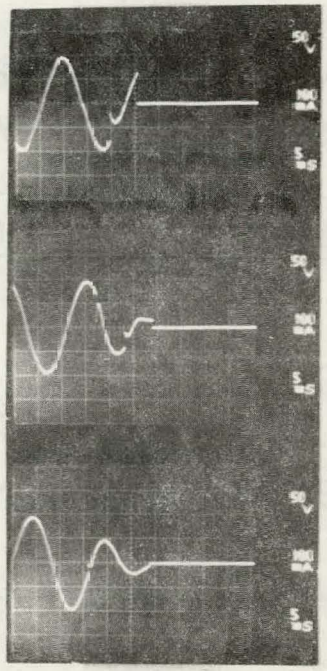


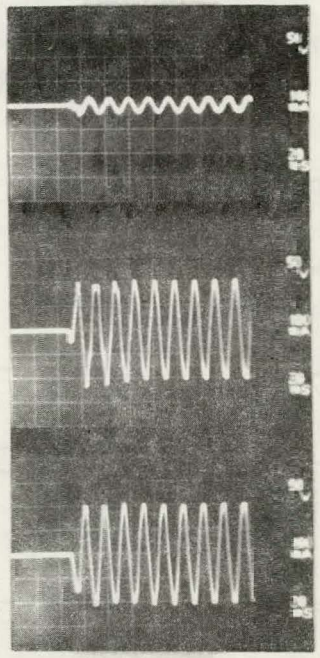
CASE NO. C-25 ENERGIZATION INTO SINGLE LINE TO GROUND FAULT

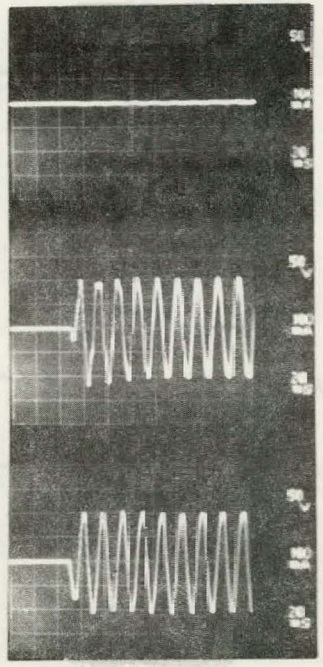


BREAKER RESISTORS	R_1 = 1500 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

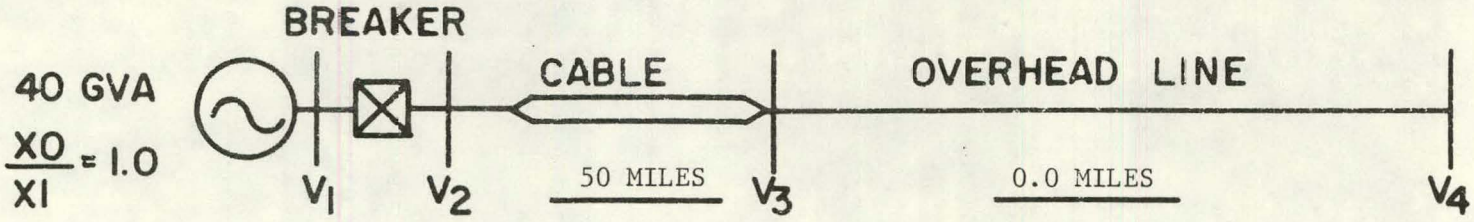
MAX. P.U. OVERVOLTAGE	1.0 p.u.	1.2 p.u.	1.2 p.u.	
LOCATION	V_{1-2}	V_2	V_3	V_4





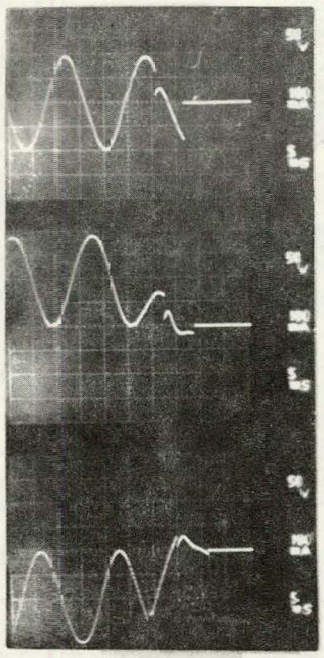


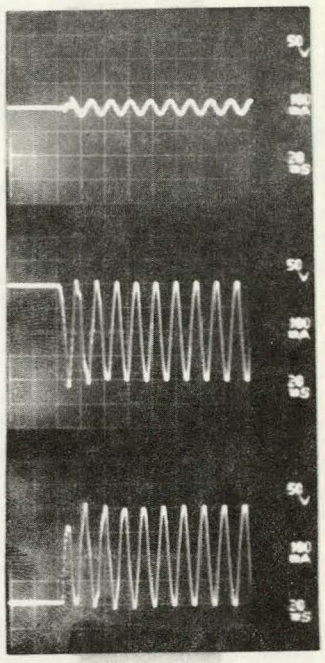
CASE NO. C-26 HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT

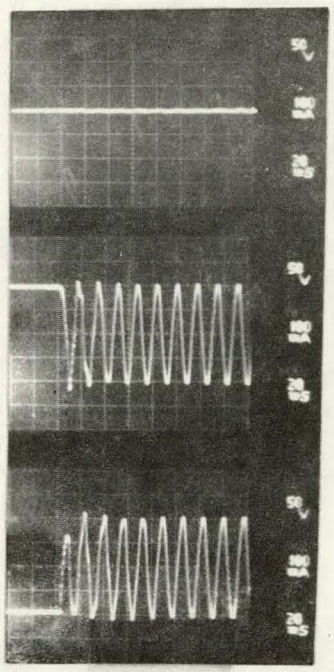


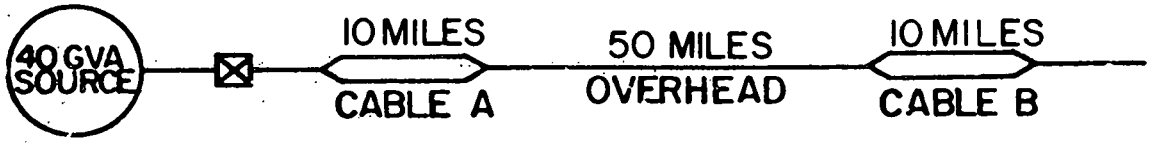
BREAKER RESISTORS	R_1 = 1500 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

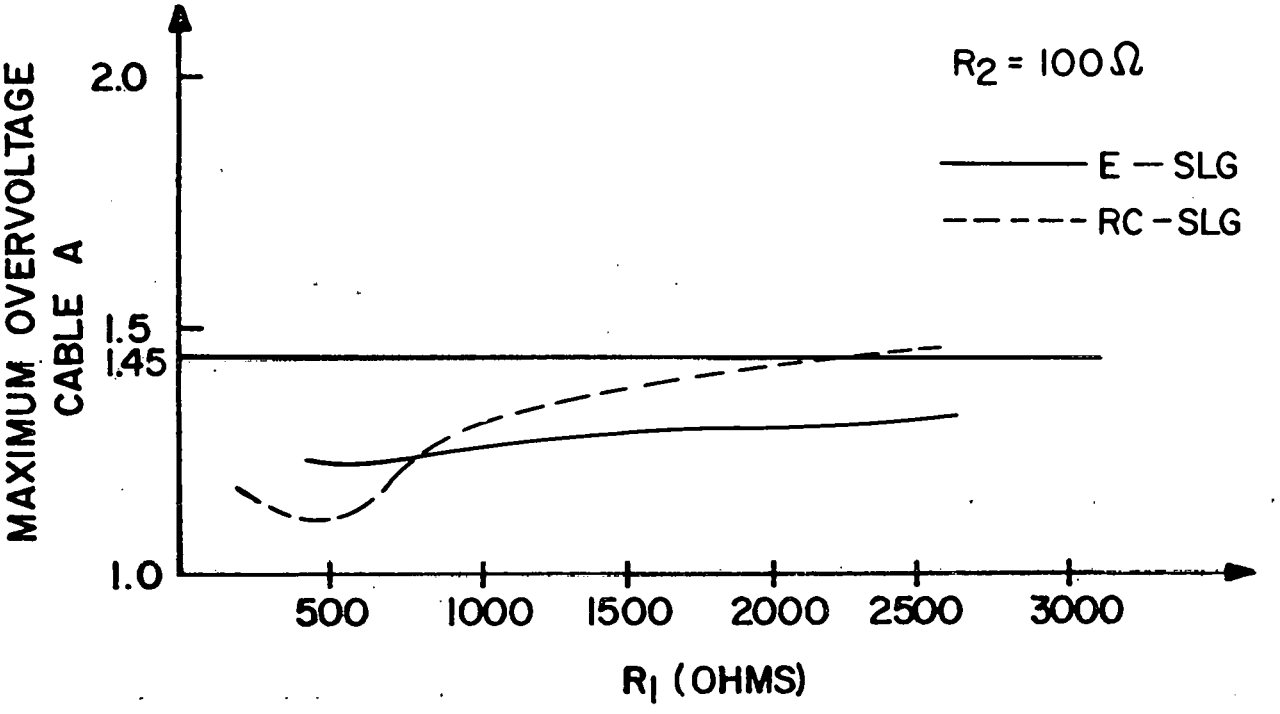
MAX. P.U. OVERVOLTAGE	2.0 p.u.	1.2 p.u.	1.2 p.u.	
LOCATION	V_{1-2}	V_2	V_3	V_4

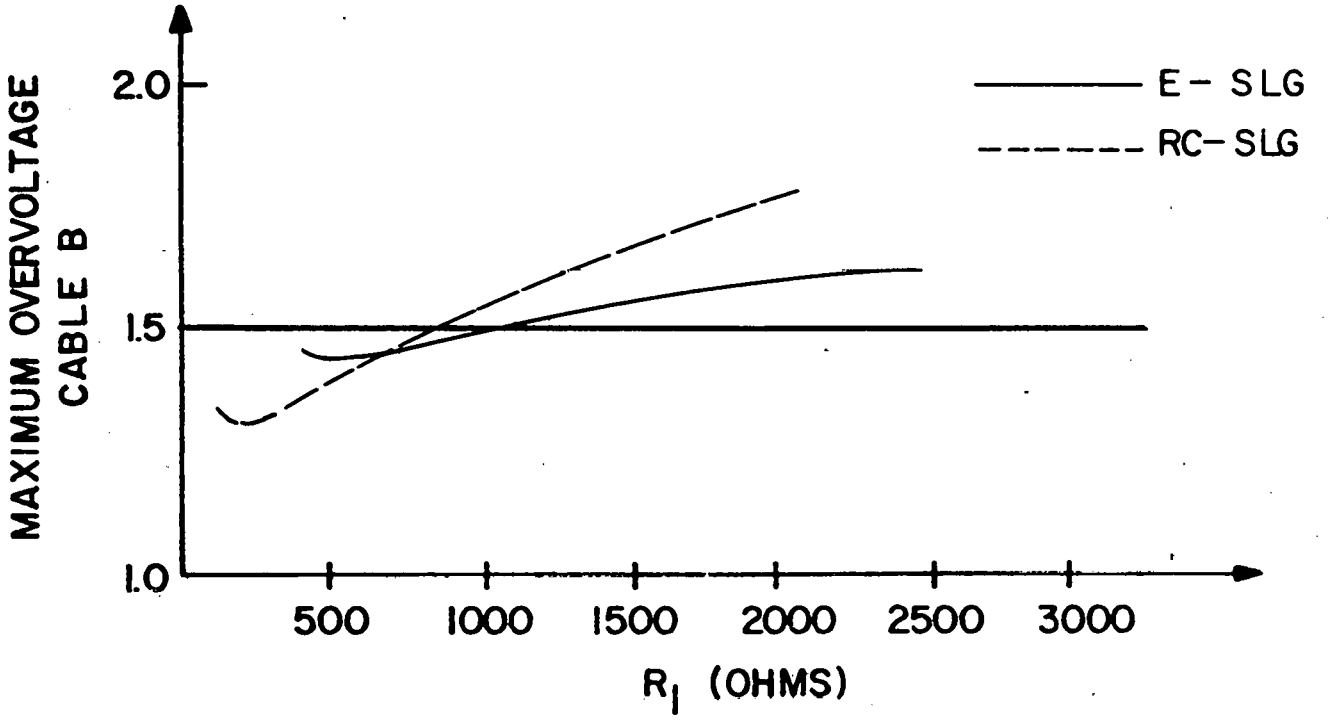


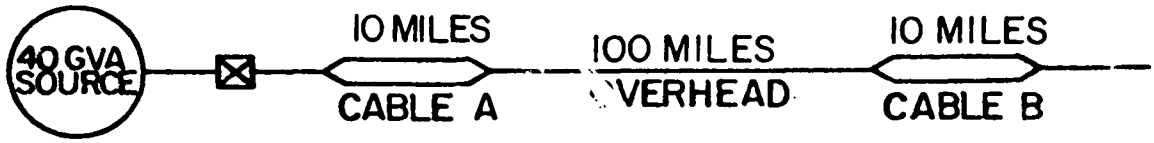


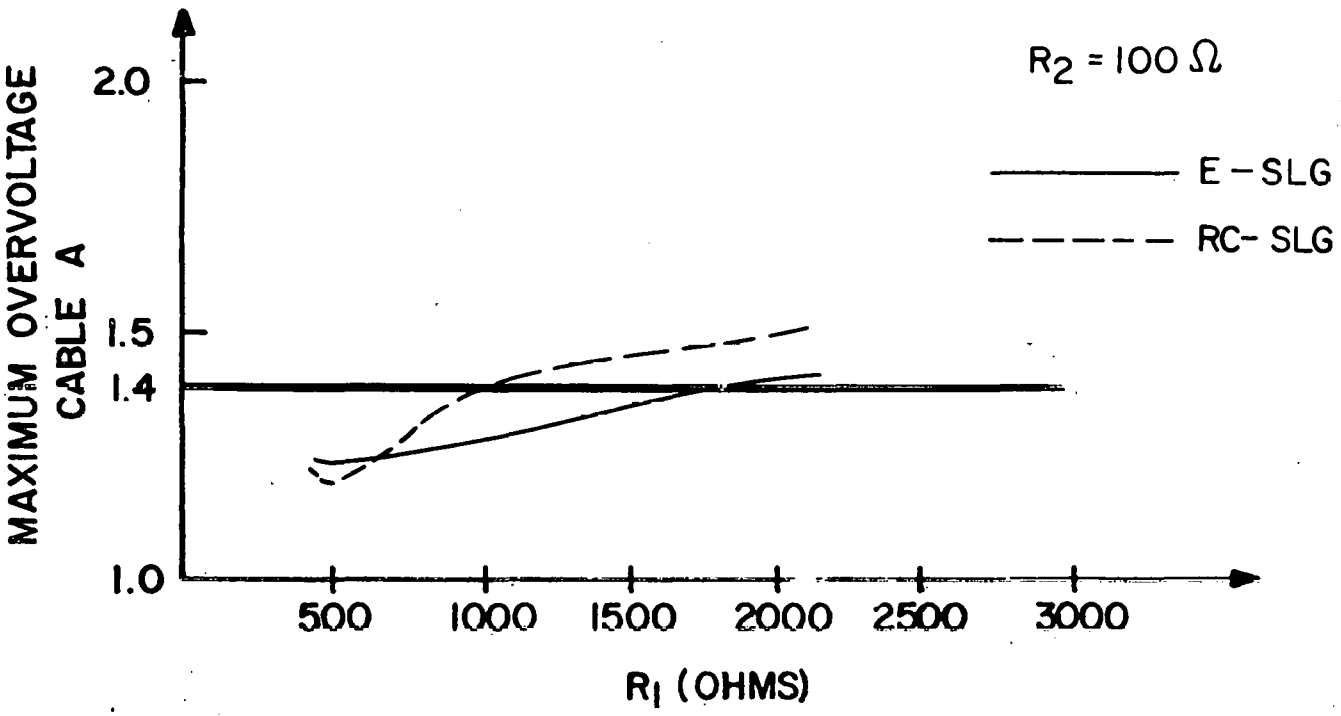


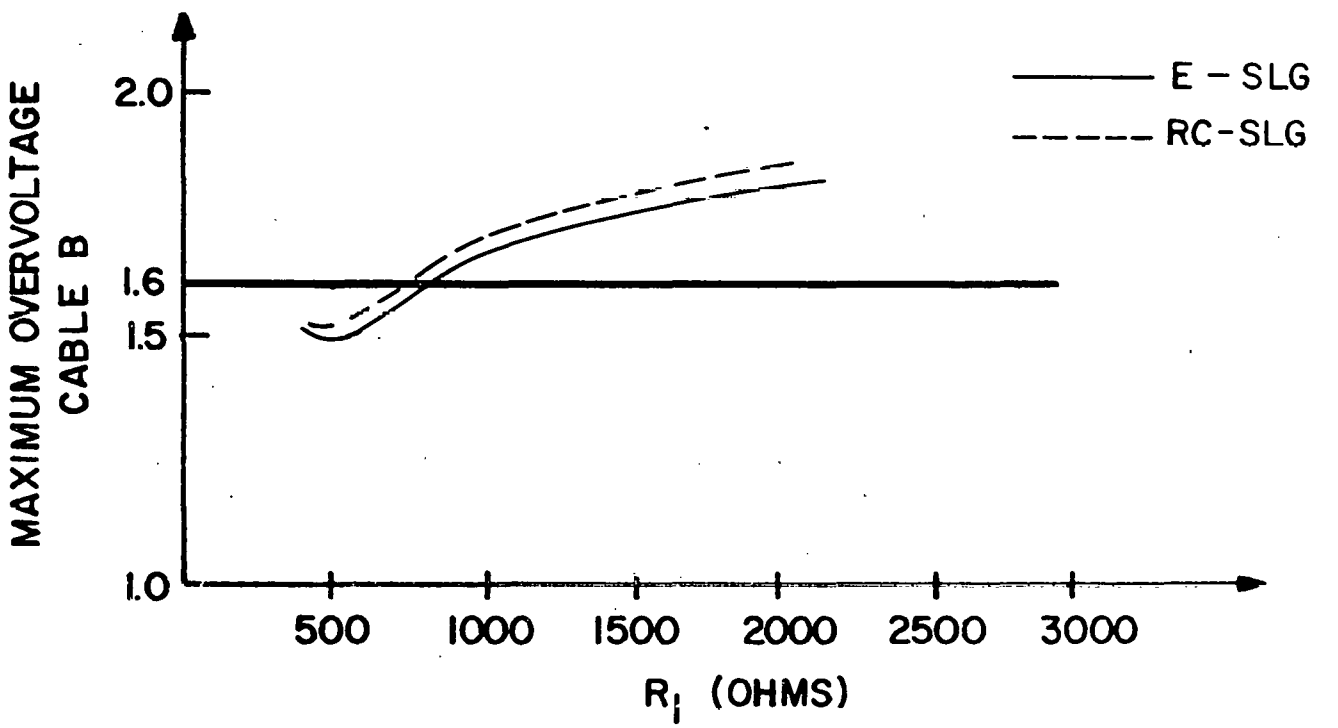

40 GVA SOURCE
10 MILES
CABLE A
50 MILES
OVERHEAD
10 MILES
CABLE B

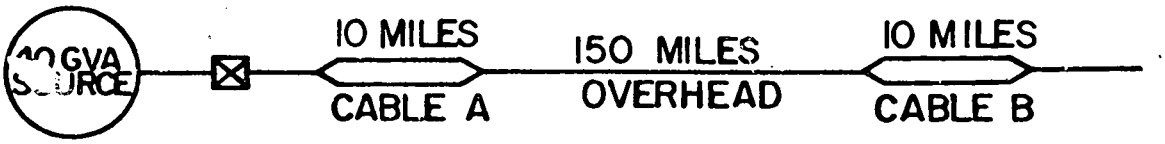

MAXIMUM OVERVOLTAGE
CABLE A
2.0
1.5
1.45
1.0
$R_2 = 100\,\Omega$
E – SLG
RC – SLG
500
1000
1500
2000
2500
3000
R_1 (OHMS)

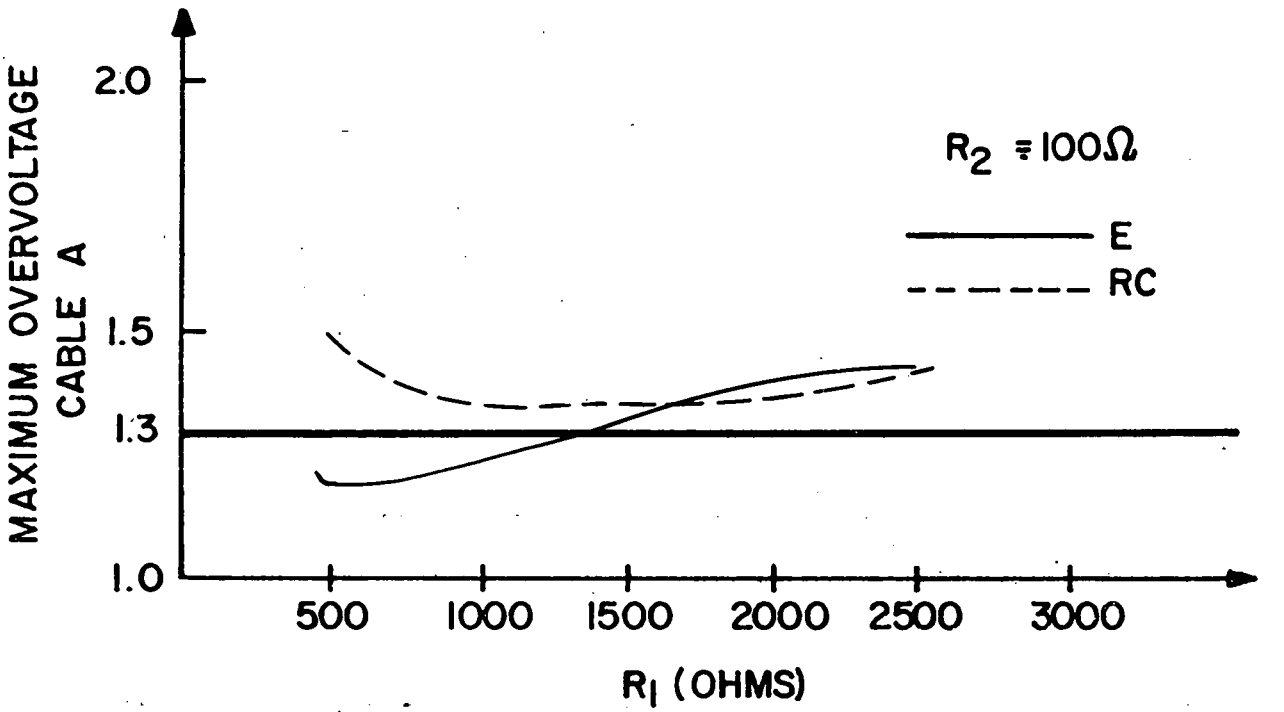

MAXIMUM OVERVOLTAGE
CABLE B
2.0
1.5
1.0
E – SLG
RC – SLG
500
1000
1500
2000
2500
3000
R_1 (OHMS)

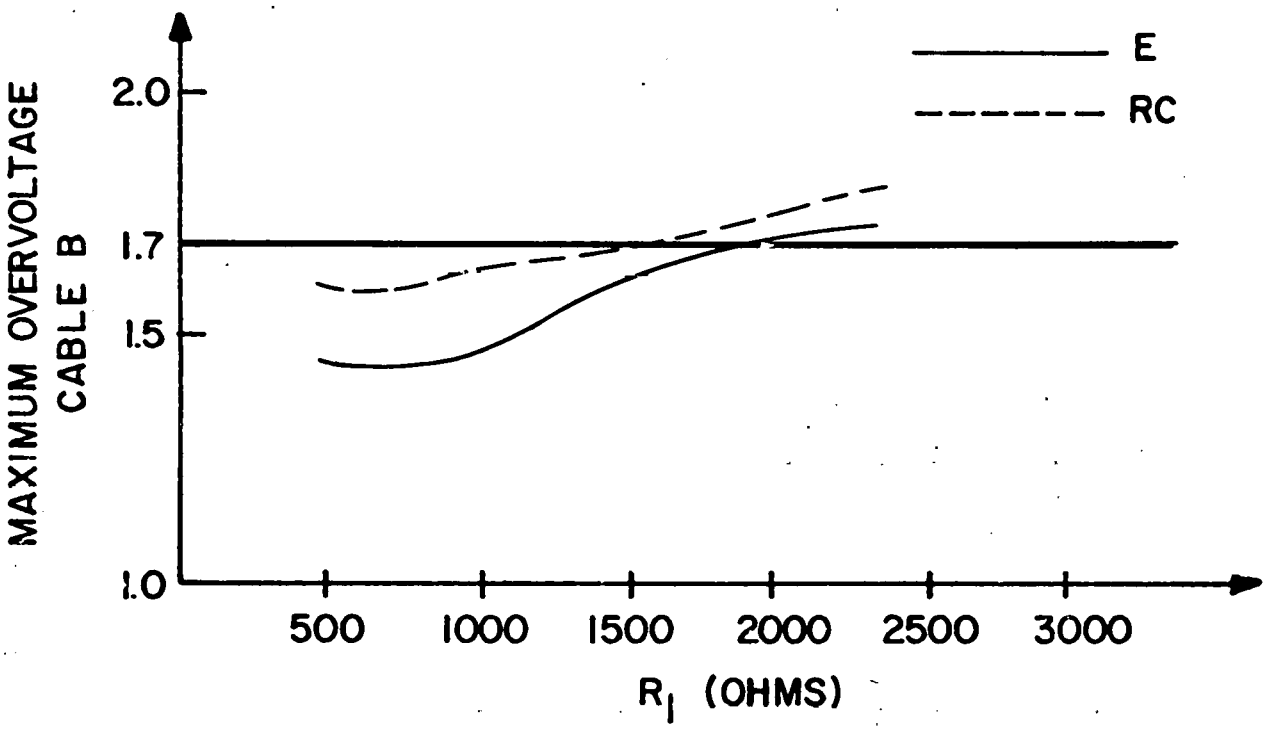

40 GVA SOURCE
10 MILES
CABLE A
100 MILES
OVERHEAD
10 MILES
CABLE B

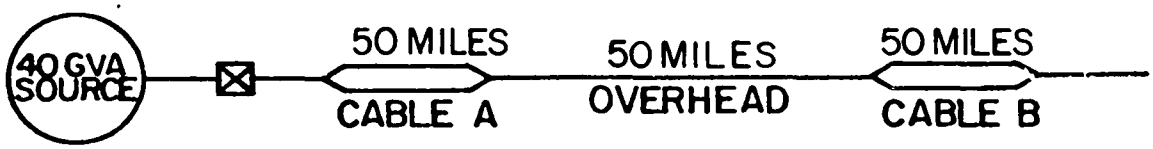

MAXIMUM OVERVOLTAGE CABLE A
2.0
1.5
1.4
1.0
500
1000
1500
2000
2500
3000
R1 (OHMS)
R2 = 100 Ω
E - SLG
RC - SLG

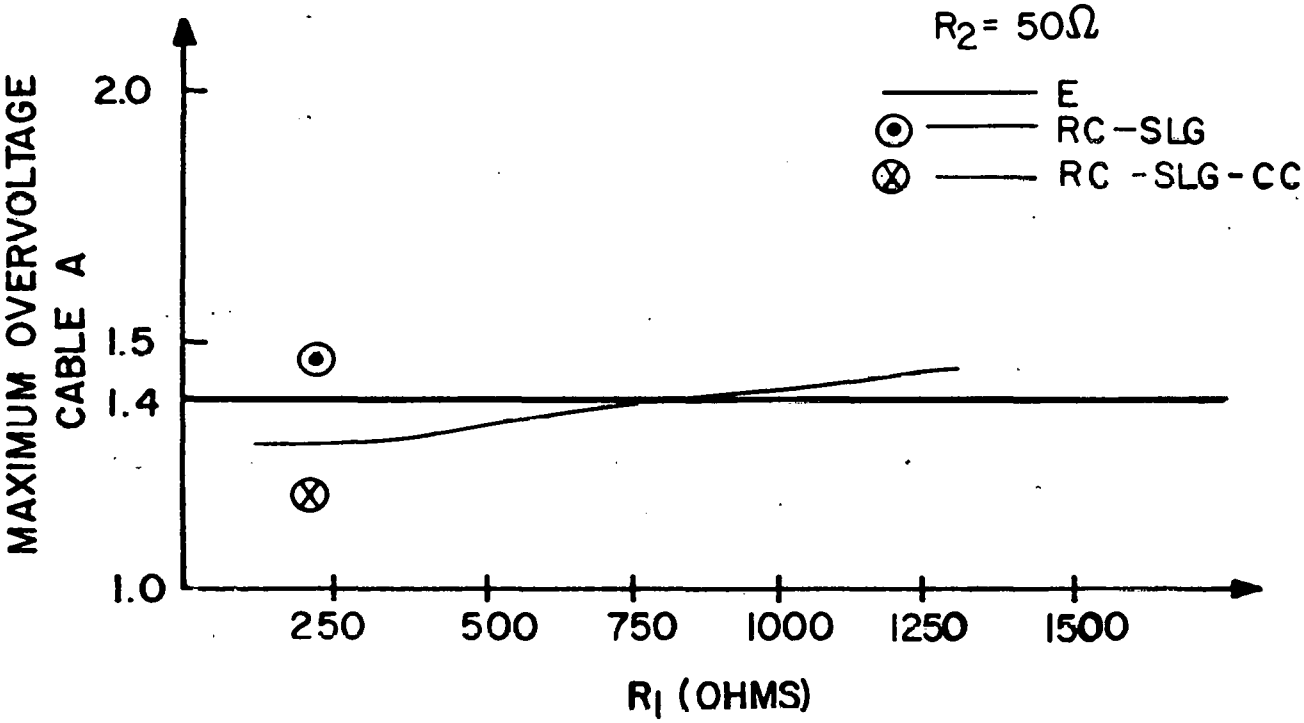

MAXIMUM OVERVOLTAGE CABLE B
2.0
1.6
1.5
1.0
500
1000
1500
2000
2500
3000
R1 (OHMS)
E - SLG
RC - SLG

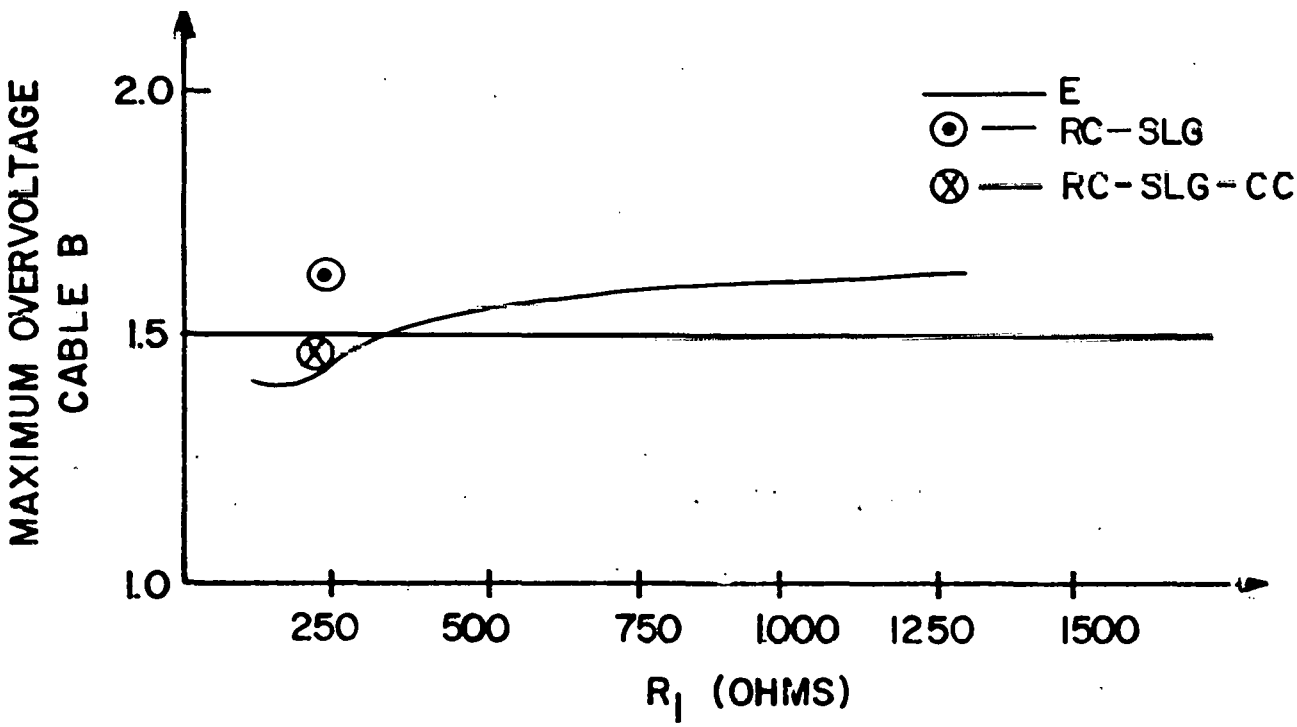

GVA
SOURCE
10 MILES
CABLE A
150 MILES
OVERHEAD
10 MILES
CABLE B

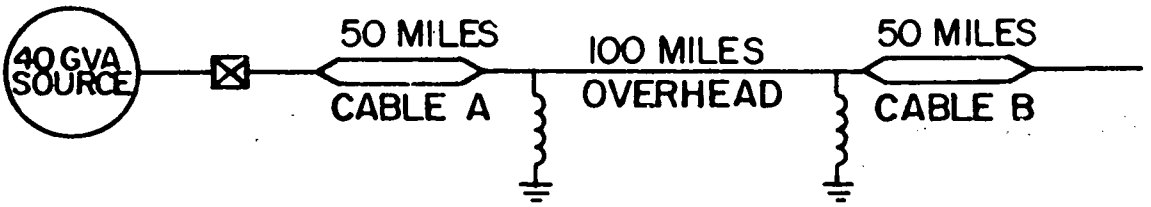

MAXIMUM OVERVOLTAGE
CABLE A
2.0
1.5
1.3
1.0
$R_2 = 100\Omega$
E
RC
500
1000
1500
2000
2500
3000
R_1 (OHMS)

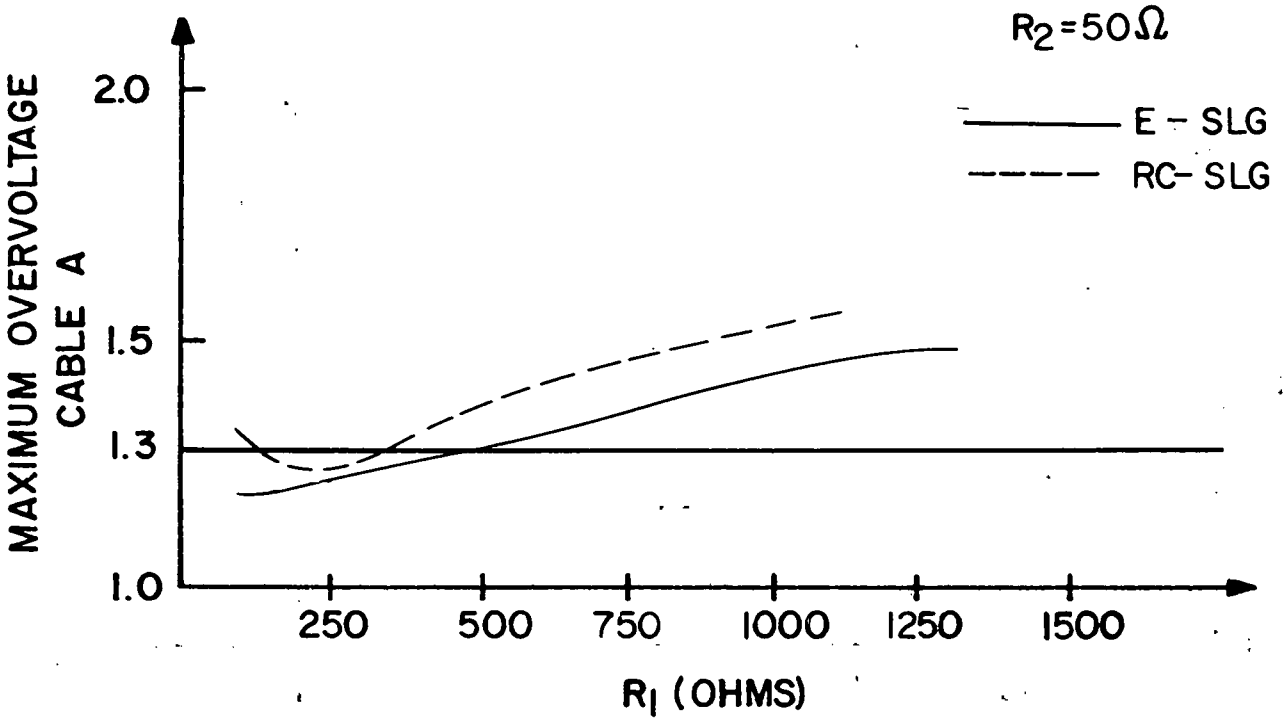

MAXIMUM OVERVOLTAGE
CABLE B
2.0
1.7
1.5
1.0
E
RC
500
1000
1500
2000
2500
3000
R_1 (OHMS)

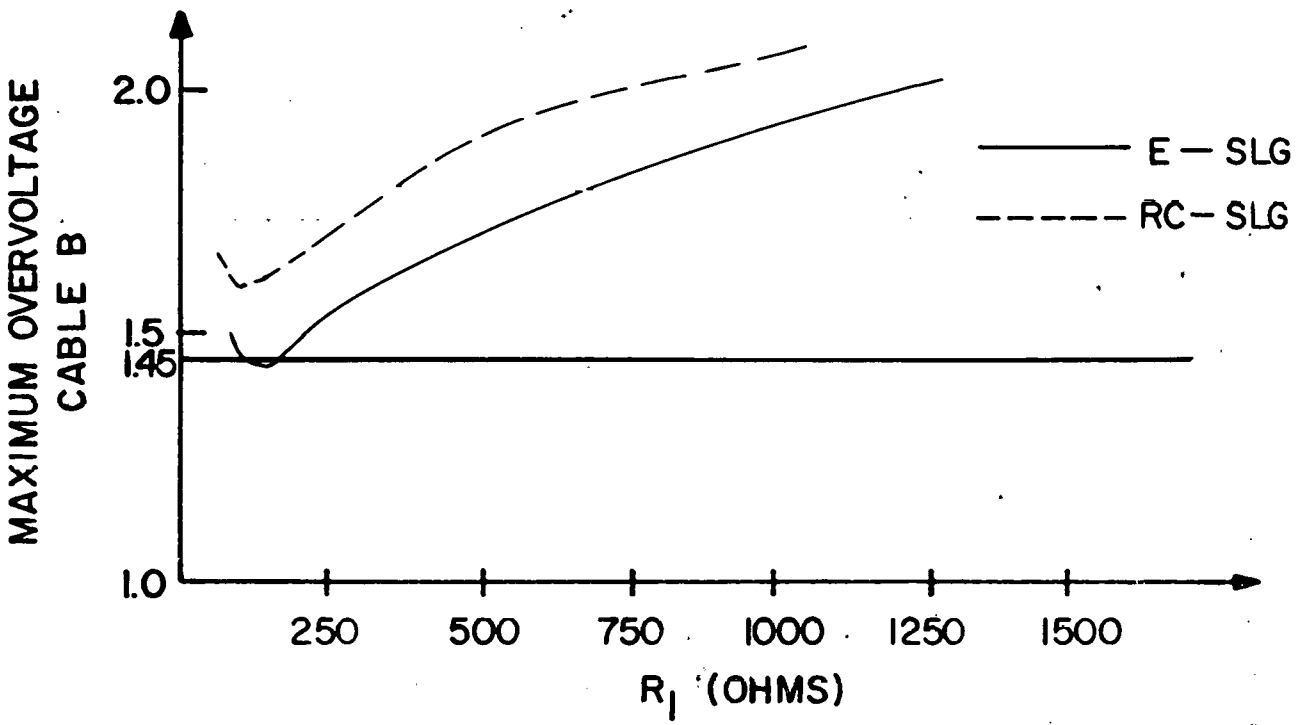

40 GVA SOURCE
50 MILES
CABLE A
50 MILES
OVERHEAD
50 MILES
CABLE B

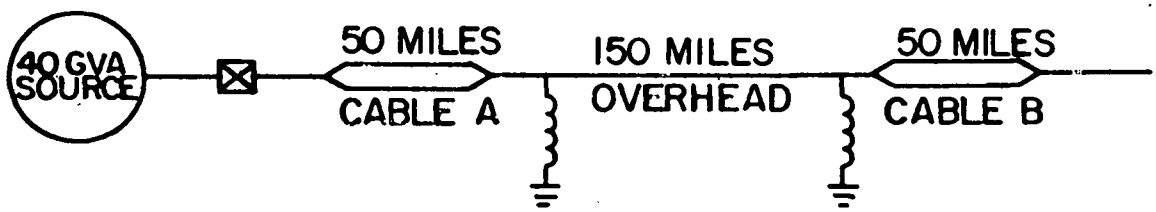

$R_2 = 50\Omega$
E
RC-SLG
RC-SLG-CC
MAXIMUM OVERVOLTAGE CABLE A
2.0
1.5
1.4
1.0
250
500
750
1000
1250
1500
R_1 (OHMS)

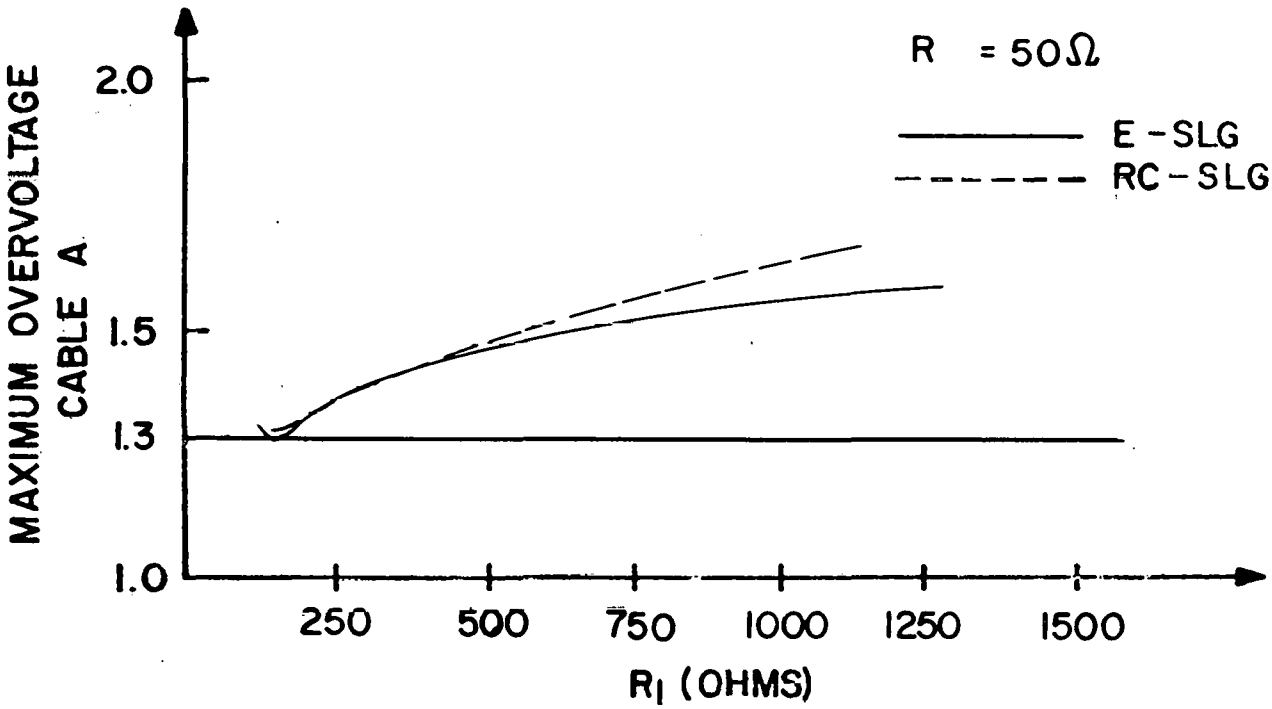

E
RC-SLG
RC-SLG-CC
MAXIMUM OVERVOLTAGE CABLE B
2.0
1.5
1.0
250
500
750
1000
1250
1500
R_1 (OHMS)

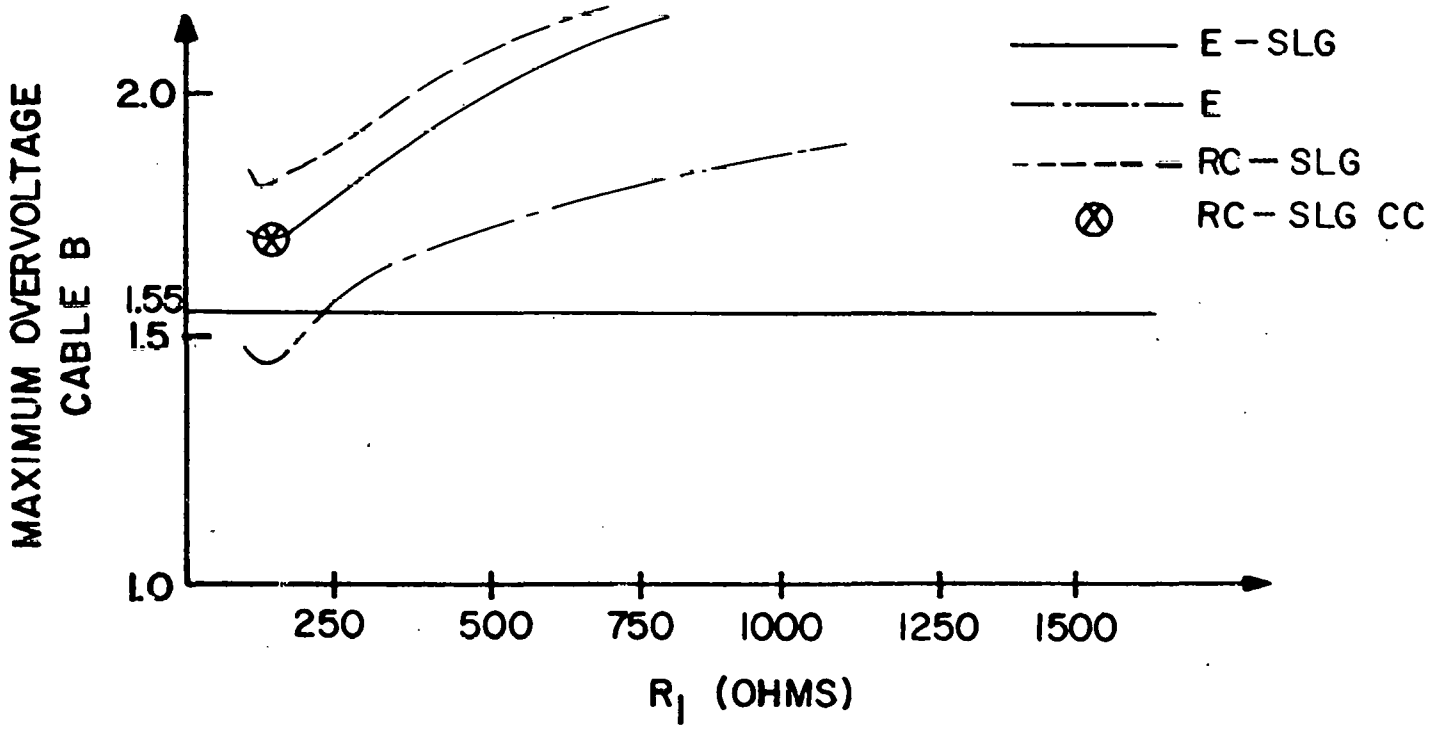

40 GVA SOURCE
50 MILES
CABLE A
100 MILES
OVERHEAD
50 MILES
CABLE B

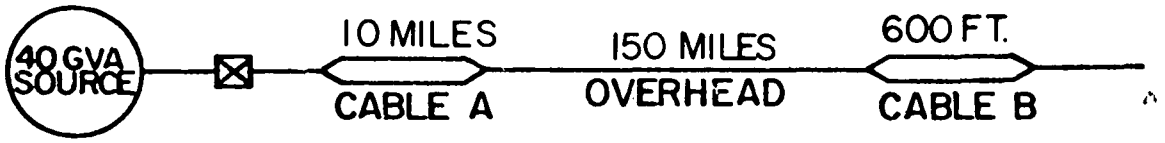

$R_2 = 50\Omega$
E - SLG
RC- SLG
MAXIMUM OVERVOLTAGE CABLE A
2.0
1.5
1.3
1.0
250
500
750
1000
1250
1500
R_1 (OHMS)

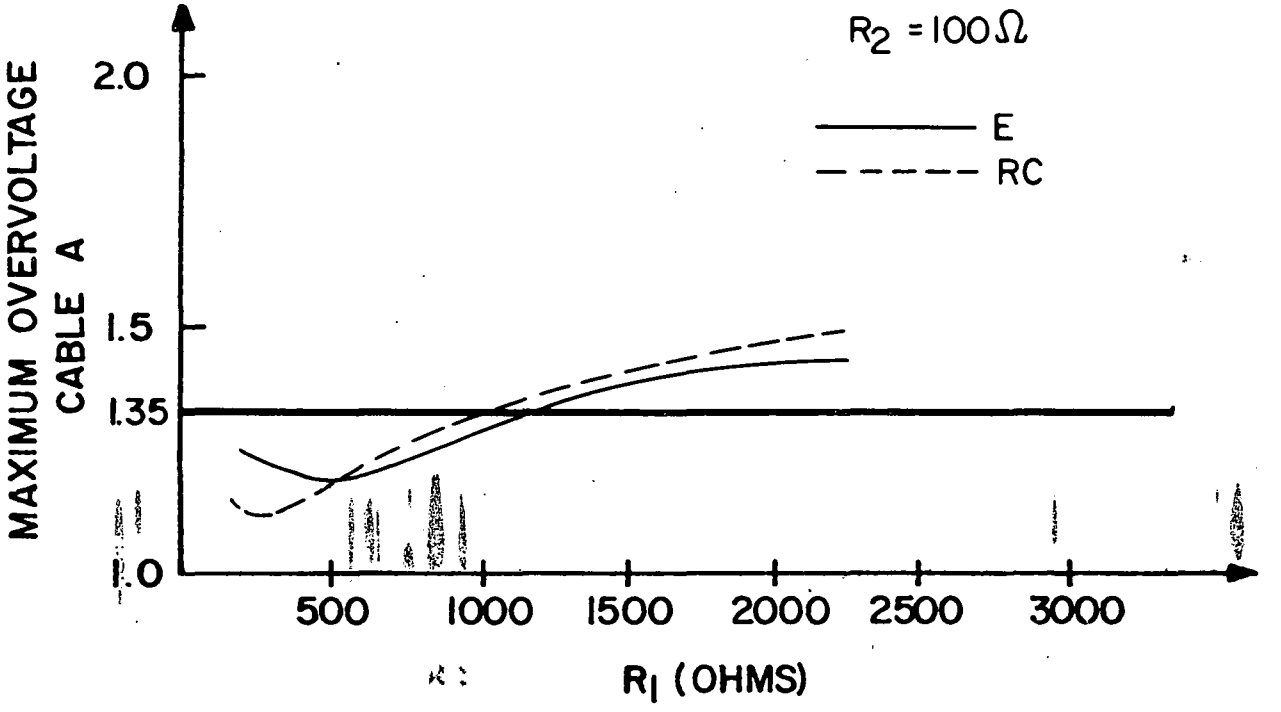

E — SLG
RC— SLG
MAXIMUM OVERVOLTAGE CABLE B
2.0
1.5
1.45
1.0
250
500
750
1000
1250
1500
R_1 (OHMS)

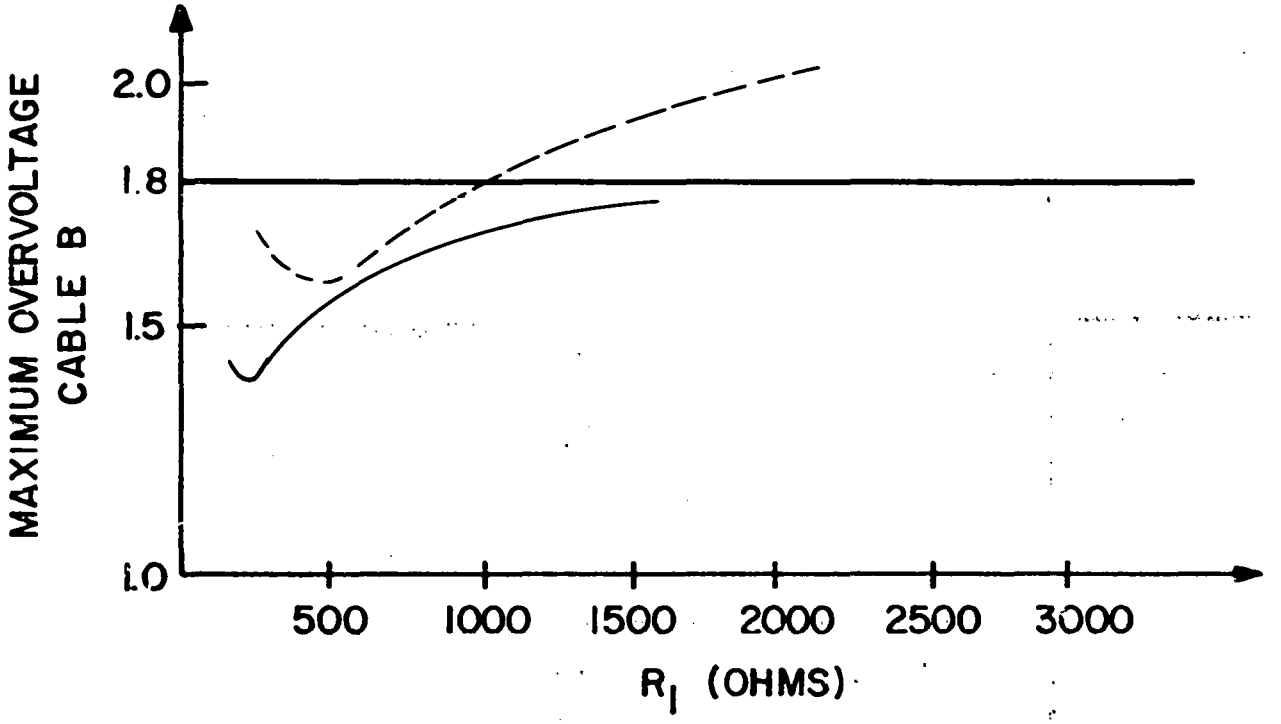

40 GVA SOURCE
50 MILES
CABLE A
150 MILES
OVERHEAD
50 MILES
CABLE B

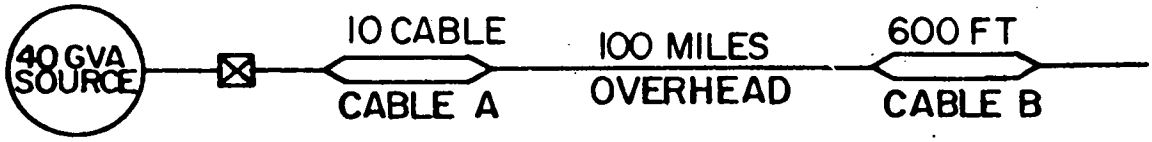

R = 50Ω
E-SLG
RC-SLG
MAXIMUM OVERVOLTAGE
CABLE A
2.0
1.5
1.3
1.0
250
500
750
1000
1250
1500
R1 (OHMS)

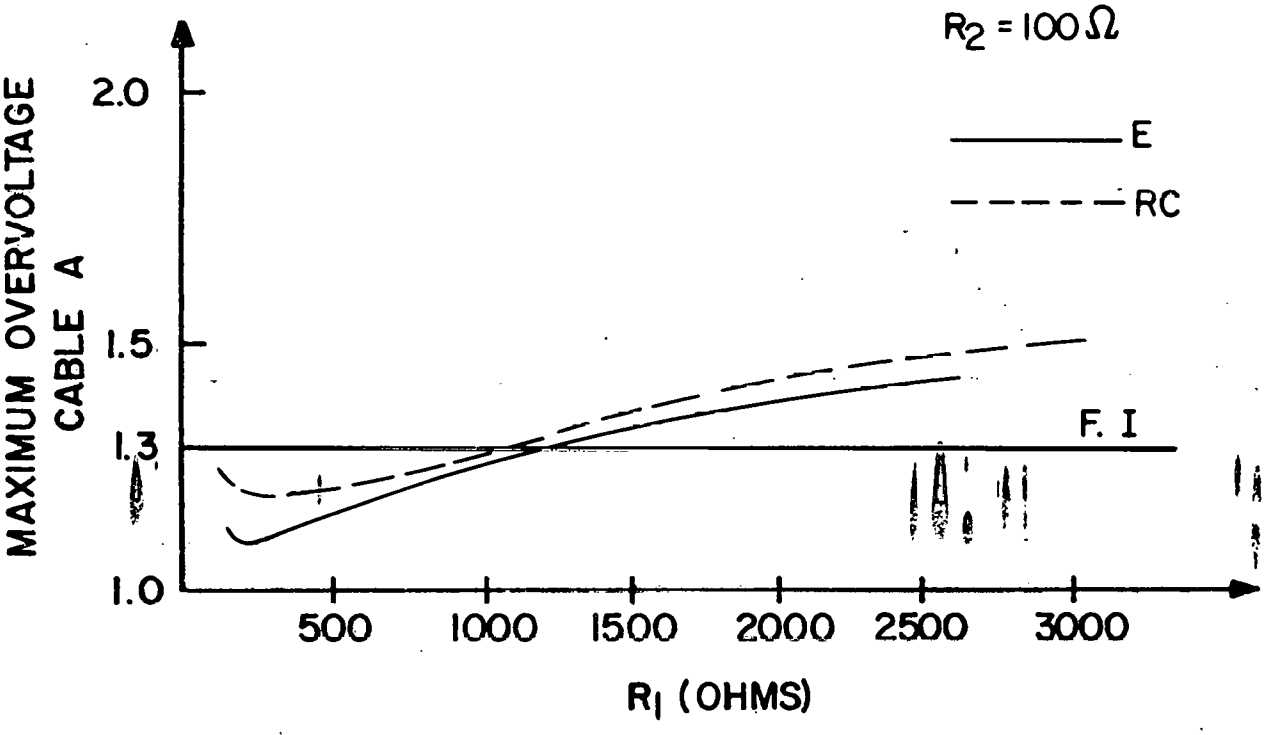

E-SLG
E
RC-SLG
RC-SLG CC
MAXIMUM OVERVOLTAGE
CABLE B
2.0
1.55
1.5
1.0
250
500
750
1000
1250
1500
R1 (OHMS)

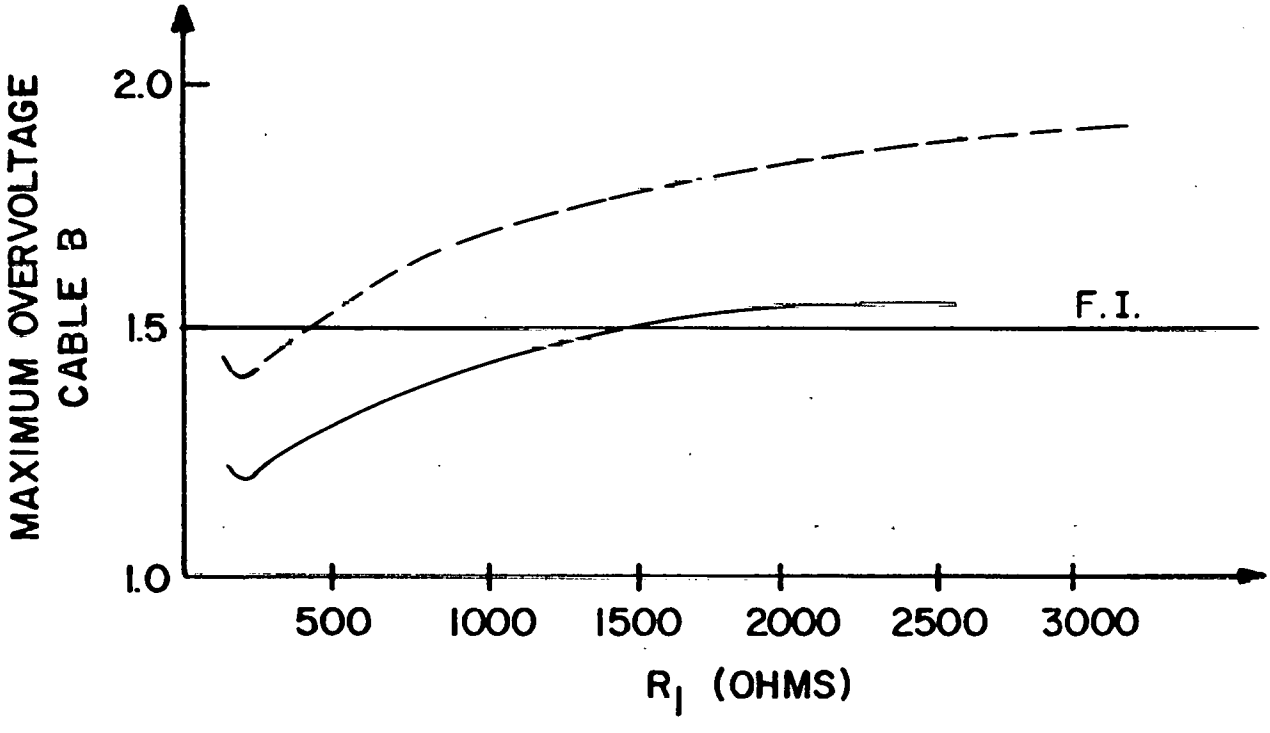

40 GVA SOURCE
10 MILES
CABLE A
150 MILES
OVERHEAD
600 FT.
CABLE B

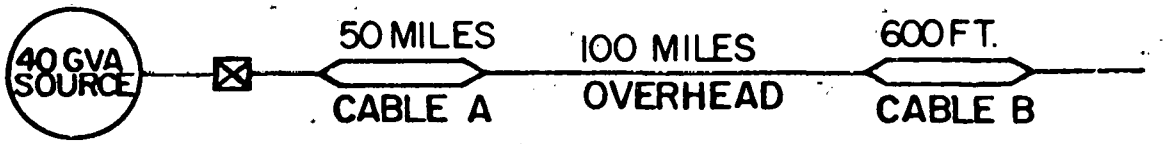

$R_2 = 100\Omega$
E
RC
MAXIMUM OVERVOLTAGE
CABLE A
2.0
1.5
1.35
1.0
500
1000
1500
2000
2500
3000
R_1 (OHMS)

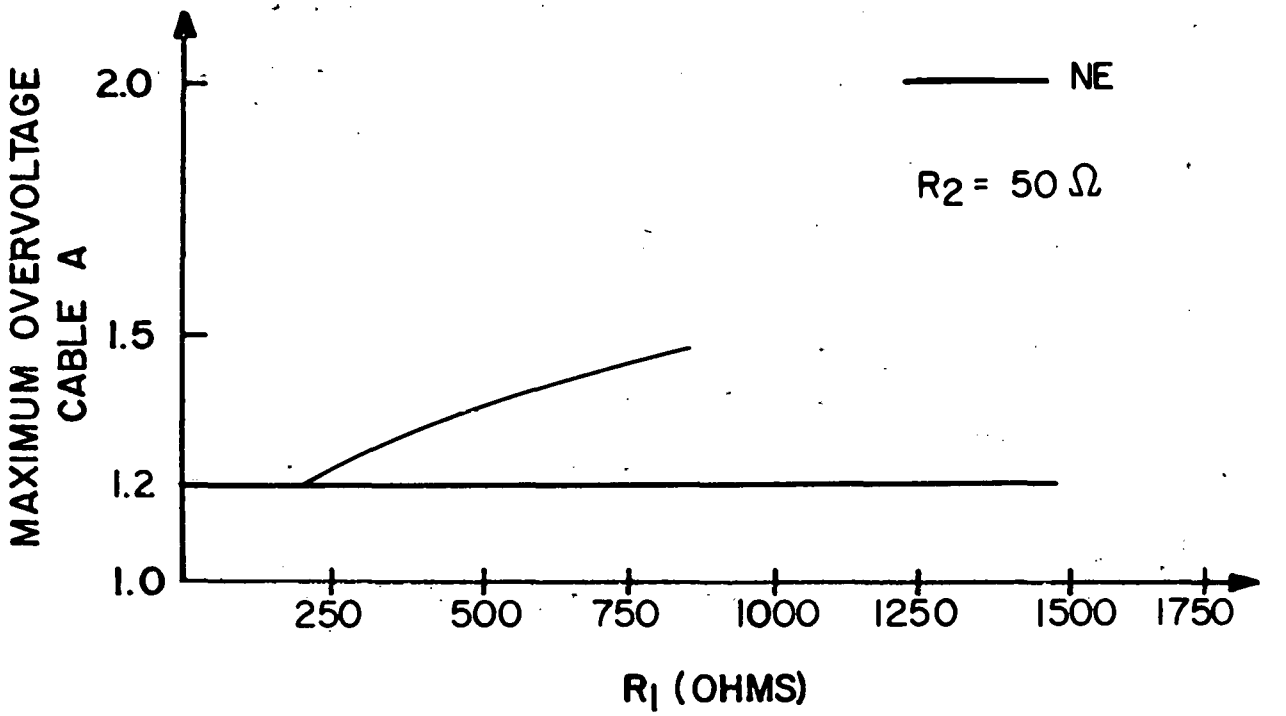

MAXIMUM OVERVOLTAGE
CABLE B
2.0
1.8
1.5
1.0
500
1000
1500
2000
2500
3000
R_1 (OHMS)

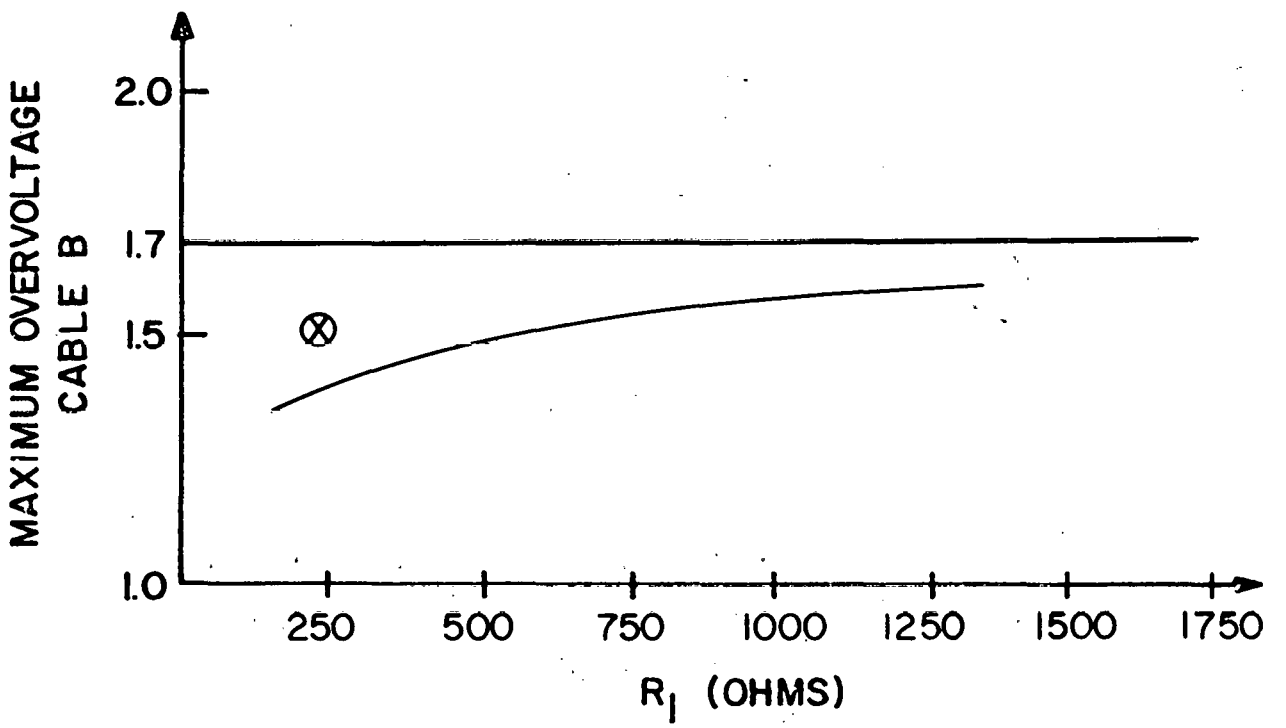

40 GVA SOURCE
10 CABLE
CABLE A
100 MILES
OVERHEAD
600 FT
CABLE B

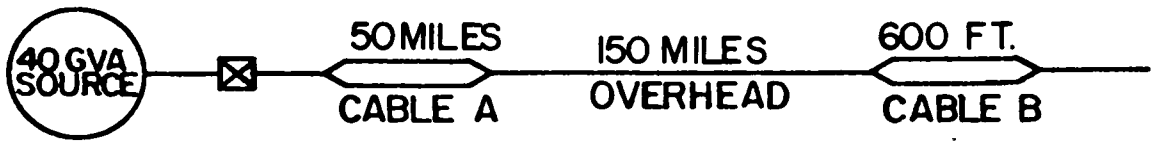

$R_2 = 100\,\Omega$
E
RC
F. I
MAXIMUM OVERVOLTAGE CABLE A
2.0
1.5
1.3
1.0
500
1000
1500
2000
2500
3000
R_1 (OHMS)

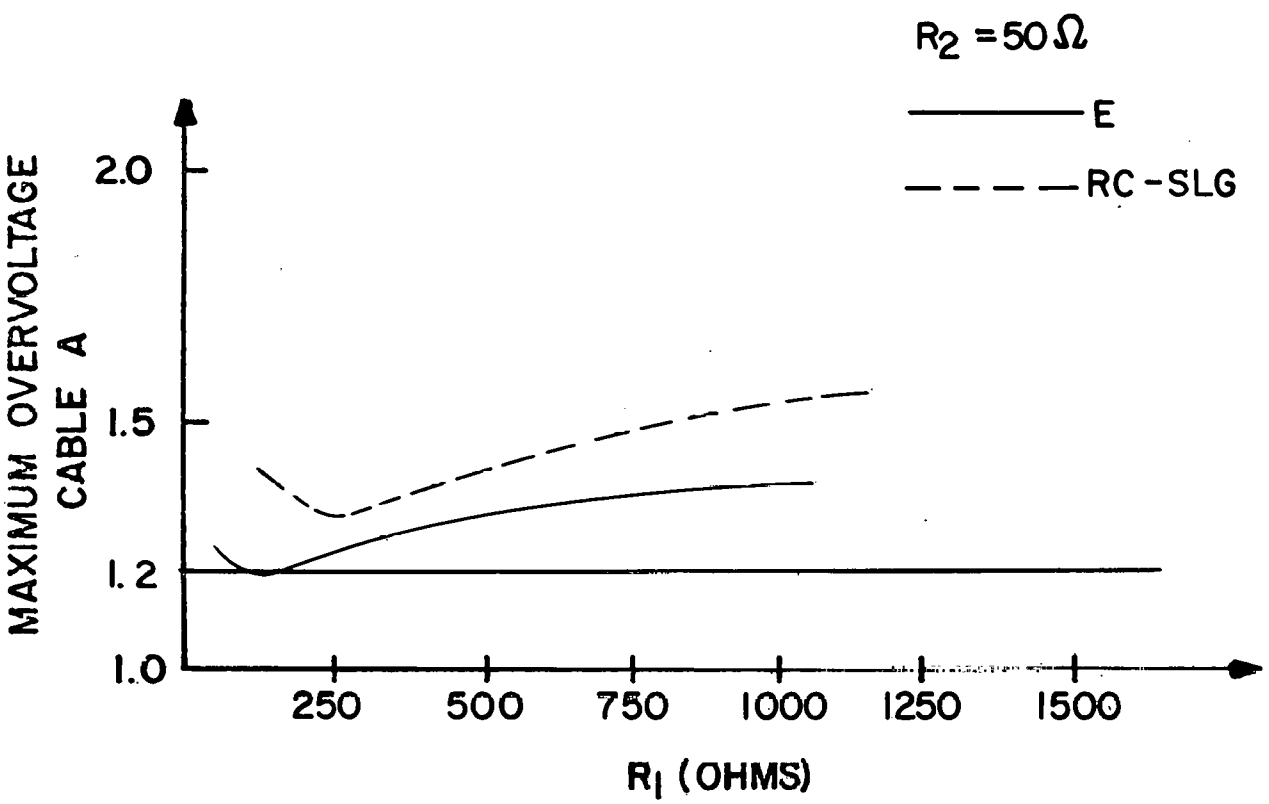

MAXIMUM OVERVOLTAGE CABLE B
2.0
1.5
1.0
F. I.
500
1000
1500
2000
2500
3000
R_1 (OHMS)

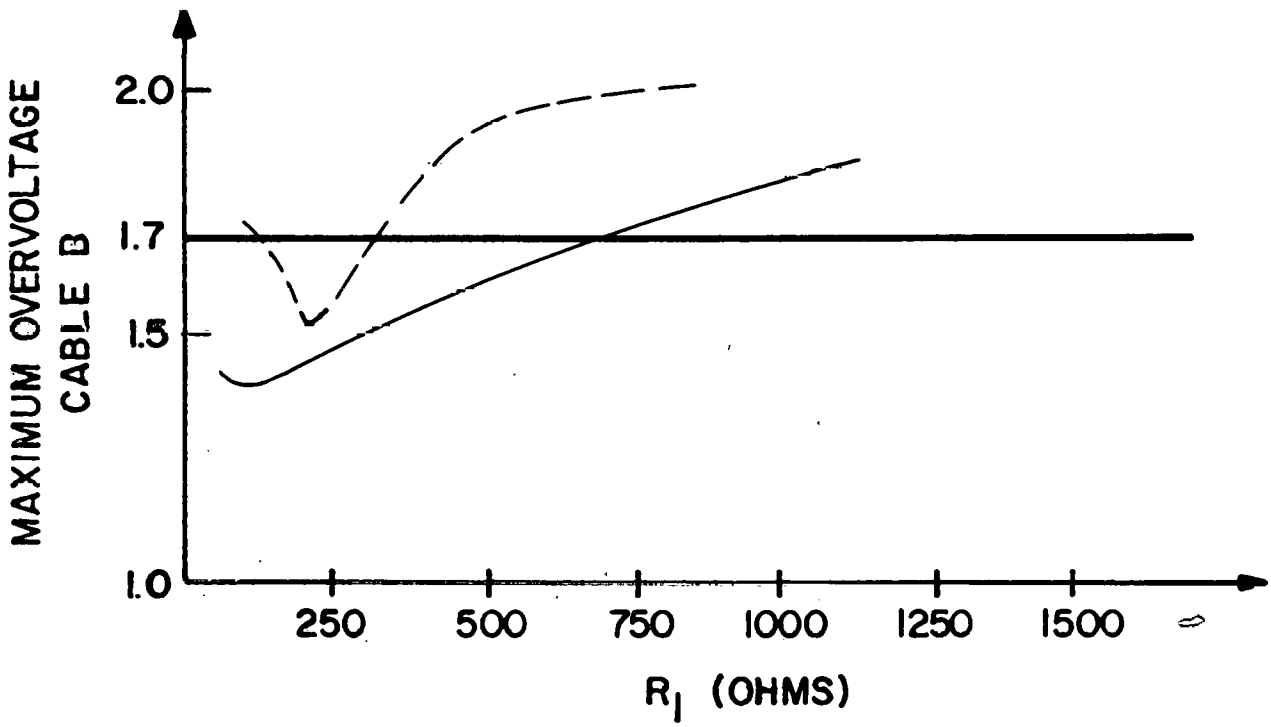

40 GVA SOURCE
50 MILES
CABLE A
100 MILES
OVERHEAD
600 FT.
CABLE B


MAXIMUM OVERVOLTAGE CABLE A
2.0
1.5
1.2
1.0
NE
$R_2 = 50\ \Omega$
250
500
750
1000
1250
1500
1750
R_1 (OHMS)

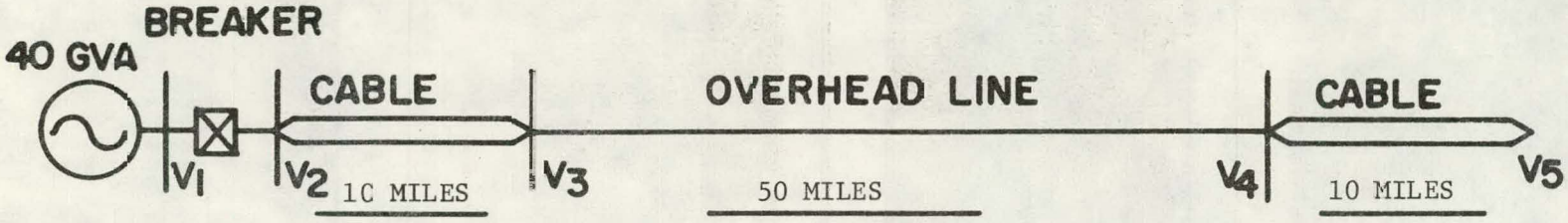

MAXIMUM OVERVOLTAGE CABLE B
2.0
1.7
1.5
1.0
250
500
750
1000
1250
1500
1750
R_1 (OHMS)


40 GVA SOURCE
50 MILES
CABLE A
150 MILES
OVERHEAD
600 FT.
CABLE B


$R_2 = 50\,\Omega$
E
RC-SLG
MAXIMUM OVERVOLTAGE
CABLE A
2.0
1.5
1.2
1.0
250
500
750
1000
1250
1500
R_1 (OHMS)


MAXIMUM OVERVOLTAGE
CABLE B
2.0
1.7
1.5
1.0
250
500
750
1000
1250
1500
R_1 (OHMS)

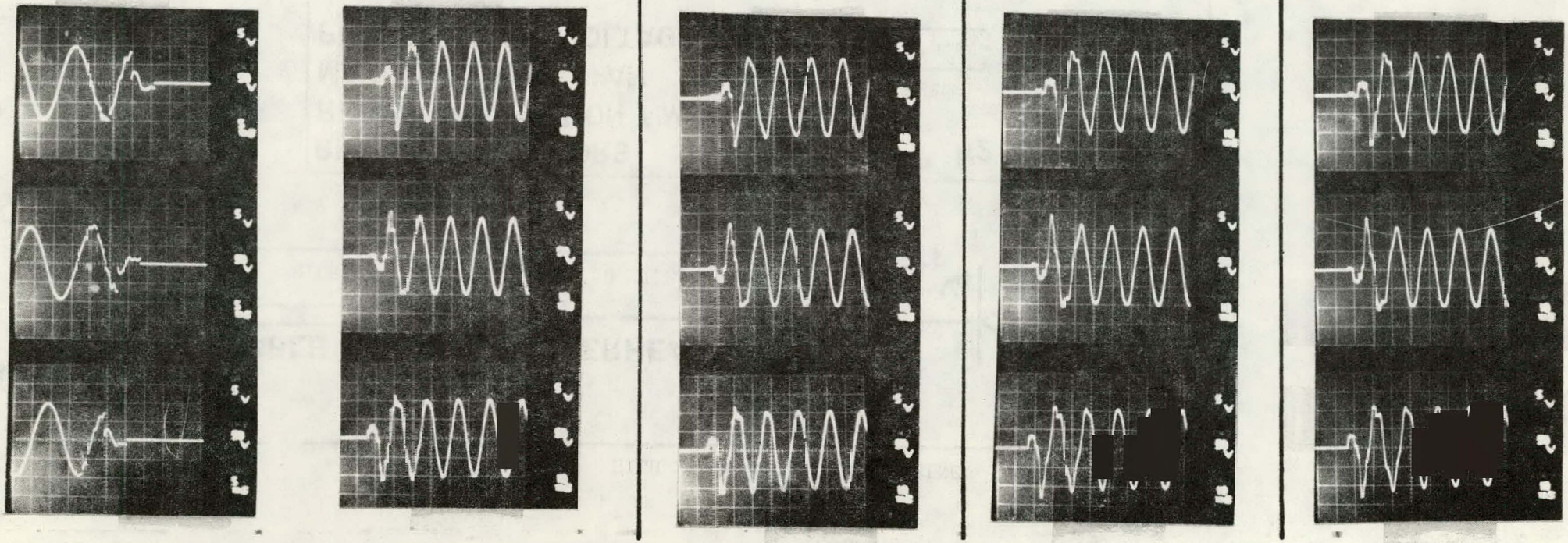
CASE NO. D-1 ENERGIZE LINE



XO/X1 = 1.0

BREAKER RESISTORS	R_1 = 500 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

1.0 p.u.	1.2 p.u.	1.2 p.u.	1.35 p.u.	1.35 p.u.
$V_1 - 2$	V_2	V_3	V_4	V_5

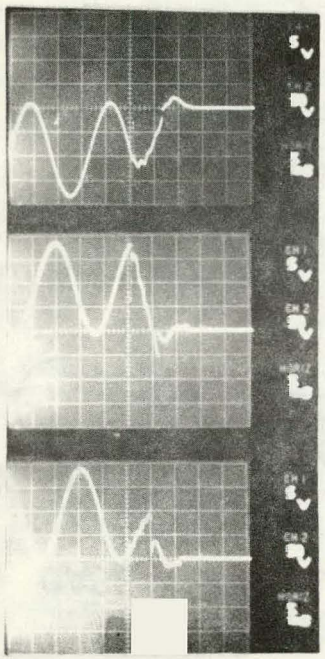
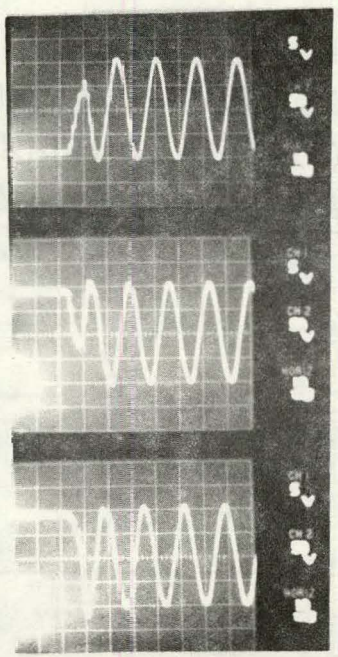
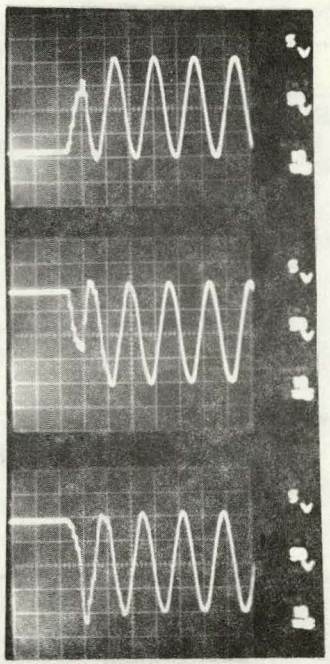
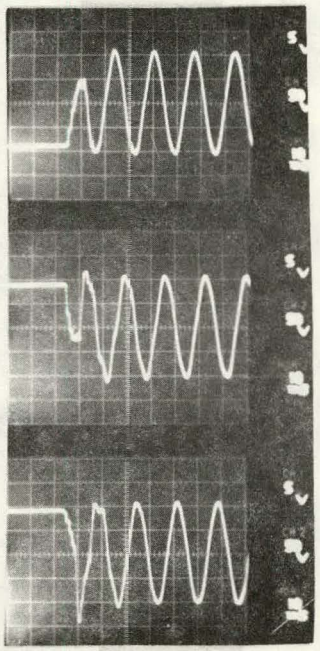
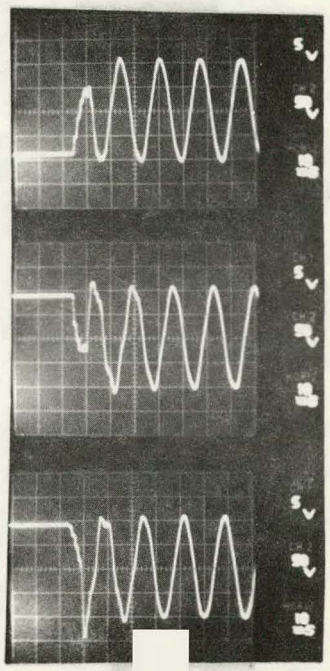


CASE NO. D-2

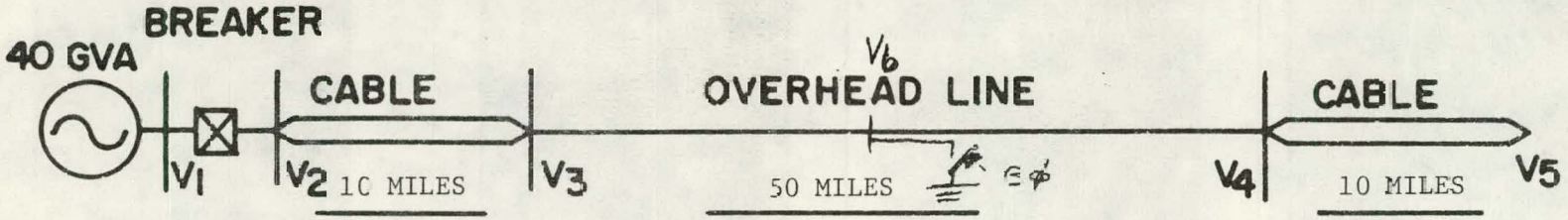
HIGH SPEED RECLOSING OF LINE

XO/X1 = 1.0

BREAKER RESISTORS	R_1 = 500	R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC	6 MSEC
MAXIMUM POLE SPAN	5 MSEC	
PRE-SWITCHED VOLTAGE	1.0 p.u.	

2.0 p.u.	1.2 p.u.	1.2 p.u.	1.45 p.u.	1.45 p.u.
V_{1-2}	V_2	V_3	V_4	V_5
				

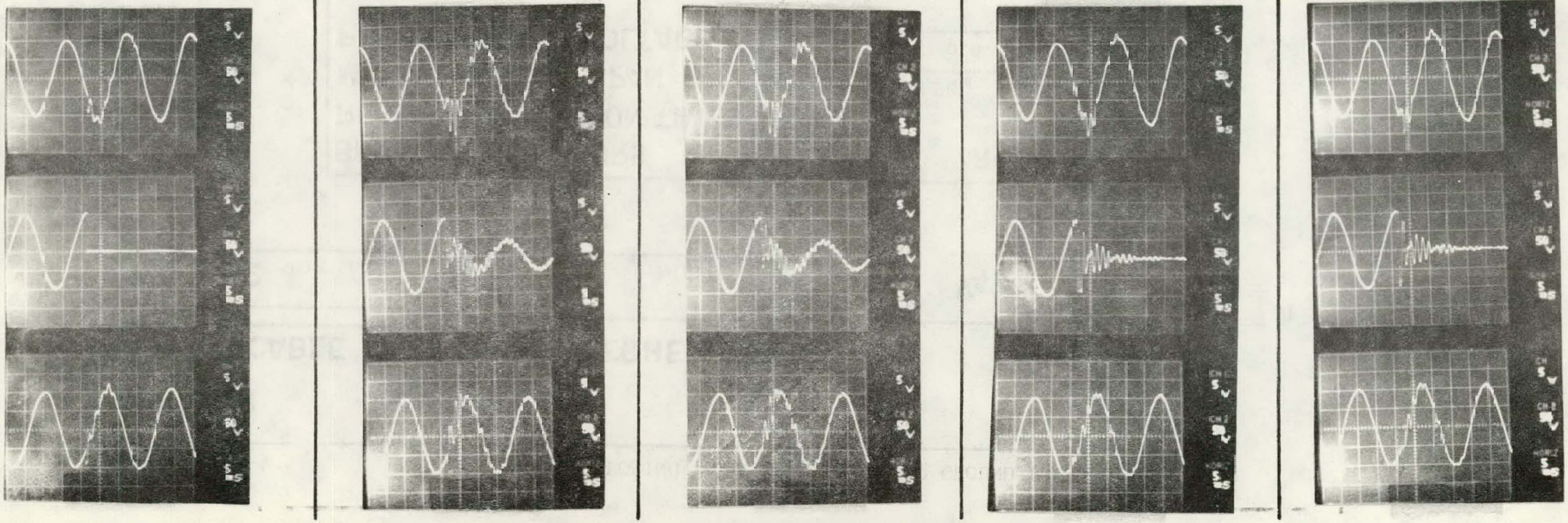
CASE NO. D-3 FAULT INITIATED OVERVOLTAGES



XO/X1 = 1.0

BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

1.25 p.u.	1.45 p.u.	1.45 p.u.	1.5 p.u.	1.5 p.u.
V_6	V_2	V_3	V_4	V_5

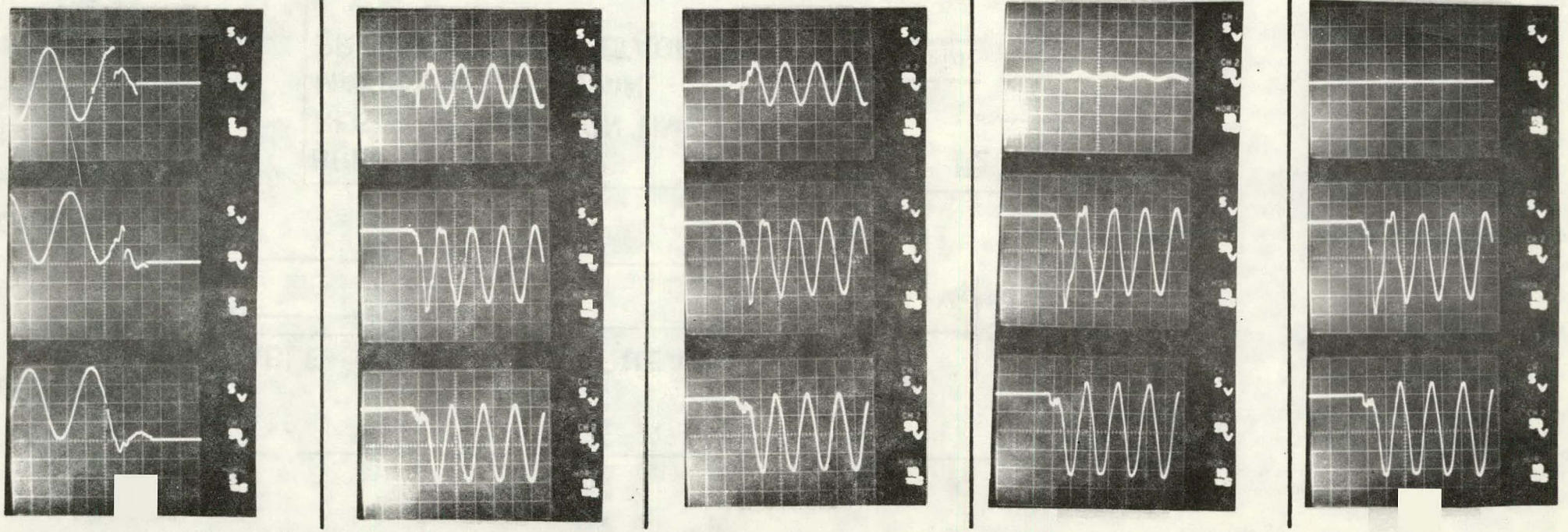


CASE NO. D-4 HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT

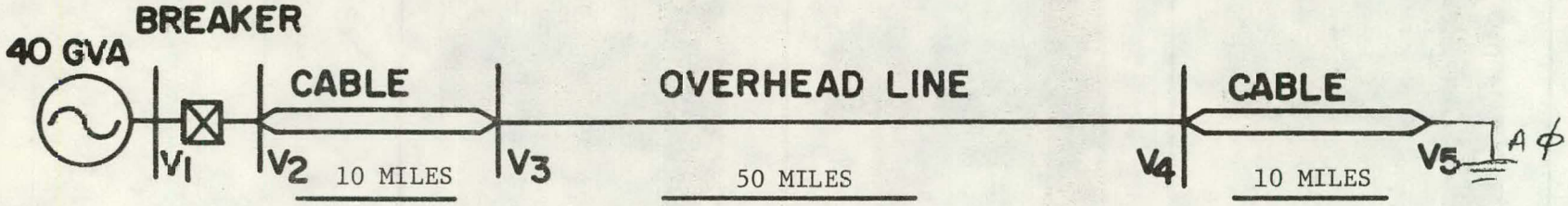
XO/X1 = 1.0

BREAKER RESISTORS	R_1 = 500 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

2.0 p.u.	1.2 p.u.	1.2 p.u.	1.3 p.u.	1.3 p.u.
$V_1 - 2$	V_2	V_3	V_4	V_5



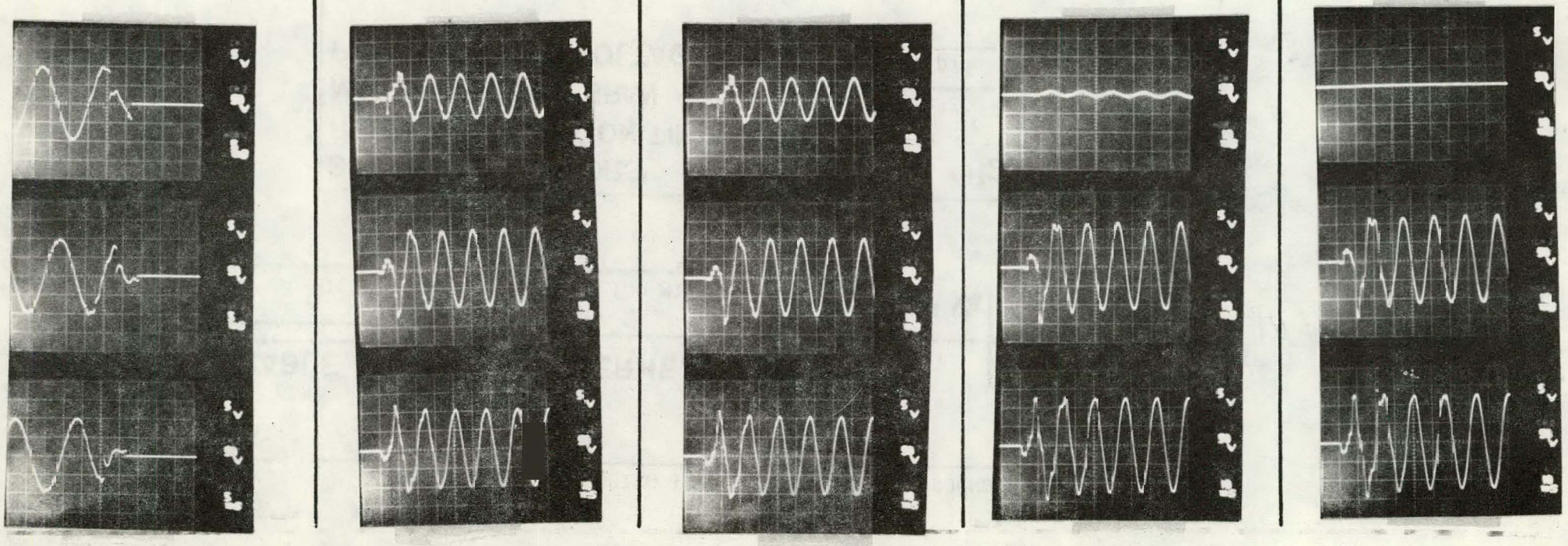
CASE NO. D-5 ENERGIZING INTO SINGLE LINE TO GROUND FAULT



XO/X1 = 1.0

BREAKER RESISTORS	R_1 = 500 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

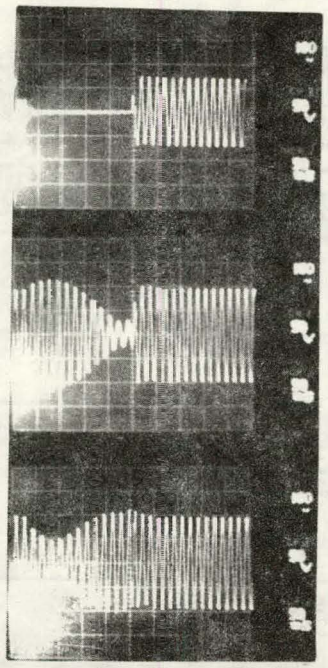
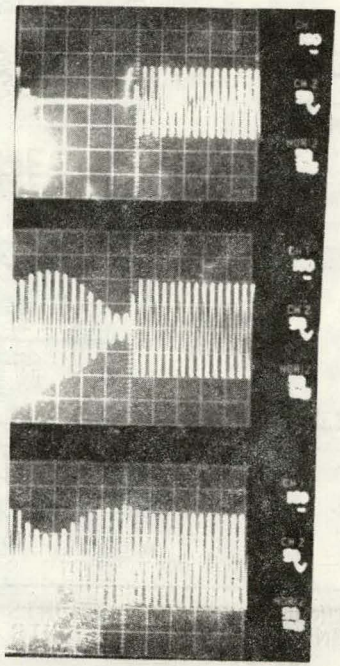
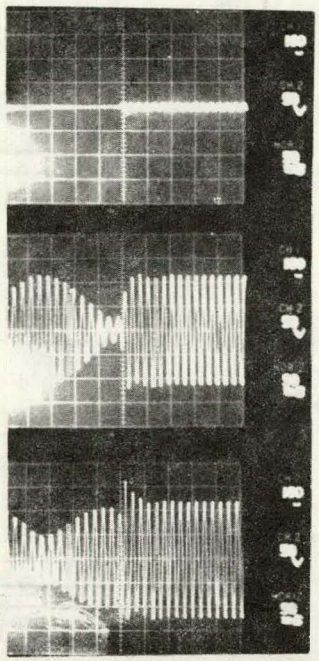
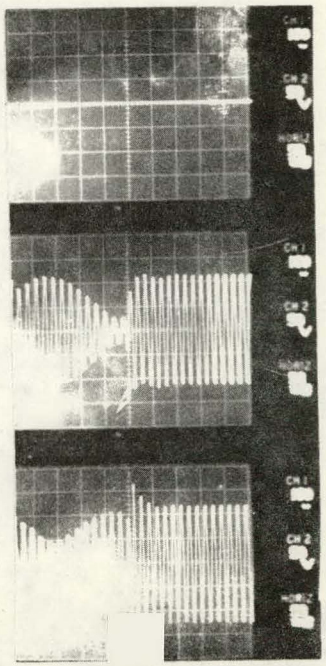
1.0 p.u.	1.25 p.u.	1.25 p.u.	1.45 p.u.	1.45 p.u.
$V_1 - 2$	V_2	V_3	V_4	V_5



CASE NO. D-6 HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT

XO/X1 = 1.0

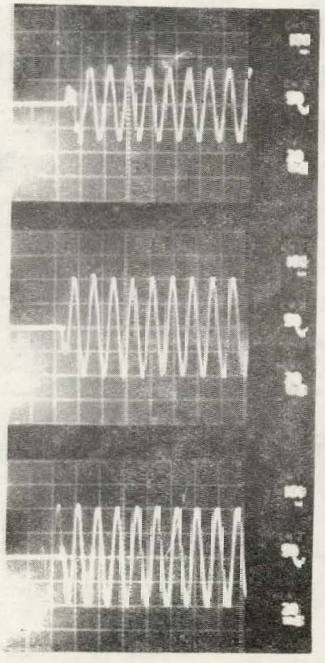
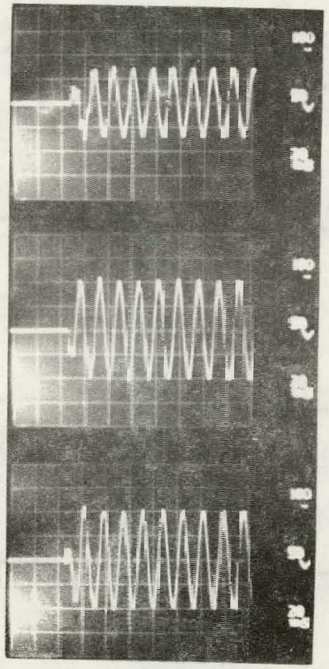
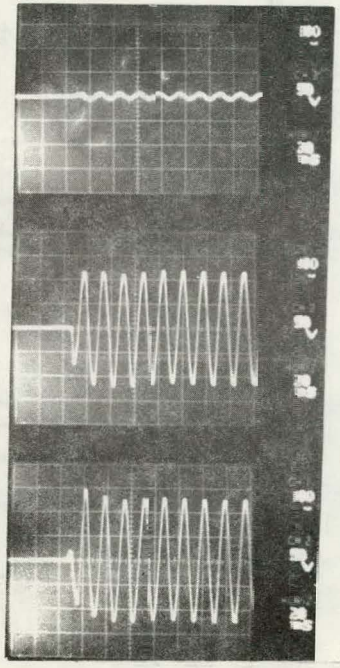
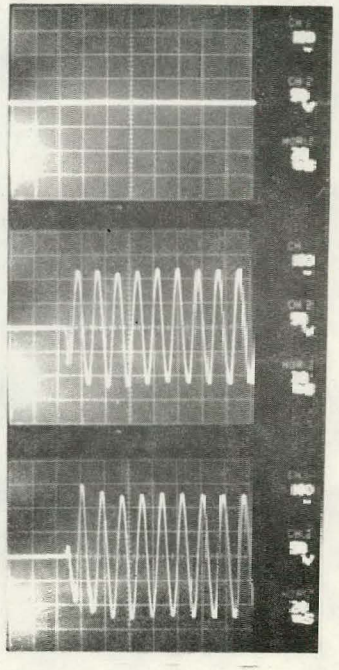
BREAKER RESISTORS	R_1 = 200 R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

$V_1 - 2$	1.1 p.u. V_2	1.1 p.u. V_3	1.6 p.u. V_4	1.6 p.u. V_5
				

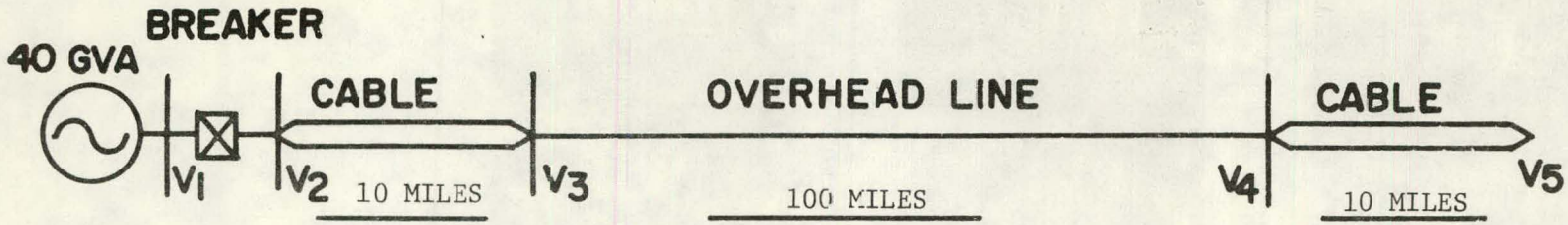
CASE NO. D-7 ENERGIZING INTO SINGLE LINE TO GROUND FAULT

XO/X1 = 1.0

BREAKER RESISTORS	R_1 = 200 R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

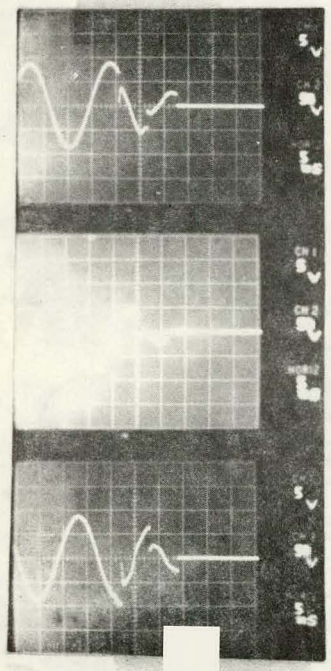
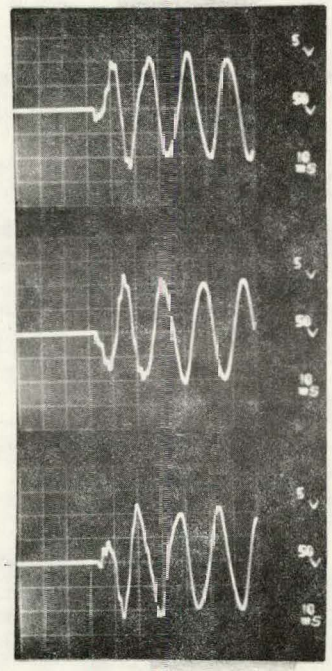
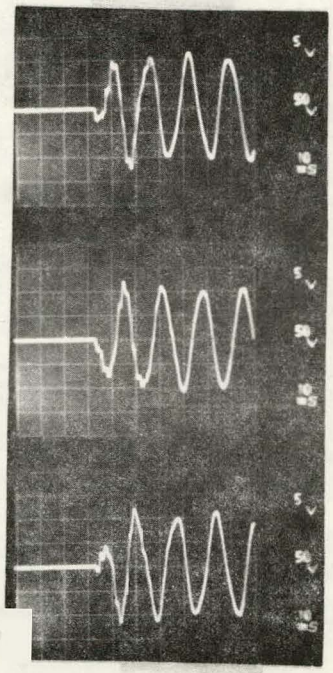
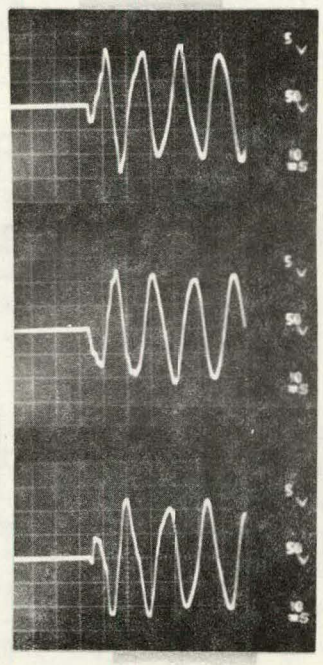
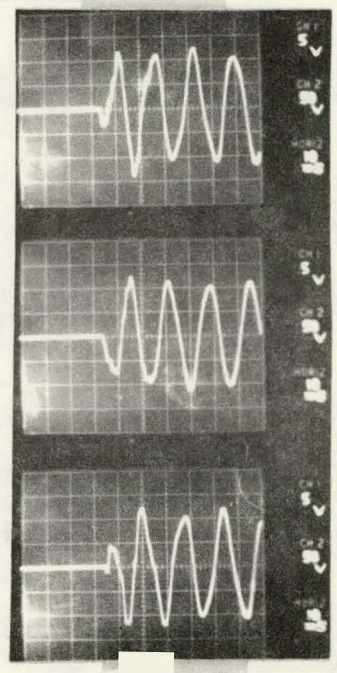
$V_1 - 2$	1.15 p.u. V_2	1.15 p.u. V_3	1.45 p.u. V_4	1.45 p.u. V_5
				

CASE NO. D-8 ENERGIZE LINE



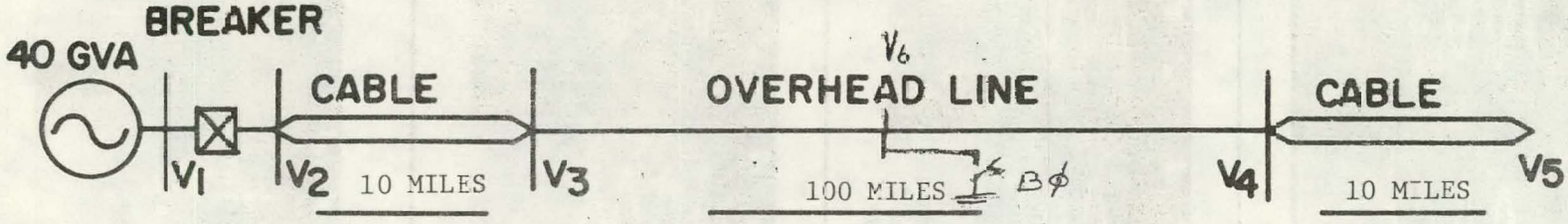
XO/X1 = 1.0

BREAKER RESISTORS	R_1 = 500 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

1.0 p.u.	1.25 p.u.	1.25 p.u.	1.4 p.u.	1.4 p.u.
$V_1 - 2$	V_2	V_3	V_4	V_5
				

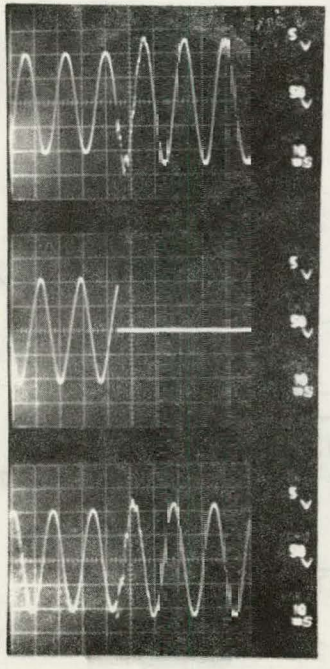
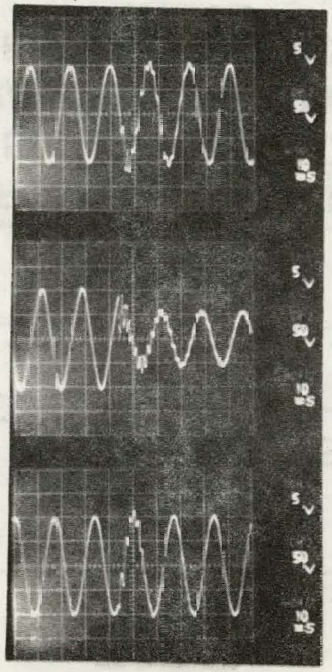
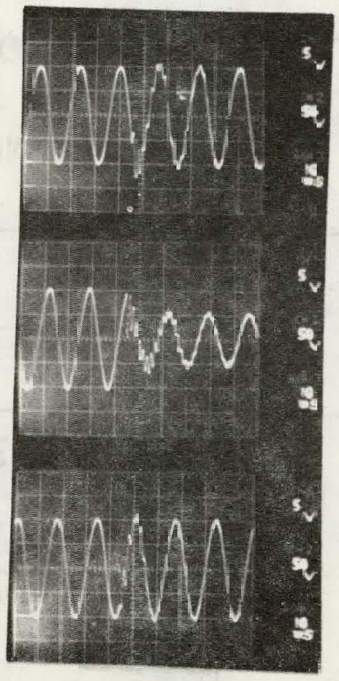
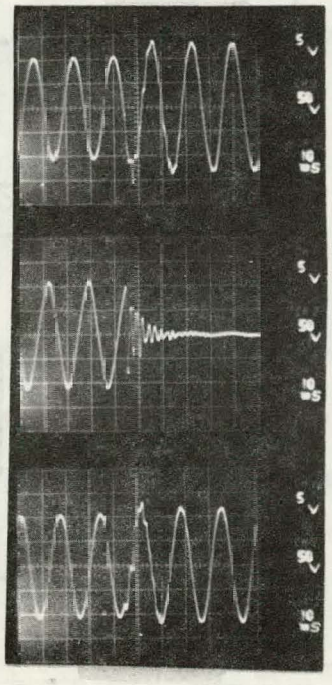
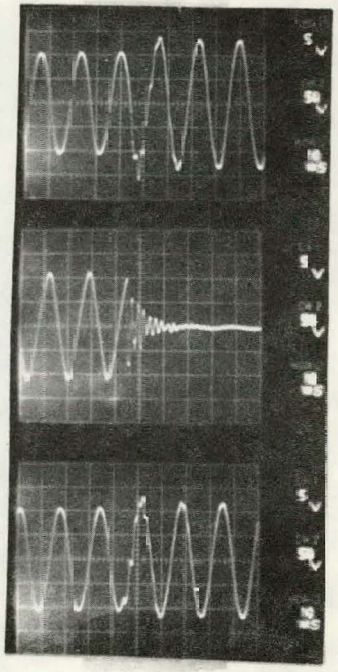
CASE NO. D-9

FAULT INITIATED OVERVOLTAGES

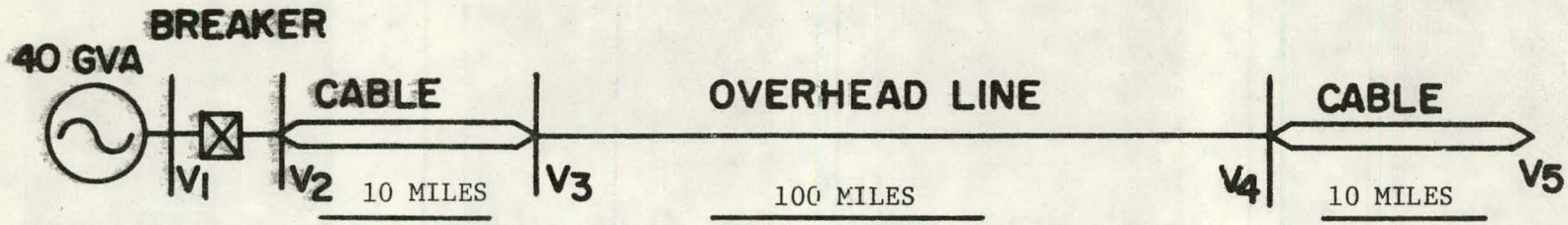


XO/X1 = 1.0

BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

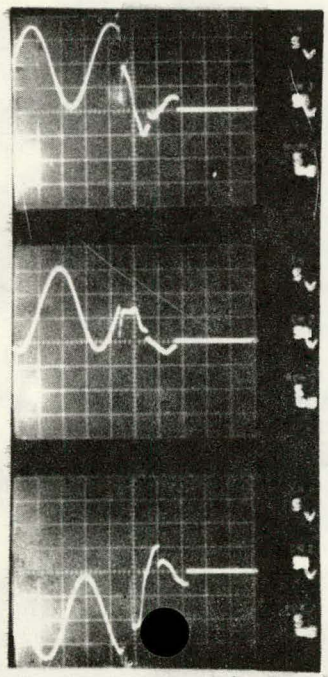
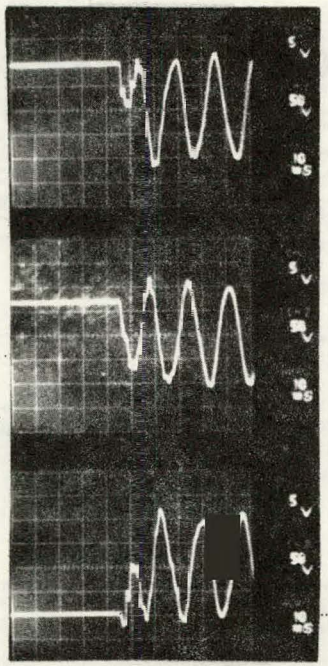
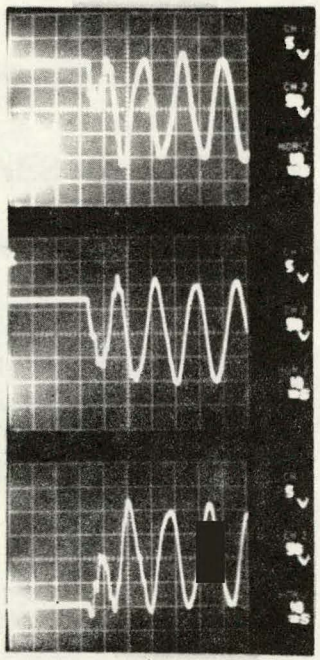
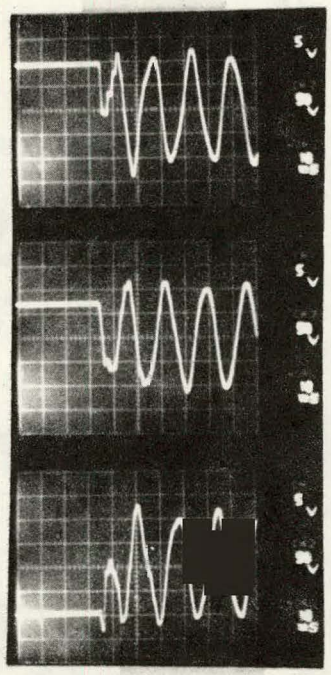
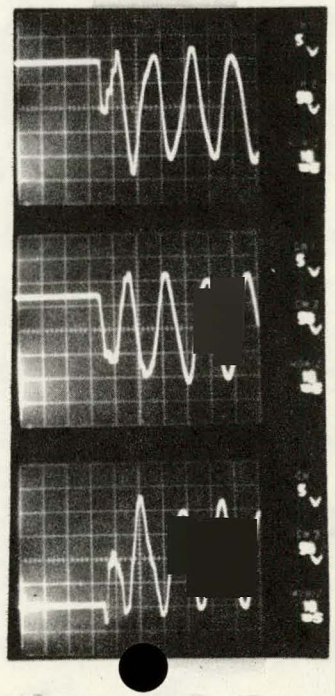
1.5 p.u.	1.25 p.u.	1.25 p.u.	1.6 p.u.	1.6 p.u.
V_6	V_2	V_3	V_4	V_5
				

CASE NO. D-10 HIGH SPEED RECLOSING OF LINE



XO/X1 = 1.0

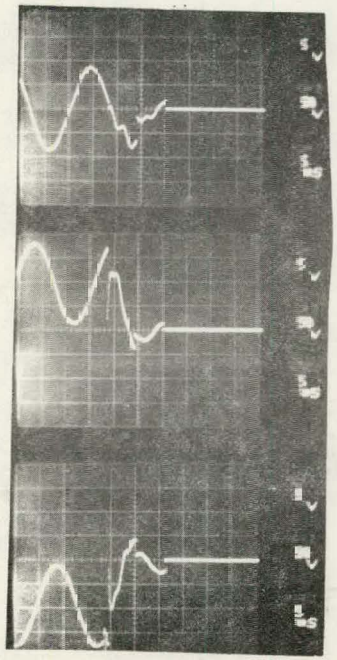
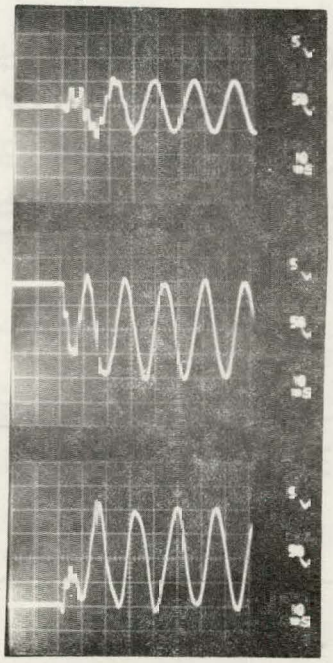
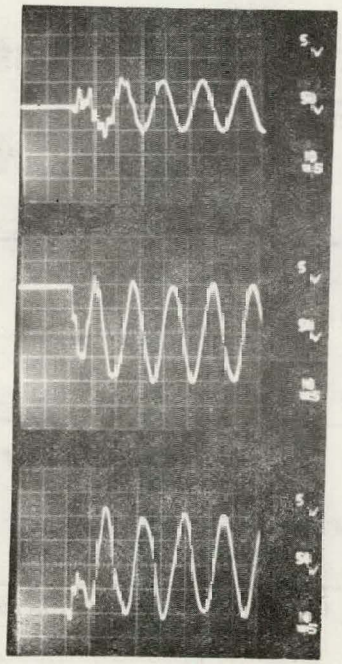
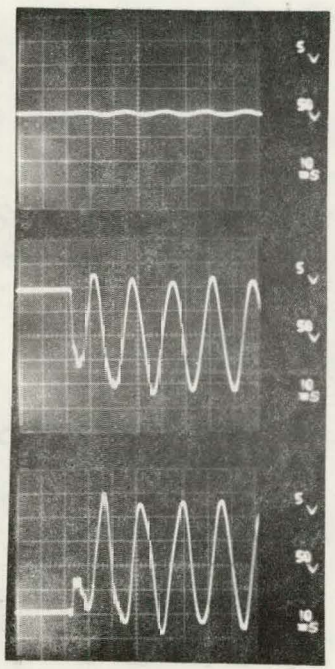
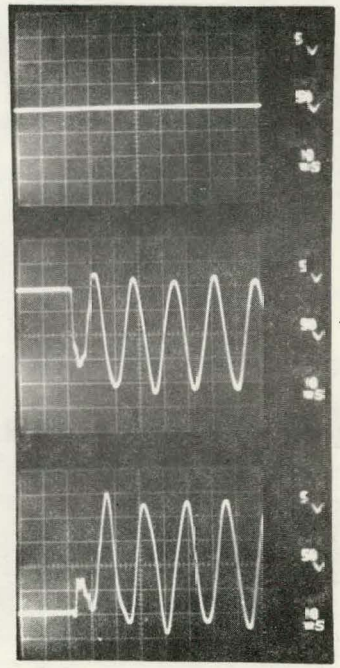
BREAKER RESISTORS	R_1 = 500	R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC	6 MSEC
MAXIMUM POLE SPAN	5 MSEC	
PRE-SWITCHED VOLTAGE	1.0 p.u.	

2.0 p.u.	1.3 p.u.	1.3 p.u.	1.4 p.u.	1.4 p.u.
$V_1 - 2$	V_2	V_3	V_4	V_5
				

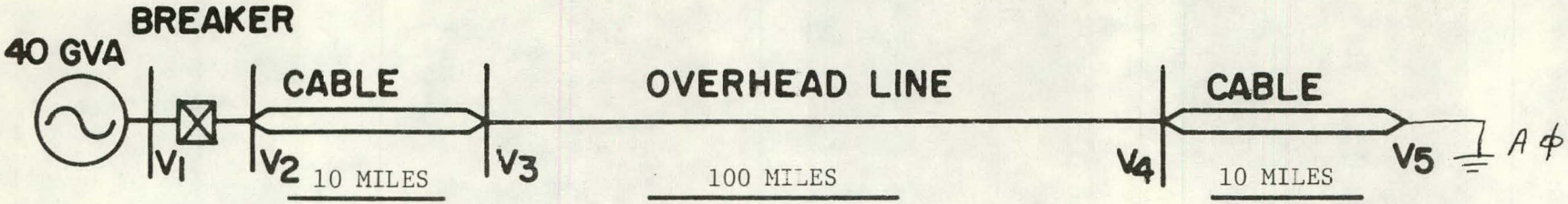
CASE NO. D-11 HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT

XO/X1 = 1.0

BREAKER RESISTORS	R_1 = 500 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

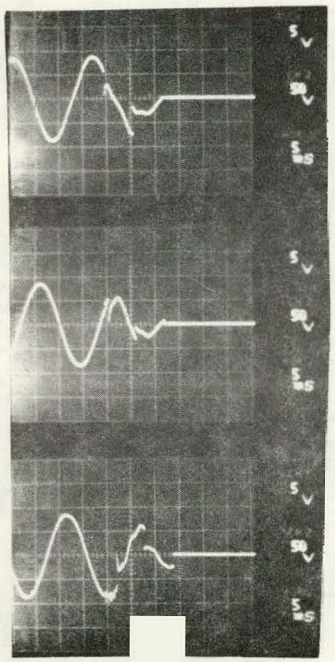
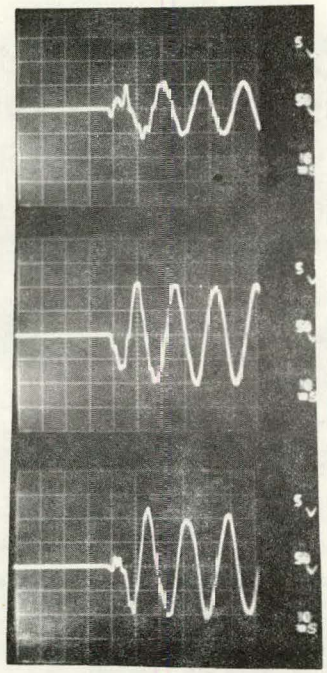
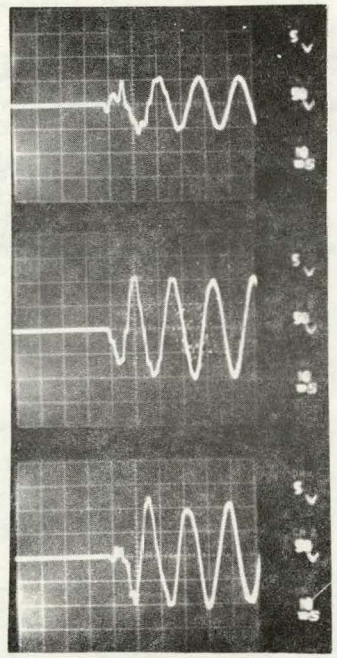
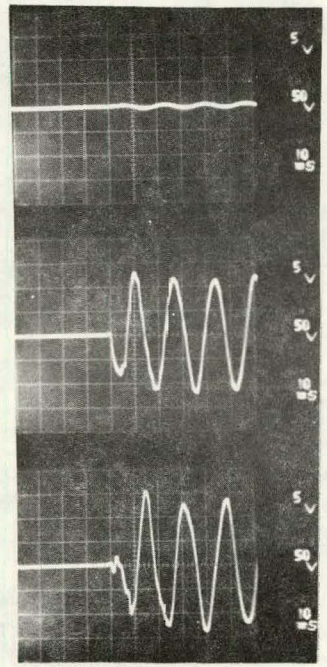
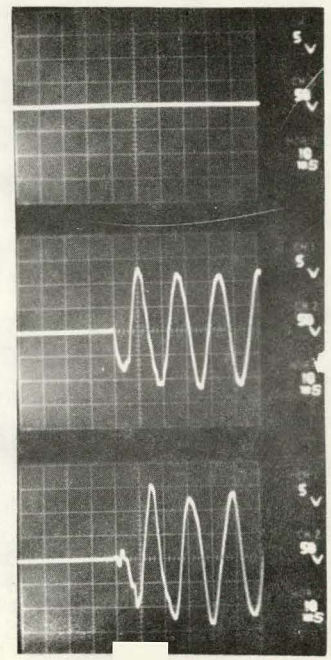
2.0 p.u.	1.2 p.u.	1.2 p.u.	1.5 p.u.	1.5 p.u.
$V_1 - 2$	V_2	V_3	V_4	V_5
				

CASE NO. D-12 ENERGIZING INTO SINGLE LINE TO GROUND FAULT

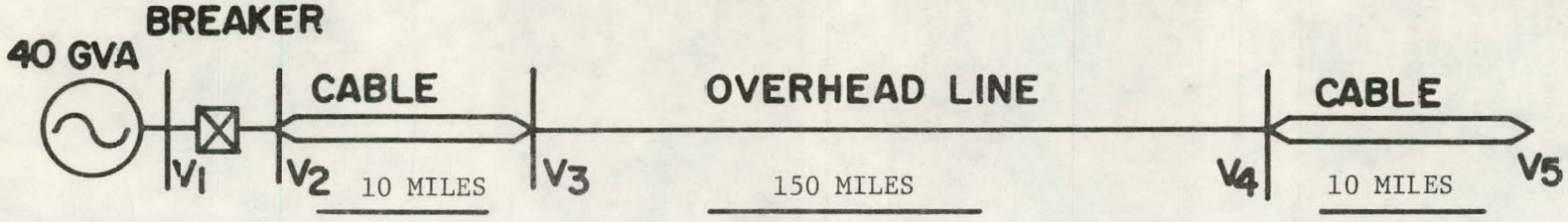


XO/X1 = 1.0

BREAKER RESISTORS	R_1 = 500 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

1.0 p.u.	1.3 p.u.	1.3 p.u.	1.5 p.u.	1.5 p.u.
$V_1 - 2$	V_2	V_3	V_4	V_5
				

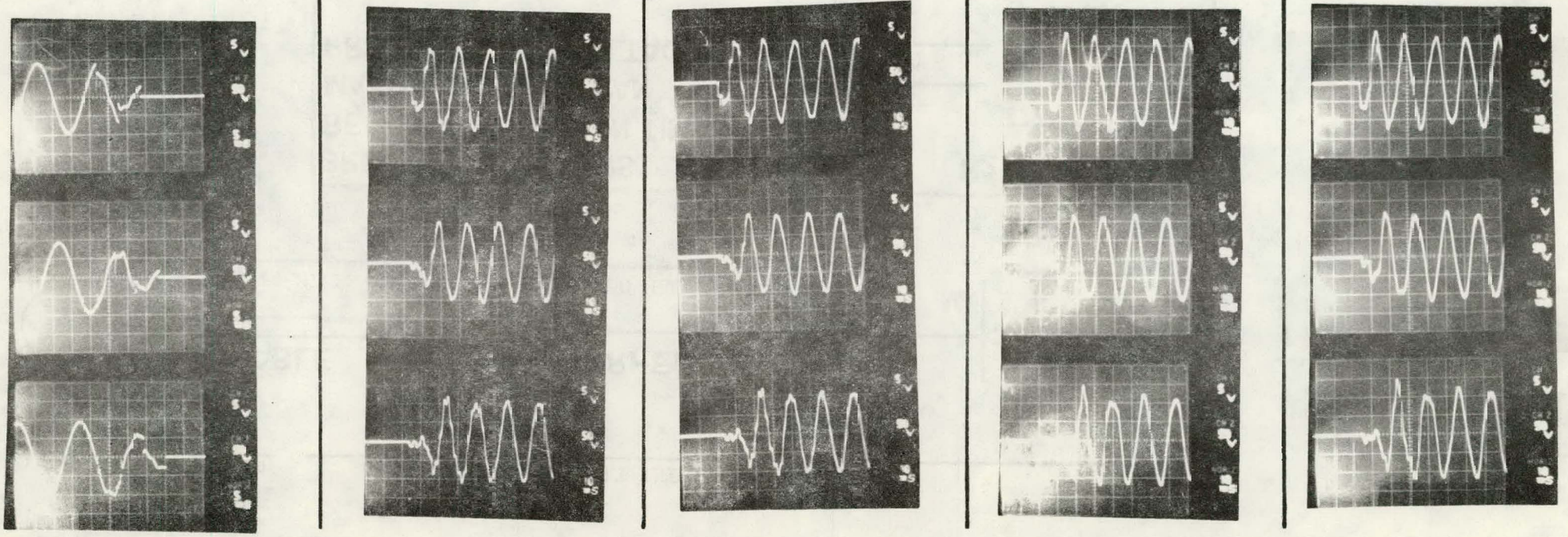
CASE NO. D-13 ENERGIZE LINE



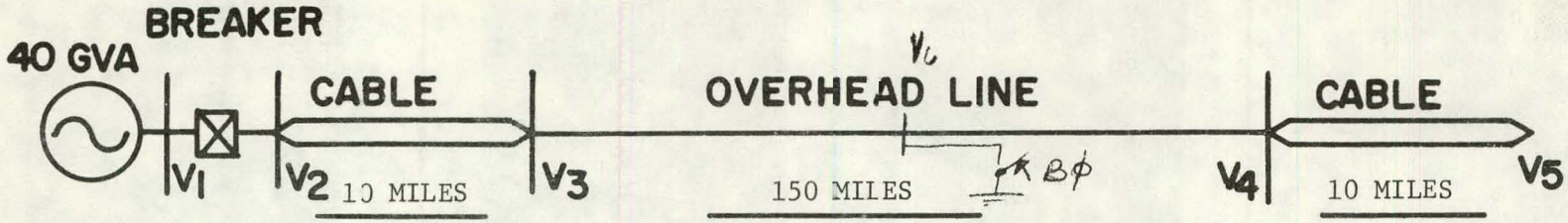
XO/X1 = 1.0

BREAKER RESISTORS	R_1 = 500 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

1.0 p.u.	1.25 p.u.	1.25 p.u.	1.45 p.u.	1.45 p.u.
$V_1 - 2$	V_2	V_3	V_4	V_5

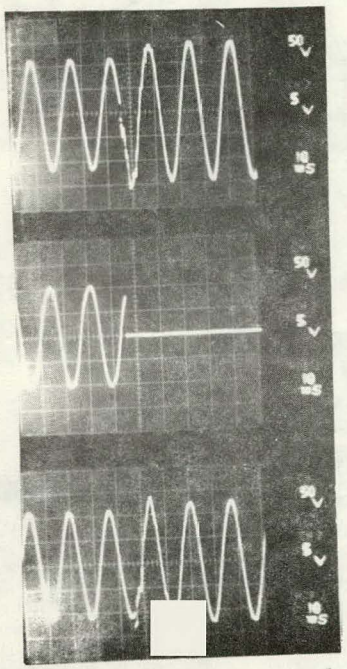
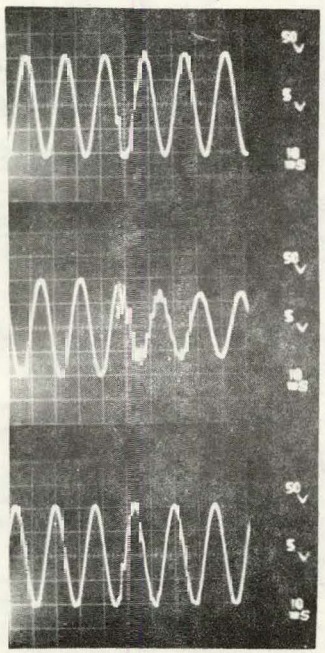
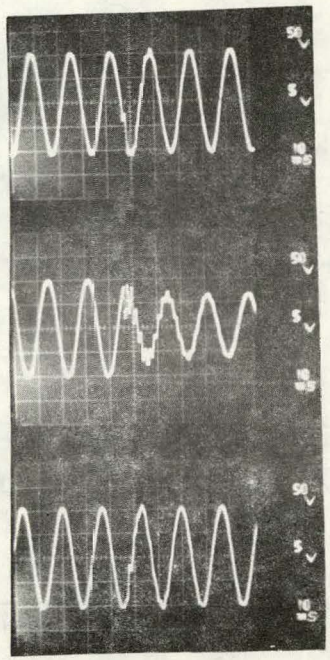
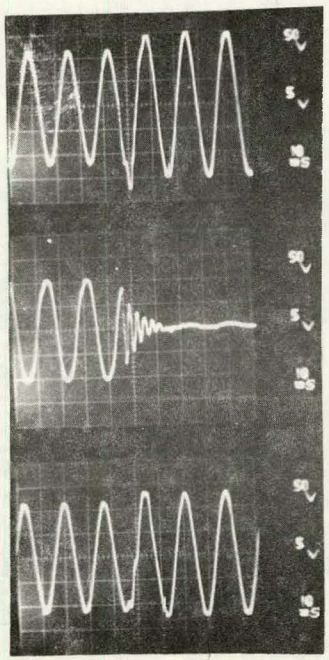
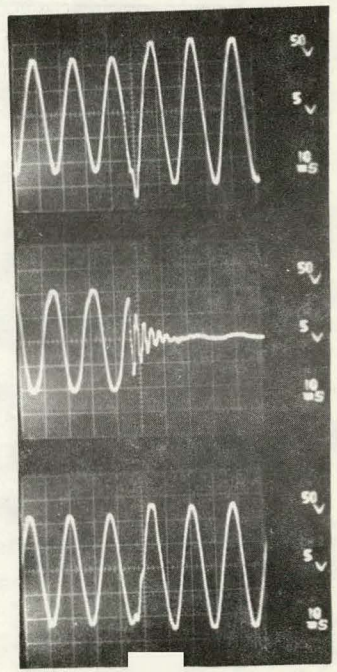


CASE NO. D-14 FAULT INITIATED OVERVOLTAGES

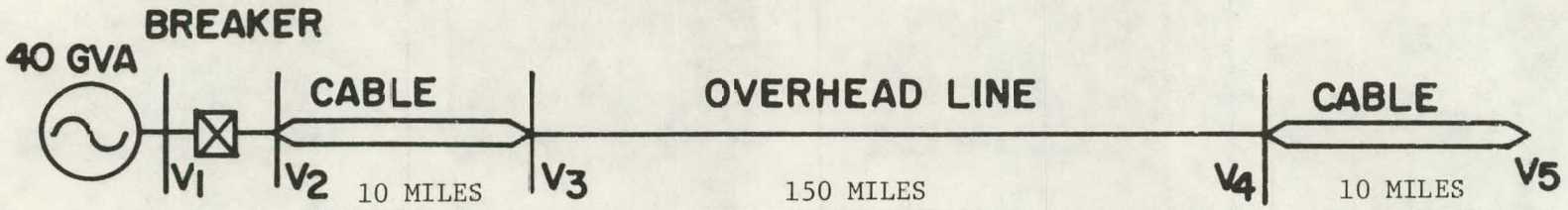


XO/X1 = 1.0

BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

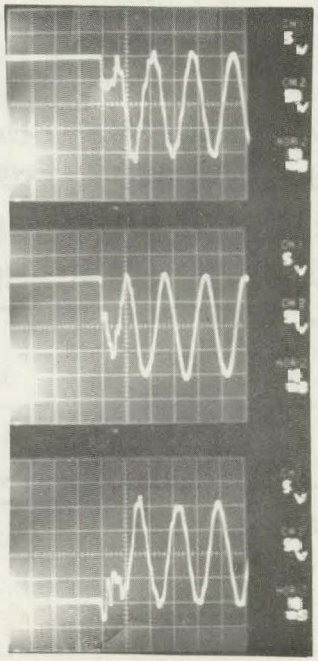
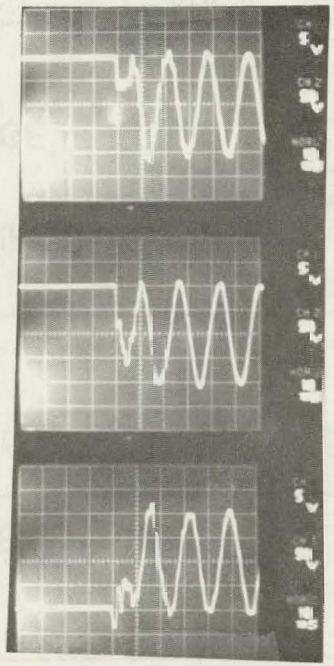
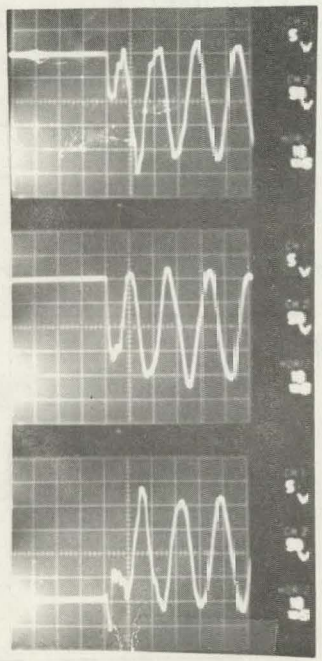
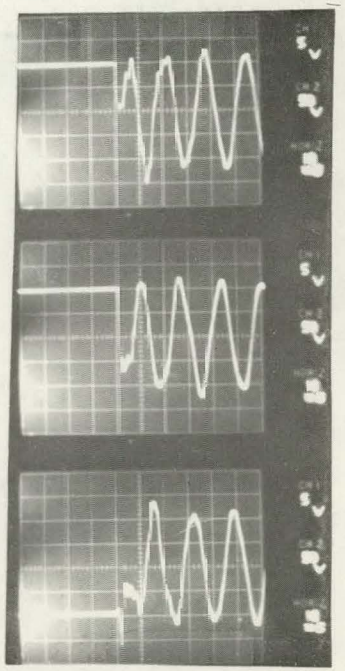
1.6 p.u.	1.2 p.u.	1.2 p.u.	1.7 p.u.	1.7 p.u.
V_6	V_2	V_3	V_4	V_5
				

CAS NO. D-15 HIGH SPEED RECLOSING OF LINE



XO/X1 = 1.0

BREAKER RESISTORS	R_1 = 500 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

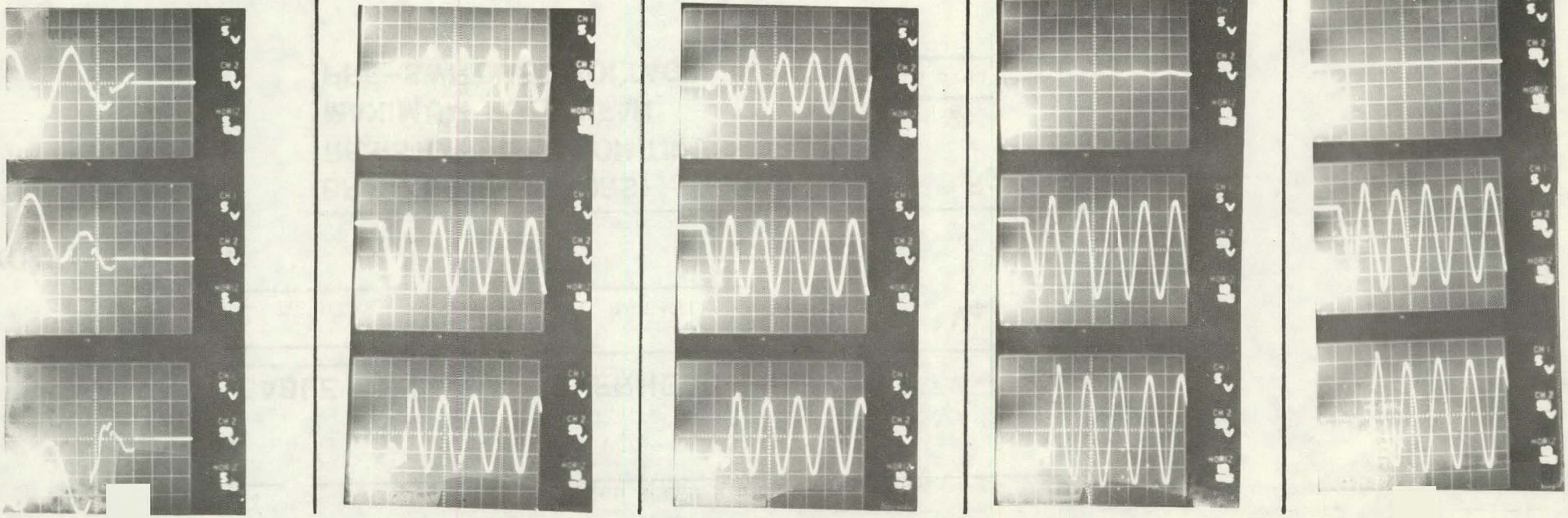
2.0 p.u.	1.35 p.u.	1.35 p.u.	1.65 p.u.	1.65 p.u.
$V_1 - 2$	V_2	V_3	V_4	V_5
				

CASE NO. D-16 HIGH SPEED RECLOSING IN SINGLE LINE TO GROUND FAULT

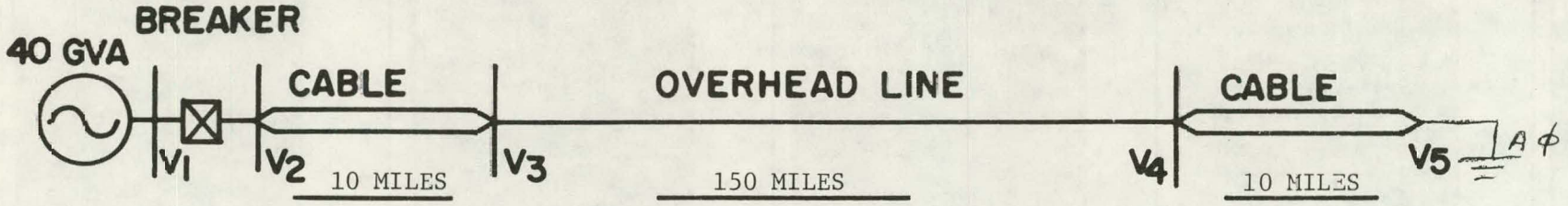
XO/X1 = 1.0

BREAKER RESISTORS R_1 = 500 R_2 = 100
RESISTOR INSERTION TIMES 6 MSEC 6 MSEC
MAXIMUM POLE SPAN 5 MSEC
PRE-SWITCHED VOLTAGE 1.0 p.u.

2.0 p.u.	1.3 p.u.	1.3 p.u.	1.75 p.u.	1.75 p.u.
$V_1 - 2$	V_2	V_3	V_4	V_5



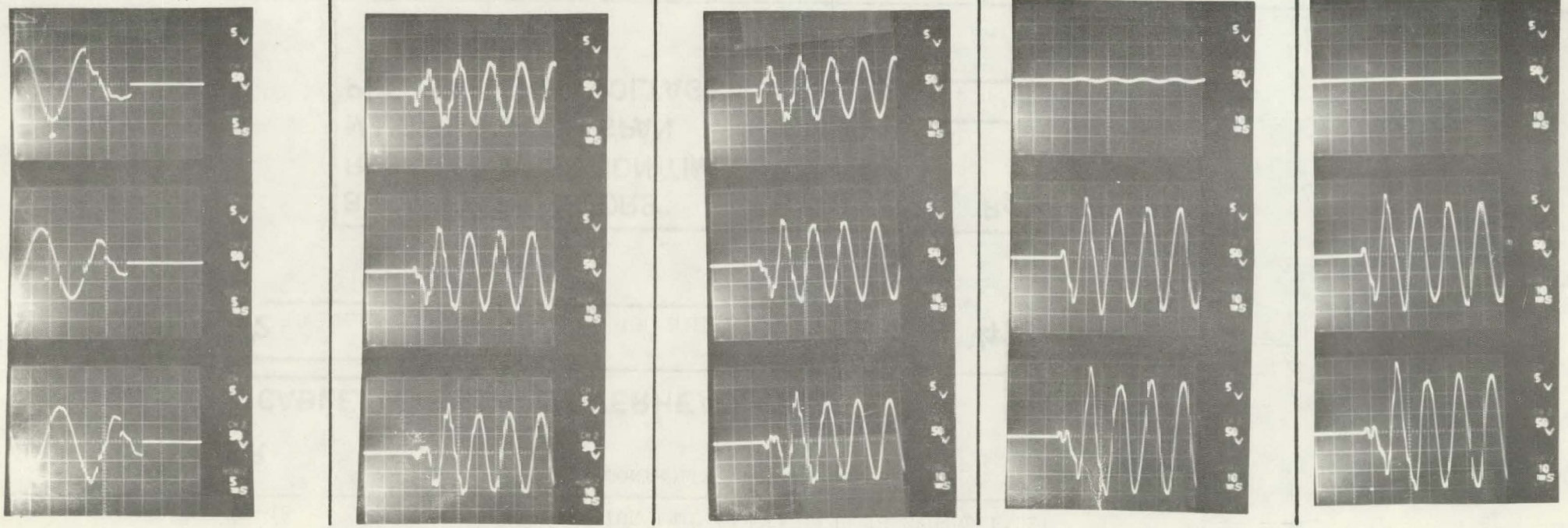
CAS NO. D-17 ENERGIZE INTO SINGLE LINE TO GROUND FAULT



XO/X1 = 1.0

BREAKER RESISTORS	R_1 = 500 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

1.0 p.u.	1.35 p.u.	1.35 p.u.	1.85 p.u.	1.85 p.u.
$V_1 - 2$	V_2	V_3	V_4	V_5



CASE NO. D-18

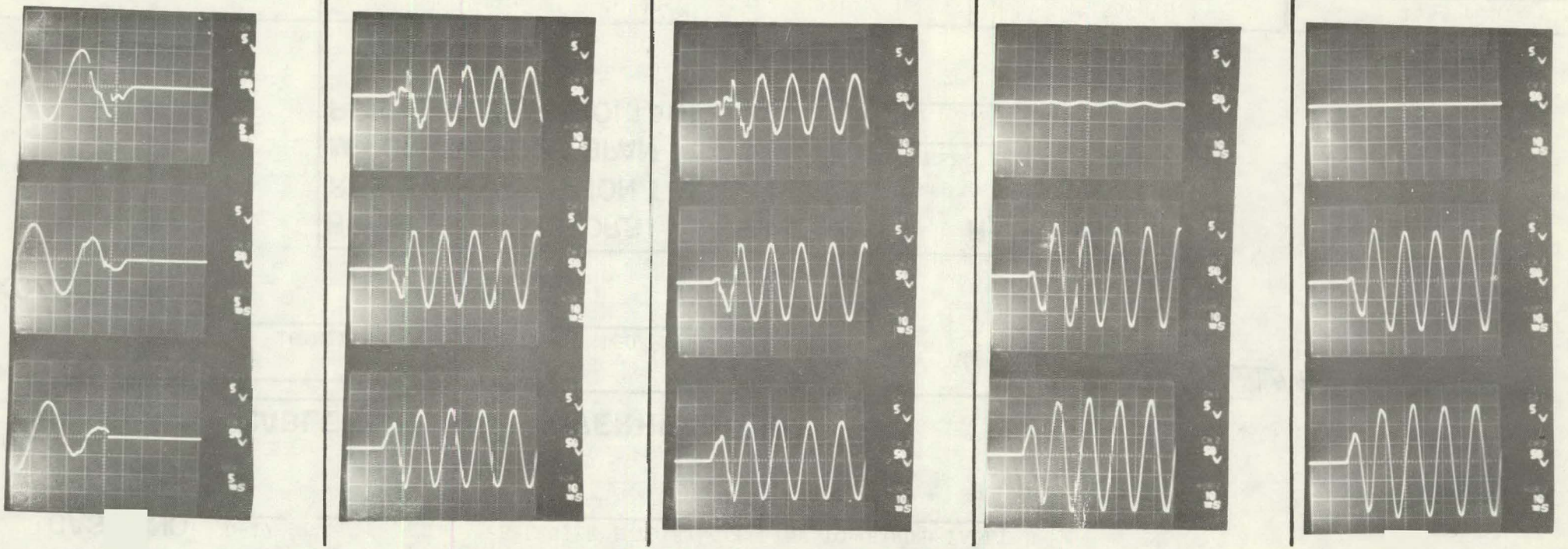
ENERGIZATION INTO SINGLE LINE TO GROUND FAULT

(CONTROLLED BREAKER CLOSING)

XO/X1 = 1.0

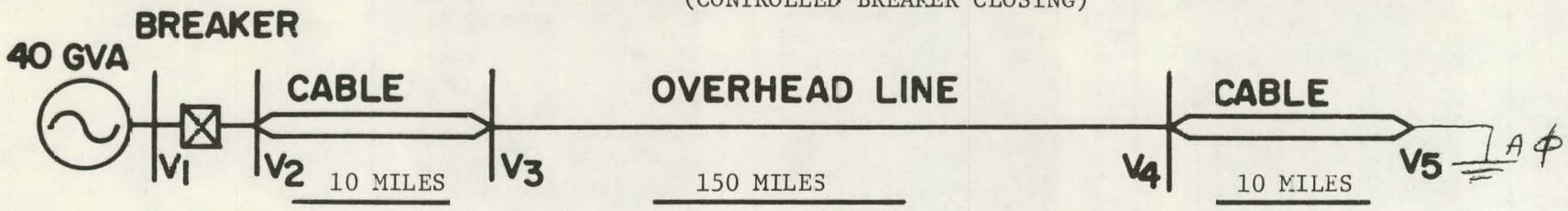
BREAKER RESISTORS	R_1 = 500 R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

1.0 p.u.	1.1 p.u.	1.1 p.u.	1.5 p.u.	1.5 p.u.
V_{1-2}	V_2	V_3	V_4	V_5



CASE NO. D-19 HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT

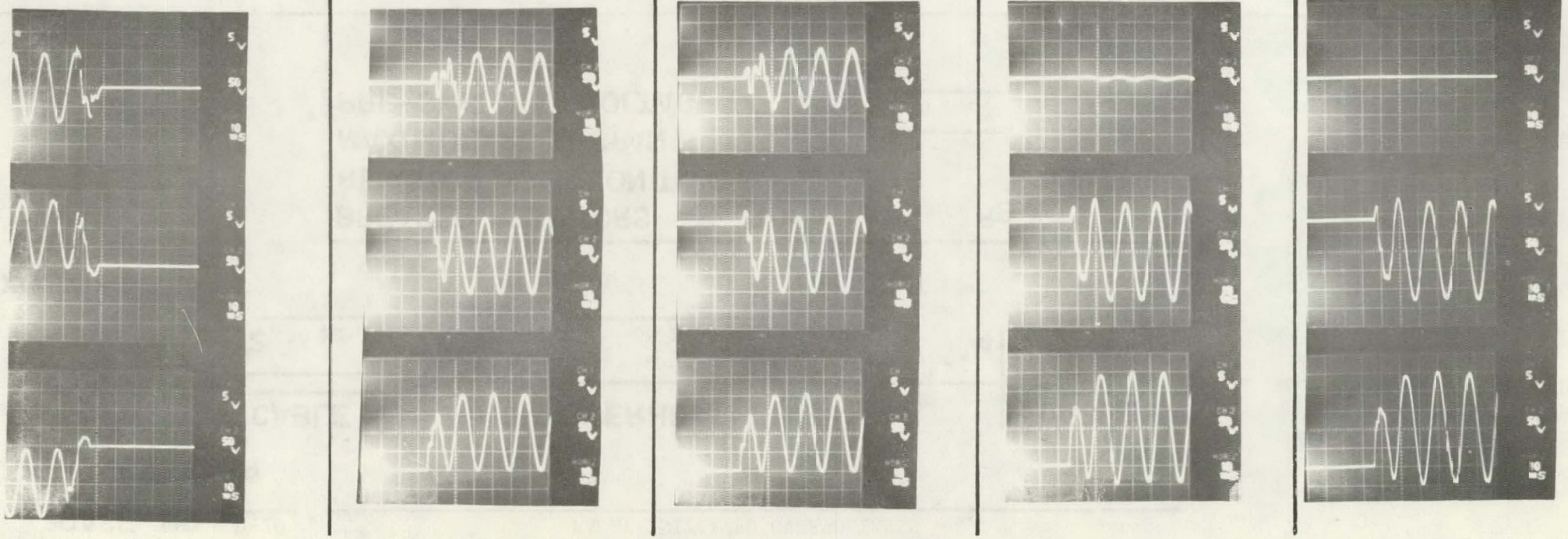
(CONTROLLED BREAKER CLOSING)



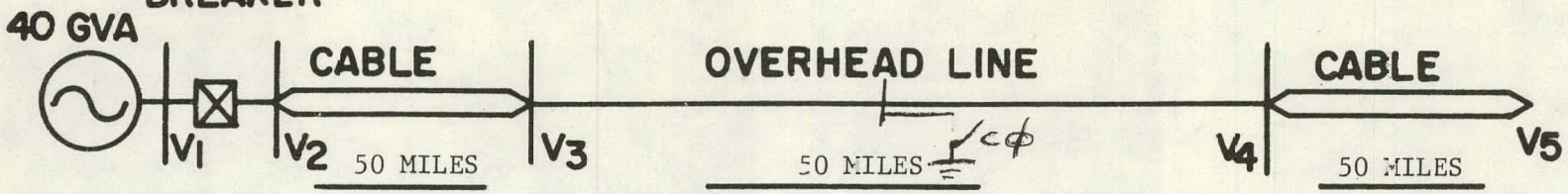
XO/X1 = 1.0

BREAKER RESISTORS	R_1 = 500	R_2 = 100
RESISTOR INSERTION TIMES	6 MSEC	6 MSEC
MAXIMUM POLE SPAN	5 MSEC	
PRE-SWITCHED VOLTAGE	1.0 p.u.	

2.0 p.u.	1.2 p.u.	1.2 p.u.	1.5 p.u.	1.5 p.u
$V_1 - 2$	V_2	V_3	V_4	V_5

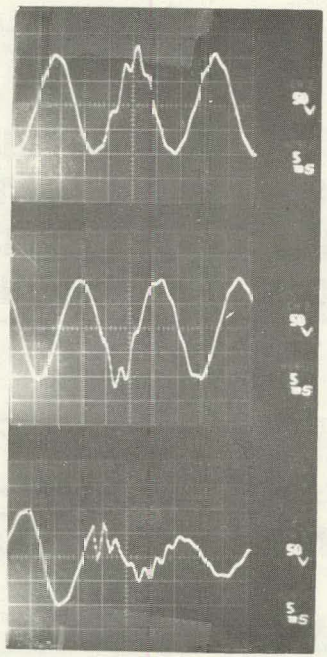
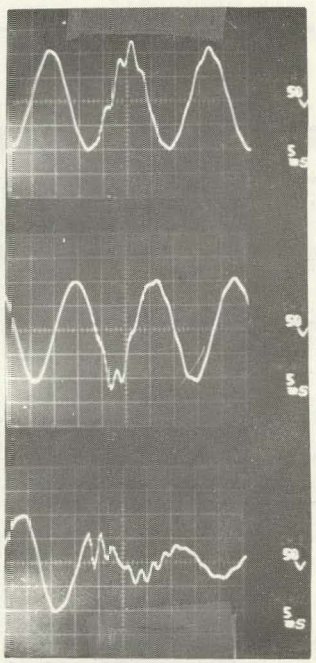
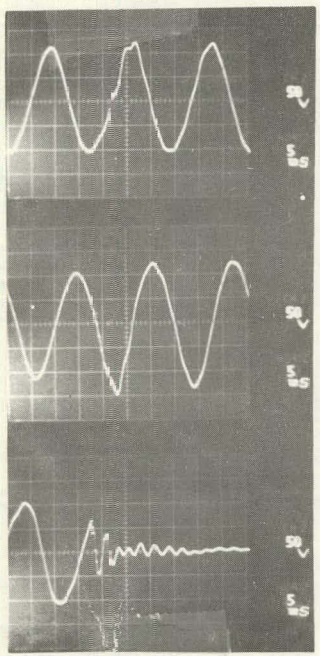
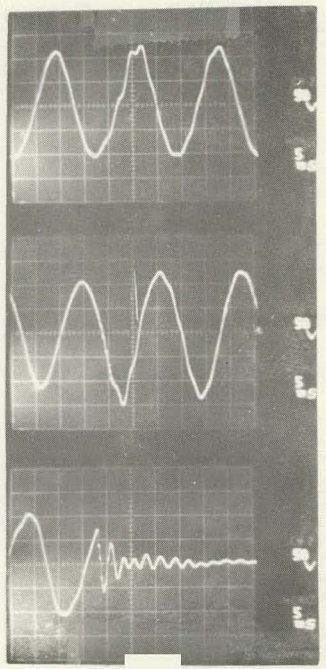


CASE NO. D-20 FAULT INITIATED OVERVOLTAGES

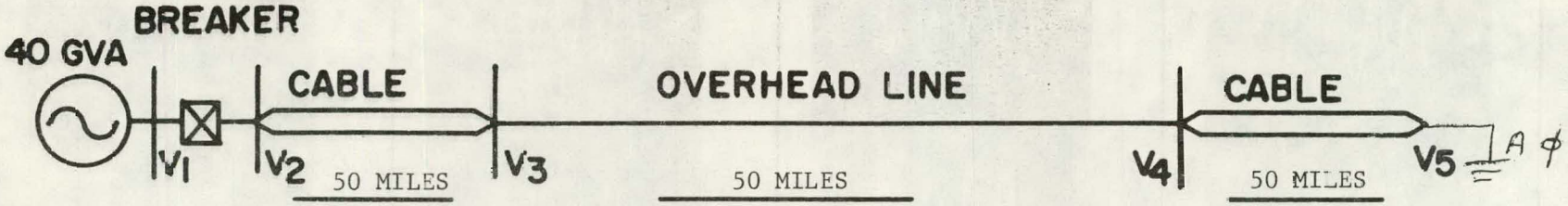


XO/X1 = 1.0

BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

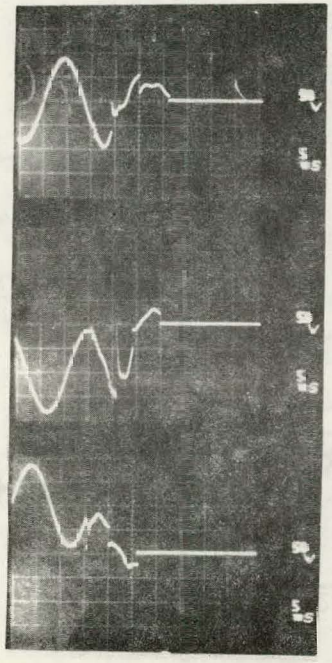
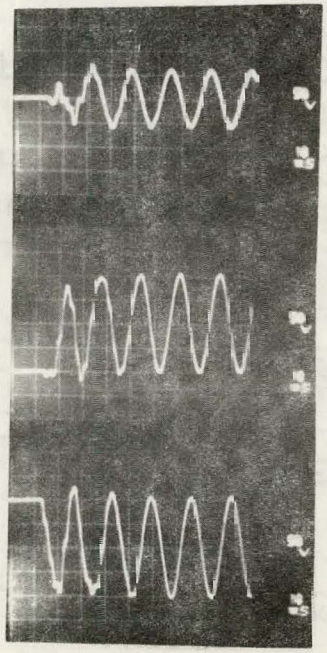
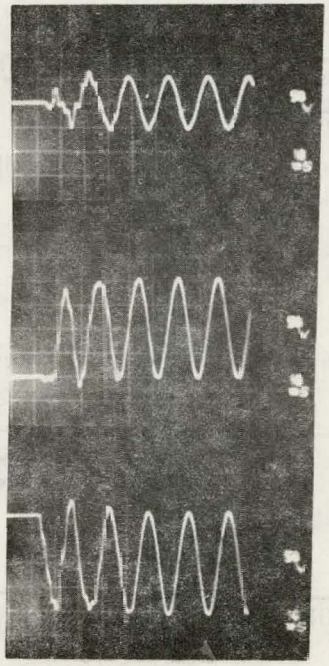
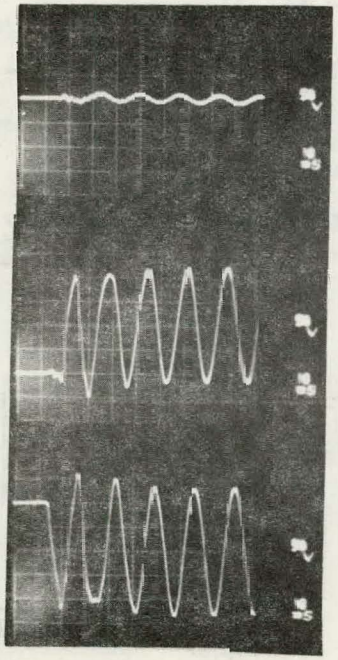
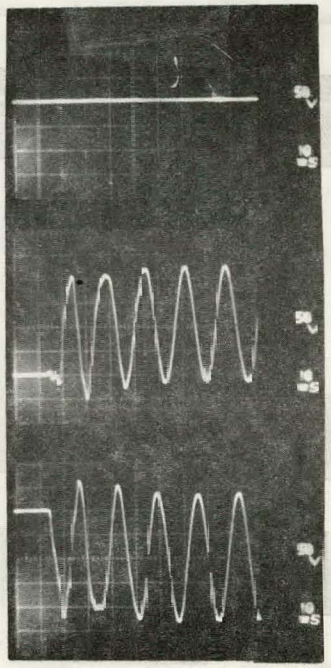
$V_1 - 2$	1.3 p.u. V_2	1.3 p.u. V_3	1.5 p.u. V_4	1.5 p.u. V_5
				

CASE NO. D-21 HIGH SPEED RECLOSING INTO A SINGLE LINE TO GROUND FAULT

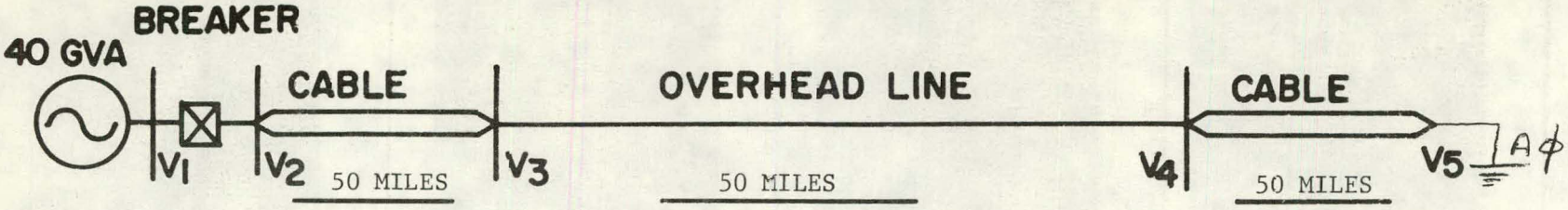


XO/X1 = 1.0

BREAKER RESISTORS	R_1 = 200 R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

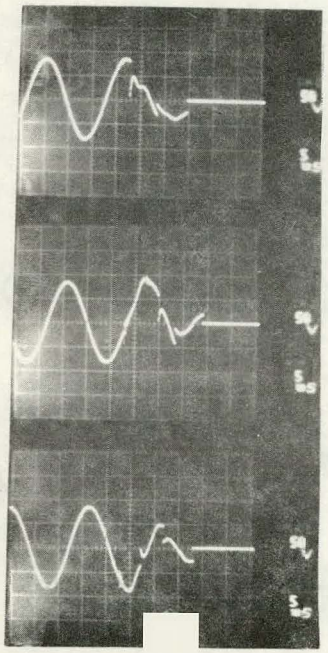
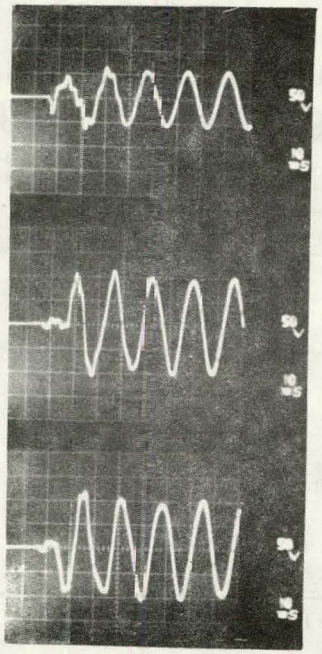
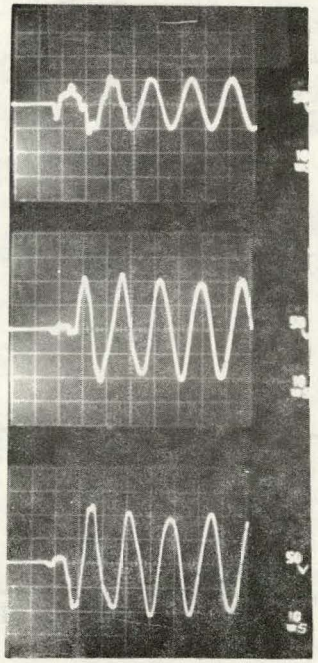
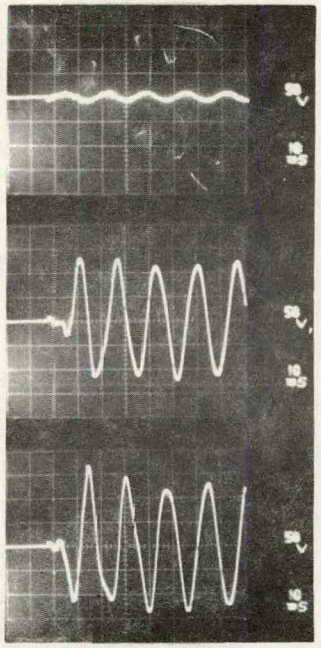
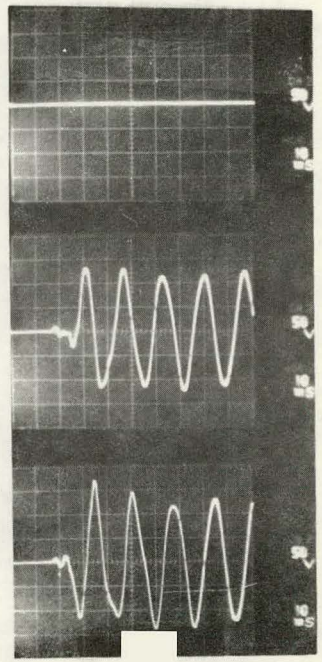
2.0 p.u.	1.2 p.u.	1.2 p.u.	1.6 p.u.	1.6 p.u.
$V_1 - 2$	V_2	V_3	V_4	V_5
				

CASE NO. D-22 ENERGIZATION INTO A SINGLE LINE TO GROUND FAULT



XO/X1 = 1.0

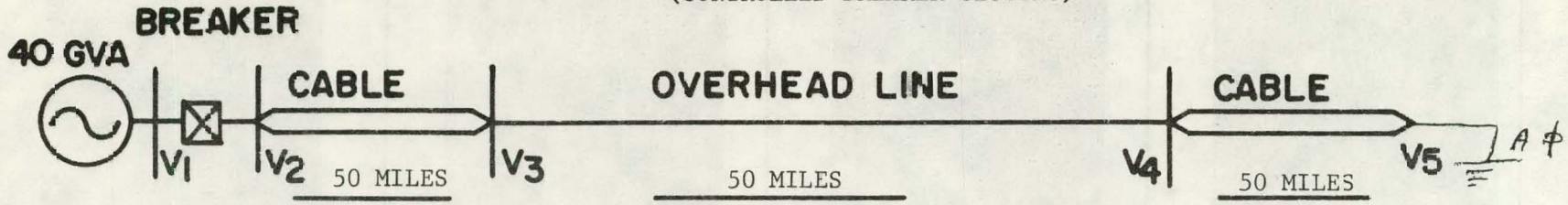
BREAKER RESISTORS	R_1 = 200 R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

1.0 p.u.	1.25 p.u.	1.25 p.u.	1.7 p.u.	1.7 p.u.
$V_1 - 2$	V_2	V_3	V_4	V_5
				

CASE NO. D-23

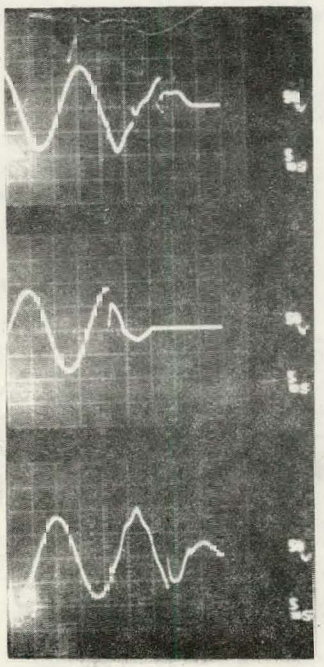
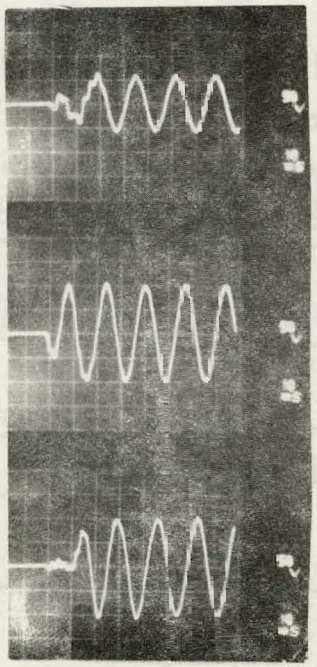
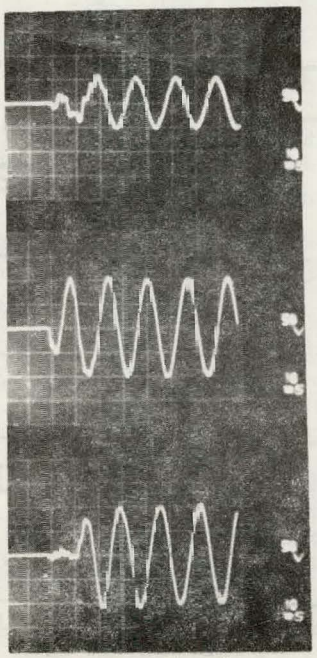
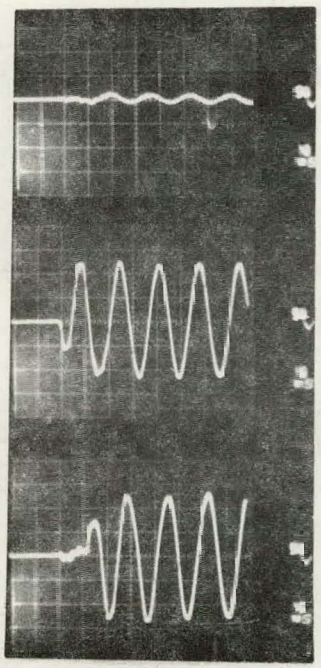
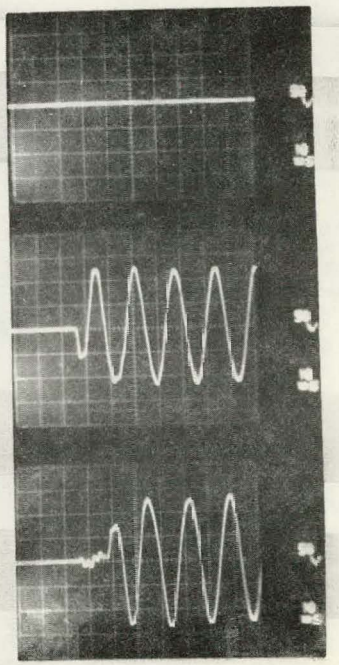
ENERGIZATION INTO A SINGLE LINE TO GROUND FAULT

(CONTROLLED BREAKER CLOSING)



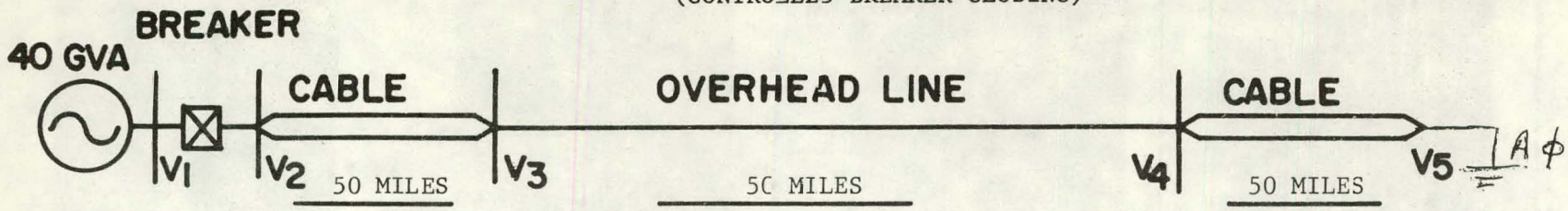
XO/X1 = 1.0

BREAKER RESISTORS	R_1 = 200 R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

1.0 p.u.	1.1 p.u.	1.1 p.u.	1.3 p.u.	1.3 p.u.
$V_1 - 2$	V_2	V_3	V_4	V_5
				

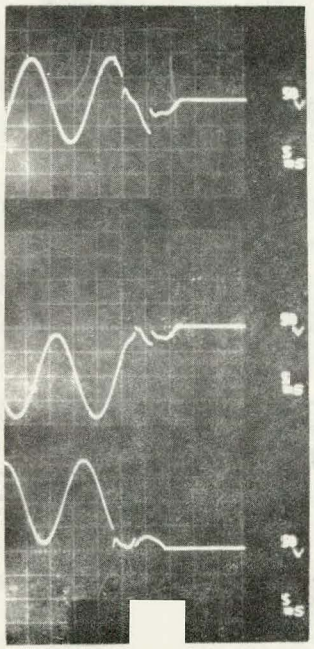
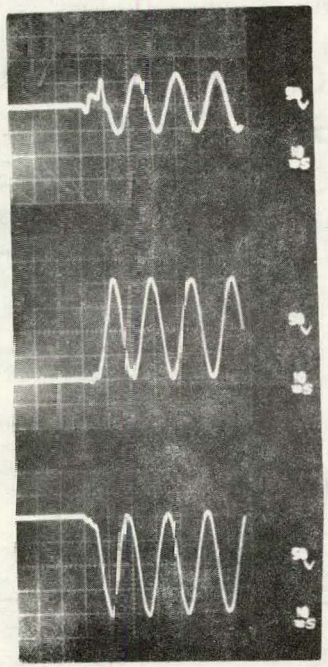
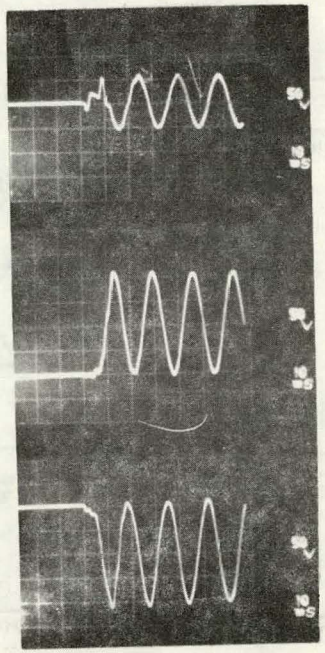
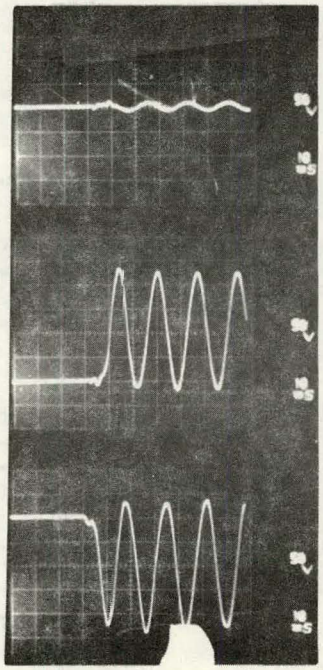
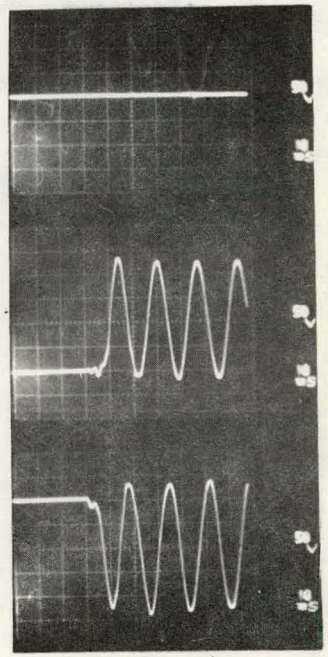
CASE NO. D-24 HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT

(CONTROLLED BREAKER CLOSING)

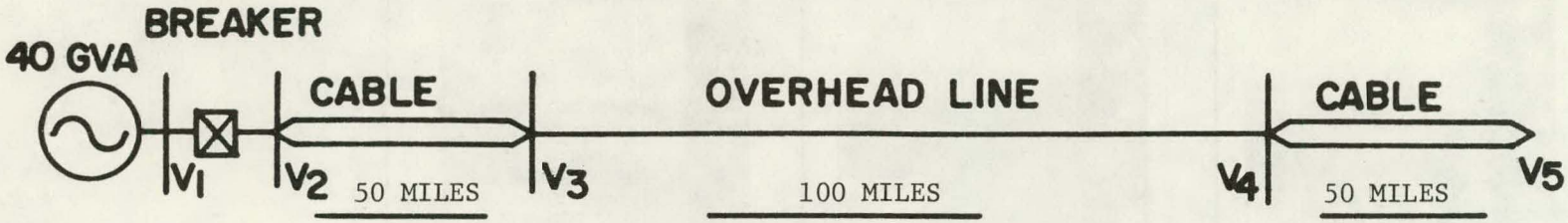


XO/X1 = 1.0

BREAKER RESISTORS	R_1 = 200 R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

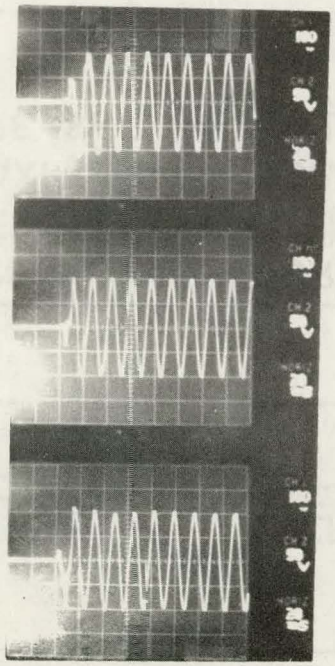
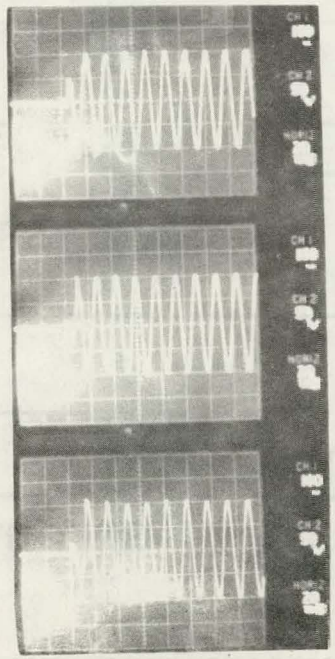
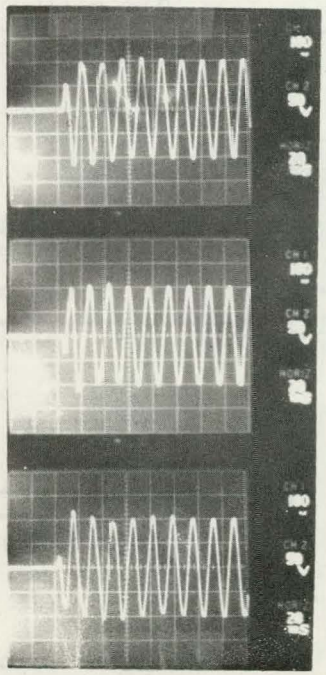
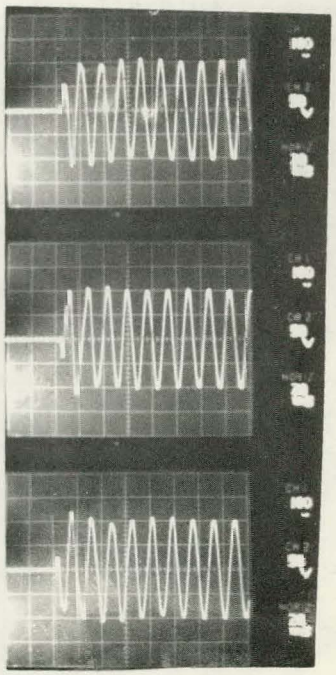
1.0 p.u.	1.1 p.u.	1.1 p.u.	1.4 p.u.	1.4 p.u.
$V_1 - 2$	V_2	V_3	V_4	V_5
				

CASE NO. D-25 ENERGIZE LINE

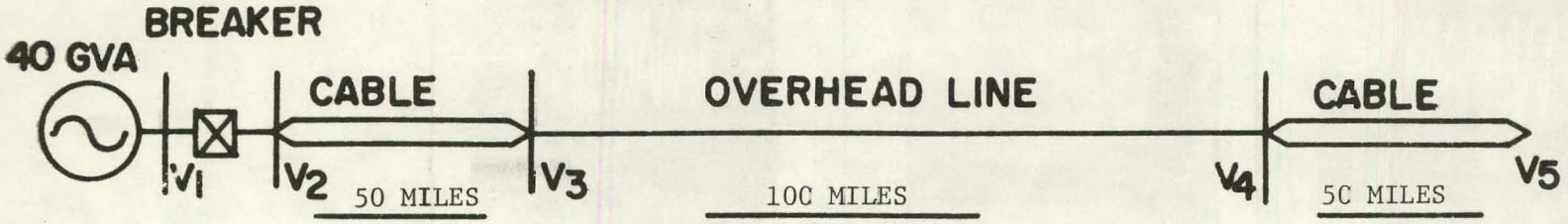


XO/X1 = 1.0

BREAKER RESISTORS	R_1 = 200 R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

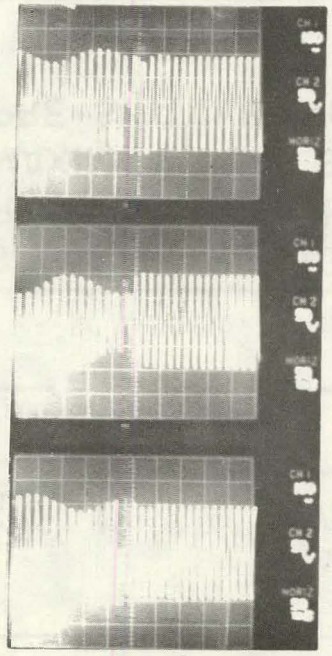
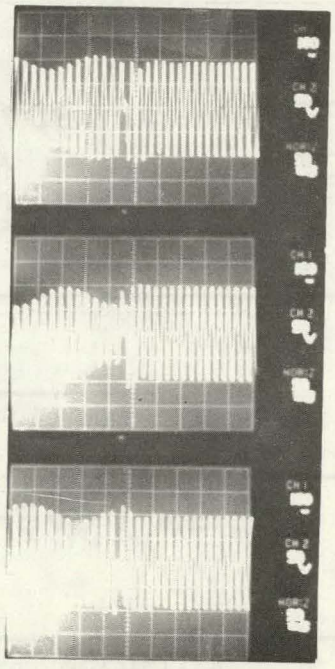
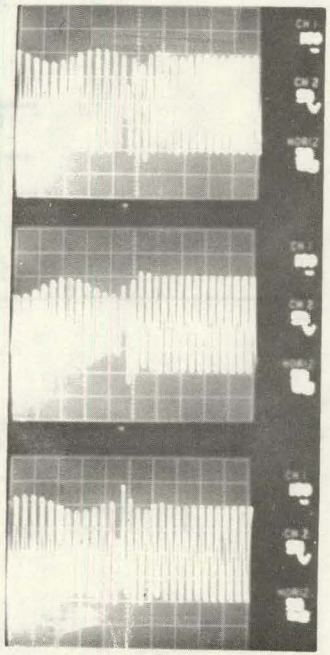
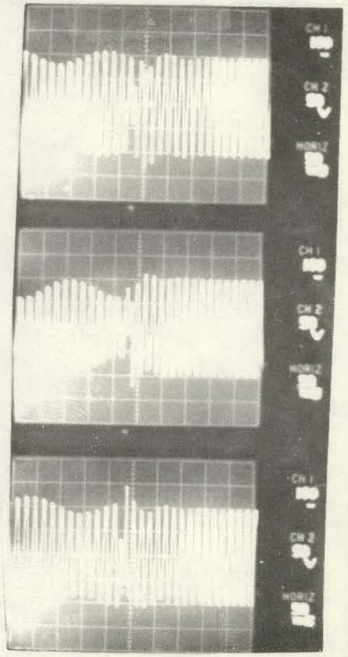
$V_1 - 2$	1.1 p.u. V_2	1.1 p.u. V_3	1.25 p.u. V_4	1.25 p.u. V_5
				

CASE NO. D-26 HIGH SPEED RECLOSING OF LINE

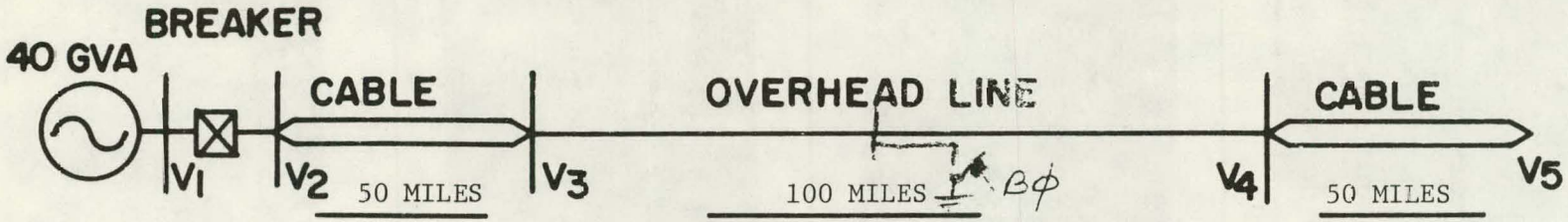


XO/X1 = 1.0

BREAKER RESISTORS	R_1 = 200	R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC	6 MSEC
MAXIMUM POLE SPAN	5 MSEC	
PRE-SWITCHED VOLTAGE	1.0 p.u.	

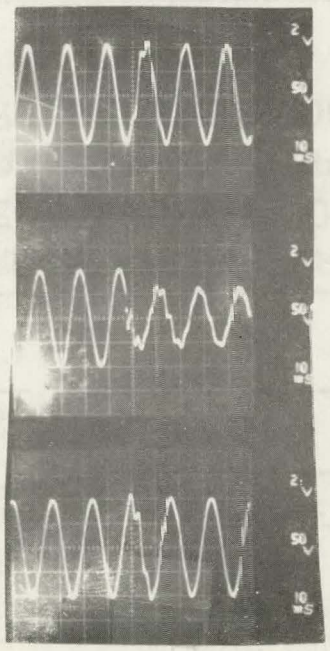
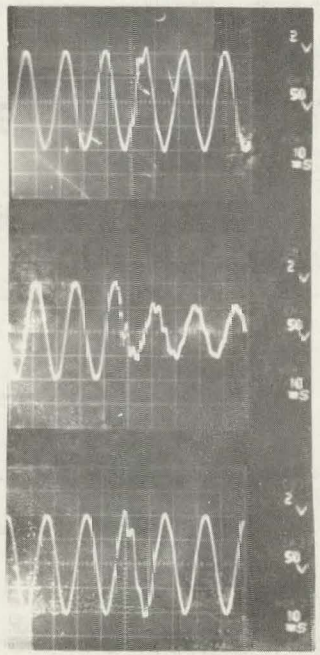
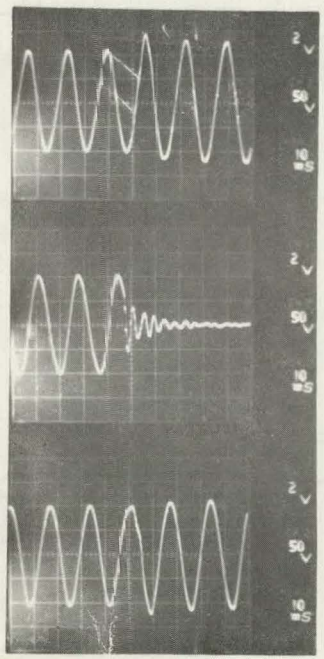
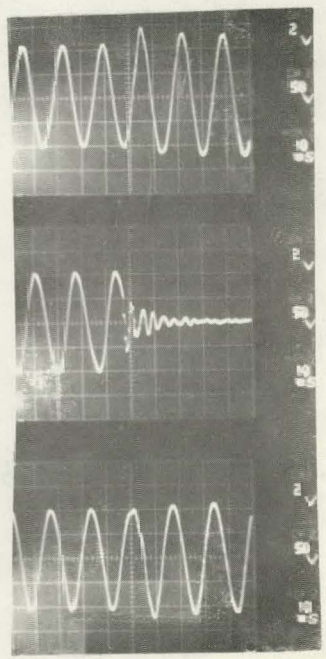
$V_1 - 2$	1.2 p.u. V_2	1.2 p.u. V_3	1.4 p.u. V_4	1.4 p.u. V_5
				

CASE NO. D-27 FAULT INITIATED OVERVOLTAGES



XO/X1 = 1.0

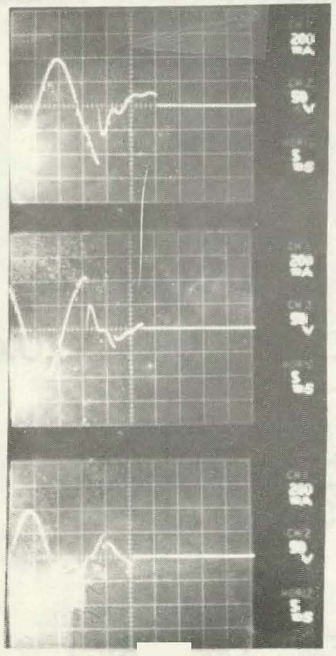
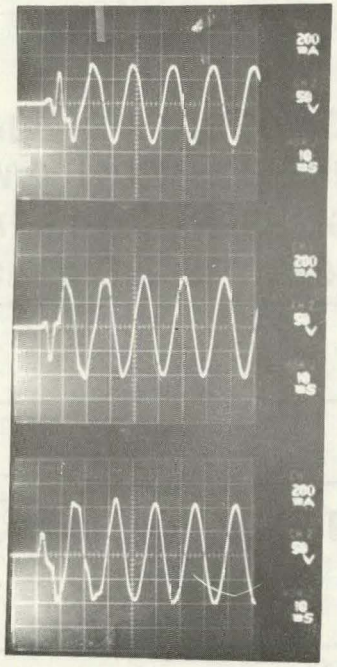
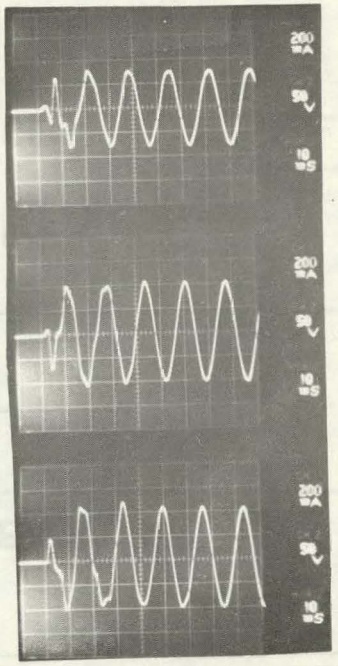
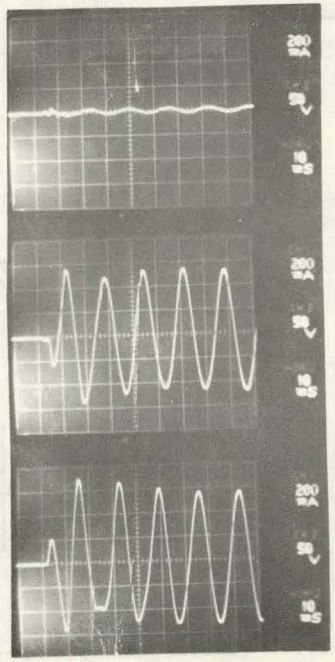
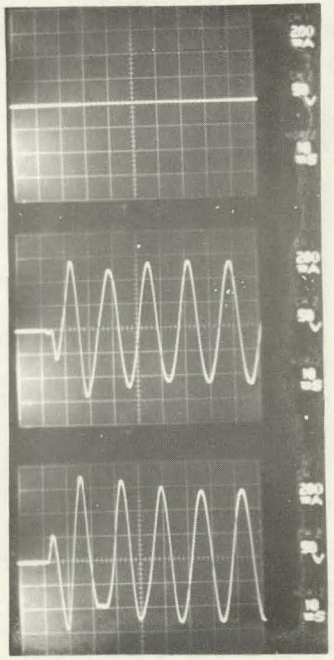
BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

$V_1 - 2$	1.15 p.u. V_2	1.15 p.u. V_3	1.45 p.u. V_4	1.45 p.u. V_5
				

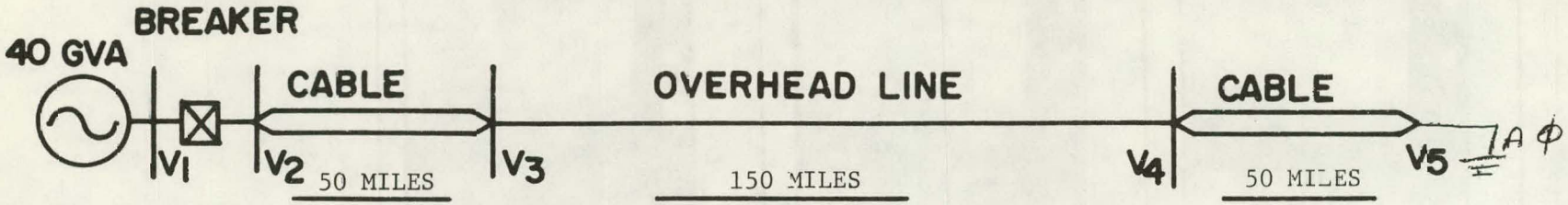
CASE NO. D-28 ENERGIZATION INTO SINGLE LINE TO GROUND FAULT

XO/X1 = 1.0

BREAKER RESISTORS	R_1 = 125 R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

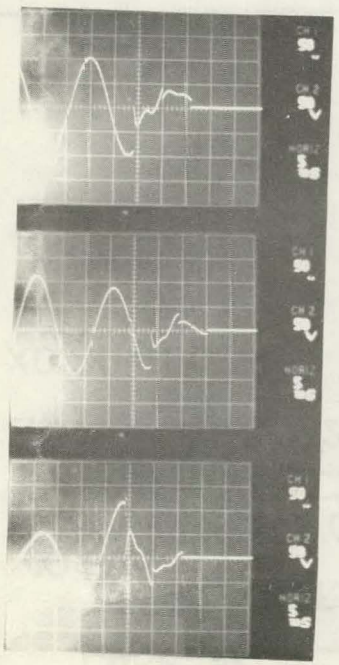
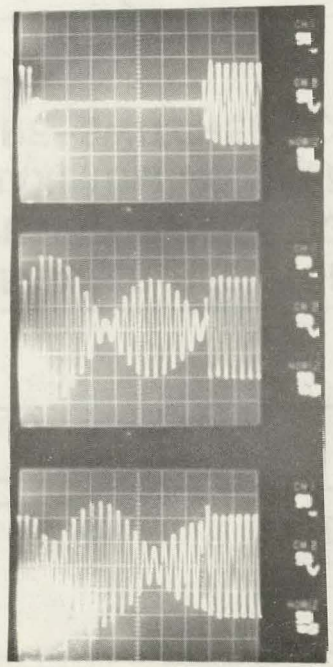
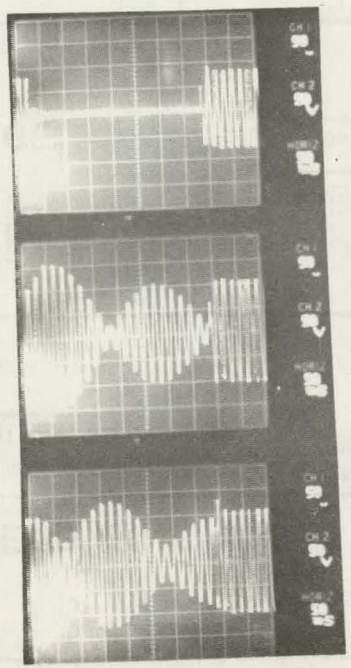
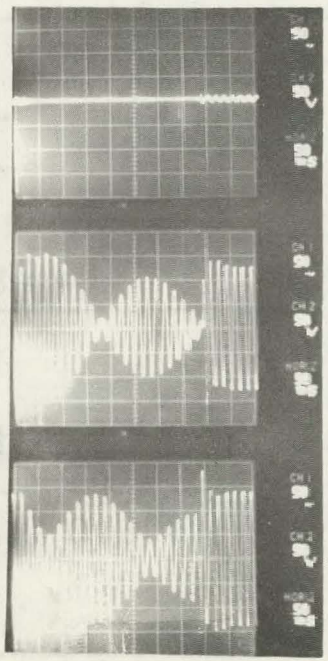
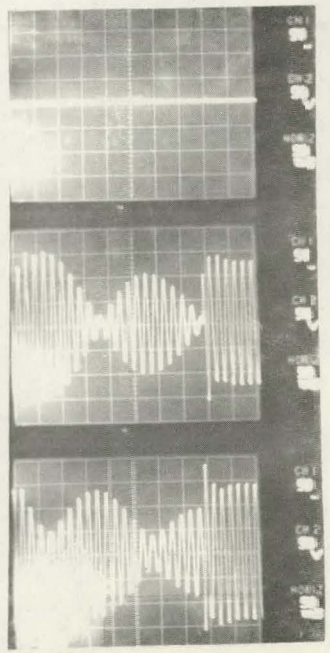
1.0 p.u.	1.2 p.u.	1.2 p.u.	1.7 p.u.	1.7 p.u.
$V_1 - 2$	V_2	V_3	V_4	V_5
				

CASE NO. D-29 HIGH SPEED RECLOSING SINGLE LINE TO GROUND FAULT

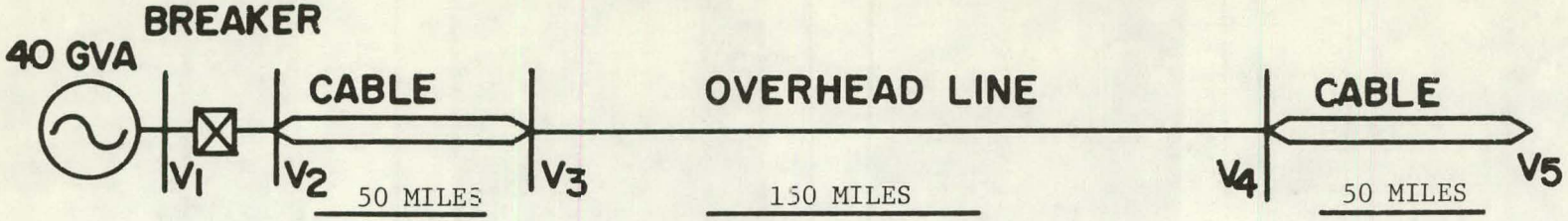


XO/X1 = 1.0

BREAKER RESISTORS	R_1 = 125 R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

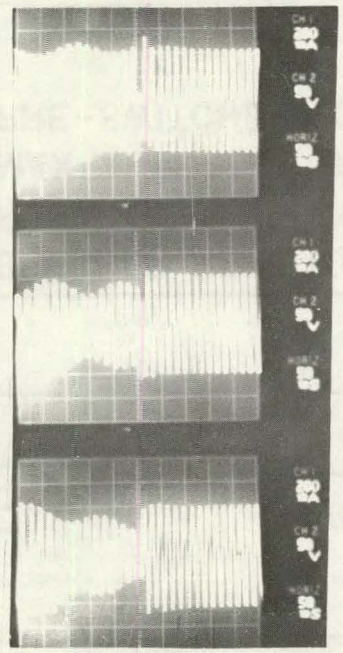
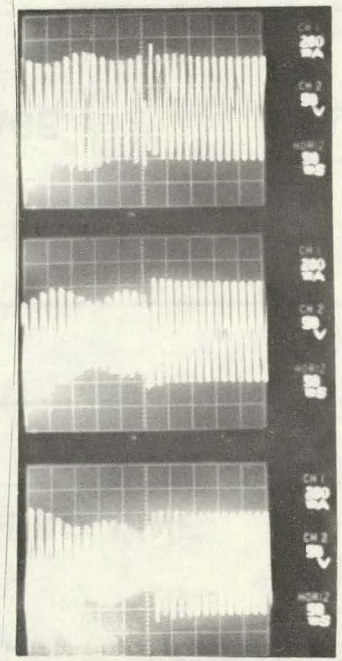
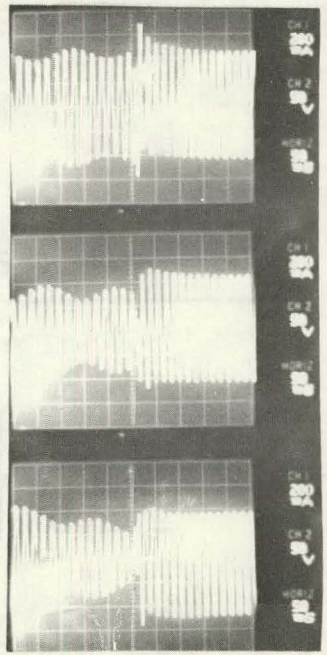
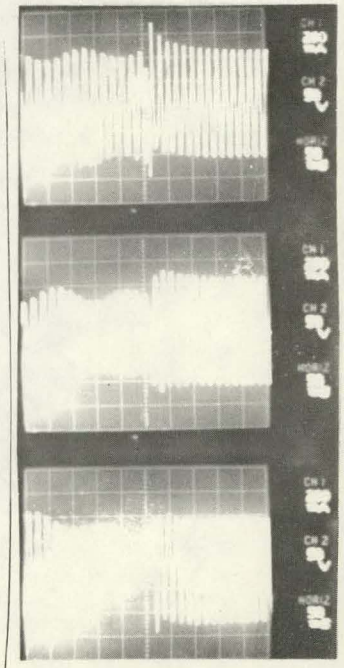
1.0 p.u.	1.3 p.u.	1.3 p.u.	1.8 p.u.	1.8 p.u.
V_{1-2}	V_2	V_3	V_4	V_5
				

CASE NO. D-30 HIGH SPEED RECLOSING OF LINE

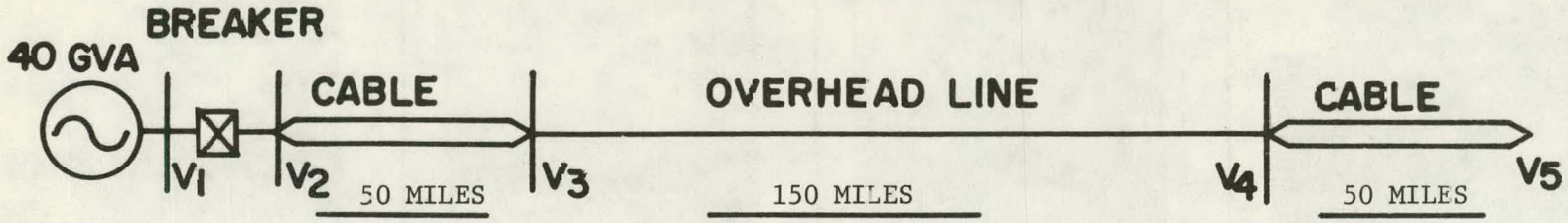


XO/X1 = 1.0

BREAKER RESISTORS R_1 = 125 R_2 = 50
RESISTOR INSERTION TIMES 6 MSEC 6 MSEC
MAXIMUM POLE SPAN 5 MSEC
PRE-SWITCHED VOLTAGE 1.0 p.u.

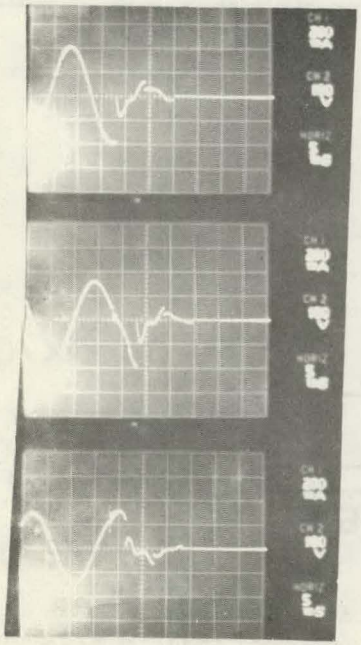
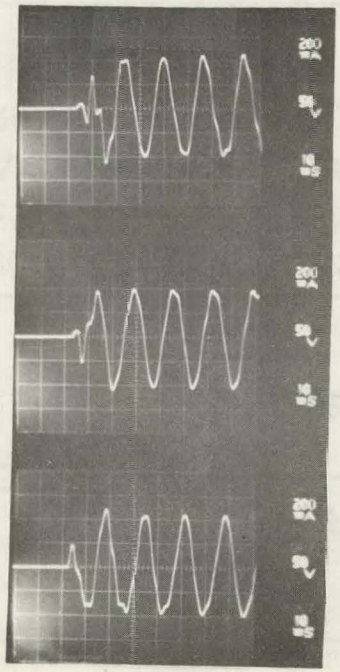
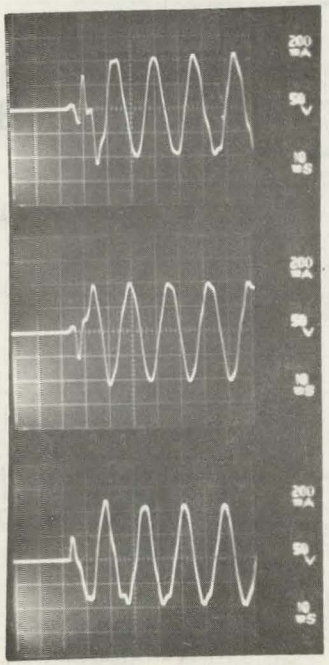
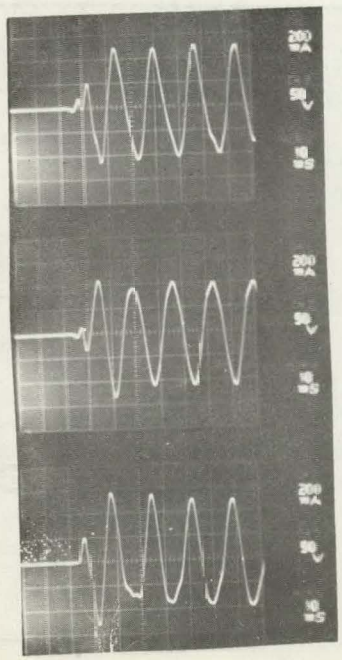
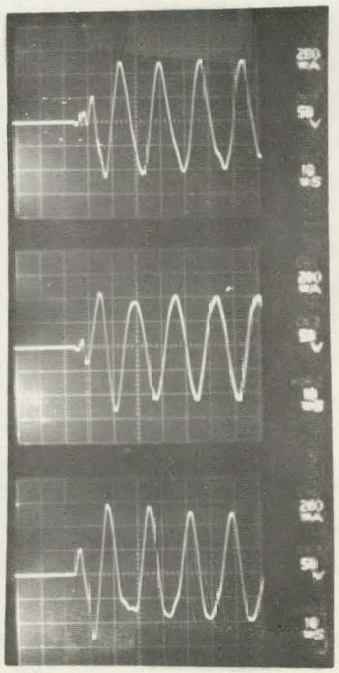
$V_1 - 2$	1.5 p.u. V_2	1.5 p.u. V_3	1.75 p.u. V_4	1.75 p.u. V_5
				

CASE NO. D-31 ENERGIZE LINE



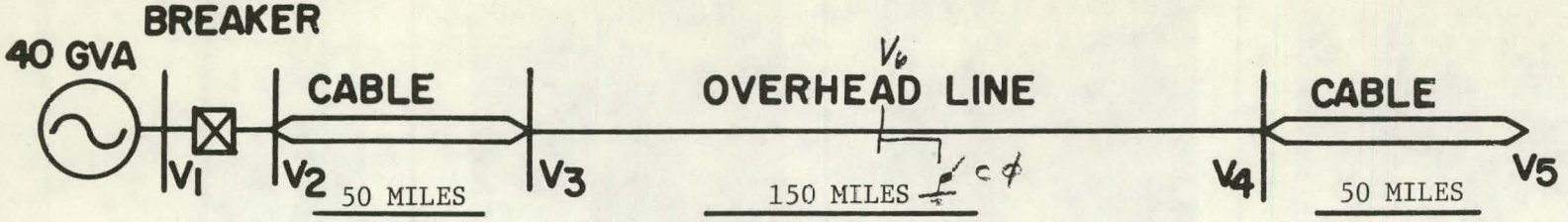
XO/X1 = 1.0

BREAKER RESISTORS	R_1 = 125 R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

	1.2 p.u.	1.2 p.u.	1.45 p.u.	1.45 p.u.
$V_1 - 2$	V_2	V_3	V_4	V_5
				

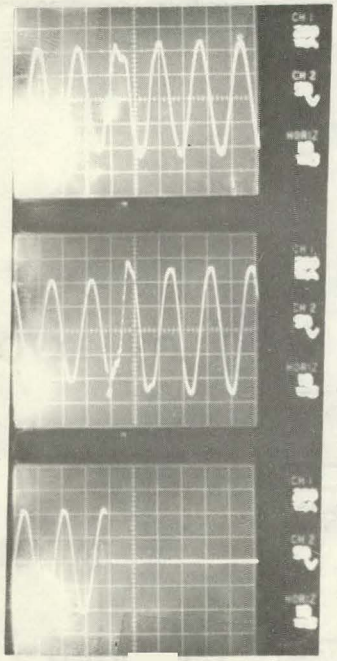
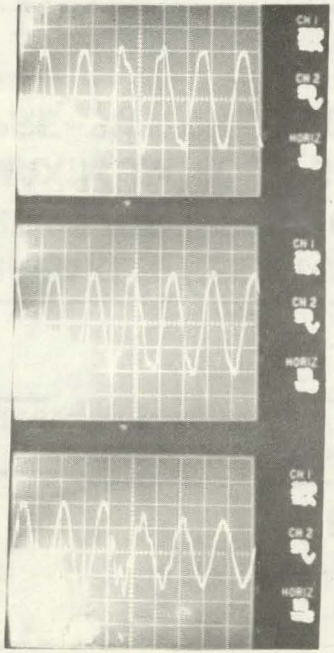
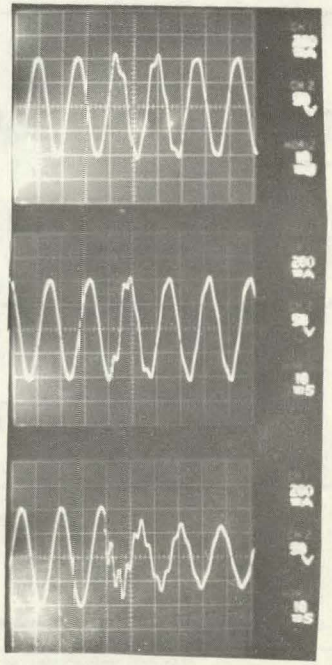
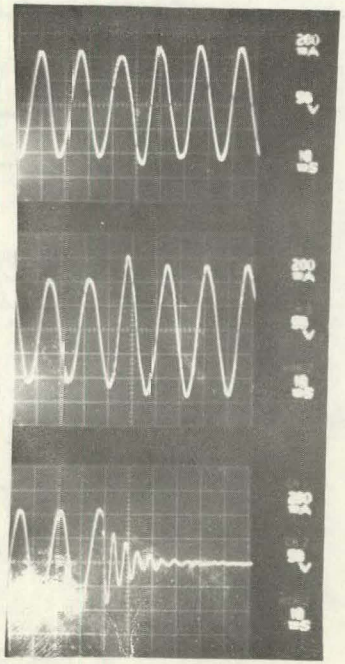
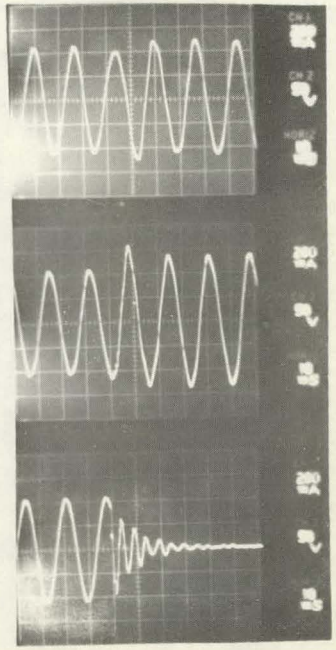
CASE NO. D-32

FAULT INITIATED OVERVOLTAGES



XO/X1 = 1.0

BREAKER RESISTORS	R_1 = - R_2 = -
RESISTOR INSERTION TIMES	- -
MAXIMUM POLE SPAN	-
PRE-SWITCHED VOLTAGE	1.0 p.u.

1.45 p.u.	1.1 p.u.	1.1 p.u.	1.55 p.u.	1.55 p.u.
V_6	V_2	V_3	V_4	V_5
				

CASE NO. D-33 HIGH SPEED RECLOSING INTO SINGLE LINE TO GROUND FAULT

(CONTROLLED BREAKER CLOSING)

XO/X1 = 1.0

BREAKER RESISTORS	R_1 = 125 R_2 = 50
RESISTOR INSERTION TIMES	6 MSEC 6 MSEC
MAXIMUM POLE SPAN	5 MSEC
PRE-SWITCHED VOLTAGE	1.0 p.u.

1.5 p.u.	1.2 p.u.	1.2 p.u.	1.6 p.u.	1.6 p.u.
$V_1 - 2$	V_2	V_3	V_4	V_5