Chapter 12

Operation and Operating Problems

Operation of power cables under their normal conditions of intended use seldom presents major problems. Reference data in previous chapters (mostly Chapter 9) enable the designer and user to predict voltage drop as a function of load and to specify the maximum current to be carried per conductor (at 100% or reduced load factors) on a thermal limitation basis. Circuit fuses, limiters, circuit breakers, cut-outs, etc., are usually selected or adjusted to limit the current in the cable to its design short-circuit capability, and relays, regulators, and signal circuits enable the load dispatcher to maintain the load within operating limits or control its extension into the emergency load range as required.

The basic relationship of kV, ampere, kW and kVA factors in the usual power circuit are well understood by designers and operating employees but, as a reminder, Fig. 12-1 is included. It lists equations for two-phase systems that are frequently encountered. The designation “star” is used instead of the term “Y-connected.” For the probable approximate ampacity loading of branch and main circuits for residential and light industrial uses, refer to NEC Articles Nos. 220, 230 and 430.

The load factors and corresponding loss factors that apply to the typical daily load curves are explained in Chapter 9. These factors are related to the heat-sink effect of the surrounding earth on conductors that are directly buried or are in underground ducts. A load factor of 100 percent is used for circuits in air or conduit in air. It is important to consider the worst case “limiting factor” when deciding the load carrying capability of a circuit.

Emergency Overloads

The conditions that permit the cable to be subjected to temporary emergency overloads, within recognized limits of good practice, were outlined in Chapter 9, and the emergency-load temperatures that the insulation can sustain are listed in Table 9-7. The load dispatcher, however, does not measure insulation temperature to indicate that the emergency-overload limit has been reached. Instead, he is supplied with the ammeter readings that correspond to the emergency-load temperatures. Precomputing of these ampacity values for the emergency-overload temperature is an operating problem solved by applying the constants from the ICEA—IEEE Ampacity Tables, described in Appendix 9A, principally Eq. 9A-1.

Example: 4/0 triplexed concentric standard rubber insulated cable in air; 40°C ambient; operating temperature 75°C; 15 kV

From Table 9A-2, rated ampacity is 233 amp and Delta TD is 0.50. What is the corresponding emergency-load ampacity if the emergency-load temperature of the insulation is 90°C?

Applying Eq. 9A-1

$$I_e = 233 \sqrt{\frac{90 - 40 - 0.50}{75 - 40 - 0.50}} \times \frac{228.1 + 75.0}{228.1 + 90.0} = 272 \text{ amp}$$

The Delta TD value is unchanged because it is assumed that the dielectric constant and insulation pf are the same at both temperatures.

Appendix 9A describes further adjustments of the above relationship for variations of ambient temperature, and properties of the insulation.

Short-Circuit Loading

Short circuits, either between the conductors of a power cable or from the conductors to ground or occurring in some part of the load being served by the cable, can cause a rapid rise of current values, as much as 100 times normal or more.

A discussion of short-circuit currents in aluminum conductors insulated with various materials is in Chapter 9 (see Figs. 9-5, -6, and -7). Additional information applying to bare conductors is in Chapter 6, and much of it is applicable to insulated conductors. The essential difference is that insulated conductors fail under short-circuit conditions because of loss of insulation value, whereas bare conductors fail because of loss of strength of the conductor caused by high-temperature annealing. The allowable temperatures under short-circuit conditions for insulated aluminum conductors are 150°C, 200°C, and 250°C, depending on the kind of insulation, as listed in Table 9-7.

The problem of system fault-current is beyond the scope of this publication. The reference to zero-sequence impedance of bare aluminum conductors in Chapter 3, applying to elementary circuits and to average earth resistance, may aid such calculations, but for network analysis and where terminal impedances must be considered, the method of computation is the same for aluminum as for copper, except for differences of electrical properties of the conductors.
covered and insulated aluminum wire and cable

Fig. 12-1. Diagrams and formulas showing relationships between electrical and power quantities in various types of circuits.

Some of the operating conditions that bring about short-circuits of various kinds are considered herein as a guide to what is to be avoided, if possible.

Short Circuits in Shields and Sheaths

Consideration should be given to the performance of the cable metallic shield under the influence of a line-to-ground fault.

Though several other metals are sometimes employed as sheath/shield material, (see Tables 12-4 and 12-5) copper is by far the most commonly used.

Cable shielded with these helically applied copper tapes or concentric servings of fine (20-24 AWG) copper wires have generally performed satisfactorily in the past because of relatively low fault currents and because these circuits were often installed in ducts in three-conductor groups with a bare ground conductor.

The increasing use of solid dielectric power cable on electric utility distribution systems with higher available fault currents underlines the importance of proper shield size for the expected fault duty.
Equation 12-1* gives the minimum effective cross-sectional area of metallic shield required for a given fault time period.

Table 12-1 shows the corresponding formulae for calculating the effective cross-sectional area of various types of sheaths/shields.

Table 12-2 shows the approximate shield normal operating temperature for various steady-state conductor operating temperatures for cables rated 5 kV through 69 kV.

### TABLE 12-1

<table>
<thead>
<tr>
<th>Type of Shield or Sheath</th>
<th>Formula for Calculating A (See notes 1 and 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Wires applied either helically, as a braid or serving; or longitudinally with corrugations</td>
<td>\text{nd}</td>
</tr>
<tr>
<td>2. Helically applied tape, not overlapped</td>
<td>1.27 \text{ nwb}</td>
</tr>
<tr>
<td>3. Helically applied flat tape, overlapped</td>
<td>\frac{4\text{bd}_m}{\sqrt{2(100-L)}} \text{ see note 3}</td>
</tr>
<tr>
<td>4. Corrugated tape, longitudinally applied</td>
<td>1.27 \left(\text{dis}+\text{B}\right) \text{ b}</td>
</tr>
<tr>
<td>5. Tubular sheath</td>
<td>\frac{4\text{bd}_m}{\text{n}}</td>
</tr>
</tbody>
</table>

**NOTE 1:** Meaning of Symbols

- \text{A} = \text{Effective cross-sectional area, shield or sheath.}
- \text{B} = \text{Tape overlap, mils (usually 375).}
- \text{b} = \text{Thickness of tape, mils.}
- \text{dis} = \text{Diameter over semiconducting insulation shield, mils.}
- \text{d}_m = \text{Mean diameter of shield or sheath, mils.}
- \text{d}_n = \text{Diameter of wires, mils.}
- \text{w} = \text{Width of tape, mils.}
- \text{n} = \text{Number of serving or braid wires or tapes.}
- \text{L} = \text{Overlap of tape, percent.}

**NOTE 2:** The effective area of composite shields is the sum of the effective areas of the components. For example: the effective area of a composite shield consisting of a helically applied tape and a wire serving would be the sum of the areas calculated from Formula 2 (or 3) and Formula 1.

**NOTE 3:** The effective area of thin, helically applied overlapped tapes depends also upon the degree of electrical contact resistance of the overlaps. Formula 3 may be used to calculate the effective cross-sectional area of the shield for new cable. An increase in contact resistance may occur after cable installation during service exposed to moisture and heat. Under these conditions, the contact resistance may approach infinity where Formula 2 could apply.

*From ICEA publication P-45-482, 2nd Edition, 1979. The user is cautioned to read this publication in order to fully understand the derivation and basis for this calculation and the associated parameters.

### TABLE 12-2

<table>
<thead>
<tr>
<th>Rated Voltage, kV</th>
<th>Shield or Sheath Temp. °C at Conductor Temp.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>95°C</td>
</tr>
<tr>
<td>5</td>
<td>90</td>
</tr>
<tr>
<td>15</td>
<td>90</td>
</tr>
<tr>
<td>25</td>
<td>90</td>
</tr>
<tr>
<td>35</td>
<td>85</td>
</tr>
<tr>
<td>46</td>
<td>85</td>
</tr>
<tr>
<td>69</td>
<td>80</td>
</tr>
</tbody>
</table>

**NOTE:** The maximum conductor temperature should not exceed the normal temperature rating of the insulation used.

Table 12-3 shows the maximum allowable transient temperature for shields in contact with various materials.

Tables 12-4 and 12-5 give the “M” values for use in Equation 12-1. As shown by the tables, the “M” values are constants and depend upon the shield material, the shield normal operating temperature and the maximum allowable transient temperature of the shield.

Example calculation: Determine the size copper wire shield required to carry a fault current of 10000 amperes for 10 cycles for a 15 kV XLP cable having a semiconducting thermoplastic insulation shield and a thermoplastic overall jacket.

**Step 1**
Determine the approximate shield operating temperature for 90°C conductor temperature (which is the maximum temperature for normal operation of XLP insulated cables). From Table 12-2:

- \( T_1 = 85°C \)

**Step 2**
Determine the maximum allowable shield transient temperature for the cable materials in contact with the shield, which in this case is thermoplastic. From Table 12-3:

- \( T_2 = 200°C \)

**Step 3**
Determine the “M” value for a copper shield with \( T_1 \) equal to 85°C and \( T_2 \) equal to 200°C. From Table 12-4:

- \( M = 0.063 \)
covered and insulated aluminum wire and cable

TABLE 12-3

<table>
<thead>
<tr>
<th>Cable Material in Contact with Shield or Sheath</th>
<th>T₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crosslinked (thermoset)</td>
<td>350°C</td>
</tr>
<tr>
<td>Thermoplastic</td>
<td>200°C</td>
</tr>
<tr>
<td>Impregnated Paper</td>
<td>200°C</td>
</tr>
<tr>
<td>Varnished Cloth</td>
<td>200°C</td>
</tr>
</tbody>
</table>

NOTE:
The temperature of the shield or sheath shall be limited by the material in contact with it. For example, a cable having a crosslinked semi-conducting shield under the metallic shield and a crosslinked jacket over the metallic shield would have a maximum allowable shield temperature of 350°C. With a thermoplastic jacket, it would be 200°C.

* For lead sheaths this temperature is limited to 200°C.

Step 4

Calculate the required shield cross-section for a fault duration of 10 cycles (0.167) seconds. Applying Equation 12-1:

\[ A = \frac{10000 \sqrt{0.167}}{0.063} = 64866 \text{ circular mills} \]

Step 5

Determine the number and size of the wires necessary to equal or exceed 64866 circular mils. Inspection of Table 12-1 shows that the effective cross-sectional area of a wire shield is equal to \( n d_a^2 \) or the number of wires multiplied by the circular mil area of each wire. The number required for any specific wire size is simply the total cross-sectional divided in step 4 divided by the individual wire circular mil area and rounded up to the nearest whole number:

Number of 14 AWG wires = \( 64866 \div 4110 \)

= 15.8 or 16

Similarly, the number of any other wire size may be determined:

\[ A = \frac{1 \sqrt{t}}{M} \quad \text{(Eq. 12-1)} \]

where: \( I = \) short-circuit current in shield, amperes
\( t = \) time of short-circuit, seconds
\( M = \) constant, see Tables 12-4 and 12-5

Causes of Insulation Failure

The majority of cable failures occur unexpectedly. Most often, the power dissipated in the failed area burns the insulation to the extent that the cause is destroyed.

Examination of the areas near the fault and the external appearance of the cable may also provide evidence which helps determine the apparent cause of failure. The reasons for insulation failures which are not obviously the result of physical damage may be found during laboratory investigation by electrically testing cable samples to destruction. A brief review of the most frequent causes found by this method is found in the following paragraphs.

Imperfections in extruded insulations are a major cause of failure. They are often found as voids, contaminants

TABLE 12-4

<table>
<thead>
<tr>
<th>Shield/Sheath Material</th>
<th>Values of M for the Limiting Condition Where ( T₂ = 200°C )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shield/Sheath Operating Temperature (T₁), °C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>90</td>
</tr>
<tr>
<td>Aluminun</td>
<td>0.041</td>
</tr>
<tr>
<td>Commercial Bronze</td>
<td>0.045</td>
</tr>
<tr>
<td>Copper</td>
<td>0.062</td>
</tr>
<tr>
<td>Lead</td>
<td>0.012</td>
</tr>
<tr>
<td>Steel</td>
<td>0.023</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.030</td>
</tr>
<tr>
<td>Cupro-Nickel</td>
<td>0.018</td>
</tr>
</tbody>
</table>

TABLE 12-5

<table>
<thead>
<tr>
<th>Shield/Sheath Material</th>
<th>Values of M for the Limiting Condition Where ( T₂ = 350°C )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shield/Sheath Operating Temperature (T₁), °C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>90</td>
</tr>
<tr>
<td>Aluminun</td>
<td>0.068</td>
</tr>
<tr>
<td>Commercial Bronze</td>
<td>0.086</td>
</tr>
<tr>
<td>Copper</td>
<td>0.088</td>
</tr>
<tr>
<td>Steel</td>
<td>0.032</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.044</td>
</tr>
<tr>
<td>Cupro-Nickel</td>
<td>0.028</td>
</tr>
</tbody>
</table>
operation and operating problems

or sharp projections into the insulation at the conductor shield or insulation shield interface. The presence of some voids is inevitable due to the chemical reaction and medium used to vulcanize insulation.

Contaminants are found in the raw materials purchased from reputable compound suppliers. To a lesser extent, they may also be introduced through inadequate quality control procedures and poor handling techniques at the cable manufacturing plant. Screens are used in the insulation extruders to help filter out solid contamination. However, some inevitably passes through into the cable insulation.

Sharp projections into the insulation may be formed as a cable is extruded. These create points of high electrical stress which can lead to premature cable failure.

In recent years, much has been learned about deterioration of insulation known as “treeing.” Treeing of two types is known to occur in solid dielectric cable — water or electrochemical and electrical. Treeing sites are usually at high stress points at the insulation/shielding interface or at voids or contaminants which cause discontinuities in the insulation. Such trees can be seen by optical examination when suitably stained and magnified. If cables without a moisture-proof barrier are operated in a wet environment, water trees will likely form at high stress points in the insulation since moisture can easily penetrate the insulation. It is believed that these trees will ultimately lead to cable failure. The failure mechanism is not completely understood. Cable manufacturers have introduced compounds which retard tree growth and much research is taking place to develop improved tree-resistant insulating materials.

The major cause of failure in paper insulated cable is sheath deterioration or rupture. This permits water or other harmful liquids to penetrate the insulated cable. Voids occur in such cable due to expansion of the cable core under electrical load. Upon cooling, the core can contract away from the sheath leaving voided areas. Ionization of the voids can polymerize the oil, forming wax. The wax may fill the voids and retard further ionization.

Surface discharge or tracking will deteriorate cable insulation. It may occur at cable terminations where the insulation is exposed. Serious discharge can also develop on non-shielded cable. In each of these instances, differences in voltage gradient on the insulation surface produces current flow. Over long periods of time, the current will erode and char the insulation, leaving tracks.

External Causes of Cable Failure

Failures of 600 volt cable are most often caused by mechanical damage. The cables are often directly buried at a shallow depth. Digging into the cable occurs quite frequently. Often, little attention is paid to the quality of the fill used to cover the cable. When tamped, sharp rock may pierce the insulation. Also, multiple cables may be laid across each other or in such close contact that poor heat dissipation results in insulation embrittlement.

Other trouble may occur from poor connections, inadequate short-circuit protection and contact with harmful chemicals. Occasionally, water may enter the conductor from inadequate or non-existent sealing. Conductor corrosion can result, particularly in aluminum cable.

High voltage cable is usually carefully installed and protected. Thus, mechanical damage is less prevalent. “Dig-ins” do occur, however. Cables that are plowed in are susceptible to damage unless care is taken to feed them into the equipment smoothly, without jerking. In some areas of the country, rodents attack buried high voltage cable. For these conditions, special metal protected cables are often used.

Installation and Maintenance Proof-Testing

Proof-testing is an accepted procedure by which higher than normal operating voltage is applied to cable. Most often this is done on high voltage cable after installation and before the cable is placed in service. The test is quick and simple, only requiring the cable to withstand the voltage for a period of minutes. However, a short time test can only detect gross defects or damage.

Normally, d-c voltage is applied because such equipment can be made lightweight and portable. Often, leakage current is read and recorded. However, the readings can vary greatly since leakage is readily influenced by the condition of the terminations. Humidity, cleanliness and the leakage distance all permit wide variations which may be mistaken for insulation deterioration. Leakage current is of value if a record is maintained over a long period of time. In this way, comparison from one year to previous years will indicate any deterioration.

Table 12-6 lists the present industry-recommended voltages after installation and for subsequent maintenance evaluation.

Fault Location

The necessity of developing good cable-fault locating techniques is probably more important today than ever before. The growing direct-buried residential distribution system has dramatized the need for reliable techniques to pinpoint cable faults as quickly as possible to minimize downtime and unnecessary excavating. Many power utilities are now staffed with well equipped, specialized crews, trained in the methods for locating faults.

The following material outlines in general the types of equipment commercially available for the many different kinds of fault conditions. Unfortunately, no one piece of apparatus is sufficient in itself. However, they are divided into two general categories, as follows:
Terminal Equipment — is employed where the entire test and determination of the fault location is made at one or more terminals of the cable.

Tracer Equipment — is employed where some form of electrical signal is injected into the cable at one of its terminations. The signal is traced to the fault by patrolling the cable with some form of detector used as a signal sensor.

**TABLE 12-6**

<table>
<thead>
<tr>
<th>dc Proof Test Voltage (kV)</th>
<th>After Installation (15 minute duration)</th>
<th>During Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Voltage kv</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>5.0</td>
<td>35</td>
<td>25</td>
</tr>
<tr>
<td>8.7</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>15</td>
<td>55</td>
<td>40</td>
</tr>
<tr>
<td>25</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td>28</td>
<td>85</td>
<td>65</td>
</tr>
<tr>
<td>34.5</td>
<td>100</td>
<td>75</td>
</tr>
<tr>
<td>46</td>
<td>120</td>
<td>90</td>
</tr>
<tr>
<td>69</td>
<td>170</td>
<td>125</td>
</tr>
</tbody>
</table>

**NOTE:**
When equipment such as cable terminals, motors, transformers, etc. are connected to the cable circuit voltage, limitations of such equipment may require the use of lower values. In such instances, it would be advisable to contact the equipment manufacturer before testing. It is recommended the rate of increase of the voltage to the desired value be done uniformly. The voltage level should be reached within 60 seconds but not sooner than 10 seconds. The voltages in the table are 60 percent and 60 percent respectively, of the factory dc test voltages applied to the cable prior to shipment.

Identify and Isolate
The faulted section in any branch circuit should be clearly identified, de-energized and isolated. For all of the locating techniques discussed here, it is necessary to disconnect and free all terminals. Ground connections may be left intact, if desired.

The fault resistance can be measured with an ohmmeter or megohmmeter and then classified as a parallel or grounded fault (conductor-to-conductor, conductor-to-sheath or conductor-to-ground) or a series or open fault (open circuit or excess resistance in series).

In many cases, the relative magnitude of resistance determines the type of equipment to be used to achieve good results. High resistance sometimes requires reduction of the fault resistance by “burning.”

**Location**
The method of locating a fault is influenced by such variables as type of cable, fault resistance and equipment available. Having meggred the affected circuit, several important factors are determined:

- Parallel Fault — Conductor-to-conductor
  - (grounded)
  - Conductor-to-sheath
  - Conductor-to-ground
- Series Fault — Open circuit
  - (open)
  - Open sheath

**Fault Resistance**
The types of equipment described below are among those commercially available which can, individually or in combination, locate power cable breakdowns. The Cable Radar Test, Bridge and Capacitance Instruments are classified as terminal instruments since they provide an approximate location as a percentage of circuit length. The longer the length, the greater the actual error, therefore, additional equipment is usually required to pinpoint the exact fault location.

Pulse and tone generators with companion detectors (Acoustic, Electromagnetic, Earth Gradient) are known as tracer methods and these function without knowledge of the circuit length. The tracer methods apply an input signal to either end of the faulted cable. The signal is then physically traced along the cable route until a change is detected which will reveal the location of the fault.

**Radar**
Radar transmits a series of high frequency pulses along the cable and observes the reflections from changes or discontinuities. In essence, it takes an electronic picture of the cable under test and displays it on an oscilloscope. The time required for the generated pulse to reach a discontinuity and return is measured, converted to feet and shown on a digital display. Locations better than 1 percent of the range are possible for circuits up to 80,000 feet.

For parallel faults, the fault resistance should be less than 2000 ohms. However, no limitation is placed on open circuits, loose connections or series type faults.

**Bridge**
The Murray-Loop Bridge with numerous variations has been used for many years to calculate parallel fault locations. The faulted conductor is normally joined to a similar unfaulted conductor and the bridge measurement made on the resulting loop at the opposite open end. The fault resistance should be relatively low. Higher sensitivity is possible in a high voltage adaptation of the bridge where fault resistance can be as high as 5 megohms.
A low voltage version inverted Murray-Loop Bridge having electronic null indicator can provide good results with fault resistance as high as 200 megohms. Accuracies within 0.5 percent of the loop length are possible with resolution to 0.01 percent.

**Capacitance**

A capacitance bridge is useful on very high series resistance, open-circuit faults. The capacitance of conductor-to-shield fault is measured from one end of the de-energized circuit. Knowing the capacitance per unit length, the distance to the open circuit can be calculated. This location can be verified by repeating the procedure from the remote end. Accuracies within ± 3 percent are possible.

**Impulse Generator (Thumper)**

High voltage, high energy impulses generated from a capacitor bank are applied to one end of a faulted circuit. The impulse energy in the form of a traveling wave will either dissipate noiselessly at a low resistance fault or spark-over (break down) at a high resistance fault. The spark-over results in an explosive release of sound, light and current at the fault location.

For the low resistance discharge, the location can be detected by an electromagnetic or earth gradient device. For the high resistance discharge, the location can be detected as an audible thump or an amplified thump with the aid of the acoustical detector. The electromagnetic and earth gradient devices may also be used for the high resistance discharge.

**Earth Gradient Detection**

This detector system is used to pinpoint high and low resistance faults on direct-buried non-shielded cable. A continuous d-c, interrupted d-c or audio tone is applied at one end of the faulted cable, similar to the impulse generator but is usually limited to 1000 volts. The current through the fault will travel back to the generator ground connection via the earth, thereby creating a voltage gradient. A compatible detector measures the gradient between two movable earth probes. The probes are applied as a pair over the surface route in football chain fashion. The accuracy with this method of detection is extremely high.

**Acoustic Detection**

The sharp report of the periodic discharging from a high-resistance fault reveals the location when exposed. On direct-buried cable this can be heard as a dull thump on the surface through several feet of earth; however, an acoustic pickup detector is applied along the surface to amplify a weak thump and thus locate the fault at the point of maximum intensity.

**Electromagnetic Detection**

The field generated by any transmitted impulse along a cable is sensed by means of an electromagnetic pickup coil and detector. Often, at the fault, there is a change of signal strength and if a d-c impulse is used there will be a change in the signal direction.

The electromagnetic surface coil can also be used to trace the cable route and a sheath pickup coil can be used to find faults on ducted cable.

**Audio Tone**

As a preliminary step of fault locating, a low voltage audio frequency (e.g. 1000 Hz) is sometimes matched to one end of the cable in order to transmit a signal. A selectively tuned pickup coil and amplifier is used to trace the signal which can indicate a null or peak over the cable route.

On direct-buried non-shielded cable, the same pickup coil can be used for earth gradient fault location. Some tracers also respond to energized 60 Hz current and incorporate filters for dual operations.

**Burndown**

The level of fault resistance must sometimes be reduced to enable pinpoint location with some methods. This is true for radar, Murray-Loop Bridge and some signal generators. Fault resistance may be reduced by burning the insulation at the fault with a repeated arc, or continuous ac or dc current.

A high voltage d-c, impulse or a-c resonant generator may be used to initiate the lowering of fault resistance. Ac without resonance would lose considerable effect in capacitive charging current.

**Recommendations**

Generally most faults can be detected successfully by selecting a limited number of methods and equipment.

**Recommendations:**

*High voltage, shielded conductor faults in a trench lay system* — should first be generally located with radar. An impulse generator with the appropriate detector, either electromagnetic or acoustical, can then be applied to pinpoint the exact fault location.

*High voltage, shielded conductor faults in a conduit system* — should be located with a radar set and impulse generator as with trench lay systems. However, the impulse generator with detector is usually sufficient in most instances.

*Low voltage trench lay, non-shielded, insulated neutral cable fault* — can be very successfully located with any of the voltage gradient devices available. Faults can be located quickly with excellent accuracy.

*Low voltage, non-shielded cable faults in a conduit* — can usually be located with a bridge. However, most repairs on this kind of system can be more economically performed by replacing the faulted cable section.