CHAPTER 5

UNDERGROUND AND SUBMARINE CABLES

Section 1 - ASSOCIATED GUIDANCE

5-1. Relevant cable guidance.

Maintenance work involving underground or submarine cable changes requires an understanding of the basic design premises of such cables.

a. Types of installations. Underground cables may be installed in conduit, in duct banks, or by direct burial in the earth; submarine cables are usually submerged directly in the water and lie on the bed of the waterway. The terminal ends of both underground and submarine cables are often above-ground. The burial depth of raceways or cables should never be less than the depths permitted by the NEC or the NESC and, in most cases, will be more to conform to facility design practice.

(1) *Cable in conduit removal freplacement.* Although it is easy enough to install several cables in one conduit and mechanically easy to withdraw them, the removal usually ruins the cable. Cables become impacted in a conduit, and, when one is drawn out, the sheath may be stripped either from the withdrawn cable or from one of the other cables. Therefore, when one cable of a set in a conduit fails, all cables must be replaced.

(2) Direct-burial cable reinstallation. Direct-burial cables being replaced must be installed below the frost line.

b. Joint electric supply and communication circuits. Unlike aerial lines, joint structure use is not allowed for electric supply and communication circuits. Communication cables are installed to be completely isolated from electric power cables and require separate ducts and structures. Economy may dictate contiguous structures and duct lines having a common trench excavation. Direct-burial power and communication lines should be separated at least the minimum required distance, usually set by the local communication agency. Control, alarm signalling, and other low-current and low-voltage circuits may be installed in electric manholes, dependent upon facility requirements, but require special shielding or increased insulation levels.

5-2. General construction guidance.

Rights-of-way for navigable waters and identification must meet the following requirements. The influence of conditions which can generate cable failures in the following discussion should be checked for their impacts.

a. Rights-of-way requirements. When the system is being extended across navigable waters within the United States, permission must be obtained from the nearest District Engineer of the U. S. Army Corps of Engineers, who will specify depth requirements and any other pertinent conditions. When crossings are made in waterways under the jurisdiction of other authorities, those authorities should also be consulted.

b. Identification requirements. Because underground and submarine cables cannot be visually traced between structure access points, it is important that they be marked at all points at which they are accessible. Any such cables will be identified by plastic or corrosion-resistant tags wherever they can be worked on and wherever they can possibly be mistaken for another cable. Identification tags will be located at terminations and at least in every structure. If tags become missing or illegible, they will be replaced as part of the maintenance program.

c. Cable impacts. The major cause of electric failure is the breakdown of insulation. Even under normal conditions, an electrical cable experiences stress that will gradually weaken it, leading to failure. Cable tests provide data which permits the anticipation of cable failures. An understanding of items which can accelerate insulation deterioration is of help in determining inspection and testing intervals.

(1) *Cable Loading.* The current-capacities or allowable loading of underground cables is based on the conductor size, material, and assumed ambient temperatures. Complex calculations are required to take all these effects into account. IEEE S-135-1 and IEEE S-135-2 are used as the basis for ampacities given by the NEC. The factors used by the NEC represent a theoretical average value and may be considered to be safe factors, especially if the loading is based on a loo-percent load factor. The load factor for primary circuits on most facilities will probably range from 45 to 65 percent at the time of initial design. Voltage drop, especially at lower voltages, may also have been a factor in determining the cable sizing. The actual temperature conditions affecting the cable become an important consideration. Added loads and variable loads affect cable temperatures both directly and indirectly.

(a) Directly. In general, the higher the temperature, the faster the rate of deterioration in the physical properties of the insulation, including the formation of voids in solid-type or paper-insulated

cable. The deterioration usually results in increased dielectric losses and decreased dielectric strength. Large variations in daily temperatures accelerate the possibilities of cable sheaths cracking and bolted or clamped connections loosening. A, short-time large overload, and accompanying high temperature, can produce aging of insulation equivalent to operation for a longer time at a smaller overload. Since power surges contribute to cable aging, a cable serving large motors with full-voltage starters having intermittent loads, or a cable subjected to a higher level of lightning or switching surges, will probably have a shorter life than an identical cable with a constant load and infrequent low-level switching surges.

    (b) Indirectly. The temperature of the soil adjacent to a buried cable or conduit system must also be considered as affecting cable life. If cable temperatures become high enough, the moisture in the soil will migrate away from the cable causing a considerable increase in the soil thermal resistivity. This may lead to thermal instability of the soil and further increase its thermal resistivity which, in turn, may cause excessive cable temperatures and, perhaps, even cable failure.

    (2) *Cable insulation failure.* Underground primary distribution cables with solid-dielectric insulation have experienced a high rate of electrical failure after several years of operation as the result of carbonized paths (electrochemical tree design markings) usually caused by the presence of water in the conductor.

    d. Termination and splicing impacts. Terminations and splices are usually the weakest point in a cable system, and the cable system is usually the weakest link in an electrical system. Therefore, inspection, including riser pole inspections, is doubly important at these points. Where recabling is required do not use "T" splices in manholes, except where the facility's engineering staff concur that avoiding their use is uneconomical.

    e. Lightning protection and grounding. Lightning protection for aerial to underground primary cable connections, and grounding and bonding of underground cables, contribute to the protection of the cables and to the safety of the system.

    (1) *Surge arresters.* When a transition is made between overhead conductors and underground or submarine primary cables, facility practice requires that a surge arrester be installed at the termination connecting insulated underground cables to aerial bare conductors. A ground rod should be installed and the metallic sheath or armor of the cable bonded to that ground installation. The surge arrester then protects the primary cable from switching or lightning surge overvoltages which could overstress the cable insulation. Secondary cables are usually protected from these over-voltages by primary surge arresters located at pole or ground-mounted transformer installations.

    (2) *Grounding and bonding.* All noncurrent-carrying conductive materials in the structure and any neutrals must be grounded. Most standard structures are provided with a driven ground rod. Bonding includes the metallic sheath or armor of all cables, cable shields, manhole hardware, the tanks of all equipment and apparatus, and the secondary neutral of transformer installations. Where nonmetallic-sheathed cable having a ground wire is used, the ground wire is usually brought out at the joint. These ground wires should be grounded to the neutral and the driven ground The resistance of ground connections must meet the requirements given in chapter 10, section III.

Section II - SAFETY PRECAUTIONS

5-3. Cable safety.

The compact spacing of conductors and nearness to any grounded sheaths is the reason that working on energized conductors even at low voltages is prohibited. A voltage detection tester should be used to ensure that the cable is not energized. Materials such as a lead sheath, which will act as a shield, must not be between the tester and the conductors of the circuit being tested. To prevent a de-energized circuit from being energized while it is being worked on, good safety practice requires that the disconnecting means at each end be tagged and locked in the open position, and ground clamps applied.

5-4. Structure safety.

Subsurface structures such as manholes, handholes, equipment vaults, and splicing boxes are subject to accumulation of dangerous gases that may be combustible and/or explosive, toxic, or deficient in oxygen. Before entering any manhole or vault, it must be checked for these conditions.

    a. Combustible gases. Combustible gases may be detected by means of a test instrument or safety lamp. When using this equipment, the precautions and instructions provided by the manufacturer should be followed. If it is determined that combustible gases are present, it will be necessary to ventilate the manhole or vault before any work is done.

If these tests indicate the presence of an explosive mixture in the structure, an injection of carbon dioxide (CO,) into the structure may be made, before ventilating, to reduce the possibility of an explosion. Ventilation is best provided by a power-driven portable ventilating blower. Before the structure is purged with a blower, or CO, is injected into it, personnel in connecting structures should be warned, as the gas may be blown through the ducts into connecting structures. If CO, is used, the structure must be purged with fresh air before it is entered by personnel.

b. Toxic gases. A calorimetric indicating gel tube manufactured under specifications of the National Bureau of Standards, commonly referred to as the NBS carbon monoxide detector, is available to test for toxics. It is used by breaking the seals of the tubes and aspirating gas to it from the atmosphere to be tested. Chemicals within the tube change color when carbon monoxide is present. By comparing the change in color with the color chart furnished, the concentration can be determined. Tests of this type can be made in less than one minute.

c. Asbestos-cement fireproofing. Follow instructions for handling in chapter 15, section II.

d. Ventilation. Even when tests indicate there are no combustible or toxic gases, it is good practice to force-ventilate a manhole or vault whenever personnel are in it. This is especially important if cable splicing is being performed.

e. Protection of open structures. Open structures should never be left unguarded. A barricade should be placed around the structure opening prior to removing the structure cover.

f. Ladders. Portable ladders used for access to manholes or vaults should be checked before use to ensure that they are firmly placed and will not wobble or tilt.

Section III - INSPECTION

5-5. Frequency of underground system inspections.

The frequency of inspection is largely determined by the importance of the equipment or facility it serves or contains. Inspections can vary in frequency from 6 months to 5 years, but a 2-year cycle of inspection is recommended. Records should be kept of each inspection.

5-6. Structure inspections.

Inspect structures and check their cleanliness and their physical condition, such as cracking of walls, roofs, or floor slabs, spalling of concrete, and the condition of frames and covers. Inspect for corrosion of pulling eyes; driven grounds; and other miscellaneous fixtures such as cable racks, arms, and insulators.

5-7. Cable inspections.

Walk the route of underground direct-burial cable circuits to inspect for changed conditions. Changes in grade caused by washouts can expose cables to damaging conditions. Adjacent new construction should be closely monitored. Examine connections to equipment terminals or cable terminations, whether in the structure or above-ground. Check in structures for the condition of duct entrances, fireproofing, splices, cable tags, and ground connections to cable shielding and sheaths. Anchors for submarine cables should be inspected occasionally to be sure they are in good condition and functioning as intended. Look for signs of traction on cable terminations or direct-burial cable which may be a result of expansion and contraction of the cable.

a. Cable supports. Check mountings and supports to ensure they are secure. Remove rust and corrosion and clean and repaint supports with corrosion-resistant paint.

b. Duct entrances. End bells are usually used to prevent cable damage at duct entrances. If they were not installed, or are damaged, strips of hard rubber or similar material should be used to protect the cable at the duct entrance.

c. Testing. Cable insulation integrity cannot be visually checked; it requires some type of insulation testing to determine whether the cable is reaching an insulation breakdown that will lead to a cable fault. Testing is described in section VII.

d. Cable faults. Inspection alone may reveal the location of a cable fault or it may be a more complicated process requiring test equipment. Visual and test procedures are covered in section V.

5-8. Underground equipment inspections.

Special maintenance for such distribution equipment in underground locations includes the following:

a. Keep items clean and protected from corrosion.

b. Check equipment covers to be sure that their gasketing is water-tight.

c. Keep nuts and bolts free from rust by applications of paint or heavy grease.

Section IV - MAINTENANCE AND REPAIR OF DUCT SYSTEMS

5-9. Structure maintenance and repair.

Maintenance and repair of structures is a continuous procedure but is seldom extensive. Pump out structures as necessary to allow complete inspection. Major breaks or settlement of structures causing large cracks require investigation of the structural condition and rebuilding to eliminate the cause.

a. Duct Line entrances. Grout up chipped concrete at the mouth of the duct line as necessary. Heavily loaded cables will crawl because of expansion and contraction, which results from the alternate heating and cooling effects of changing loads. The mouth of the duct line must be kept clean and free of burrs and small patches of concrete that will damage cables.

b. Water leaks. Most structure repair requirements consist of stopping water leaks in the floor and walls of frequently entered structures. Depending on the terrain, the pumping of one structure may involve the removal of water from adjacent structures. In applicable locations, all vacant ducts should be plugged with standard duct plugs, and all occupied ducts should be sealed so as to prevent water or gas from entering vaults or any users' premises.

(1) *Occupied duct sealing.* Use a nonhardening sealing material that will not harm the cable to seal occupied ducts. These nonhardening compounds consist of emulsified vegetable oils containing fibers or asphalt compounds. Oakum is often packed around the cables as backing for the sealing compound. Use a ready-mixed commercial sealer and follow the manufacturer's directions.

(2) *Wall leakage.* Water leakage through the walls of the structure will usually occur along joints or void areas. Some leakage may be found where the ducts enter the structure. Using a cold chisel and hammer, chip out the porous area so that the patch will bond against sound concrete. The hole can then be patched with calcium-chloride putty or quick-setting cement mortar.

(3) *Floor leakage.* If water is entering through the floor of the structure, clean the floor and remove accumulated silt. If the floor is generally sound except for the joints at the wall or for isolated cracks, repairs can usually be made as covered above. If the concrete of the floor shows evidence of general porosity or disintegration, it is better to pour a new floor, as follows:

(a) Where a reduction in headroom of 4 to 6 inches (100 to 150 millimeters) will not affect the utility of the structure, a new floor may be poured directly over the old floor. Otherwise, the old floor should be broken out and a new floor poured.

(b) When necessary to break out the old floor, the first step is to excavate for a temporary pump sump about 12 inches (300 millimeters) below the old floor level if the structure has no existing sump. When the floor has been removed, continued pumping may be necessary. Further excavation will be necessary if added headroom is desirable. A permanent sump or a storm drain connection should be considered when the new floor is poured.

5-10. Duct line maintenance and repair.

Most damage to duct systems results from new unrelated construction and settling of ducts. Too often, the new construction fails to locate an adjacent duct line accurately and damages the line. Ducts sometimes settle where they cross older understructures, whose overlay was completed without adequate backfilling and tamping. Duct settling is often not apparent unless cable failure results or an empty duct is rodded in preparation for pulling in new cable. In either event, the condition must be investigated and repaired. A new structure at the point of settlement may possibly be the quickest and cheapest repair.

Section V - CABLE FAULTSAND FAULT LOCATIONS

5-11. Cable faults.

Whenever cable insulation breaks down, resulting in an underground cable fault, fuses should blow or circuit breakers should open to prevent further system damage. Faulted circuit indicators (FCIs), where provided, may also provide an indication of a cable fault.

a. Reclosing on a fault. The practice of applying automatic reclosers on medium-voltage aerial distribution lines presents a problem when underground distribution lines are supplied from aerial lines which have reclosing features. The recloser is intended to prevent extended outages due to transient disturbances on aerial lines. But repeated reclosing on an underground cable fault tends to create unusually high fault resistances. Reclosing serves to aggravate an underground cable fault which may then stress upstream circuitry.

b. Aerial-to-underground line connections. Fuse protection is required to be provided at or near riser poles where such connections are made. When any aerial lines feeding underground cable systems are provided with automatic reclosing, that feature should be designed so that any permanent fault on

long underground feeder will blow the associated cable riser fuses within a time period that limits to one reclosure, the damaging effects of automatic reclosing on the faulted cable feeder.

c. Check of associated equipment and lines. Blown fuses and open circuit breakers may be caused by a cable fault or by faults on equipment or other lines connected to cables. Preliminary tests should be made to determine that the fault is actually in the cable and not in associated equipment.

d. Faulted circuit indicators. As noted, reclosing on faulted cable circuits stresses the circuit elements and can increase potential personal hazards. On critical feeders, FCIs are often installed to reduce service restoration time by providing a convenient means of determining fault current occurrences, location, and direction on underground circuits.

(1) *Operation.* An FCI can be a single or multiphase device which senses fault current has passed through the line conductors at the point where the FCI is installed. The FCI is designed to provide a fault current indication by a flag, a light emitting diode (LED) display, or other means. The current sensing is done by detecting the magnetic field strength generated by the circuit's alternating current.

(2) *Location.* Most FCIs are installed on underground distribution current-carrying elements such as cables, switch and transformer elbow terminations, and separable connectors. They are also used on aerial lines.

(3) *Application.* The proper application of FCIs is crucial to their correct operation. Units must be correctly designed for indicator trip and reset methods. Inrush restraint, time delay, and coordination may be necessary. Other considerations when selecting FCIs means that their initial provision requires engineered design.

(4) *Maintenance use.* Use FCI sets to locate distribution faults. Normally where installed, the number of FCI sets will be one less than the number of cable sets which can be sectionalized. The faulted cable section will be between a "fault" and a "normal" indication.

(5) *Concerns.* If units are damaged they must be replaced with like units having the same features. Their operation in regard to trip and reset must be understood. If loads are changed and the unit does not have an adaptive trip (tripping on a sudden increase above the nominal current followed by a loss of current) then the trip setting must be changed. The reset may require manual means or may be reset by other actions such as predetermined time, current, voltage, or other sensing methods.

5-12. Visual methods of cable fault locating.

Since visual inspection can be the easiest and quickest way to locate a cable fault, it should be tried first. Visual inspection may require checking secondary effects, such as leaks from the cable-insulating medium. If visual inspections are not effective, then testing devices will need to be used.

a. Faults in exposed cable and splices. A quick check may be made by driving over the route of the cable and looking for such things as a displaced structure cover, smoke coming from a structure, or indication of damage caused by digging operations. A more detailed inspection may be made by examining the terminal equipment and the cable and splices in the structure. Look particularly for the presence of compound on the cable sheath, smoke, and odors of a burnout. Observe the requirements of section II.

b. Faults in submarine cable. Oil slicks may occur on the surface of the water near the location of the fault, or bubbles may appear where the cable is faulted. Applying high current from a low-voltage source to the faulted cable may cause bubbles to rise to the surface near the fault, thus determining the approximate location. For short submarine cables, establishing a line of sight between the terminal ends and patrolling this area may aid in locating a point of failure. Maps used in laying the cable will be helpful in establishing the cable route.

c. Faults in gas-pressurized cable. When a fault occurs on gas-pressurized sulfur-hexafluoride (SF,) cable, do not re-energize the cable until the following steps have been taken.

(1) *Low gas pressure.* Gas pressurized cable is usually pressurized at 20 to 80 pounds per square inch gage (135 to 550 kilopascals gage). A record of the installed gas pressure should be kept for all gas-pressurized cable sections.

(a) Checking pressure. Check the gas pressure at terminations and splices with a tire gage. If the pressure has dropped to zero or is dropping, the fault damaged the conduit or jacket containing the gas. Since gas is electro-negative, a gas detector similar to that used for refrigeration gases can be used to locate the leak at terminations, splices, and other points.

(b) Detecting leaks. To detect a gas leak along a buried duct or conduit line, a pipe can be driven into the ground above the line and the probe in the pipe may detect the gas. Another method to detect a leak in the line is to inject gas at one end and measure the pressure drop at access points. Dry nitrogen can be used for this method. Then plot the pressure reading to locate the spot in accordance

with the manufacturer's directions. After a leak is located, a repair can be made in accordance with section VI.

(2) *Satisfactory gas pressure.* If the pressure is satisfactory, do not re-energize the circuit until the fault has been located and repaired, since the high fault current reimposed on the failed cable can further damage the cable.

5-13. Determining type of cable fault.

Use fault locating equipment when a check of associated equipment and lines confirms that the fault is actually in the cable, and visual methods fail to locate the fault. Since no single test will locate all types of faults, the type of fault must be determined in order to use the best test method to locate it. To determine the type of fault, any source of direct-current voltage can be used with a voltmeter or a suitable low-voltage lamp. A portable testing set, such as a multimeter of the volt-ohm meter (VOM) type is most commonly used. The section of cable under test must be disconnected from feeders, buses, and equipment. Alternating current should not be used, because the charging current of the cable is sufficient to prevent accurate indications of the condition of the cable.

a. Types of faults. Cable insulation failures result in low- or high-resistance faults, because one or a combination of the following conditions occur.

(1) One or more of the conductors may be grounded.

(2) Two or more conductors may be short circuited.

(3) One or more conductors may be open circuited.

b. Checking for fault types.

(1) *Grounded conductor.* In checking for a grounded conductor, the VOM is successively connected between each conductor and ground with the far end of the cable open circuited. A good conductor will indicate a resistance commensurate with that of its insulation. A grounded conductor will show a very low resistance.

(2) *High-resistance grounded.* Some installations are grounded through a high resistance. These systems operate like an ungrounded system and the first ground fault does not trip out the system, but only sounds a warning. The ground fault can be traced using an integral system pulser and a detector furnished as a part of the system.

(3) *Short circuit.* In checking for a short circuit, the VOM is successively connected between each possible combination of conductors. Far ends of the cable must be open-circuited. A low reading indicates a short circuit between the conductors under test.

(4) *Open circuit.* The continuity of the conductors is determined by grounding the conductors at the far end and then testing between each conductor and ground. If the conductors are continuous, the resistance reads low; and, if an open circuit exists, the tester will indicate a very high resistance.

5-14. Cable fault locating test methods.

The methods generally used may be separated into two major classifications: terminal measurement methods and tracer methods. Except in the case of faults on series lighting circuits (which usually result in considerable carbonization because of the constant-current system involved) the resistances of faults are often quite high, ranging from several hundred ohms to megohms when measured at a low-voltage level.

a. Terminal measurement methods. Terminal measurement methods involve determining the chosen electrical value of the faulted conductor from one of the cable terminations to the fault, and comparing this value with the same electrical value on unfaulted cable. The proportions of the electrical values in regard to the length of the unfaulted cable provides the fault distance. The effectiveness of all terminal measurement methods is dependent upon the accuracy of installation records. While most of the work is done at one terminal, access to the other terminal may be necessary to connect or disconnect conductors as required. Terminal methods include the Murray loop, the capacitance bridge measurement method, the quarter-wave or half-wave resonance methods, and the pulse (time domain reflectometer) method.

b. Tracer methods. These methods require test equipment at the cable terminal but rely on checks along the cable tracer to locate the fault. Tracer methods include the modulated direct-current method, the modulated alternating-current method, the impulse (thumper) method, the audio frequency (tone tracing) method, and the earth gradient method.

(1) *Tracer method warning.* Some of the tracer methods of fault locating can ignite residual gas in the vicinity of a fault and cause explosions. The likelihood of such an occurrence, while extremely remote, cannot be ignored.

(2) *Structure testing.* Normal gas tests with combustible gas detectors should be made prior to entering structures during all fault-locating operations, regardless of the urgency of the situation or the type of fault-locating equipment being used. It is also advisable to use a carbon monoxide (CO) tester to check the atmosphere in structures where fault repairs are to be made, particularly in cases where

substantial quantities of cable insulation have been destroyed by the fault. Gas concentrations in structures can be dispersed by a thorough purging with a positive-pressure blower. Gas testers and their application are discussed in section II.

5-15. Simplifying cable fault locating.

Locating faults in cables can be a complicated process. The following paragraphs provide some helpful hints which can simplify the process and increase fault-locating accuracy.

a. *Fault reduction.* In cases where the parallel resistance of a fault is too high to allow effective application of either tracer or terminal measurement devices, the fault resistance must be reduced, that is it should be carbonized or "burned down". Direct-current high-potential test sets, as described in section VII can be used for this purpose. The fault reduction is accomplished by applying a continuous potential between the faulted conductor and ground. The voltage level is adjusted to give the maximum current allowed by the rating of the test set. As the fault carbonizes, a continually decreasing voltage will be required to sustain this current. The fault reduction has been accomplished when virtually no voltage results in a steady flow of current and fault-locating operations can then proceed.

b. *Conductors grounded.* If one conductor of the faulted cable remains ungrounded, terminal measurement devices can be used. If the fault grounds all conductors and low parallel resistance results, only tracer methods can be effectively applied. The ohmic value of the fault may be used in some cases to anticipate the effectiveness of the various tracer methods that could be applied.

c. *Conductor-to-conductor resistance.* When a fault results in a low-resistance short circuit between two conductors and the resistance to ground is high, reflection methods may be made effective if the single phase fault can be reduced to a ground fault before attempting to locate the fault. If the single-phase fault cannot be reduced to a ground fault, one of the conductors involved may be grounded at a termination. Depending upon the relative location of the grounded termination, the signal pattern and its level and direction may be quite different from that obtained when locating an ordinary grounded fault.

d. *Conductor continuity.* Use of a bridge-type terminal measurement device depends upon the availability of a continuous ungrounded conductor in the faulted cable, which can be looped to the faulted conductor at the far end of the circuit. The faulted conductor, though grounded, must also be continuous. The required continuity is best checked by making a bridge measurement of the resistance of the closed loop to be used for fault-locating measurements and comparing this measurement to known circuit constants. Conductor continuity generally will have no effect on the operation of tracer-type fault-locating equipment. Faults exhibiting both high series resistance (open conductor) and high parallel resistance (ungrounded conductor) can be located by using a capacitance-type terminal measurement device.

## 5-16. Cable fault locating equipment.

Cable fault locating equipment is available from test equipment rental companies. Member companies of the InterNational Electrical Testing Association (NETA) can be hired to test and to provide the test equipment. As with all techniques used infrequently, the skill of trained outside personnel may well be worth the additional cost,. "Electrical Equipment Testing and Maintenance" covers terminal and tracer cable-fault locating methods in more detail for those who wish an explanation of testing technique principles. Three of the methods using less complex methods of measuring some electrical characteristics of faulted cable are shown in figure 5-1. Another method uses a time domain reflectometer tester.

a. *Murray loop resistance bridge method.* To use this method, the grounded conductor must be continuous at the fault and a continuous ungrounded conductor in the faulted cable must be available. The accuracy of this method is directly related to the accuracy of the plans showing cable routing. The fault is located in terms of its distance from its cable terminal by measuring and comparing electrical characteristics of the cable's faulted and unfaulted conductors. It is essentially a Wheatstone bridge of the slide-wire type. When the bridge is balanced, the fault distance is found as indicated in figure 5-1. A number of slide-wire bridges designed for fault location are available commercially. They range from inexpensive units with limited accuracy to more expensive units which can locate a fault within one foot per mile (0.2 meters per kilometer) of cable length. Instructions for use, including applicable mathematical formulas, should be supplied with the instrument.
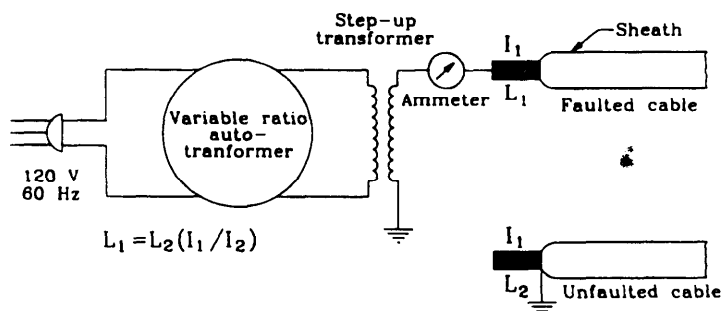
b. *Capacitance bridge measurement method.* The capacitance bridge measurement method is effective where both the parallel and series fault resistances are high enough to treat an unfaulted and the faulted conductor as capacitances to a metallic shield or sheath. This technique is simply the measurement of capacitance from one end of the faulted cable to ground and comparing it in terms of distance with the capacitance of an unfaulted conductor in the same cable. Almost any alternating-

$$X = 2xL\left(\frac{A}{A+B}\right)$$
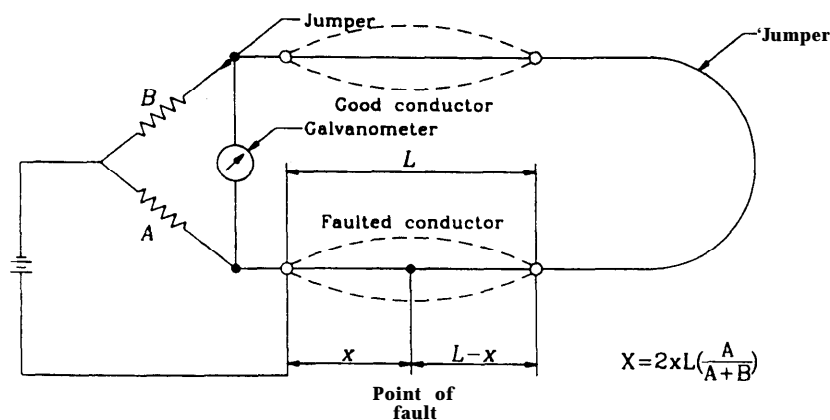
Murry loop bridge method

Capacitance bridge measurement method

$$L_1 = L_2(I_1/I_2)$$
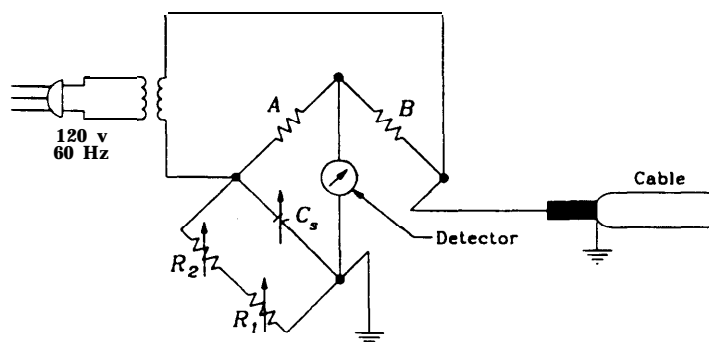
Charging current method for fault location

Figure 5-l. Terminal equipment and cable connection diagrams

current capacitance bridge is suitable, provided it measures capacitance to ground.

c. Charging current method. In the absence of an alternating-current bridge, the charging current on the faulted conductor and on a good conductor may be compared, using several hundred volts or even several thousand volts at 60 hertz as the voltage supply. This circuit with its fault distance formula is shown in figure 5-1.

d. Time domain reflectometer (TDR) method. This method is based upon the measurement of the time "t" it takes a generated pulse to reach a fault and be reflected back. The fault distance "d" equals the

cable propagation velocity "v" multiplied by "t" and divided by two which results in equation 5-l.

$$d = vt/2 \qquad \text{(eq. 5-1)}$$

(1) *Distance determination.* The TDR/analyzer measures the reflection time and the fault distance is automatically calculated based on the entered velocity of the pulse travel which is usually the ratio of the cable's propagation factor to the speed of light or a value of less than one. The analyzer can determine whether the fault is open-circuited or short-circuited based on waveform reflections as shown in figure 5-2.
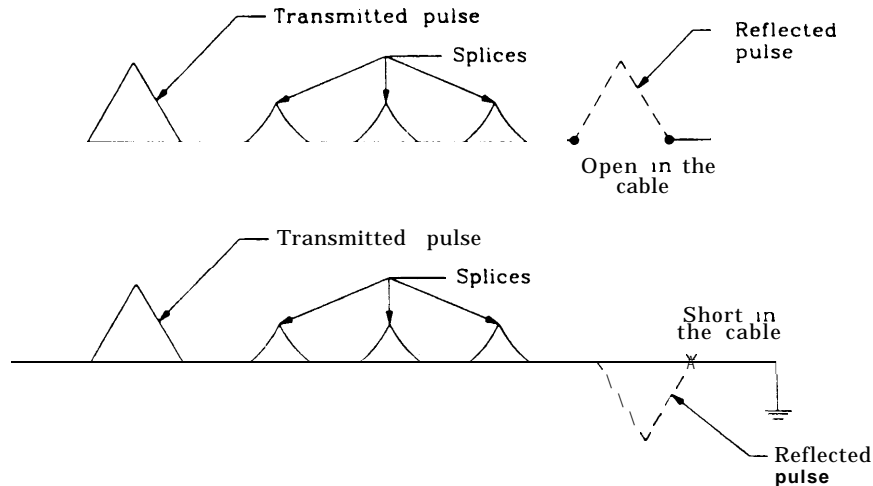
Figure 5-2. Cable fault waveform reflections

(2) *TDR test settings.* Tests require selecting a pulse duration and a propagation factor.

(a) *Pulse duration.* The pulse duration must be wide enough to be interpreted by the TDR analyzer and at least about one percent of the transit time for the entire length of the tested cable. TDRs should have provisions for changing the pulse width depending on cable length.

(b) *Propagation factor.* This is the velocity of the pulse in an insulated cable and will vary inversely as the square root of the product of the cable's line constants, that is, its inductance and capacitance. Therefore it will vary dependent upon cable insulation. A propagation factor of 500 feet (152 meters) per microsecond for medium-voltage cables or 600 feet (183 meters) per microsecond for low-voltage cables is sufficiently accurate when fault distance measurements are made by two-end fault pin-pointing.

(3) *Two-end fault pin-pointing.* A propagation factor set to any value (which must remain unchanged for both measurements) can be used to provide a TDR-measured fault distance from each end of the tested cable. These two distances will either come short of meeting or overlap each other. The true distance to the fault "d_t" can be calculated by equating the determined fault distance from end one "d_1" to the fault distance from end two "d_2" and the distance between these two points "d_p" using equations 5-2 and 5-3, respectively, based on whether the determined fault distances fall short or overlap.

$$d_f = d_1 + (d_2 + d_p)/ (d, + d_2)$$
$$d_f = d_1 - (d_2 + d_p)/ (d, + d,)$$

5-17. Tracing the cable fault signal.

A halving procedure can be used to trace faults where the signal cannot be traced along the entire length of the cable in any other way. It is time consuming and costly, and more modern methods utilizing the sophisticated signalling instruments available should always be applied if possible.

a. *Procedure.* The procedure consists of localizing the fault by progressively limiting it to one half of the previously considered length of cable. The points along the cable route chosen for signal measurement must be selected so that maximum fault localization results from each and every measurement. Thus, the first measurement should be made as close to the midpoint of the circuit as possible; the second at the one-quarter or three-quarter point, depending on the fault location given by the first measurement; and so on.

b. *Drawbacks.* This procedure requires cutting the cable. For cable in duct an access point is needed, or the duct line must be broken and a new structure provided for resplicing. For direct-burial systems good cable will need to be respliced in a new splice box. Resplicing can introduce other possible trouble points.

5-18. Selecting cable fault locating methods.

The fault locating method differs dependent upon the way the cable is installed. Most installations will be in duct lines, but direct-burial and submarine cable installations must also be considered.

a. *Duct line.* The fault-locating equipment used is generally a tracer type. Pinpointing of the fault between structures is unnecessary. The entire length

between structures of a faulty cable must be replaced. If a structure does not contain a cable splice it may be augmented by a resonance or radar terminal method.

b. Direct burial. Fault-locating for direct-burial installations must pinpoint the fault, so that the repairs can be made at the point of failure. Such faults generally can be best located with impulse equipment such as the TDR method. Faults can also be located by patrolling the cable and listening for the noise of an impulse discharge at the fault. On longer cables it may be preferable to use some other means, such as a terminal measurement, to obtain an approximate fault location. In the absence of audible noise, test holes must be dug so that detector tests can be made using a tracer method.

c. Submarine cable. The approximate location of a submarine cable fault must be determined by terminal measurements.

(1) *Locating the fault.* Verification of location can be made by pulling the cable out of the water at the point indicated by the terminal measurement. When the portion of the cable suspected to be at fault is raised, it is generally necessary to apply a tracer method to verify the fault location. The impulse method is ideally suited to this application, as the noise of the discharge is usually quite evident when the faulted section leaves the water.

(2) *Cable sheath leaks.* Emergency maintenance of submarine cables frequently involves repair of a leak in the cable sheath. When a leak is evident, it should be located as soon as possible; the cable raised; and the damaged section removed to prevent migration of moisture into the cable. Repairs should be made in accordance with standard splice procedures for submarine cables covered in section VI.

d. Gas-pressurized cable. Use a high-resistance method such as any terminal method, except the Murray bridge loop, or use the impulse tracer method.

Section VI - CABLE REPAIR

5-19. Underground cable repairs.

Underground cable is usually either direct burial or installed in ducts. While repair methods described below are basically the same for any underground cable, there are some differences depending on the installation condition.

a. Direct burial. While there may be splice boxes, normally there is no structure to consider, and a hole will have to be dug to make the repair. This may be a test hole used to pinpoint the fault location. Such access may have to be enlarged, if the repair involves an appreciable length of cable. The major problem in repairing direct-burial cable may be to provide a dry environment while making the repair. A temporary shelter may be required.

b. Duct line. If the faulted cable length is in a duct line between structures, there are several repair methods. Usually, only one circuit is installed in a duct line in order to avoid cable capacity derating.

(1) *Spare duct.* If there is a spare duct available, the simplest solution may be to pull a new length of cable into this duct and connect it at both ends to the good ends of the faulted cable. Then pull out the faulted cable, if possible, to provide a spare duct. At the very least, tag at both ends to indicate that this cable has been abandoned in place and is faulty.

(2) No *spare duct.* The cable should be pulled and a new cable installed. If this is impossible because of duct damage, a new duct must be installed. Alternately, it may be faster and more economical to open up the duct line at the fault point. If the cable can be repaired without a splice, the duct line can be reclosed. It may be necessary to build one or more new structures at the point to house any new cable which needs to be spliced into the existing cable to replace the faulted section. The method to be used is largely a matter of judgment based on all the factors known at the time.

5-20. Submarine cable repairs.

When the approximate location of the fault has been determined, the cable should be lifted to the surface for examination and repairs. The cable may be located with a grapple hook and lifted with a barge-type crane. If the cable is difficult to locate, the services of a diver may be required to determine the location and to attach a line for lifting the cable. After the cable has been hoisted to the surface, it should be cut at the location of the fault to determine if (and how much) water has entered the cable. The most expedient method of determining the distance the water has entered the cable is to cut the cable 25 to 50 feet (8 to 15 meters) on either side of the fault. This distance depends somewhat on the time that the cable has remained in the water after the fault occurred and the type of cable insulation. At the point where the cable has been cut, a sample of insulation should be tested for moisture as covered in section VII. If there is evidence of moisture at the first cut, then a second section should be removed and another test made. This operation should be continued until the point

is reached where moisture is no longer present in the insulation.

a. Replacement of cable section. The cable section which has been removed should be replaced by splicing in a new cable of sufficient length. The cable manufacturer's splicing kit instructions should be followed for making splices which will probably have to be made on a boat or barge. Care should be taken not be bend the cable sharply where it enters the water or where it rests on the bottom. When the cable is again laid in the water, the top must be carried out and laid down in such manner that there will be no sharp kinks or bends in the cable.

b. Protection of submarine cables. Because submarine cable is relatively unprotected as it lies on the bottom of a body of water, special precautions must be taken to prevent damage from swift currents, boat anchors, or other causes. Normally, these precautions are taken during the original cable installation and are not the concern of repair and maintenance personnel. The following paragraphs describe steps to be taken if original precautions were omitted, or if original precautions were disturbed in the process of cable repair.

(1) *Anchors.* When a cable crossing is subjected to flow or tidal currents, cable anchors are generally required to prevent excessive drifting of shifting of the cable along the bottom. These anchors are usually made fast by a series of U-bolts which pass through a common base plate, thus affording a multiple grip of the cable. Other U-bolts, eyebolts, or alternate means are usually provided for attachment of the anchor cable or chain. Ordinarily, the anchors are masses of concrete sufficiently large to resist the draw of the current. When the water is shallow, anchors may be placed on the cable as it is being reeled out. When a deep-water crossing is encountered, attachment of the anchors to their chains must be done by a diver.

(2) *Warning signs.* Suitable warning signs indicating the location of the shore ends of a submarine cable, and stating that anchoring of vessels is prohibited in the immediate vicinity of the cable anywhere along its length, are required for every submarine cable crossing.

(3) *Pile clusters.* Clusters of piles are frequently driven at the shore lines of important cables where they enter and leave the water. These aid in locating the points where the cable is anchored. Pile clusters also provide a certain amount of mechanical protection for the cables and furnish platforms on which to mount warning signs.

(4) *Maps.* The development of accurate maps is one of the most important tools in maintenance and repair of a submarine cable installation. It ensures that the cable can be picked up at any desired point for repair or inspection. Maps should indicate the exact location of the cable at various points along its length, as established by measurements with surveying instruments. Maps should also indicate the exact length of cable installed between any two reference points, so that any movement or drifting of the cable on the bottom can be estimated.

5-21. Cable repair safety.

Cable repair will involve: working with other cables which may or may not be energized; ensuring that the grounds and bonds essential for safe operation are in good condition; and, in some cases, dealing with hazardous substances.

a. Energized cables. Repair work on electric cables should be done unenergized. However, other cables in the manhole may be energized and inspections will usually be done with cables energized. Moving cables while energized should be restricted to low-voltage cables in good condition and with adequate bending radii. When the condition of any insulation is questionable, or cables are installed to their permissible bending radius limits, a small change in radius to an energized cable could cause a fault.

b. Grounding and bonding. Inspection and maintenance of cable grounds are as important as the inspection and maintenance of cables, both for safety and for corrosion mitigation. Ground rods should also be inspected.

c. *Hazardous substances.* Hazardous substances, such as lead or asbestos, should be replaced when the cable repair work requires their removal; such as pulling new cable in ducts sealed with lead or asbestos or splicing cables having asbestos fireproofing. Encapsulating materials are available which will prevent asbestos fibers from becoming airborne. See chapter 15, section II.

5-22. Making cable repairs.

In many cases, the fault will be in either an existing splice or a termination, and the repair is comparatively simple. In other cases, the fault will be in the cable itself, and the repair involves removing a defective cable length and splicing in a good length. The replacement must be the same as the original cable or a type of cable comparable to and compatible with the original cable. Splice kits and termination kits should be used as much as possible. The following paragraphs contain general instructions for the various types of cables. More detailed instructions are given by the manufacturers of the cable and splice kits used for any specific job. After the repair is completed (and before backfilling for direct-burial cable) insulation resistance and poten-

tial tests should be made to determine that the cable, including the new repair, is suitable for use. Refer to section VII.

5-23. Solid dielectric cable repairs.

The vast majority of cable used in most installations will be solid dielectric cable. Solid insulation for power cables is divided into two main categories-thermosetting and thermoplastic. A thermosetting material is one that requires heat to vulcanize or crosslink it. This process causes a chemical reaction and the insulation will have little tendency to soften if reheated. Thermoplastic insulation will soften repeatedly when heated. Ethylene-propylene rubber and cross-linked polyethylene solid dielectric cable, which are both thermosetting, should be considered when replacing any old medium-voltage cable.

a. Use. Most facility cable will be single-conductor type installed in duct. Direct-burial concentric-neutral cable, usually installed in housing areas, may be single-phase or three-phase. Direct-burial or submarine cable, armored or gas pressurized, is usually three-conductor cable.

b. Repair. The repair of solid dielectric medium-voltage cable may be accomplished by the use of preassembled splice kits, which are available for the various types of cables and their protective coverings, if any. Particular attention should be given to ensure that the material used for the repair is compatible with the cable insulation. Low-voltage cables which do not have cable shields and are not provided with armors or metallic sheaths can be repaired with jacket repair sleeve kits which seal and repair insulation damage. These sleeves may be appropriate on medium-voltage cables when only the jacket is damaged.

5-24. Other cable insulation and covering repairs.

Cable insulations other than solid dielectric compositions are now being installed only where special circumstances justify their use. Varnished cambric and paper insulated cables, however, may still be in service at this time. Gas-pressurized cable with solid dielectric insulation is used for underwater installations to provide mechanical protection, prevent the entrance of water, and minimize electrical losses which can arise from armor protection. Protective cable coverings require appropriate repair.

a. Varnished-cambric insulated cable. Varnished-cambric insulation requires little or no maintenance where cables terminate in potheads. Some varnished-cambric insulated cables are provided with lead sheaths. However, where terminations

are not in potheads, the terminal ends should be checked periodically for leakage of compound and breaks in insulation where moisture can enter and cause deterioration. Where the cable is not terminated with potheads, leakage of compound may occur. In such instances, an electrical adhesive tape, designed for medium-voltage splices, should be applied over the varnished cambric and should be painted with a sealer paint to stop the flow of compound. If it is suspected that the varnished-cambric insulation has absorbed moisture, a moisture test (as described in section VII) should be made. Should the insulation become damaged, it may be replaced with varnished-cambric and covered with friction or adhesive tape, or the ends of varnished-cambric tape can be secured with cotton tape and painted with an insulating paint.

b. Paper-insulated lead-covered cable. A paper-insulated lead-covered (PILC) cable always has a lead sheath and therefore requires little maintenance. Testing at regular intervals will indicate the condition of the insulation. A break in the lead sheath will expose the paper to moisture and a moisture test should be made. If several layers of paper have been removed, they should be replaced with varnished-cambric tape. In order to do this, it may be necessary to remove a longer section of lead sheath. The section of lead sheath removed should be replaced with a new lead sheath and wiped in place in the same manner as a splice. The repairs described above can only be made in a structure. If it appears there has been a break in the lead sheath within a duct, it will be necessary to replace a length of cable between structures or between terminals.

(1) Should a PILC cable fail again shortly after a repair or lengthy de-energization, the cable may be completely unusable. However, prior to replacing, make an attempt to "dry out" the cable by forcing a low-voltage, high current through the cable (via an arc welder) for not less than 12 hours. Current should be as high as possible but must not exceed 80 percent of rated cable ampacity.

(2) Do not support PILC cables by using metal straps or supports or by laying them on metal trays because of the deteriorating galvanic action.

c. Lead-sheathed cable. Lead sheaths may crack or suffer other damage as a result of fatigue due to cable movement or bending. If a section of lead sheath is seriously damaged or badly cracked, the section of sheath should be removed and the area covered with a lead sleeve. The sleeve should be wiped in place in the same manner as a splicing sleeve. Where the damage is not too serious, repairs may be made as follows:

(1) Scrape the lead in the vicinity of the damage.

(2) Preheat area using an acetylene or gas blow torch. Care should be taken not to melt lead.

(3) Apply a good flux such as stearine.

(4) Apply solder and heat to a point where it is pliable.

(5) Work solder into sheath with a paddle or stick and smooth.

(6) Wipe with wiping pad.

d. Concentric-neutral cable construction. The neutral conductor of this type of cable consists of equally spaced strands of wire or flat strap wrapped spirally around the outside of the cable insulation. Concentric neutral cables may be of a single or multiple conductor configuration and may have an outer protective jacket over the neutral conductors. Care must be used in handling the cable to prevent the concentric-neutral conductors from loosening or bunching together in one place around the cable circumference. If this occurs, it may cause tracking of the insulation or affect the voltage stress distribution within the insulation. The number and size of the concentric conductors are determined by the manufacturer in accordance with ICEA standards. Repairs should ensure that the operating characteristics of the concentric neutral are not adversely affected.

e. Gas-pressurized cable. Repairs may be required for this cable because of a loss of pressure from a leak in the outer covering or conduit or a puncture in the solid dielectric cable.

(1) *Gas pressure.* The high density of the gas may result in a zero gage reading even though sufficient gas is still present to keep out air and moisture. If the cable is under a water-pressure statichead, then a pressure of 0.5 pounds per square inch gage (3.5 kilopascals gage) is needed for each foot (0.3 meters) of water head to continue to keep water out.

(2) *Repair of gas Leaks.* Follow the manufacturer's recommendations. A beep detector should be used to ensure all leaks have been repaired. Surfaces should be clean and smooth, and the pressure must generally be dropped back to zero.

(3) *Treatment of gas.* The SF, gas used is nontoxic and odorless. However any arcing produced by the fault will result in the gas producing toxic materials that smell like sulfur and rotten eggs. Do not breath this gas. Let it dissipate to the air and clear it from a structure. Since the gas will be outside the shield with a solid dielectric cable, the cable can fail without arcing the gas. If a cable were to fail and burn a hole through the insulation and then be re-energized, a very small amount of gas in the hole could arc and may be noticeable. The smell and toxic gas will dissipate fast. Follow instructions for SF, gas handling in chapter 15, section II.

(4) *Cable insulation.* If the cable insulation fails, the repair should be made as given for solid dielectric insulated cables.

f. Armor. There are various types of armor to provide mechanical protection for the cable insulation and some armor is provided with a protective jacket.

(1) *Flat metal armor.* When flat metal armor is broken, it can be repaired in place by soldering the broken part or by overlapping a short piece of armor and soldering. The armor should be thoroughly cleaned and tinned before soldering. If the armor becomes loose at the ends of the cable, it may be wired to the lead sheath or a lead sleeve installed at each end.

(2) *Inter-Locked armor sheath.* The interlocked armor sheath may sometimes be separated during installation. Short sections of this armor can usually be worked into place (one section at a time) by using a hammer and screwdriver or other blunt instrument. The armor may sometimes become dented. When not too seriously dented, no repair should be attempted. However, if the dent is serious enough to cause possible injury to the cable, a section of armor should be removed and replaced with a sleeve.

(3) *Wire armor* The wire armor over submarine cable may sometimes become bent and separated. In such cases, the armor should be replaced, bound with wire, and soldered. The binding wires should be of a metal similar to that of the armor. If the wire armor is broken, it can be repaired in a similar manner. After the link has cooled it should be painted with a heavy coat of insulating compound to reduce any possible dissimilar metal corrosion.

(4). *Protective jacket over armor.* Sometimes a protective jacket such as rubber, thermoplastic, or braid is placed over the armor for protection against corrosion. Should these jackets become damaged, the damaged area can be repaired by wrapping with thermoplastic tape or self-vulcanizing tape.

5-25. Other cable component repairs.

Potheads and terminations should be checked along with any cable fireproofmg.

a. Terminations. The insulators should be kept clean, and bodies of the compound-filled terminations, such as potheads, should be checked for leaks. A leak will usually be indicated by oozing out of the compound. In such instances, the leak should be repaired and the pothead refilled. A power factor test (as covered in section VII) of the termination and cable will give some indication of the condition of the termination so far as electrical leakage and

losses are concerned. Installation of other terminations should be in accordance with the instructions of the termination manufacturer for the type of cable involved.

b. Cable fireproofing. Where cables of more than one circuit pass through structures, any fireproofing material around cable sheaths should be maintained to prevent damage from adjacent cables.

Section VII - CABLE TESTING

5-26. Cable tests.

Tests are made on installed cable for two reasons-to check the condition of the cable and for a cable requiring maintenance to ensure that the repair was properly made.

a. Type of voltage tests. Insulation resistance measurements and direct-current, over- or high-potential test (direct-current hi-pot test) are the usual direct-current voltage tests for cables. A dielectric absorption test which takes longer than a standard insulation resistance test may also be appropriate. A fourth test is the power factor test.

b. Testing frequency. The periodic testing of installed medium-voltage cables is known as proof testing, since its purpose is essentially a means of proving that weak spots in existing cables have been recognized before failure occurs. Cables normally have a higher failure rate in the first 2 years of service, which is the period when manufacturing defects will show up. An alternating-current test is used for factory testing of new cable. Acceptance and proof testing utilizes direct-current testing which, while not as effective as alternating-current, is less liable to damage cable. Direct-current testing provides extremely valuable historical data and allows comparison of the acceptance testing value to the periodic proof testing values. A yearly overvoltage test for the first 2 or 3 years, and then testing every 5 or 6 years, is the optimum and can reduce in-service failures by a factor of about nine to one as opposed to not having a proof testing test program. Insulation resistance tests should be based on the importance of the circuit; once a year is usually adequate.

c. Other tests. Varnished-cambric and paper-insulated cables may require moisture tests. Gas-pressurized cable may require leak tests. Refer to section V.

5-27. Cable insulation resistance tests.

Insulation resistance is the resistance which the insulation presents to a flow of current, from an impressed direct-current voltage. An insulation resistance test is a short-time test made to indicate the suitability of the insulation for the purpose intended, or to indicate whether an overpotential test can be made without damaging the insulation. It is not a dielectric strength test, but will give an indication of the insulation's condition with respect to moisture and other contamination. Because any insulation resistance test will measure the insulation resistance of all items connected together, the cable to be tested must be completely disconnected from all other cable and equipment.

a. Measuring equipment. All measurements require a direct-current source which can be a hand-cranked generator, a motor-driven generator, a battery-supplied power pack, rectified alternating current, or its own internal power source. The measuring devices can be as follows.

(1) A megohmeter which is a contained instrument (commonly called "megger," although "Megger" is the trade name of a tester of this type made by James C. Biddle Co.) consisting of an indicating ohmmeter and an internal source of direct-current voltage.

(2) A resistance bridge.

(3) A voltmeter.

(4) A voltmeter and micro-ammeter.

b. Megohmeter. The most convenient and commonly used way to measure resistance is to use a self-contained instrument giving a direct readings in ohms, kilohms, or megohms. Measurement is obtained by connecting one instrument terminal to the cable conductor or the equipment terminal and the other instrument terminal to the metal sheath, frame, container, or support of the insulation under test. Instruments are available in voltage ratings of 500 to 2,000 volts or more. Care must be taken to use a voltage which does not exceed the insulation rating of the item being tested. Follow specific instructions provided with the instrument being used. This type of instrument is not very accurate or sensitive in very low ranges and should not be used to measure a few ohms or fractions of ohms, such as resistances of conducting paths.

c. Resistance bridge method. A self-contained instrument, called a Wheatstone Bridge, containing a battery, a galvanometer, and known resistances, is used to compare an unknown resistance with a known resistance. Each instrument contains detailed instructions for its use. While very accurate results can be obtained, a bridge is basically a laboratory instrument and requires a fairly skilled operator. It is not recommended for field work.

d. Other methods. Both the voltmeter method and the voltmeter/micro-ammeter method require laboratory type instruments and a separate source of direct-current voltage. They are inconvenient to use in the field and are not recommended. However,

if desired, some details can be found in the "American Electricians' Handbook.

e.Factors affecting insulation resistance. Personnel making and interpreting the results of insulation resistance tests should consider the following factors which affect the test readings:

(1) *Temperature.* Insulation resistance varies with the temperature, and the effect of temperature depends on many other things, such as type of insulation, amount of moisture in and on the surface, and the condition of the surface. All spot-test readings should be corrected to a base temperature such as 40 degrees C.

(2) *Moisture.* The amount of moisture in the insulation has a large influence on its resistance. For meaningful results, tests of insulation resistance should be made under as near similar conditions as practical. A long cable can be exposed to different conditions along its length so a comparison of readings not made at the same point may be misleading.

f. Interpretations. Usually, because of the stored capacitance of the cable there will be an initial ampere dip toward zero followed by a steady rise. The spot-test reading should be taken after a 60-second voltage application. A cable 1,000 feet (300 meters) long will have an insulation resistance of one-tenth of that for a l00-foot (30-meter) cable, provided all other conditions of both tests were identical. A gradual decline in resistance with age is normal; however, a sudden decline means insulation failure is imminent and a continued downward trend indicates insulation deterioration, even though measured resistance values are above the minimum acceptable limits.

g. Dielectric absorption test. This test is usually conducted at higher voltages for extended periods of from 5 to 15 minutes. Since the current is inversely related to time, insulation resistance will rise gradually for a good cable but will flatten rapidly otherwise. Periodic readings should be taken and plotted against time. The ratio of the lo-minute to the l-minute resistance is known as the polarization index. A polarization index of two or higher indicates good insulation, while a polarization index of less than one indicates cable deterioration the need for immediate maintenance.

5-28. Cable overvoltage tests.

A hi-pot or overpotential test is an overvoltage test used to check a cable for its relative condition after it has been repaired or otherwise worked on. Neither the insulation resistance test nor the dielectric absorption test can determine the dielectric strength of cable insulation under normal use. A hi-pot test is the only way to gain proof that the cable insulation can still withstand over-voltages caused by normal system surges. As noted, alternating-current tests are reserved for factory tests to determine whether the insulation had any discontinuities, voids, or air pockets. Less destructive, direct-current tests are used for installation proof testing. Also, most equipment for direct-voltage testing is smaller and more readily portable. A 115-volt alternating current power supply is rectified to provide direct-current for testing. Several commercial types are available. Each type comes complete with transformers, rectifiers, instruments, and controls.

a. Voltage. Normally, the maintenance proof tests performed on cables are at a test voltage of 60 percent of the final factory test voltage for new cable/equipment. Determination of voltages for acceptance and proof tests should be made by qualified electrical engineers, and such tests should be made only when specifically directed by an engineering activity having jurisdiction over the installation. Tests should be performed in accordance with ANSI/IEEE 400. It is always appropriate to conduct the insulation resistance measurement test first; and, if the data obtained is within acceptable limits, to proceed with the direct-current overpotential test.

b. Procedure. For each cable, the test should be made between each conductor and every other conductor and between each conductor and ground. For the test to ground, all conductors may be connected together. There is no need to disconnect other equipment from the cable, but caution must be observed to ensure the test voltage is not greater than recommended for any of the equipment. Some preassembled or premolded cable accessories may have a basic insulation level lower than the cable tested, and the lower voltage should be taken from IEEE 48 test limits or the manufacturer's test limits, whichever is smaller. If a test shows poor results, items and/or conductors should be retested separately until the defective portion is identified. Specific instructions furnished with the tester being used should be carefully followed. Additional information is contained in chapter 7, section II.

c. Safety. When making high-voltage tests, all applicable precautions regarding live electrical conductors should be observed to avoid dangerous electrical shock. After testing, the terminals should be short circuited before disconnecting the tester from the equipment. The short circuit should be maintained for at least as long as the time the proof voltage was applied.

d. Test data. There are three types of direct-current hi-pot tests commonly performed. In all cases, leakage (conduction) current is measured and

the values compared either on a voltage or a time basis for initial to steady-state values or for a constant rate of leakage current.

(1) *Initial leakage current.* The initial leakage current upon a test voltage application will include transient capacitive charging and dielectric absorption currents. Two other currents, corona current and surface leakage current, can be bypassed by installing correct guarding circuits.

(2) *Steady-state leakage current.* The initial value will decrease to a steady-state value consistent with the system's charging current. If correctly done, only the volumetric leakage current will be left. This current is of primary interest in the evaluation of an insulation's condition. The decay of transient current time is known as the stabilization time.

(3) *Constant leakage current.* In some cases, a constant leakage current is measured. This is maintained by increasing the test voltage in a manner which maintains the same current.

e. Tests for relative cable condition. Two tests are used to determine the relative cable condition as an identification of its dielectric strength under medium-voltage tests.

(1) *Leakage current versus voltage test.* In this test, equal voltage steps are applied until the maximum test voltage is reached or an indication of a breakdown voltage is indicated. It is usually recommended that no less than five and, if possible, eight equal steps be made with no less than 1 and up to 4 minutes stabilization time allowed. The steady-state leakage current is plotted against the applied voltage. As long as the slope of the plot is the same, the insulation is in good condition. If the leakage current increases noticeably, so will the slope of the curve. Any change in the slope indicates that any voltage increase may cause insulation breakdown and the test should be stopped.

(2) *Leakage current versus time test.* This test is made after the maximum test voltage of the previous test has been determined. The maximum voltage is left on for 5 minutes and the leakage current is read after 30 seconds, 1 minute, and then at 1 minute intervals thereafter up to 5 minutes. The leakage current is plotted against time as the initial high value reduces to a steady-state value. A continuous decrease indicates a good cable. There should be no increase in current during this period.

f. *Test for cable withstand strength.* A go/no-go test is usually performed after repair if only cable withstand strength requirements need be verified. The test provides a rising voltage up to the specified value applied to maintain a constant leakage current. A period of 1 to 1.5 minutes for reaching the final test voltage is usually adequate. The final test voltage is held for 5 minutes. If the current has not increased sufficiently in that time to trip protective devices, the cable withstand voltage is adequate.

5-29. Cable power factor tests.

Power factor testing is a nondestructive ac test which has been utilized for many years to measure or test the integrity of substation insulation systems including cables.

a. Test theory. An insulation to which voltage is applied will act like a resistor and capacitor in parallel as shown in figure 5-3. The capacitive current I_C will be much larger than I_R so the angle θ will be close to 90 degrees and the power factor (cosine of θ) will be very small.

b. Cable power factor test limitations. Cable insulation can be considered to consist of a simple element of capacitance in parallel with resistance as shown in figure 5-3. The measured power factor is the average of the entire length of the cable. If a section of cable increases in power factor the high value obtained for that section will be averaged with the normal value obtained for the remainder of the cable. The influence that the defective section of the cable has on the overall cable power factor depends on the relationship of the defective section length to the overall cable length. Thus, the ability
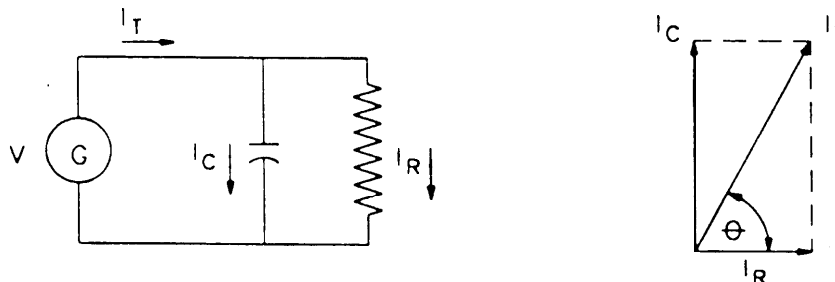
$$\text{POWER FACTOR} = \frac{\text{WATTS}}{\text{VOLTAMPERES}} = \frac{VI_R}{VI_T} = \text{COSINE } \theta$$

Figure 5-3. Insulation power factor equivalent circuit and vector diagram

to detect a localized fault diminishes as the length of the cable under test increases.

c. Effectiveness of power factor tests. Power factor tests can be effective in detecting defective insulation for short cable runs which are common in electrical substations and industrial complexes, and for indicating general deterioration and/or contamination of longer lengths of cable insulation runs. This test can be performed at any voltage that does not exceed the line-to-ground voltage rating of the cable. In addition to checking cable insulation, this test can be used to find:

(1) Any defects in the shield circuit which can lead to localized problems. The measurements should be performed on each end of the cable. The shield should be grounded for the test only at the end where the test connections are made. An increase in power factor can indicate discontinuities or breaks in the shield.

(2) Any defects in cable terminations, particularly compound-filled potheads, can be determined by using collar tests as covered in chapter 3, section VII.

d. Power factor tip-up testing. Normally, power factor should be independent of voltage as shown by the formula of figure 5-3. An increase in power factor at an increased test voltage is usually an indication of insulation voids. These voids are ionized at the higher voltage and act as resistors resulting in a greater resistive current and therefore a greater power factor. This increase in voltage is called power factor tip-up test.

(1) Two to five measurements should be made at voltages with an overall 5 to 1 ratio in order to determine whether there are any significant differences in the measured power factors.

(2) Generally differences are not a concern unless the higher value exceeds 25 percent of the lower value. This much change indicates that further investigation of the cable insulating quality is required.

e. Cable test data. Power factor data obtained from the field tests should be compared with any available previous test data in order to detect any changes. Lacking any initial test data, evaluation of the condition of the cable insulation may be made by a comparison of the field data with tabulated power factors obtained for similar insulated cables known to be in good condition, or with the manufacturer's published specifications. Table 5-1 indicates typical acceptable power factors for various cable insulations which may be used if no other data is available. Ranges given should not be used to justify variations in tip-up test values.

Table 5-l. Typical power factor ranges for various cable insulating materials

Cable insulation	Power factor ranges[1]
Polyethylene	0.001 to 0.002
Cross-linked polyethylene	0.001 to 0.002
Oil and paper	Less than 0.005
Rubber	0.005 to 0.04
Varnished cambric	0.04 to 0.08

[1] At 20 degrees centigrade

f. Temperature correction. Temperature has an influence on the power factor values. However, at the operating temperature normally encountered in the field, this influence is minimal for modern insulation systems. Older forms of insulation may require a temperature-correction factor. It is difficult to obtain accurate field cable temperature measurements; hence, most utilities evaluate the condition of the insulation of their cables based on test data, uncorrected for temperature. If it appears that high cable temperature may have influenced the results it is recommended that a cable having a high power factor be retested at a time when a lower cable temperature will occur.

5-30. Cable moisture tests.

Tests for moisture may be made on paper and varnished-cambric insulation by removing one or two layers of the insulation and dipping it into oil heated to a temperature of 260 to 285 degrees F (125 to 140 degrees C). If the insulation contains moisture, a concentration of bubbles will be emitted from the paper. If there is no moisture present, there will be little or no bubbling. Generally, the outer layers of insulation are tested first, as they are the most accessible for testing and the most apt to show moisture. Where moisture is indicated in the insulation, successive layers should be removed and tested until there is no evidence of absorbed moisture. All moisture-damaged cable should be replaced with new cable.

5-31. Cable test records.

It is very important that cable records be made for any inspection or test on any circuit. Such records should flag when the next inspection or maintenance outage is to be made. Since these tests require taking the cable out of service, advantage can then be taken of the maintenance outage, rather than taking a cable out of service for tests only. The trend of the reading obtained will determine whether the cable is stable, slightly aging, or rapidly deteriorating. Slight decreases in the insulation resistance each year are to be expected as the cable ages. Tests should be made more frequently if more than the usual decrease indicates that deterioration is approaching a critical state.

Section IX - UNDERGROUND CORROSION CONTROL

5-32. Importance of corrosion control.

As corrosion often results in deteriorated equipment leading to electrical outages, its control is necessary. While corrosion can occur because of many reactions, underground corrosion of metallic cable sheaths and grounds is the most common and costly type of corrosion found in electrical distribution systems.

5-33. Types of corrosion.

There are two basic types of corrosion. One is purely chemical in nature and is the reaction between elements, such as water and iron to cause rust. The other is galvanic corrosion and is an electrochemical reaction between dissimilar metals in an electrolyte. An example of the first type is rusting of a steel nail in a glass of water with no other metal involved in the reaction. An example of the second type is corrosion between copper and aluminum conductors, in which moisture serves as the electrolyte.

5-34. Prevention of corrosion.

Maintenance personnel must be alert to minimize the effects of corrosion inherent in exposure to the elements or resulting from installation methods that did not properly address galvanic effects.

a. Chemical corrosion. Prevention of chemical corrosion is relatively easy to accomplish by proper painting or other surface protection.

b. Galvanic corrosion. In electrical systems, galvanic corrosion is caused primarily by protective metallic cable coverings, such as lead or steel; by the grounding system, which is usually copper or copper coated; and by metal conduit, either galvanized or ungalvanized. TM 5-811-7, MIL-HDBK-1004/10 and AFI 32-1054 cover galvanic corrosion in detail.