Worker Protection While Working De-Energized Underground Distribution Systems

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***Abstract*—This paper describes three methods of working de-energized underground distribution systems. The three methods can be applied individually or simultaneously as necessary to ensure the least exposure to any possible potential. The items to be considered with the use of each work method used to protect workers from voltages that might develop in the work area are discussed. This paper applies to underground residential distribution (URD) and underground commercial distribution (UCD) looped and radial cable systems and their associated devices, operating at nominal voltages between 600 V and 46 kV. This paper does not cover transmission cables, submarine cables, lead sheath cables, or network systems.**

***Index Terms*—Grounding for worker protection, personal protective grounding of underground systems, underground grounding.**

I. Introduction

THE popularity of underground distribution electrical systems spread from high-density urban cities into small towns, suburbs, and rural parts of the U.S. in the 1960s, 1970s, and 1980s. These systems were often direct buried with sectionalizing points at each transformer or disconnect point. The bracket grounding method has been used when work was required on the de-energized cables. There are circumstances where a hazardous voltage could exist between the cable's conductor and/or system neutral that is under repair, and the remote ground. This occurs if a system fault occurs at a location where the fault current flows into, and through, the system neutral at the terminals of the cable under repair.

Underground distribution systems pose many of the same safety challenges as overhead distribution systems. However, detailed solutions to challenges in overhead and underground systems can be very different. Due to the limited ability to visually verify underground circuit routes, there is a greater reliance on circuit maps, cable tags, switch numbers, and equipment location addresses than in overhead systems. In addition, if not properly grounded initially, cable concentric neutrals and sheaths can develop induced potentials due to close capacitive coupling with energized phase conductors. Backfeed is a hazard to workers in both overhead and underground distribution systems and must be addressed at each worksite. In both underground vaults and padmount equipment, a significant arc exposure hazard exists in the event of a fault at the work location. Personal protective equipment, along with proper work methods, must be reviewed before any work begins. Step-and-touch voltage hazards exist at the work location under all of the conditions listed above; therefore, workers should be aware of their position and contact with the earth at all times.

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Insulation, isolation, and equipotential zone work methods have been widely used throughout the electric utility industry as an acceptable method of worker protection when working on overhead systems. Older methods of temporary overhead grounding such as remote grounding, grounding at the source(s), and bracket grounding, may provide some protection from electrostatic and electromagnetic induced voltages and will force rapid clearing if energized accidentally, but may not protect the worker working on the line or cable during a fault. Therefore, for de-energized overhead systems, grounding at the worksite using the equipotential grounding method with a cluster bar (pole band) tied to the temporary protective grounding equipment is now the standard accepted procedure in the industry [1]–[4]. However, little has been done to extend equipotential grounding protection methods to workers working on or near de-energized underground electric systems.

Refer to IEEE 1048 [1] for basic protective grounding principles. General principles and application of protective grounding described in IEEE 1048 [1] can be applied to both overhead and underground practices. IEEE 1048 [1] also provides principles including body currents and resistance, temporary protective grounding equipment, selection and application of voltage detectors, and a number of other subjects requiring review when developing de-energized underground work practices.

If concentric neutral corrosion is suspected, precautions should be taken to ensure cables and grounding accessories are solidly grounded to an intact system neutral, or other safety measures are used.

II. Underground System Neutral Design

Current and past industry installations of underground system neutrals included the following methods:

- direct buried bare concentric neutral cables;
- direct buried jacketed concentric neutral cables;
- bare concentric neutral cables installed in conduits;
- jacketed concentric neutral cables installed in conduits.

Earth's ground resistance can vary anywhere from 5 to as much as 2500 Ω across the earth and even within short distances in some areas.

Much of the industry has considered a direct buried bare concentric neutral to be effectively grounded since it is in direct contact with the earth. However, if a grounding jumper is installed between the conductor and the neutral at a location along the circuit where both the cable's conductor and bare concentric neu-

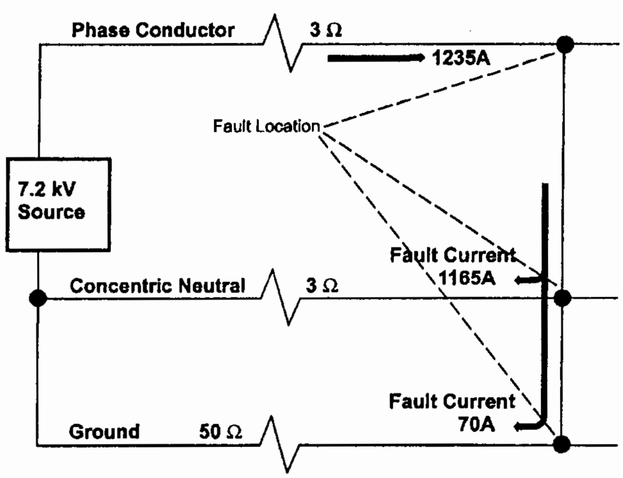

Fig. 1. Example of voltage rise during fault conditions.

tral have 3-Ω resistance, respectively, and the earth in direct contact with the concentric neutral has 50-Ω resistance, the voltage rise on the phase conductor and the neutral, at the grounded point, during an accidental re-energization of the circuit could be nearly half the system voltage. If the neutral is open, due to neutral corrosion or some other reason, the voltage rise on the phase conductor and the neutral could be nearly system voltage.

Example: An accidental 7.2-kV re-energization occurs on a single-phase direct buried bare concentric neutral cable. See Fig. 1. A temporary grounding jumper has been installed at a location where the cable's conductor and concentric neutral has a resistance of 3 Ω, respectively, and earth's ground resistance is 50 Ω. The ground potential rise at the fault location will be 3495 V, and 1165 A will return back through the neutral, while 70 A returns through the earth. Workers in contact with the phase conductor, its neutral, or the ground point will see 3495 V. If the neutral is open between the source and the location, the voltage at the fault location will be 6792 V.

The use of direct-buried, jacketed concentric neutral cables, and bare and jacketed concentric neutral cables installed in conduit can develop even higher ground potential rise if grounding systems (ground rods) have high ground resistance.

Concentric neutral corrosion and deterioration of neutral and ground connections can increase the overall resistance in the common neutral conductor which, in turn, increases the voltage at the worksite during fault conditions.

III. Current Practices

The current accepted practice of providing worker protection while working on a de-energized cable is to temporarily ground both ends of the cable's conductor (bracket grounding) to the system neutral using temporary protective grounding jumpers and the cable's concentric neutral left connected to the system neutral. During a system fault, the system neutral potential will rise above remote ground as described above. If the de-energized and grounded conductor and/or its concentric neutral being worked on are/is near the system fault, and is in contact with the worker, the worker could be exposed to a transfer of potential and fault current traveling through the cable conductor and concentric neutral to the worksite.

With only bracket grounding and no additional insulation, isolation or equipotential zone work methods, workers contacting the cable, concentric neutral, or device connected to the cable, could be subjected to hazardous voltages. Workers standing near the grounded cable or equipment could also be exposed to excessive step-and-touch voltages if proper work procedures are not followed. As with overhead distribution systems, there are three acceptable methods that workers can use when operating, maintaining, and constructing de-energized underground electric utility systems. They are:

- insulation;
- isolation;
- creating an equipotential zone.

A. Insulation Work Method

Workers can insulate themselves from any possible transfer of potential between de-energized cables, devices, and earth by using approved rubber gloves (and possibly sleeves), insulated footwear, live-line tools, insulated platforms, insulated mats, or insulated cable accessories. When using this method, workers must treat all cables and devices as if they were energized at their nominal voltage [5].

Items to consider are as follows.

- This method uses work methods (rubber glove methods or live-line tool methods) that are familiar to some groups of workers.
- The use of live-line tools allows workers to remain a distance from an electrical arc exposure hazard.
- Many underground systems may not provide adequate clearances for using live-line tool work methods.
- Lubricants, solvents, and cleaners used in underground work practices may destroy insulated rubber gloves and rubber protective equipment.

B. Isolation Work Method

Workers can isolate themselves from any possible transfer of potential through de-energized cables or a temporary grounded cable or device by first installing bracket grounds on both ends of the cable, then removing the temporary protective grounding jumpers and disconnecting the cable's concentric neutral, shield, ground, or equipment ground from the system neutral and all other ground sources.

It is very important that any connection of the cable's concentric neutral, shield, or ground to other cables must be eliminated, such as bare concentric neutrals lying on or in contact with other cables. Three-phase cable systems must have the other two concentric neutrals, shields or grounds isolated from the neutral of the cable to be worked or all three concentric neutrals disconnected.

Extreme caution must be followed when the concentric neutral is disconnected from the system neutral. When the concentric neutral is disconnected, the system neutral is opened. In overhead distribution work practices, the overhead system neutral is never opened. The workers must understand that the electrical theory of an underground concentric neutral is identical to the electrical theory of an overhead system neutral.

A temporary system neutral may need to be installed to bridge the gap left when the cable is removed from the system. This can be accomplished by installing a temporary conductor between the two open points.

Before the cable being worked is placed back in service, the concentric neutral, shield, or ground and all equipment ground(s) must be reconnected to the system neutral on both ends of the cable or device.

Items to consider are as follows.

- This method allows workers to use existing underground work methods with little changes.
- This method may work better on jacketed cable systems.
- All neutral and ground connections associated with the cable to be worked must be disconnected and isolated from all neutral and ground sources.
- The work method is difficult to use on bare concentric neutral cable systems.
- Workers must ensure that all neutral and ground connections are reconnected before energizing the system.
- The de-energized cable may pick up electromagnetic or electrostatic induction from other nearby cables if left ungrounded for long periods (a number of days) of time.
- Disconnecting the concentric neutral, shields, and grounds may open the system neutral.

C. Equipotential Zone Work Method

Workers can provide an equipotential zone at the worksites by first isolating the cable on both ends by use of insulating cable accessories (insulated standoffs). At the worksite, the cable would be tested de-energized, and grounds applied to drain any capacitive charge. A conductive ground grid (ground mat) covering the area where worker(s) will be standing during contact with the cable's concentric neutral and system neutral is installed and connected to the cables concentric neutral or system neutral.

Items to consider are as follows.

- This method allows workers to use the existing work methods with little changes.
- This method works on all types of cable systems and devices.
- Provides protection from re-energization, backfeed, and electromagnetic and electrostatic induction.
- The work area may need to be larger to accommodate the use of a ground mat.
- Workers should be aware of their position with the earth at all times while within the equipotential work zone.

D. Combination of Work Methods

Depending on the underground system configuration (e.g., live-front equipment versus dead-front equipment), the best work method may be a combination of the above three work methods. For example, live-front equipment may require a full equipotential zone application; however, dead-front equipment would require a combination of equipotential zone methods, isolation, and insulation work methods. In a dead-front situation, the neutral conductor might be worked using the equipotential zone method. The phase conductors can be worked using insulation or isolation methods since the cables at either end are on insulated standoffs, and the cable at the worksite has been de-energized, tested for voltage, and grounded, thus isolating the end of the conductor. Rubber gloves could be used to handle the cable until the conductor is bared and connected to the equipotential zone.

IV. Work Procedures

A. Job Preparation

During the job briefing conducted before work begins, workers must decide which methods will be used to protect workers in contact with de-energized cables and devices. Personal protective equipment must also be reviewed before work begins to ensure a safe work area.

B. Voltage Detection Methods

Underground voltage detection methods differ from those procedures used in overhead temporary grounding practices. Underground terminals and equipment are either insulated, considered dead front, or the distance between phases and ground are often small. A commercially available voltage detector designed for underground systems must be used to determine whether nominal voltage, backfeed, or induction is present.

C. Controlling the Work Area

Other causes of accidental re-energization of de-energized and grounded cables are switching errors and cable "dig-ins." During underground switching, human error or incorrectly marked cables could be the reason for incorrect switching or reconnection of cables, creating a fault in all associated cables in the area.

Work by others using earth-moving equipment (backhoes, trackhoes, etc.), in the area of planned work, could cause a "dig-in" into cables associated with the underground system which has been de-energized and grounded. A "dig-in" could re-energize previously de-energized and grounded cables, creating a fault in all of the cables in the area.

When work is to be done on an underground cable system and associated devices, which are de-energized and grounded, all switching and system operations in the area of the work should be completed before any work on the cable or device begins. All earth-moving projects close to energized cables should be stopped for the duration of the work on the de-energized and grounded cable or equipment.

D. Using the Insulation Work Method on Cables

Workers who choose to use the insulation work method must follow approved work methods developed for working on energized lines and devices, even though the cable(s) and devices may have been de-energized from the normal source of energy, a lockout/tagout procedure completed, and the system tested for no energy using a commercially available voltage detector. Refer to IEEE 516 [5] for approved methods.

The insulation work method may include either the use of approved rubber gloves (and possibly sleeves) and/or live-line tools which are rated for the nominal voltage of the cable or device. Also proper approach distances specified in IEEE 516

[5] or National Electric Safety Code (NESC) [6] must be maintained from exposed energized devices that have not been covered with approved insulated materials.

E. Using the Isolation Work Method on Cables

The isolation method is an acceptable method if the conductor and concentric neutral or shield can be totally isolated from the system neutral, system ground, and all current carrying ground sources, including contact with other concentric neutrals, and telephone and CATV grounds. Since total isolation of the concentric neutral may be difficult to obtain, and the chance the concentric neutral would not be reconnected after the work is complete, this method may not be an acceptable option in some cases. This method may also require a temporary neutral to be installed to ensure neutral continuity during the time the concentric neutral is disconnected.

Workers who choose to use the isolation method on cables should consider the following.

- Conduct a job briefing.
- De-energize and isolate both ends of the cable using approved work methods.
- Test both ends of the cable for potential using an approved voltage detector.
- Ground both ends of the cable to the system neutral or system ground using temporary protective grounding jumpers.
- Complete a lockout/tagout clearance procedure.
- Remove the temporary grounding jumpers at each end of the cable terminal and isolate (park) the cable on an insulated bushing.
- Disconnect and isolate the cable's concentric neutral or shield wire from the system neutral, system ground, and all ground sources. Note that this will open the system neutral on looped systems, and should always be done with properly rated rubber gloves (and possibly rubber sleeves) or live-line tools.
- Proceed with the planned work after ensuring there is no connection between the conductor and the neutral, and neutrals of other cables.

Note: Live-line tools can be used and are possibly preferred by some users.

F. Using the Equipotential Zone Work Method

Workers can provide an equipotential zone at the work location by isolating the ends of the cable at adjacent locations and bringing the potential of the cable to ground. To achieve this isolation, one method is to first temporarily ground both ends of the cable by an approved method. Then the temporary grounds are removed and the cable ends are installed on an insulating device. Another method would be to place both ends of the cable on insulated standoffs using an approved work procedure, and then temporarily applying grounds at the worksite, and then removing them. At the worksite, workers must connect a conductive ground mat to the cables concentric neutral or shield and install it at the work location, providing an equipotential zone should a fault occur at or near the work area. This eliminates the transfer of potential through the main conductor of the cable, but protects the workers through equipotential grounding when the cable's concentric neutral, shield, or ground becomes energized.

Workers who choose the equipotential zone work method should consider the following.

- Conduct a job briefing.
- De-energize and isolate both ends of the cable using approved work methods.
- Test both ends of the cable for energy using an approved voltage detector.
- Ground both ends of the cable to the system neutral or system ground using temporary grounding jumpers.
- Complete a lockout/tagout clearance procedure.
- At the work location, identify the cable to be worked and verify the cable is de-energized by an approved method (grounding spear, test instrument, etc.).
- Install a temporary ground grid (ground mat) at the work location. Attach the ground grid to the cable's concentric neutral, shield, or ground cable. If the cable is to be cut, connect both ends of the ground grid to either side of the cut. Ensure the cable's concentric neutral, shield, or ground cable is solidly connected to the system neutral at both ends of the cable's terminals.
- Remove the grounds from both ends of the cable and isolate (park) the cable terminals on the insulated parking bushing (stands).

G. Cable Pulling Equipment

Protection for workers operating on or near cable-pulling equipment used in pulling cable near existing, exposed, energized conductors or apparatus should include isolation, insulation, or creation of an equipotential zone around the equipment.

H. Work at Underground and Padmounted Equipment

Work on de-energized underground and padmount electrical equipment requires similar practices as working on de-energized cable systems. One method of creating a safe work area is to isolate the area by disconnecting the underground or padmount equipment from all electrical connections. In the case of an underground or padmount transformer, the equipment is first grounded by an approved method, then all primary connections, secondary connections, system ground connections, and temporary protective grounds should be disconnected. When work is complete, system ground connections must be reconnected.

Underground and padmount equipment can be worked using the insulation method. This includes the use of approved insulated rubber gloves (and possibly sleeves), insulated footwear, insulated tools, platforms, or insulated mats.

The third method of providing a safe work area is the use of equipotential grounding at the worksite. This includes grounding the underground or padmount equipment using approved grounding methods and installing a ground grid at the area that work is to be preformed. The ground grid must be connected to the system neutral along with the other protective grounding tools.

A combination of the three work methods can be considered.

V. Conclusion

Temporary protective grounding procedures developed for an overhead distribution system back at the turn of the century may not provide adequate protection for workers in physical contact with underground cable and electrical equipment systems during fault conditions. The three methods described in this paper currently in use with overhead distribution systems can be applied, with some modifications, to an underground distribution system. Insulation, isolation, and/or the development of the equipotential zone will provide protection for workers if a fault occurs in the electrical system being worked.

VI. Glossary

Bracket grounding. A grounding method where temporary ground sets are installed on both sides of the worksite.

Equipotential grounding (equipotential zone). An identical state of electrical potential for two or more items. For the purposes of protective grounding, a near identical state of electrical potential.

Ground (or grounded). A ground is a conduction connection, whether intentional or accidental, by which an electrical circuit or equipment is connected to earth, or to some conductive body of relatively large extent that serves in the place of earth, resulting in the circuit or equipment to be grounded.

Ground grid (temporary). Temporarily installed metallic surface mats or grating to establish an equipotential surface, which may be bonded to ground rods temporarily driven around and/or within their perimeter to increase the grounding capabilities and provide convenient connection points for grounding devices. Refer to IEEE 80 [3] for detailed information of the use of ground grids and mats.

Insulation work method. Working on a conductor or device using the same methods employed when the cable or device is normally energized. These methods include using approved insulating tools, insulated gloves or accessories, which are rated for the voltage involved, and the associated work methods.

Isolation work method. Isolation is accomplished when the cable or device has no possibility of being re-energized with the system voltage, backfeed, or electromagnetic or electrostatic induction. The isolation method includes the physical separation of the cable's conductor and concentric neutral or shield from the system neutral.

Standoff (insulated parking bushing). A device used to position (park) and isolate the elbow system located on one or both ends of a primary cable. The device does not ground the primary cable run, but will insulate the cable's conductor from energized sources.

System neutral (system ground). The development of a system neutral or system ground for electrical underground circuits and electrical equipment includes the concentric neutral, conductor shield, a separate neutral conductor, ground rod or plates, and electrical equipment cases and structures which are all bonded together to develop the equivalent of ground (refer to the definition of "ground") and connected to the source's system neutral.

Temporary protective grounding equipment. A system of ground clamps, ferrules, ground mat(s), and cables designed and suitable for carrying fault current as specified in ASTM F855 [7].

Voltage detection. A method of testing for nominal voltage by use of a field intensity meter (voltage detector) extended, by use of a hot stick, to the close proximity of the exposed conductor. The field intensity meter responds to the magnitude of the field gradient between the field intensity meter's end probe and the instrument's floating electrode.

Working grounds. Working grounds consist of temporary protective grounding equipment installed between the cable's conductor and the cable's system neutral.

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