Live Work Guide for Substations

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Technical Update, October 2004

EPRI Project Manager

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ABSTRACT

Live work (work on energized circuits) is the preferred method of maintenance where system integrity, system reliability, and operating revenues are at a premium and removal of a circuit or a substation from service is not acceptable. Live work (LW) may also be beneficial in construction and storm damage repair. Furthermore, live work may be unavoidable in the case of substations that serve essential facilities such as hospitals, law enforcement, fire departments, and intrusion alarms if standby local generation is not available.

Over the last decade, EPRI has helped many utilities achieve significant savings and technological advances in the maintenance and refurbishment of energized transmission lines. The results of this work, performed mainly through tailored collaboration (TC) projects, are consolidated into a practical “Live Work Guide for Transmission Lines” for work on energized circuits.

The “Live Work Guide for Substations” is an outgrowth and a natural extension of EPRI’s research in the area of live working.

This EPRI Technical Update is an outline of the Guide that will be developed and completed in 2005. This EPRI Technical Update has been circulated to the members of the EPRI Task Force on LW for comment.

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INTRODUCTION

Live work (work on energized circuits) is the preferred method of maintenance where system integrity, system reliability, and operating revenues are at a premium and removal of a circuit or a substation from service is not acceptable. Live work (LW) may also be beneficial in construction and storm damage repair. Furthermore, live work may be unavoidable in the case of substations that serve essential facilities such as hospitals, law enforcement, fire departments, and intrusion alarms if standby local generation is not available.

Over the last decade, EPRI has helped many utilities achieve significant savings and technological advances in the maintenance and refurbishment of energized transmission lines. The results of this work, performed mainly through tailored collaboration (TC) projects, are consolidated into a practical "Live Work Guide for Transmission Lines" for work on energized circuits.

The "Live Work Guide for Substations" is an outgrowth and a natural extension of EPRI's research in the area of live working.

This Section will be quite brief and will introduce the Guide. It will describe, from the LW viewpoint, several types of substations, including:

- Conventional substations that were usually designed and built decades ago and have fairly large electrical clearances,
- Compact substations in which electrical clearances are reduced,
- Mobile substations that are also compact by necessity to meet transportation restrictions.

Furthermore, substations can be:

- Attended or unattended,
- Air insulated or gas (for example, SF_6) insulated,
- Open air or enclosed,
- Built above ground or below grade (underground substations).

The scope of the guide will be presented with the focus on air-insulated substations. Other insulating media will be mentioned for completeness, but the point will be made that LW is generally possible only in air-insulated substations.

Conventional and compact substations will be discussed briefly in terms of available clearances between energized phases, and between energized phases and grounded objects (walls, fences, equipment tanks, etc.). The concept of a minimum required distance, later defined more precisely as the Minimum Approach Distance, will be introduced briefly to highlight the essential differences between conventional and compact substations.

The focus of the entire Guide will be on LW. Other issues related to substations, such as construction, location, equipment and instrumentation, external and environmental influenced (contamination, environmental impact), etc., will be addressed on as needed bases.

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WHAT IS LIVE WORK?

Live work (LW) will be described briefly, with extensive references to other EPRI documents for details, such as the published LW Guide for Transmission Lines and EPRI reports. The emphasis in this Guide will be on LW in substations. A brief history of substation LW will be included, emphasizing that LW in substations is a more recent development than transmission and distribution line LW.

The four types of substation LW that are similar to transmission LW will be described briefly:

- De-energized work
- Gloving Method (Distribution voltages – will be mentioned, but no details)
- Insulating Tool Method (At-A-Distance Method)
- Barehand Method (Contact Method)

The Gloving method will be mentioned for completeness, but it will not be described in detail since the focus of the Guide is on transmission substations. The Guide will emphasize, however, that transmission substations often are adjacent to, or are located close to (even within the same fence perimeter) the distribution yards.

Examples of some subsections are included below.

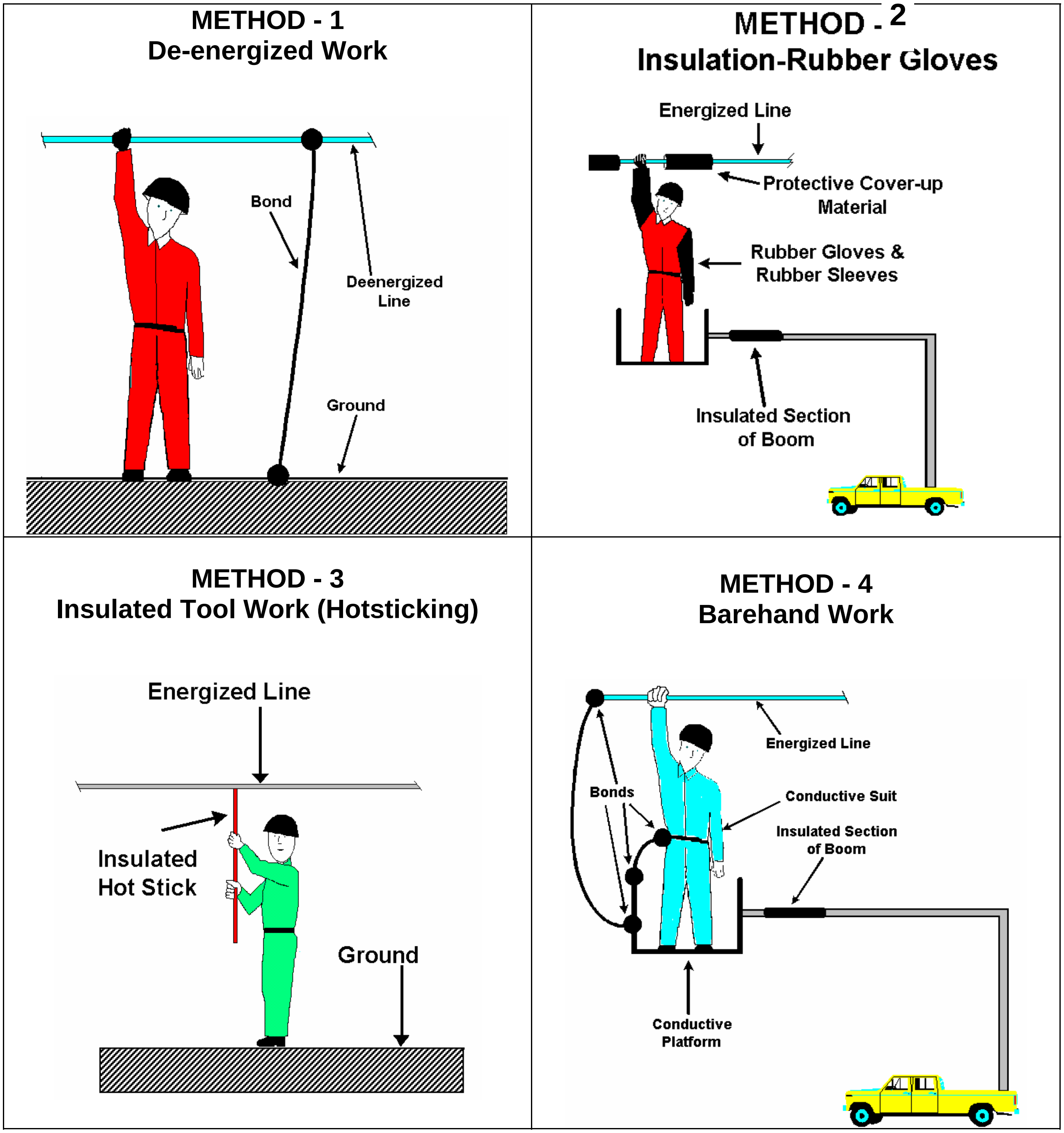
Types of LW

There are four basic types of live work, see Figure 2-1:

1. **De-energized work –** Once the circuit has been disconnected from all known sources of electrical supply, the circuit is still considered to be energized until all system, equipment, and personal protective grounds have been installed at the worksite(s) using insulating tool(s).

2. **Gloving –** Distribution circuits are worked energized by using insulating gloves, blankets, line hoses, and other cover-up equipment.

3. **Insulating tool work (also known as hotsticking and at-a-distance work) –** Work is done with insulating tools, non-conductive rope, and aerial devices. The worker is essentially at ground potential and is separated from the energized circuit by insulating tools. Insulating tool work may be done from an insulated or an uninsulated aerial device as long as the appropriate minimum approach distances are observed.



METHOD - 1
De-energized Work

METHOD - 2
Insulation-Rubber Gloves

METHOD - 3
Insulated Tool Work (Hotsticking)

METHOD - 4
Barehand Work

Figure 2-1
Sketches of the four types of live work. Note: Insulated aerial devices are often being used when gloving above 15 kV where phase-to-phase and phase-to-ground MAD cannot be achieved. Gloves, and sleeves if required, should be the primary protection for workers and should be rated for the voltage being worked. The insulation of the aerial device cannot be used as part of worker protection.

4. **Barehand method (also known as contact work)** – The worker is in direct contact with energized parts and is separated from ground by air and a combination of insulating tools. Barehand work can be performed from insulating ladders or aerial devices.

In addition to these four types of live work, this guide also covers other topics related to substations, including:

- Vegetation and animal related issues,
- Inspection ,
- Work in substations by workers who are not qualified to perform LW.

Live work should not be performed, and should be discontinued if started, while there is any indication of lightning or other inclement weather conditions in the surrounding area (some utilities use five miles as a guide). Other inclement weather conditions may include high relative humidity, high wind speed, presence of fires (grass, forest), presence of debris in the air, etc.

Historical Notes

Live work is sometimes considered a recent development in the electrical power industry. However, forerunners of modern insulating tools made their appearance as far back as 1913. These initial tools were homemade, crude, and bulky; still, they launched the development of the efficient and refined tools that are used by utilities today. LW was initially used on low voltage distributions lines, then it was extended to higher voltages and to transmission lines. Introduction of LW methods to substations lagged behind initially, but in the second half of the 20th century has reached a comparable level of acceptance and sophistication.

In 1916, a tool known as an "electrical hook" was introduced in Atlanta, Georgia. This was essentially a spring-type clamp mounted on an insulating wooden stick that was used to tap energized circuits. Its use identified the need for live working tools for other applications, and tools were soon developed for applying parallel-groove clamps, handling conductors, pulling insulator cotter pins, and manipulating tie wires. Soon to come were a hacksaw, a live work come-a-long, and saddles that could be attached to structures (usually wood poles) for supporting other tools.

Live work tools were first accepted for work on lines up to 34 kV; however, many linemen were hesitant to perform live work at this voltage. Because of this reluctance, many companies initially restricted live work to 22 kV or less. As time progressed, special tools and dedicated equipment were developed (see Figure 2-2 as an example) and linemen began to acquire confidence in performing live work when they realized that the tools always kept them at a safe distance from energized parts. Restrictions were gradually relaxed, until by 1930 several utilities were permitting live work operations on 66 kV lines. The permitted voltage limit soon rose to 110 kV, and in the late 1930s the astonishing news was circulated that a 220 kV line on the West Coast had been successfully worked energized ("hot"). Another milepost was passed in March of 1948, when linemen changed suspension insulators on a 287 kV Hoover Dam-Los Angeles transmission line with live work tools specifically designed for the job.

Live work tools with fiberglass sticks were introduced in 1959. The fiberglass sticks consisted of layers of resin-coated glass fibers wound around and laid lengthwise over a plastic foam core. They were formed into a single unit by curing in an oven maintained at a constant temperature. It was the introduction of these fiberglass sticks, which were highly resistant to moisture absorption and damage, that allowed electric utilities to develop the live work maintenance practices they currently employ on 345 kV, 500 kV, and 765 kV transmission lines.

First Barehand Work

Harold L. Rorden, a high-voltage practices engineer for the American Electric Power Service Corporation, conceived the live work barehand method on overhead lines in late 1960. The method was developed and perfected in extensive field and laboratory tests. The tests were conducted in the Ohio Brass Company's high-voltage laboratory. Rorden was assisted by a co-developer of the new method, Dr. Charles J. Miller, Jr., an Ohio Brass high-voltage research engineer. The Holan Division of the Ohio Brass Company designed and produced the insulated aerial device and equipment that was used during the development of the barehand work.

Today, aerial devices with insulating boom segments have become integral parts of many live work procedures. Insulating tools, such as sticks and non-conductive rope, are required components of most barehand procedures.

The development of barehand work required tight control of overvoltages at the worksite. Switching impulses (SI) were controlled (reduced) by blocking the reclosing features of the system to be worked; however, this did not provide control of temporary (transient) overvoltages (TOV). With the construction of both 500 kV transmission lines and more compact line designs, control of TOV became an urgent necessity. In 1965, the first portable protective air gap (PPAG) was developed and tested for use on 500 kV lines. At present the use of PPAGs at 500 kV is becoming more common, and PPAGs have been developed for all transmission voltages between 115 kV and 550 kV.

The barehand method or overhead lines was developed as a result of:

- Rapidly increasing load levels
- Cumbersome live work tools needed for the insulating tool method
- A lack of parallel, backup, or loop support facilities in many transmission systems

The barehand method and other methods of LW were subsequently applied also to substations and special tools, scaffolding and detailed procedures were developed. Figure 2-3 shows scaffolding recently used by a European utility to perform work on a 400 kV substation switch.

Figure 2-2
Live line maintenance truck, vintage 1920s.

Figure 2-3
Example of scaffolding for maintenance on an energized 400 kV switch.

3

DEFINITIONS

The Definitions section is included in this guide to explain the terms used in the text.

Definitions pertinent specifically to substations and substation LW will be listed. It is not the intent of this Guide to develop and suggest a standard terminology. Various names for substation and LW equipment will be listed for completeness and to avoid confusion.

An example of definitions that will be included in the Guide is provide below. This list will be amended with additional entries as needed.

The sources of definitions are identified in square brackets. Most definitions were taken from Ref. [1].

barricade. A physical obstruction such as tapes, cones, or A-frame type wood or metal structures intended to provide a warning about and to limit access to a hazardous area. [2]

barrier. A physical obstruction which is intended to prevent contact with energized circuits or, to physically prevent access to other hazardous areas, and to prevent unauthorized access to a work area. [2, modified]

bond (bonding). The electrical interconnection of conductive parts to maintain a common electrical voltage. [2, 3, modified]

blocked reclosing. The disabling of all devices that would allow circuit breaker reclosure.

certified. (1) A person who possesses valid documentation attesting that he is qualified and has satisfactory completed tests as to his knowledge and skill to safely perform in a specific field of endeavor.

(2) A piece of equipment that has passed all required manufacture and utility inspections and tests and has a certificate (form) in the permanent maintenance file

clearance. A work procedure. See “work permit.” [3]

cold end. The grounded or structure end of an insulator string.

corona. A luminous discharge due to ionization of the air surrounding a conductor caused by a voltage gradient exceeding a certain critical value. [3]

crazing. The creation of small cracks on a surface.

de-energized. Disconnected from all sources of electrical supply by open switches, disconnectors, jumpers, taps, or other means. *NOTE:* De-energized conductors or equipment could be electrically charged or energized through various means, such as induction from energized circuits, portable generators, lightning, etc. [3]

dead. The term "dead" is no longer used in National Standards or papers when associated with "de-energized". The term "dead" was used to indicate a zero voltage or equipotential zone. A circuit is at equipotential only at the site where ground cable(s) are installed. During fault conditions, grounding cables are energized and carry current to ground. Grounding cables are also energized by continuous induction from nearby energized buswork or equipment. Induction can produce dangerous step and touch voltages between metal structure on which work is performed, and the station grounds. The induced voltage increases significantly as one moves away from the grounded worksite.

deadend. A structure or insulator string that is designed to withstand conductor tension loads without additional support.

distance. The measurement between energized circuits and the nearest grounded object. See "electrical clearance."

electrical clearance. The measurement between energized circuits and the nearest grounded object, determined by design and operations, to prevent electrical sparkover or flashover during circuit operation. See "distance"

electrically isolated. Removed from all primary sources of electrical energy by opening switches, disconnectors, jumpers, taps, or other means of electrical supply. The current is isolated when all switches, disconnectors, jumpers, taps or other means through which known sources of electrical energy may be supplied to the particular lines and equipment have been opened on a de-energized electrical circuit or equipment.

energized. Electrically connected to a source potential difference, or electrically charged so as to have a potential slightly different from that of the earth in the vicinity. [1, modified]

fault (current). A current that flows from a conductor to ground or to another conductor because of an abnormal connection (including an arc) between the two.

fire resistance. The property of a *material* to give protection from fire [1, modified]

fire retardant. *Material* treated to slow the burning process

flashover. A disruptive discharge through air around or over the surface of insulation, between parts of different potential or polarity, produced by the application of voltage wherein the breakdown path becomes sufficiently ionized to maintain an electric arc. [1, modified]

gloving. The use of rubber insulating gloves and sleeves, matting, blankets, covers, line hose, and plastic guard equipment, to insulate the worker from phase-to-phase and phase-to-ground exposure when working on energized distribution circuits.

ground or grounded. A conducting connection, whether intentional or accidental, by which an electrical circuit or equipment is connected to earth or station ground, or to some conductive body of relatively large extent that serves in place of the earth, resulting in the circuit or equipment to be grounded. *Syn:* ground (earth). [5]

hazard analysis. A written document which addresses the possible hazards associated with a specific task and the utility work practices which minimize the hazard.

HLO. - Hot Line Order (aka, Headway Tag, Hold Order (blocks reclosing))

hot end. Energized end of an insulator string.

hydrophobic. Having little or no affinity for water (sheds water).

hydrophilic. Having a strong affinity for water (water beads).

induction (coupling). The process of generating time-varying voltages and/or currents in conductive objects or electric circuits by the influence of the time-varying electric and/or magnetic fields. [1, modified]

insulating tool. A tool or device designed primarily to provide insulation from an energized part or conductor. It can be composed entirely of insulating materials (i.e., conductor, stick, insulating tape, etc.). [1, modified]

ionization. A breakdown that occurs in parts of a dielectric when the electric stress in those parts exceeds a critical value without initiating a complete breakdown of the insulation system. [1]

isolated (physical). Not readily accessible to persons unless special means for access are used. Barriers or barricades are used to prohibit access. [1, modified]

jobsite. The assembly point at the structure or equipment where workers, tools, and vehicles are assembled to perform the work activity. [6, modified]

jumper. (1) A permanent section of the circuit phase conductor(s) connecting a dead-ended circuit phase to a second dead-ended circuit phase or to equipment, so that continuity is maintained. *Syn:* dead-end loop.

(2) A temporary conductor placed across the clear space between the ends of two conductors or metal pulling lines.

(3) A conductive tool used to maintain electrical continuity across equipment, or a conductor that shall be open mechanically to enable various operations of liveline work to be performed. *Syn:* bypass. [5]

minimum air insulation distance (MAID). The shortest distance in air between an energized electrical apparatus and/or a line worker's body at different potential. With a floating object in the gap, it is equal to or greater than the sum of the individual minimum approach distances. This is the electrical component and does not include any factor for inadvertent movement. [4]

minimum approach distance (MAD). The minimum air insulation distance plus a modifier to inadvertent movement [4]

OCF. Overload Capacity Factor (in reference to insulators)

overvoltage. Voltages greater than the normal operating voltage of the circuit, either through switching impulses or induction.

polymer insulator. Also referred to as non-ceramic insulator, NCI, composite insulator. See Section 11 for further details.

qualified electrical worker. A worker who has received, as part of a training program, formal instruction and training in electrical systems and associated hazards, and who is familiar with OSHA, NESC, and state and local electrical rules and regulations. *NOTE:* An apprentice in training and under the direct supervision of a qualified worker is considered to be an electrical worker.

qualified worker. A worker who by reason of training and experience, understands the methods and has routinely demonstrated proficiency in knowledge or hazards, tools, and equipment associated with the technical aspects of his profession based on supervisor's assessment in concurrence with the next higher level supervisor. [6, modified]

sparkover. A disruption discharge between electrodes of a measuring gap, voltage-control gap, or protective device. [1 definition (3)]

step voltage. The potential difference between two points on earth's surface separated by a distance of one pace (assumed to be 1 m (3.3 ft.) in the direction of maximum potential gradient). This potential difference could be dangerous when current flows through the earth or material upon which the worker is standing, particularly under fault conditions. Step voltage is of particular concern at the edges of substation ground grids and mats. *Syn*: step potential. [5]

switching impulse (SI). Ideally, an aperiodic transient impulse voltage that rises rapidly to a maximum value and falls, usually less rapidly, to zero. Switching impulses generally have wave front times of the order of tens to thousands of microseconds, in contrast to lightning impulses, which have wave front times from fractions of a microsecond to tens of microseconds. [1, modified]

temporary overvoltages (TOV). An oscillatory phase-to-phase or phase-to-ground overvoltage at a given location of relatively long duration (seconds, even minutes) and that is undamped or only weakly damped. Usually through circuit disturbances or induction. [1, modified]

touch voltage. The potential difference between a grounded metallic structure and a point on earth's surface separated by a distance equal to a person's normal maximum horizontal reach, approximately 1 m (3.3 ft.). This potential difference could be dangerous and could result from induction, fault currents, or both. [5]

transfer touch voltage. A special case of touch voltage where a conductive element, such as a vehicle, grounded to the structure brings the potential from the structure to a point spanning more earth than one meter. The transfer touch voltage is of particular concern in substations when the conductive element is beyond the station ground grid or mat. [83, modified]

unqualified worker. A worker that does not meet the requirements of qualified worker.

variance. (1) A written document which allows work practices to deviate from the norm due to abnormal circumstances.

(2) An oral agreement between crew members to deviate from normal work procedures under abnormal circumstances such as storm damage.

withstand. The crest value attained by an impulse of any given wave shape, polarity, an amplitude, that does not cause disruptive discharge on the test specimen. [1]

worksite. The immediate area where the specific or assigned task is to be performed.

written work procedure. A written document used to describe required tools, safety procedures, hot line order (HLO), variances, hazard analysis, and specific work procedures for live work.

4

RULES AND PROCEDURES APPLICABLE TO LW IN SUBSTATIONS

This Section will discuss the relevant safety rules, regulations, standards and administrative issues that are pertinent to LW.

The focus will be on LW, and other related topics will be mentioned only as needed.

Rules, Regulations and Standards

US, international, regional, local, and industry standards will be referenced, including:

- OSHA, NESC
- IEEE, ANSI, ASTM
- IEC

OSHA (Occupational Safety and Health Administration) is the federal organ in the USA that regulates occupational safety issues. OSHA rules are mandatory in the USA and are also followed or used as a reference model for development of rules by other countries. As a regulatory rather than a technical body, OSHA utilizes information and data related to LW from the NESC [3], IEEE Std-516 [4], other IEEE, ANSI and ASTM standards, scientific papers and EPRI reports, and industry experience.

NESC (National Electrical Safety Code) is a voluntary standard that has been adopted in entirety or with modifications as state regulation by most states in the USA. It also is often used as a reference model for development of rules by other countries. Similarly to OSHA, NESC draws information related to LW from the IEEE, ANSI and ASTM standards, scientific papers and EPRI reports, and industry experience.

IEEE is the largest professional transnational organization in the world and develops technical standards and guides based on sound scientific knowledge and experience. IEEE publications are voluntary and serve as technical background for OSHA rules and many other regulations both with the USA and abroad. The most relevant IEEE publications to LW include Refs. [4, 5, 6, 24, and 33].

ANSI (American National Standards Institute) develops its own mandatory standards and adopts many IEEE publications as mandatory ANSI standards. ANSI standards are technical in nature and content and serve as technical background for OSHA rules.

ASTM (American Society for Testing and Materials) develops standards that also serve as technical background for OSHA rules.

IEC (International Electrotechnical Commission) is an international standardization body for the electrical industry. Technical Committee 78 (TC78) “live working” prepares standards that are directly related to LW. IEC publications are voluntary and are adopted in entirety or with modifications as mandatory standards by national or regional regulatory bodies. A recent agreement between IEC and IEEE provides for submission of IEEE standards for full consideration as dual-logo IEC-IEEE Standards.

Administrative Issues

This Subsection will discuss administrative issues pertinent to LW, such as:

- Training requirements for LW personnel
- Record keeping (LW-related records)
- Use of transmission LW crews to perform substation LW, and *vice versa*
- Contracting LW
- Activities of non-LW trained personnel within energized substations

Prevention of access by general public will be mentioned only briefly, since this topic is not the main subject of the Guide.

Examples of processes, recordkeeping requirements and forms will be presented. A draft of this subsection is included. It will be modified, expanded and amended needed.

General

Each employee involved in live working is responsible for being knowledgeable of the applicable safety requirements and proper live work procedures. Managers and supervisors are responsible for ensuring that each worker complies with all company guidelines and procedures.

Training

General training should be in accordance with OSHA 1910.269 (a) (2), which includes familiarizing crew members with safety-related work practices, safety procedures, applicable emergency procedures (such as structure rescue), and other safety requirements that pertain to their respective job assignments.

A qualified person should be trained and competent in:

- The skills and techniques necessary to distinguish exposed live parts from other parts of electric equipment
- The skills and techniques necessary to determine the nominal voltage of exposed live parts
- The minimum approach distances (phase-to-phase and phase-to-ground) corresponding to the voltage to which each employee will be exposed

- The proper use of special precautionary techniques, personal protective equipment, insulating and shielding materials, and insulated tools and equipment used on or near exposed energized parts of electrical circuits

The employer should (at least annually) determine through regular supervision and inspections that each employee is complying with safety-related work practices.

Additional training or retraining should be required if:

- The supervision and annual inspections indicate that the employee is not complying with the safety-related work practices, or
- If new technology, new types of equipment, or work procedures are different than those that the employee would normally use, or
- If the employee must use safety-related work practices that are not normally used during regular job duties, or
- When tasks are performed less than once per year.

Training may be either classroom or on-the-job. The training should establish employee proficiency in the required work practices.

Qualified personnel doing or supervising barehand work should be required to have additional training in use of the barehand technique.

Certification

The employer should certify that each employee has received the required training. The certification should be made when the employee has demonstrated proficiency in the related work practices and safety procedures. Certificates of training and certification should be kept in the employees' files for the duration of their employment. (See Figures 4-1 and 4-2 for sample certificates.)

Craftsmen Instruction and Certification

Only certified personnel should perform or supervise work on energized lines or equipment. Certification for live work should ensure that an individual is not only knowledgeable but also competent in performing work on energized equipment. Exception: During training sessions, personnel may be uncertified but should be under the direct supervision of a qualified person. The rank of each apprentice and the extent of his specific involvement in live work training should be determined by the employer. The employer should designate a responsible manager to certify that personnel performing live work have obtained the following:

1) **Certification –** Certification is required for those performing the barehand or insulating tool methods. If certification is received in the barehand method, then a separate insulating tool method certification is not required. However, if insulating tool method certification is received and a worker needs to perform barehand work, the barehand certification must be completed.

        a. **Barehand method –** The employer should determine the number of hours required for an employee to complete a satisfactory training program that should consist of a combination of classroom and hands-on or on-the-job training and competency testing. The required number of training hours should be documented in company procedures and should be consistent for all trainees. The classroom portion should include discussions on the applicable safety rules and barehand live work procedures.

        b. **Insulating tool method –** The employer should determine the number of hours required for an employee to complete a satisfactory training program that should consist of a combination of classroom and hands-on or on-the-job training and competency testing. The required number of training hours should be documented in company procedures and should be consistent for all trainees. The classroom portion should include discussions on the applicable safety rules and insulating tool methods.

    2) **Physical condition –** Craftsmen should pass an annual physical examination in accordance with employer regulations.

Supervisor Instruction and Certification

The employer should certify that supervisors of live work have obtained the following:

5. **Certification –** Supervisors should have previous journeymen certification in the methods they are to supervise and should be current in the applicable safety rules and live work procedures. Authority to supervise barehand and insulating tool methods should be documented by the individual’s superior. The certificate of certification shall be a permanent part of the supervisor's file. The certification should state whether the individual is certified for insulating tool, barehand, or both.

6. **Physical condition –** Supervisors should pass an annual physical examination in accordance with employer regulations.

Certificate of
Live Work Proficiency

This document of certification is testament that

John C. Doe

has completed the training and has demonstrated the
proficiency required to perform Live Work by the

Barehand Technique

on ______ Utility Name ______ energized facilities
in accordance with the maintenance and safety standards
established by the EPRI Solutions Training Center

Administrator, EPRI

Chairman, International Brotherhood of Electrical Workers, GCC-1

Trainer

Utility Manager

This Certification is Valid Through
Date ______

Supervisor's Certificate of
Live Work Proficiency

This document of certification is testament that

John C. Doe

has completed the training and has demonstrated the
proficiency required to perform Live Work Supervision by the

Barehand Technique

on ______ Utility Name ______ energized facilities
in accordance with the maintenance and safety standards
established by the EPRI Solutions Training Center

Administrator, EPRI

Chairman, International Brotherhood of Electrical Workers, GCC-1

Trainer

Utility Manager

This Certification is Valid Through
Date ______

Certificate of
Live Work Proficiency

This document of certification is testament that

John C. Doe

has completed the training and has demonstrated the
proficiency required to perform Live Work by the

Hotstick Technique

on ______ Utility Name ______ energized facilities
in accordance with the maintenance and safety standards
established by the EPRI Solutions Training Center

Administrator, EPRI

Chairman, International Brotherhood of Electrical Workers, GCC-1

Trainer

Utility Manager

This Certification is Valid Through
Date ______

Supervisor's Certificate of
Live Work Proficiency

This document of certification is testament that

John C. Doe

has completed the training and has demonstrated the
proficiency required to perform Live Work Supervision by the

Hotstick Technique

on ______ Utility Name ______ energized facilities
in accordance with the maintenance and safety standards
established by the EPRI Solutions Training Center

Administrator, EPRI

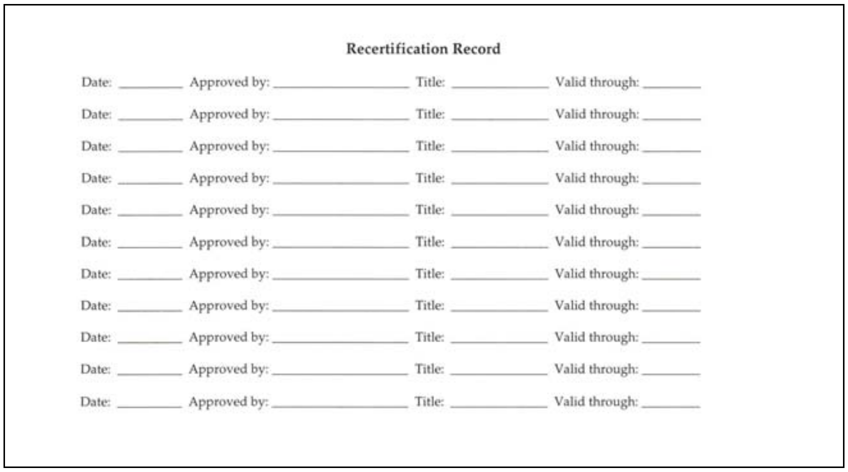
Chairman, International Brotherhood of Electrical Workers, GCC-1

Trainer

Utility Manager

This Certification is Valid Through
Date ______

Figure 4-1
Sample proficiency certificates.



Recertification Record

Date: ________ Approved by: __________________ Title: ____________ Valid through: ________
Date: ________ Approved by: __________________ Title: ____________ Valid through: ________
Date: ________ Approved by: __________________ Title: ____________ Valid through: ________
Date: ________ Approved by: __________________ Title: ____________ Valid through: ________
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Date: ________ Approved by: __________________ Title: ____________ Valid through: ________

Figure 4-2
Reverse side of all proficiency certificates.

Records

Initial certification for each individual should be recorded and kept in the employee's permanent personnel file. A copy should be kept at the duty station.

Contracting Live Work

Contracts

The utility is responsible for the safety of contracted workers doing maintenance on energized facilities and construction of facilities near energized facilities. It is essential that contracts specify compliance with OSHA, state, local, and utility regulations and safety manuals. The utility should also have a trained inspector at the job site who is familiar with all aspects of live work.

Live Work

The utility should ensure that all contract workers performing live work are qualified and certified electrical workers in accordance with OSHA regulations/standards. Minimum approach distances for qualified electrical workers must be maintained, and hazard analysis and written work procedures for each task should be supplied by the contractor to the utility. If a contractor’s employees are represented by a labor union(s), the utility should be provided with the union’s name(s), representative(s), and the number(s) of the union’s local chapter.

Work in the Proximity of Energized Facilities

Barriers and barricades must be provided for safety of the public and nonqualified electrical workers. These barriers and barricades should be placed at the minimum approach distances for nonqualified electrical workers. If practical during work periods, the reclosing of nearby energized facilities should be blocked.

Preparation for LW in Substations

This Subsection will address such issues as switching orders, hazard analysis prior to planning of LW, preparation of workers, job briefings and tailgate meetings, training in related areas (rescue, first aid, etc.), supervision and communication in case of emergency.

Switching Order

All switching operations, such as blocking reclosing, should be performed in accordance with company-authorized oral and written polices and, when required, should be recorded on proper company form(s). When required, all associated automatic reclosing devices should be deactivated and properly tagged. Live work or tests that could result in the disabling of circuit breakers or loss of communications between crews and the operations center should not be performed on protective relays, control circuits, or communications systems. OSHA 1910.269 (q) (3) (iv) requires that reclosing be blocked for barehand live work [18].

Written Procedures

Written procedures should be available to the live working crew for each type of live work activity. Each written procedure should specify the minimum crew size by classification, the principal tools to be used, and each major step in the procedure. Apprentices must meet the requirements of the OSHA's "Certification" paragraph. Procedures should be periodically reviewed or updated to reflect the latest work practices, safety concerns, and new equipment and tools. The specific written procedure for the specific live work task(s) should be available to the crew at the job briefing. Live work should not be attempted with less than the minimum number of qualified personnel stated in each written procedure.

Job Briefing

The employee in charge should conduct a live work job briefing prior to the start of each new task in accordance with OSHA 1910.269 (c). As a minimum, the briefing should include discussion of:

- Hazards associated with the job
- Work procedures
- Special precautions
- Control of energy source
- Personal protective equipment.
- Specific and detailed job location (for ambulance)
- Contact person(s) and telephone numbers to phone in case of an accident

Additional job briefing(s) should be held if significant changes, which might affect the safety of employees or the public, occur during the course of the work. Changes to written procedures should be discussed at the job briefing.

A short job briefing is satisfactory unless the work is unusually complicated or hazardous or if any of the crew cannot be expected to recognize and avoid the hazard(s) associated with the task(s).

Hazard Analysis

A written hazard analysis should be required for each live work task. A hazard analysis should be an integral part of the written procedure for each live work task and should be reviewed at the job briefing.

Variances

It is not uncommon for employees to confront a situation that is at variance or in conflict with written procedures. This is especially true with storm damage. As such, the employer should establish a variance policy for these situations that is both stringent enough to prevent abuse of the variance process and lax enough to allow live work to continue in unusual situations.

Supervision

Live work should be monitored by a supervisor or acting supervisor trained and certified in accordance with the training and certification paragraphs. The supervisor should observe and direct the live work. The supervisor should remain on the jobsite in a non-work status and should pay strict attention to ongoing activities. The supervisor should be aware of the physical and mental condition of each crew member. No one, including the supervisor, should be allowed to work in a condition, such as excessive fatigue due to large number of hours worked, that could jeopardize the safe operation of the crew or equipment. Work should not begin until all crew members agree that the task and procedures are safe.

5

MOST COMMON LW TASKS, EXAMPLES AND LESSONS LEARNED

This is one of the most important and extensive section of the guide. It will require a very significant effort to prepare.

Most Common LW Tasks

The subsection will describe the common tasks performed using LW methods. The preliminary list of tasks includes:

- Insulator Cleaning
- Bus Repair
- Replacement of Equipment
- Repair of Equipment
- Installation of New Equipment
- Vegetation Management
- Wildlife Management
- Access Management during work
- Switch alignment with one side energized
- Testing near energized circuit (power factor, Doble, CTs, etc. – LW considerations only)
- Inspection of energized substation equipment (LW considerations only)
- Other work

This Section will also describe the type of training and skills required for each task, and a generic inventory of needed tools.

Note: prevention of unauthorized access at times other than during LW is outside the scope of this guide.

Examples of LW in Substation

This Subsection will be very practical in tone and will contain examples of actual LW tasks performed in various substations. The descriptive text will be augmented with pictures and sketches.

Examples of task sheets will be given in a format similar to that in Section 16 of the Field Guide [36]. The sheets will include the following information:

- Description of the task,
- Discussion of typical crew size and composition,
- Identification of concerns and hazards specific to the task,
- List of tools and equipment needed for the task
- Procedure for performing the task, including several different procedures is applicable,
- Additional relevant comments

An example of the task sheet for the job briefing/tailgate meeting is included below.

Job Briefing/Tailgate Meetings

- The employee in charge shall conduct a live work job briefing (tailgate meeting) prior to the start of each new task in accordance with OSHA 1910.269(c).
- All personnel, including management and safety observers at the worksite shall participate in the job briefing.
- The specific written procedure for the specific live work task(s) should be available to the crew at the job briefing.

The job briefing should include a discussion of:

- Hazards associated with the job
- Work procedures
- Special precautions
- Control of the energy source. The HLO and switching procedure should be read to the crew. Each member of the crew and all management safety and maintenance observers should sign the HLO.
- Changes to written procedures (if any). The crew should be asked if there are any questions or concerns to be resolved (any member can shut down the operation if there is disagreement).

All insulating tools should be wiped of contamination and placed on a tool rack or clean tarp. Workers must insure that LW rope that has been stored in moisture-proof containers has not become wet or contaminated. Workers must insure that all insulating tools to be used in contact with energized circuits have hand guards or are marked with nonconductive tape for the MAD that has been established for the specific job.

Lessons Learned

This subsection is intended to be very instructional. It will describe actual case studies that provide both positive and negative field experience. Successful methods and unique approaches will be described. Also, lessons learned from incidents will be analyzed and discussed to help avoid re-occurrence of similar incidents.

The reviewers are requested to provide specific case studies for this section. All information will be treated confidentially and will be edited to remove the utility's identity and non-technical non-essential details.

6

SAFETY CONSIDERATIONS

This Section will discuss the main technical requirements that must be met to perform LW in substations:

- Minimum Approach Distance for Qualified Workers
    - Ergonomic Component
- Minimum Approach Distances for Non-Qualified workers who need to perform tasks other than LW tasks in substations
- Equipotential Zones
    - Induced Voltages
    - Backfeed (LW issues only)
        - Several Lines on a Common Bus
        - Other
    - Step, Touch and Transfer Voltages
    - Permanent Station and Temporary Grounds
- Personal Protective Equipment
- Station Entrance Gaps

Minimum Air Insulation Distance (MAID) and Minimum Approach Distance (MAD)

The Minimum Approach Distance (MAD) and the derivation and significance of the Minimum Air Insulation Distance (MAID), which is the electrical component of MAD will be described. Extensive references to applicable standards (IEEE 516, IEC 61472) will be made. The concept of the Ergonomic Component of Inadvertent Movement component of the MAD will be discussed in relation to LW personnel and also in relation to moving fixed-size equipment within the substation (is the ergonomic component still required in this situation?).

Table 1 provides the MAID values from Ref. [4] as an example. Table 2 provides the accepted (newly revised) default overvoltage pu factors from Ref. [4].

The data in Tables 6-1 and 6-2 will be discussed and the differences between these data and the data in Ref. [2] (OSHA) and Ref. [3] (NESC) will be highlighted.

It should be noted that the old overvoltage factors were 3.0, 2.4 and 2.0 pu, for system voltages below 362 kV, 500-500 kV and 765-800 kV, respectively.

The MAD is obtained from the MAID by adding the inadvertent movement distance. The recommended inadvertent movement distance is 0.30 m (1 ft) for system voltages 72.501 kV and above.

Table 6-1
Minimum Air Insulation Distance (MAID) without tools, ac energized work (MAID does not include the inadvertent movement component) [4].

Voltage in kV Phase-to-Phase	Distance to Employee			
	Phase-to-Ground		Phase-to-Phase	
	(ft)	(m)	(ft)	(m)
72.6–121	2.45	0.75	3.56	1.09
138–145	2.94	0.90	4.27	1.31
161–169	3.42	1.05	4.96	1.52
230–242	5.14	1.57	7.46	2.28
345–362	9.44	2.88	13.69	4.18
500–550	14.68	4.48	22.61	6.90
765–800	20.44	6.24	33.53	10.22

Table 6-2
New overvoltage factors used in calculation of Table 1.

Voltage phase-to-phase (kV)	New overvoltage factor (pu)
72.501-362	3.5
500–550	3.0
700–800	2.5

NOTE - Higher or lower overvoltage factors may occur depending on the design and the operation of the system

Equipotential Zones

Establishment of equipotential zones will be discussed in detail. Issues of induced voltages, backfeed, step-touch-transfer voltages, permanent station and temporary ground mats will be discussed. Examples of establishing equipotential zones, and examples of hazards will be given.

Grounding systems are a case in point. In a basic worksite grounding system all conductive objects that could be touched simultaneously are bonded together. This includes, but is not limited to, vehicles, equipment, and guy wires. However, induced currents and voltages may be present and must be considered along with the continuous flow of current. It should be noted that induced currents are a common occurrence and that these currents are continuous (i.e., not short duration). Induction is often a result of partial parallel circuits that are not visible from the worksite. As such, workers must realize that although the grounding system is at equipotential, it still may be energized. The grounding cables may be carrying a continuous current to earth, creating step, touch, and transfer touch voltages at the worksite. There have been a number of accidents in which a worker in an aerial device in contact with a grounded conductor on a wood-pole structure has simultaneously come into contact with an ungrounded guy wire and has been severely injured.

Personal Protective Equipment (PPE)

Personal protective equipment (PPE), such as conductive clothing, non-conductive barriers and shields, flame retardant (FR) clothing, and non-conductive clothing will be discussed. Overvoltage control by station entrance gaps, station arresters and Portable Protective Air Gaps will be described.

The discussions of these topics will be presented in a simple and user-friendly way assuming a typical level of training in electrical theory of LW personnel.

Conductive Clothing

Protective conductive clothing is not required when using hotstick procedures; however, conductive clothing may be worn at any time during live work at the employee's discretion. Personnel using the barehand technique would normally wear:

- A parka or jacket, conductive footwear, and gloves when working from a metal-lined platform aerial device
- A parka, pants, conductive footwear, and gloves when working from an insulated ladder or open-metal platform.

A large amount of work has been done recently to understand the characteristics and performance of conductive clothing used for barehanding [23-26]. A worker positioned near energized conductors will experience currents induced in his or her body. The purpose of the conductive clothing is to shield the worker’s body from the electric field of the energized conductor and to conduct (divert) any induced current away from the worker’s body. An estimate of the induced current as a function of line voltage for typical lines can be obtained from Figure 6-1.

The important characteristics of conductive clothing include:

- The clothing resistance
- The screening efficiency of the material
- The shielding efficiency of the finished product

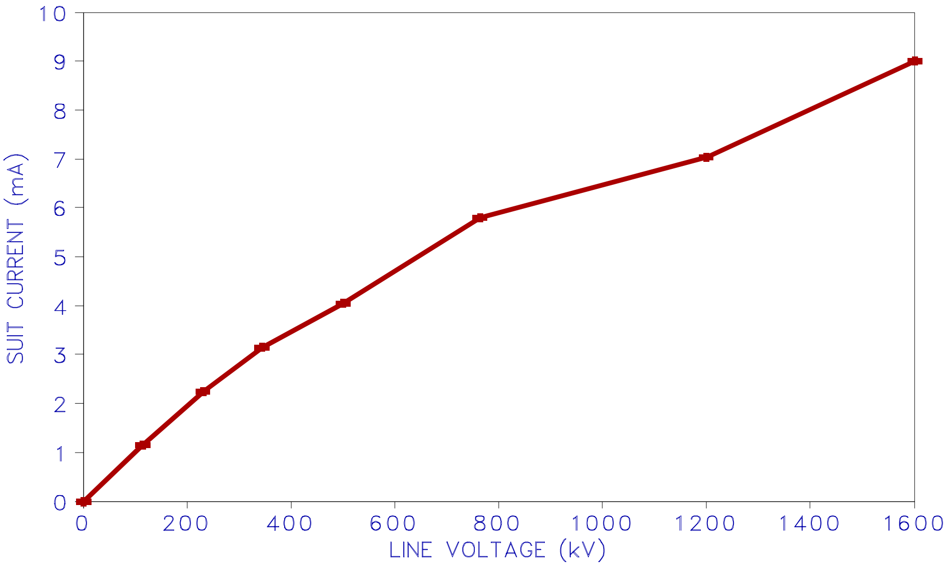

Figure 6-1
Variation of Induced Clothing Current with Line Voltage During Barehanding, Computed for Typical Line Configurations with Different Voltage Rating.

Measurement methods and maximum values for the clothing resistance and material screening efficiency are listed in IEEE Std 1067 [24] and IEC Publication 60895 [25]. These are important factors that determine the comfort of the worker wearing conductive clothing. One measure of conformance is the voltage appearing between the clothing collar and the wearer's neck. If this voltage is sufficiently high, sparking can occur, and the wearer will experience an unpleasant sensation. Figure 6-2 shows the variation of the neck-to-collar voltage as function of clothing resistance for high and low clothing-to-body contact resistances for a 10 mA clothing induced current.

Clothing Resistance

Great care has to be taken when measuring the resistance of the clothing [23-26] since this value is not constant and varies with the value of the current delivered to the clothing by the meter, or with the applied voltage. Also, the resistance depends on whether the test current (voltage) is increasing or decreasing, see Figure 6-3 for low-resistance clothing and Figure 6-4 for high-resistance clothing.

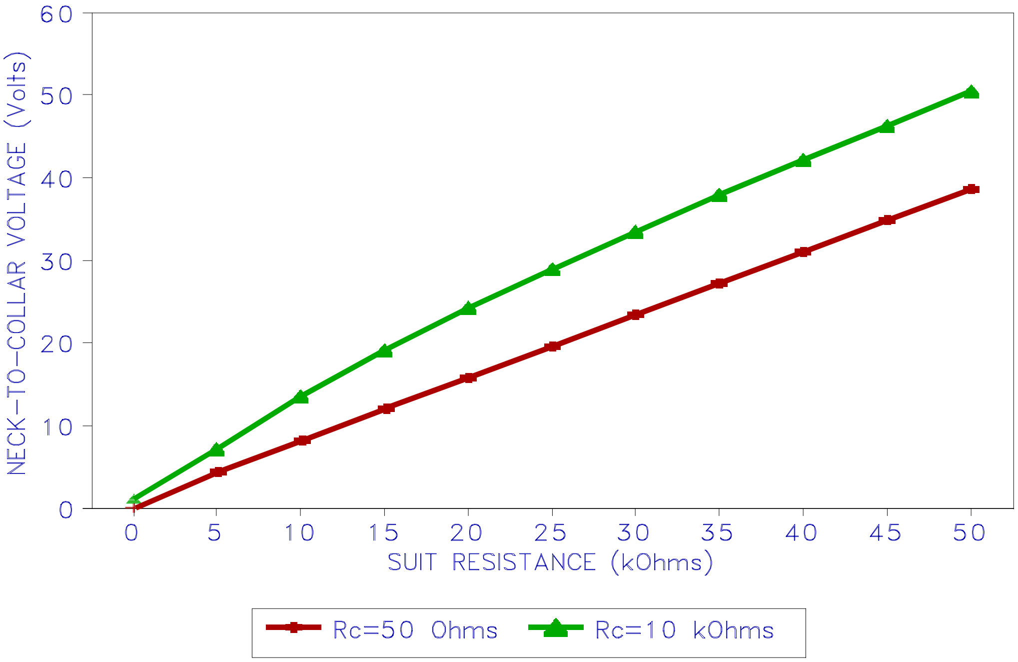

Figure 6-2
Variation of Neck-to-Collar Voltage, v_{nc}, as Function of Clothing Resistance, for High and Low Clothing-to-Body Contact Resistance. Computed for 10 mA Clothing Current.

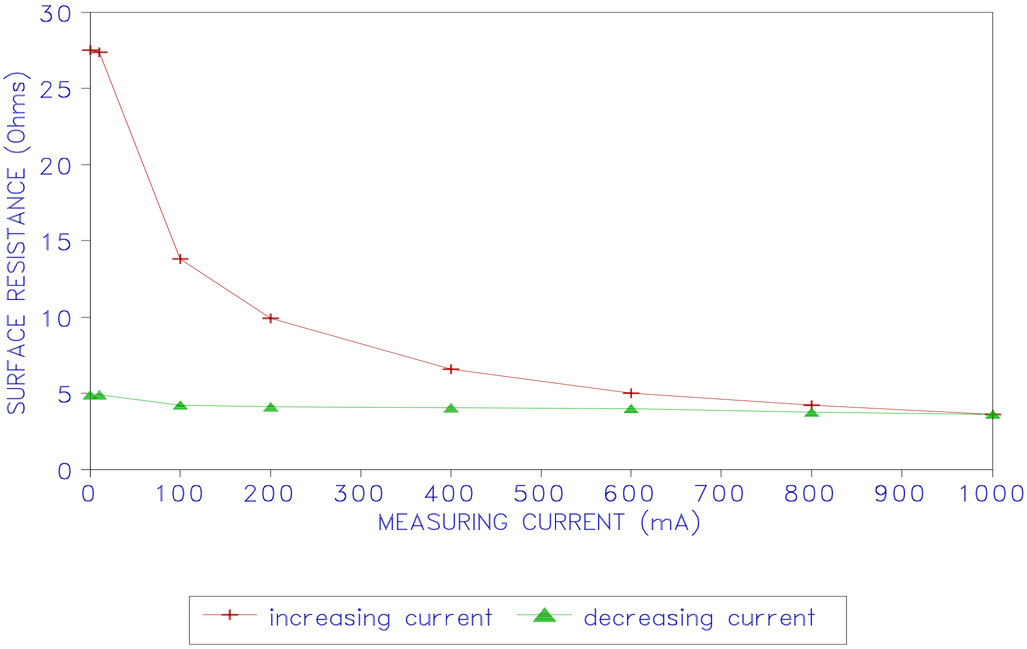

Figure 6-3
Variation of the Clothing Material Resistance (Surface Resistance Measured Between Two Electrodes) for Increased and Decreased Measuring Current, Low Resistance Clothing.

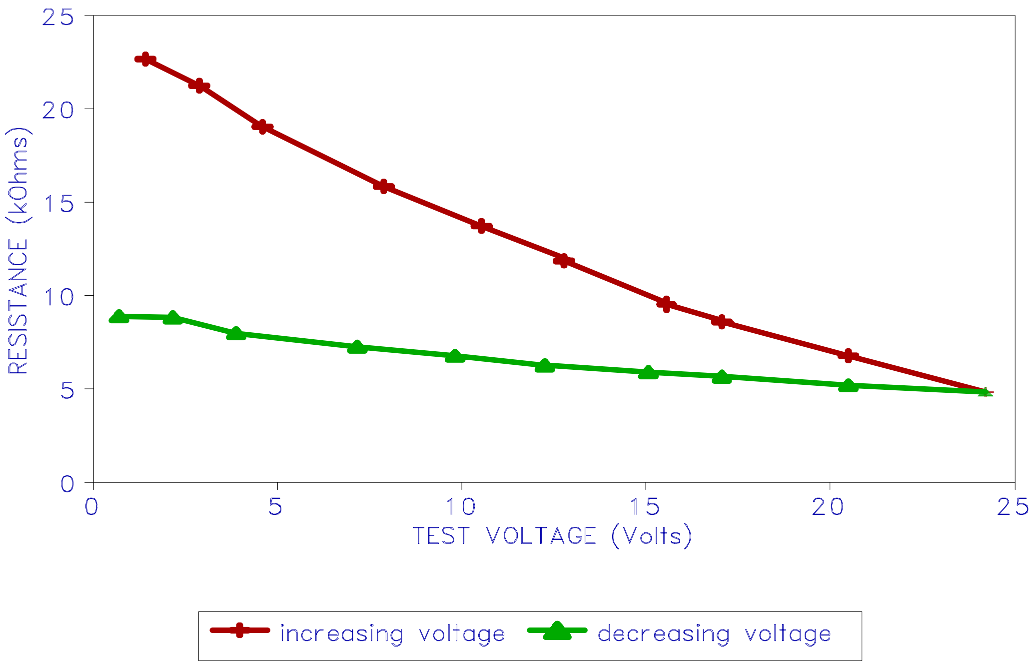

Figure 6-4
Variation of Clothing Resistance with Measuring Voltage for High Resistance Clothing.

Wear and Aging

Age and, in particular, laundering of the clothing greatly influences its performance, i.e., comfort to the wearer. It is difficult to predict when clothing will become uncomfortable to the wearer. Many variables are involved, including the system voltage, the particular configuration of the worksite, the size, location and posture of the worker, the method of bonding of the clothing to the energized conductor or grounded structure, the method of clothing-to-body bonding, the value of the clothing-to-body contact resistance, the behavior of the clothing material in the strong electric field, the age and condition of the clothing, etc. It is up to the wearer to monitor the comfort level. Figure 6-5 shows the clothing resistance as function of the number of laundering operations to which the clothing sets were subjected. Each resistance value in Figure 6-5 is an average of data points from 21 different clothing sets.

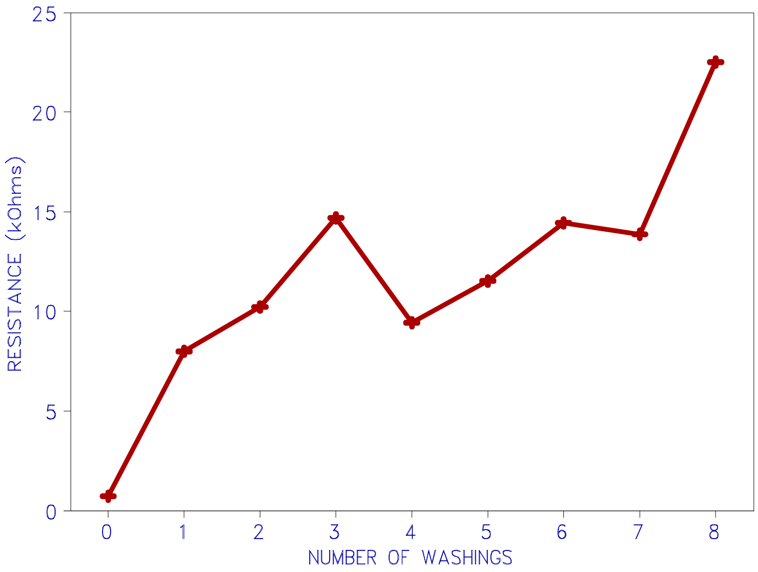

Figure 6-5
Change in Clothing Resistance with Number of Laundering Operations.

Performance of Conductive Clothing in a Strong Electric Field (i.e., Live Work in Substations)

The clothing characteristics described above are important for such purposes as standardization and acceptance testing. However, the final criterion that can separate “good” clothing from “bad” clothing is their performance in actual use during live work. Resistance measurements made on conductive clothing in a strong electric field (representing live work in substations) show that clothing behaves differently in the electric field than on a laboratory bench-top. In tests, conductive clothing was placed on a mannequin that had a conductive surface and was dressed in non-conductive coveralls. All four cuffs of the clothing (jacket sleeves and pant legs) were in firm contact with the conductive surface of the mannequin. The clothed mannequin was placed underneath a simulated buswork that was energized up to 200 kV, resulting in electric field strength of 32 kV/m at 1 m above ground at 200 kV bus voltage. This field strength is similar to that at the safe working distances from a 345 to 500 kV conductor, but it is less than that directly at the conductor during barehand work (where the field is also less uniform). Both the clothing current and the mannequin neck-to-clothing collar voltage were measured on low- and high-resistance clothing sets as the bus voltage (i.e., the electric field) was increased and decreased.

As expected, the neck-to-collar voltage, V_{nc}, on the low-resistance clothing increased steadily with increasing bus voltage (i.e., increasing field strength and clothing current). With the high-resistance clothing, however, the V_{nc} increased only up to a certain bus voltage level (i.e., up to a certain electric field strength and clothing current value), after which the V_{nc} steadily declined. As a result, at the highest tested field strength the final neck-to-collar voltage on the high-resistance clothing was only approximately 10% of the value that would be expected, based on the clothing resistance when measured with standard bench top instrumentation. The measured neck-to-collar voltage is plotted in Figure 6-6 versus the applied bus voltage, along with the measured clothing current for increasing bus voltage and the calculated neck-to-collar voltage.

Also, it is important to note that calculations of the voltage and current do not exhibit the sudden decrease of voltage that was observed experimentally. The reason for this phenomenon is thought to be related to the construction of the clothing material. The threads contain separate conductive fibers that acquire some voltage when placed in the electric field. For high-resistance clothing, the voltage differences between fibers can be large and the microgaps separating the fibers break down, thus improving the conductivity of the clothing. Thus, in effect, high-resistance clothing approaches the behavior of low-resistance clothing when it is placed in high electric fields. It should be noted, also, that the above tests were done in high fields, but not at field values that correspond to barehanding conditions. Such tests still need to be performed.

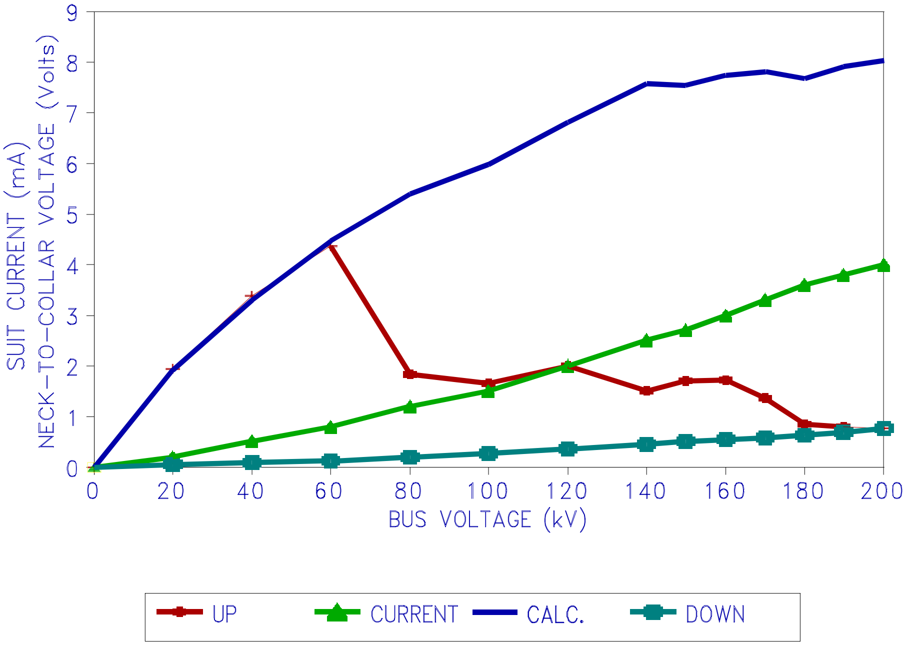

Figure 6-6
Measured and Calculated Neck-to-Collar Voltage, and Clothing Current, for High Resistance Clothing.

Conductive Footwear

Conductive footwear is not required when using hotstick procedures; however, conductive footwear may be worn at any time during live work at the employee's discretion. Conductive footwear may be part of conductive clothing discussed above. Personnel using the barehand technique should wear conductive footwear when:

- Working from a metal-lined or open-metal platform aerial device
- Transitioning between insulated ladders or scaffolding and a steel structure

Conductive socks or leg straps should also be used. Metal surfaces on aerial devices and conductive footwear should be kept clean to ensure good electrical contact.

Flame Resistant (FR) Clothing

Great advances have been made in recent years in the design, manufacture and use of flame resistance (FR). Many utilities now routinely require the use of FR clothing when the employee is subject to contact with energized circuit parts operating at more than 600 volts [11].

FR clothing should never be laundered or dried with a fabric conditioner. Most conditioners have animal fat as an ingredient, which negates the flame resistant properties of the clothing.

Fall Protection

Specific fall protection recommendations can be found in Ref. [6]. However, significant advances have been made in the last few years in the design and use of fall protection devices. For example, the new "wishbone" device was recently developed to allow simultaneous attachment to two anchor points while transferring from a mobile platform (an aerial device or a helicopter) to a stationary structure.

This subsection will be expanded and will include:

- Description of various commercially available fall protection equipment,
- Industry experience in the use of commercially available fall protection systems,
- Recent advances on the subject area and in structure-top rescue techniques.

Non-Conductive Clothing

Text to be developed next year. The text will include:

- Description of various commercially available non-conductive clothing,
- Industry experience in the use of commercially available non-conductive clothing,
- Recent world-wide trends and their rationale.

Overvoltage Control

Overvoltage control is usually accomplished by blocking reclosing (hot line order – HOL). Depending on the voltage being worked, overvoltage can be controlled by pre-insertion resistors, portable protective air gaps (PPAG), or other utility specified devices.

Additional text to be developed next year. The additional text will include:

- A brief discussion of various types of overvoltages encountered in substations,
- Hazards posed by these overvoltages,
- A brief explanation of statistical concepts used in discussions of overvoltages,
- A more detailed overview of overvoltage control strategies.

Station entrance gaps

Text to be developed next year. The additional text will include:

- A discussion of station entrance gaps,
- The purpose of station entrance gaps,
- Effectiveness of station entrance gaps in controlling overvoltages for LW purposes,
- Industry experience with the use of station entrance gaps.

Station arresters

Text to be developed next year. The additional text will include:

- A discussion of station arresters,
- The purpose of station arresters,
- Effectiveness of station arresters in controlling overvoltages for LW purposes,
- Industry experience with the use of station arresters,
- Recent advances and EPRI work in the monitoring of the condition and degradation of station arresters.

Portable Protective Air Gaps (PPAG)

Many utilities use Portable Protective Air Gaps PPAGs) to maximize worker protection and use the lowest permissible MAD at the worksite on overhead transmission lines. Use of PPAGs in substations has not gained equal popularity yet, but their advantages are being recognized and interest in the use of PPAGs for substation LW is increasing.

Portable protective air gaps are used during live work operations to limit the worksite overvoltage to a specified value. The PPAG is only required for the duration of the specific work and for the maximum overvoltages that may be anticipated during the performance of the task. The PPAG need only be installed on the phase being worked. This reduces the possibility of breaker action by one-third. The PPAG is constructed of two metal rods (rod-to-rod) attached to an insulating fiberglass tool. The rods are spaced (separated) for the specific voltage being worked.

Should a PPAG sparkover occur, either during installation or maintenance activities, there will be a fault to ground. De-energized step, touch, and transferred touch voltage protection and procedures used in de-energized work must be provided at the structure(s) where the PPAG is installed.

Text to be developed next year. The additional text will include:

- Examples of design of PPAGs for specific applications,
- A discussion of how a PPAG controls overvoltages,

- A discussion of how the use of a PPAG can allow recalculation of MAID,
- Advantages of using PPAGs in the case of compact substations,
- Examples of the effectiveness of PPAGs based on decades of experience of their use on overhead transmission lines.

7

TYPES OF INSULATORS AND BUSHINGS

Types of insulators and bushing commonly founds in transmission substations will be described. Insulating materials used construction of insulators are:

- Porcelain
- Glass
- Polymer

Various configurations of insulators are used in substations, including:

- Post
- Bus support
- Suspension
- Potheads

Selection of insulators and bushings is a design aspect and is beyond the scope of this Guide. However, storage and handling issues (including relevant installation aspects), especially in relation to polymer insulator and bushings, will be addressed.

Traditionally, insulators used in power systems have been made of porcelain and glass and these insulators are commonly referred to as “ceramic” insulators. Porcelain suspension units are very popular in North America, while toughed glass suspension units are used extensively in Europe. Porcelain units can withstand significant mechanical impact and do not shatter into pieces upon impact, which is the main reason for their popularity in North America, where vandalism and bullet damage occur in some areas. In contrast, toughed glass units shatter completely on impact, and for that reason damaged units are easy to spot during visual inspections. This is the main reason for their popularity in Europe. Other types of insulators, such as post or long-rod, standoff, etc. that are most commonly used in substations have been traditionally made exclusively from porcelain. Insulators made of organic (polymer) materials were introduced about 35 years ago. Their advantages include lightweight (desirable during transport and installation) and ease of assembly.

Porcelain Insulators

All porcelain insulators used at distribution and transmission voltages are glazed, are available in many shapes and sizes, and serve many different functions. The most common uses of porcelain insulators are:

- Suspension insulators, including cap-and-pin, clevis, ball-and-socket

- Post and standoff insulators, also called long-rod

Porcelain insulators are quite heavy and require hoists and lifts to handle.

Toughed Glass Insulators

In contrast, glass insulators are not glazed. Those used now are made toughed glass that shatters into small pieces upon impact. Glass insulators used at distribution and transmission voltages are suspension types with various attachment arrangements similar to porcelain suspension insulators, including cap-and-pin, clevis-and-pin, ball-and-socket. Post or standoff glass insulators are not used.

Glass insulators are also quite heavy and require hoists and lifts to handle.

Polymer Insulators or Non-Ceramic Insulators (NCI) or Composite

Three main types of NCI are used on overhead transmission lines:

- Suspension insulators
- Post insulators
- Phase-to-phase insulators

Each of the above may be applied in numerous ways:

- In general suspension insulators are intended primarily to carry tension loads. Suspension insulators can be applied in I- string, Vee-string, and dead-end applications
- Post insulators are intended to be loaded in tension, bending, or compression. The most common application is horizontal posts. These post insulators may be applied either alone or together with a suspension insulator in a braced post configuration. Post insulators are also applied in substations as bus supports or in disconnect switch applications.
- Phase-to-phase insulators are intended to be loaded in tension, torsion, bending, or compression. Phase-to-phase insulators couple two phases together to control conductor spacing during galloping.

This guide deals with substation insulators only.

Additional text will be developed next year. The additional text will include:

- A brief history of polymer insulators,
- A brief discussion of their advantages and disadvantages,
- A brief discussion of EPRI research on failure mechanisms,
- A brief discussion of proper handling procedures for polymer insulators.

Post Insulators

Post insulators consist of a single unit (higher voltages using porcelain have multiple units in series) of insulation between the energized parts and ground. Defective post insulators must be replaced in their entirety. Post insulators are usually used to support distribution and transmission conductors where compaction is a necessity, and they are often used for deadend jumper supports. Post insulator structures usually require shorter spans than other designs.

Post insulators require a typical overload capacity factor (OCF) of 2.5. That is, porcelain post insulators shall withstand applicable loads without exceeding 40% of the "rated ultimate strength" of the insulator in accordance with Refs. [3, 29 and 30]. When using post insulators in a horizontal position, utilities must ensure that maintenance loads do not exceed the manufacturer’s rated cantilever strength.

Porcelain Post Insulators

Porcelain post insulators are best used in the compression mode. They are most vulnerable to breakage when exposed to tension and cantilever loads.

Polymer Post Insulators

NCI post insulators are best used in the tension mode. They are vulnerable to bending when exposed to compression and cantilever loads.

Long-Rod Insulators

Long-rod insulators are made of porcelain and are similar to post insulators, but they are smaller in diameter. They are commonly used outside the USA as suspension and tension units on lines above 200 kV. A typical long-rod unit is rated for 200 kV, and two units in series are used on 400 kV systems. Defective long-rod insulators must be replaced in their entirety.

Issues Related to the Use of Polymer Insulators

Since polymer insulators technology is relatively new, utilities often confront a number of difficult issues, including:

- Life expectancy of polymer insulators
- In-service evaluation of polymer insulators
- Live working with polymer insulators
- The correct application of polymer insulators both from mechanical and electrical standpoints

Life Expectancy of Polymer Insulators

Since the oldest polymer insulators have only been in service for just over 20 years, during which time the design and manufacture of these units changed numerous times, the expected service life of present day polymer insulators is unknown. As a result, there has been a concerted effort on the part of the research community, and especially EPRI, to estimate the life expectancy of NCI and to determine the most important modes of failure.

In-service Evaluation of Polymer Insulators

Methods of evaluating polymer insulators and determining whether a unit is a potential problem and should be replaced are still in the very early stages of development. Numerous years of research lie ahead.

Technologies that may be used to evaluate the condition of polymer insulators will be discussed.

Live Working with Polymer Insulators

One method of replacing either a faulty polymer insulators or a porcelain string with a polymer insulators is to do so under energized conditions. Most live working procedures and guidelines were designed around removing and replacing porcelain insulators. As such, there are numerous issues specific to live working with polymer insulators, and they will be addressed in this document.

The Correct Application of Polymer Insulators

Because polymer insulators are still a relatively new technology, there are numerous questions with regard to their electrical and mechanical performance. For instance the use of grading rings and their influence on the overvoltage performance and life expectancy is one of the main electrical issues. Another involves the performance of polymer insulators under different environmental conditions. Although tests have shown that polymer insulators may perform better than ceramic insulators in contaminated environments, research at the EPRI Center – Lenox has shown that if the contamination is high enough to result in surface discharges on polymer insulators, over time those discharges may destroy the rubber material on the exterior surface of a polymer insulator.

Additional text will be developed next year. The additional text will include:

- Examples of misapplication of polymer insulators,
- Examples of misapplication of grading rings,
- Discussion of the effects of contamination on polymer insulators from the LW viewpoint.

8
LW TOOLS AND EQUIPMENT

This Section will describe tools used for LW. To help enhance worker's safety, the Section will address the very critical issues of:

- Use
- Care
- Storage

This Section will be quite similar to the corresponding Section in the transmission line Guide, but it will be developed as a stand-alone complete Section that will make references to the other Guide but will not require its acquisition.

Live work tools and equipment include:

- Insulating tools, such as sticks, cradles, strain sticks, etc.
- Insulated ladders
- Nonconductive handlines and taglines
- Personal Protective Equipment (PTE)
- Live working power tools
- Miscellaneous small tools
- Vehicles

Only tools and equipment designed, tested, manufactured, and approved for live work can be used. Wood insulating tools are prohibited. The equipment must be inspected and tested in accordance with the Ref. [4], the manufacturer's recommendations, and company policy. Proper care of live work tools, including substation switch tools and grounding tools, will ensure that the live work tools and equipment are safe for use. The live work tool and equipment test result documents (test records) should be filed at a location readily available to the live work crews.

Inspection

Insulating tools must be inspected visually for signs of damage before each use. The trunion, jack screw, and tension puller assemblies should also be inspected. The purpose of the inspection is to look for visible damage to the insulating portion of the tool as well as the steel jack screw thread and/or visible significant wear in the bronze trunion threads. The inspection should include the following:

- Disassemble (unscrew) the trunion assembly from the jack screw.

- Clean both elements in a suitable solvent using brushes if necessary to thoroughly clean the thread roots.
- Inspect the bronze trunion assembly for visible wear on the internal acme thread and smooth free-running of the ball thrust bearing. A "go-no go" test should be performed with the manufacturer's test tool.
- Inspect the steel jack screw for crookedness, rust, wear, nicks, or burrs. Perform a thread ware gauge manufacturer's test if it is available from the manufacturer. Jack screws should be protected by placing in an insulating tools trailer or covering with a hose or similar cover.
- Reassemble and lubricate the components using a suitable lubricant.

Alterations or modifications that may adversely affect the electrical or mechanical capability of live work tools must not be allowed. Any of the following observations warrant immediate removal of the tool from service:

- A tingling or "fuzzy" sensation when the tool is in contact with an energized conductor or piece of equipment
- A deterioration on the surface of the fiberglass reinforced plastic (FRP) rod, i.e., a lack of glossy appearance, cuts, gouges, dents, or delamination
- An electrically stressed tool showing evidence of tracking
- Tools showing evidence of bent or cracked components
- Evidence of overloading. For example, deformed rivets indicate that excessive mechanical loading has occurred and has weakened or sheared the bond between the ferrules and the FRP rod. See Table 8-1 for an example of safe working loads (courtesy of BPA).

Table 8-1
Safe Working Loads for A.B. Chance Epoxy-Fiberglass Insulating Tools Developed by BPA.

	Length of Insulating Tool (ft.)							
	6	8	10	12	14	16	18	20
Dia. (in.)	**Allowable Working Load in Lbs. (F.S. = 5)**							
1 ¼	339	191	122	84	62	47	37	30
1 ½	869	489	313	217	159	122	96	78
2	2310	1299	831	577	424	324	256	207
2 ½	4683	2634	1685	1170	860	658	520	421

Cleaning and Care

Live work tools must be maintained in a clean condition. Workers should use clean hands or gloves while handling tools to avoid contamination of the dielectric surface. The surface of each tool must be inspected for contamination such as dirt, creosote, and grease. Contaminants should be removed with a clean, absorbent cloth or paper towel. The tool should be wiped with a silicone-treated cloth. If wiping does not remove the contaminant, follow the manufacturer's recommendations for cleaning and resurfacing. Tables 8-2 and 8-3 list cleaning agents used by Manitoba Hydro.

Table 8-2
Manitoba Hydro A.B. Chance Live Line Sticks List of Cleaning and Repair Components

Item	Usage
A.B. Chance Moisture Eater	Used on a clean rag to wipe sticks. Used with the fine abrasive pad prior to refinishing sticks.
A.B. Chance Gloss Restorer	Restores the finish on the sticks. The stick must be cleaned with Moisture Eater and the fine abrasive pad before using Gloss Restorer.
A.B. Chance Hot Stick Wiping Cloths	Silicone impregnated cloth used to remove dust and minor dirt from sticks. Leaves a thin film of protection on the stick surface.
A.B. Chance Epoxy Sand Kit	A two part compound of resin and sand required to refinish rungs on epoxiglass ladders.
A.B. Chance Epoxy Plug Kit	A three component compound used to plug epoxiglass sticks which have been cut off. Some of the stick inner foam must be hollowed out before applying the plug.
A.B. Chance Tool Lubricant	A liquid compound used to lubricate threaded metal fittings.
A.B. Chance Dry Film	An aerosol spray lubricant used on threaded tools. Dries Lubricant on contact.

Table 8-3
Manitoba Hydro Hastings Live Line Sticks List of Cleaning and Repair Components

Item	Usage
Hastings All Purpose Cleaner	Non-toxic liquid to aid removal of dirt, grease, metal oxides, and other contaminants on fiberglass tools.
Hastings Ultra Fine Non-Metallic Abrasive Pads	Used with the All Purpose Cleaner to remove contaminants on fiberglass tools.
Hastings Clear Epoxy Refinishing Kit	Used to restore the surface finish when cleaning alone is insufficient. Supplied clear for fiberglass tools and white for fiberglass booms and buckets.
Hastings Silicone Treated Wiping Cloths	Used to remove light dirt and dust from sticks. Also used after light cleanings with All Purpose Cleaner.
Hastings Hot Stick, Boom and Bucket Wax	Used to produce a hard, tack free, weather resistant surface - resistant to temperature and weather extremes.

NOTE: Fiberglass wax may be required after the use of cleaner, and/or pads, to retain surface gloss.

While performing live work, workers must place live work tools on tarps or special tool holders. Tools must not be placed on the ground or against sharp objects such as barbed wire fences or steel towers.

Storage

Live work tools, when not in use, should be kept in weatherproof enclosures and stored in a dry and warm location when possible. Insulating tools should be stored in clean, dry polyvinyl chloride (PVC) tubes and secured in a protected location where indoor storage is not available. Electric heaters in live work tool trailers are designed to prevent condensation and are not recommended for drying live work tools. The tool trailer should be periodically inspected for signs of deterioration.

Testing

The employer should set a test cycle for testing live work tools. There is no established cycle for inspection of live work tools; however, OSHA and IBEW have suggested a two-year electrical test cycle. The proposed revision of OSHA Subpart V requires a two-year inspection cycle. OSHA requires an electrical test when a tool has been repaired or refinished. Tools should be inspected and tested in accordance with Ref. [4], the manufacturer's recommendations, company policy, and the following procedures for acceptance testing and in-service inspection, repair, and testing of live work tools.

General

Insulated live work tools are assembled from fiberglass reinforced plastic (FRP) rod and tube that has been manufactured in accordance with ASTM Standard Specification No. F 711 [20]. These live work tools must withstand high power frequency voltages for sustained periods of time, as well as occasional switching impulses. Acceptance tests should be performed on all new insulated live work tools, as well as periodic inspections and tests for in-service live work tools as dictated by the employer.

Acceptance Testing

Acceptance testing should be performed on new insulated live work tools prior to placing them in service. Acceptance tests performed by the manufacturer may be used to fulfill this requirement.

In-service Inspection and Repair of Live Work Tools

Insulated live work tools should be inspected upon each use, and should be inspected, maintained, electrically tested and repaired at employer specified intervals.

1. **Inspection Procedure.** When visual inspection indicates that a tool might have been mechanically or electrically overstressed, the tool should be carefully inspected, cleaned, refinished, or repaired and, if required, electrically tested before being returned to service.

2. **Repair Procedure.** FRP tools should be cleaned as recommended by the manufacturer. FRP tools should be refinished or repaired in strict accordance with the tool manufacturer's recommendations. Hardware, bolts, and pins should be replaced only with manufacturer's

replacement parts. Nondestructive evaluation (NDE) (Magnaflux, Zyglo, X-ray, or Ultrasonic) should be performed on the mechanical end-fittings after a tool has been subjected to possible overstressing or vibrating loads for an extended period of time. Light spots on FRP poles are caused by impact and may or may not have a noticeable effect on the mechanical strength or electrical properties of the tool. Numerous light spots may indicate abuse that, when coupled with surface contamination, may lower the flashover voltage or contribute to insulation degradation. Small surface ruptures or voids beneath the surface can accumulate moisture or, under electrical stress, become ionized leading to progressive degradation of the FRP. Ruptures and voids should be refinished in accordance with the tool manufacturer's recommendations. All repairs and refinishing should be followed by a high-potential (HiPot) dielectric leakage or ac dielectric-loss test.

In-service Electrical Testing of Live Work Tools

Insulated live work tools should be routinely electrically tested when required by company policy. Acceptable tests may include the high-potential (HiPot) leakage test (performed wet) and the ac watt-loss test. Ref. [4] describes four categories of electrical tests for live work tools:

1. "Portable Electronic Live-Line Tool Tester" test,

2. "Moisture or Dielectric Property Determination Meter" test,

3. "High-Potential ac" test (a dc test may be substituted),

4. "AC Dielectric-Loss (Watt-Loss)" test.

Additional text will be developed next year. The additional text will include:

- A brief summary of EPRI's research on the effectiveness of standardized tests for detection of defects in LW tools,
- Recent advances in test technologies for LW tools,
- Discussion of recent flashover events and the need for worksite care, maintenance and testing of LW tools.

9
REFERENCES

A list of relevant references will be provided, including standards, EPRI reports and technical papers available in the public domain.

A sample of relevant reference is included below.

1. IEEE Std 100, "The Authoritative Dictionary of IEEE Standards Terms"
2. OSHA Federal Register 29CFR, Part 1926, Safety and Heath Regulations for Construction
3. NESC C2, "National Electrical Safety Code C2"
4. IEEE Std 516, "IEEE Guide for Maintenance Methods on Energized Power Lines".
5. IEEE Std 1048 "Guide for Protective Grounding of Power Lines"
6. IEEE Std 1307, "IEEE Trial Use Guide for Fall Protection for the Utility Industry."
7. OSHA Federal Register 29CFR, Part 1910, Occupational Safety And Health Standards
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10. CIGRÉ Working Group 33.07, *Guidelines for the Evaluation of the Dielectric Strength of External Insulation*, CIGRÉ Document 72, 1993.
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20. ASTM Standard Specification No, F 711, "Specifications for Fiberglass-Reinforced Plastic (FRP) Rod and Tube Used in Live Line Tools.

21. ASTM F1701-96el, “Standard Specification of Unused Polypropylene Rope with Special Electrical Properties.”

22. D.A. Gillies, C.L. Nellis, K.H. Kuehn, “Field and Test Experience with Insulating Rope at BPA,” IEEE Transactions on Power Delivery, July 91, pp. 1182-1186.

23. *Service Aged Conductive Clothing Measurements ESMOL Task Force Revision of IEEE STD. 1067-1996*, panel session 17 paper at ESMO2000, Montreal, Canada, (October, 2000), p182

24. IEEE Std 1067, “IEEE Guide for In-Service Use, Care, Maintenance, and Testing of Conductive Clothing for Use on Voltages up to 765 kV ac and ± 750 kV dc.”

25. IEC 60895, “Live Working - Conductive clothing for use at a nominal voltage up to 800 kV A.C and ± 600 kV d.c.”

26. J. Lalot, C. Hantouche, P. Baraton, F. Fortin, “Conductive Clothing for Live Working (LW) and Protection against the Electrical Field,” presented at ICOLIM2000, Madrid, Spain (May, 2000).

27. L.E. Zaffanella, “Field-Effect Research at the High Voltage Transmission Research Center,” EPRI Interim Report EL-7104, Project 2472-3, February 1991.

28. “Transmission Line Reference Book/345 kV and Above” Second Edition, Electric Power Research Institute, Palo Alto, CA: 1982.

29. ANSI C29.1, Test Methods for Electrical Power Insulators

30. ANSI C29.7, Porcelain Insulators- High Voltage- Line-Post Type.

31. ANSI C29.9, Wet-Process Porcelain Insulators (Apparatus Post-Type).

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35. Storing, Transporting and Installing Polymer Insulators, Training Video, EPRI, 2002, Product ID 1006353

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37. Live Working Application Guide, 2002, Product ID 1001917

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