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IEEE Guide for Cleaning Insulators

IEEE Power Engineering Society

Sponsored by the
Transmission and Distribution Committee

IEEE

3 Park Avenue, New York, NY 10016-5997, USA

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IEEE Guide for Cleaning Insulators

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Transmission and Distribution Committee
of the
IEEE Power Engineering Society

Approved 25 April 2005

IEEE-SA Standards Board

Abstract: Procedures for cleaning contaminated electrical insulators (excluding nuclear, toxic, and hazardous chemical contaminants) of all types, using various equipment and techniques, are provided.
Keywords: cleaning, electrical insulators

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Introduction

This introduction is not part of IEEE Std 957-2005, IEEE Guide for Cleaning Insulators.

The guide for cleaning insulators is the result of the dedicated efforts of individuals and companies with practical experience in cleaning insulators. The information for this guide was drawn from electric utilities, suppliers, universities, related industries, published papers and reports, and personal observations. Included in this guide are proven, practical methods for cleaning insulators that are considered safe and up-to-date.

This revision of the guide started several years ago as the result of a desire to update and modernize the represented methodology. Changes to cleaning procedures, tools, equipment, and insulating materials have been dramatic in the last several years. These changes required newer and modern techniques, which have been incorporated into this guide. The result is a guide that represents a consolidation and accumulation of methods that have been satisfactorily used in the industry.

During preparation, the equipment, methods, tests, and safety features were investigated. The information presented is thought to be of particular benefit to a company or industry that may be initiating a cleaning program or trying to address a particular problem. It is also thought to be of value to those with an existing program.

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Contents

1. Overview 1

1.1 Scope 1

2. Normative references 1

3. Definitions, acronyms, and abbreviations 2

3.1 Definitions 2
3.2 Acronyms and abbreviations 3

4. Insulators to be cleaned 3

4.1 Introduction 3
4.2 Transmission line insulators 3
4.3 Station equipment 5
4.4 Distribution line equipment 6
4.5 Large diameter equipment 6
4.6 Greased insulator cleaning 6
4.7 Resistive glazed insulator cleaning 7
4.8 Room temperature vulcanizing coated ceramic insulator cleaning 7

5. Types of contaminants 7

5.1 Salt 8
5.2 Cement/lime 8
5.3 Dusts 8
5.4 Bird excrement 9
5.5 Chemical 9
5.6 Smog (vehicular emission) 9
5.7 Cooling tower effluent 9
5.8 Smoke 9
5.9 Organic 10
5.10 Ice/snow 10
5.11 Frequency of cleaning 10

6. Methods 10

6.1 Energized 10
6.2 De-energized 17
6.3 Results 18

7. Cleaning equipment 18

7.1 High-pressure water equipment (2750 kPa to 7000 kPa) (400 psi to 1000 psi) 18
7.2 Medium-pressure water equipment (2100 kPa to 2750 kPa) (300 psi to 400 psi) 24
7.3 Low-pressure water equipment (1400 kPa) (200 psi) 24
7.4 Compressed air, dry-type cleaner 24
7.5 Fixed spray 26

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8. Technical considerations for energized cleaning with water 26

8.1 Leakage current 26
8.2 Working distance 27
8.3 Water quality 29
8.4 Water supply 30
8.5 Water pressure 31
8.6 Nozzles 31
8.7 Grounding 31
8.8 Laboratory tests in grounded environments 31
8.9 Fixed nozzle 41
8.10 Helicopter-mounted nozzle 42

9. Industry practices 42

9.1 General industry practices 42
9.2 Individual company standards/rules 44
9.3 Public/public relations 46
9.4 Limitations 46

10. Summary 48

10.1 Grounding 49

Annex A (informative) Bibliography 51

Annex B (informative) Maintenance of ceramic insulators after cleaning 53

Annex C (informative) English units 61

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IEEE Guide for Cleaning Insulators

1. Overview

1.1 Scope

The scope of this guide for cleaning insulators is to document the procedures used for cleaning contaminated electrical insulators (excluding nuclear, toxic, and hazardous chemical contaminants), of all types, using varied equipment and techniques.

Because of the great variety of conditions, practices, electrical system designs, and contamination possibilities, this guide is offered to describe a number of approaches to insulator cleaning on power systems. All factors must be considered to specific situations in deciding whether and how to use the information in this guide.

1.2 Purpose

The purpose of this guide is to present information on the equipment needed and the methods that can be used when cleaning contaminated insulators.

The methods or equipment, or both, presented in this guide are not intended to prescribe specific procedures, but to present the successful experience of many individuals who have safely cleaned contaminated insulators. The guide is intended to serve as a reference source for a company, or persons, seeking information on insulator cleaning procedures so that they may consider the experience of others in modifying or formulating insulator cleaning programs and practices.

2. Normative references

The following referenced documents are indispensable for the application of this guide. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

Electrical Equipment Washing/Cleaning, Electrical & Utility Safety Association (Ontario) Safe Practice Guide, 2001.[1]

[1]EUSA publications are available from the Electrical & Utility Safety Association, 5580 Explorer Drive, Suite 200, Mississauga, Ontario 4Y1 Canada (http://www.EUSA.on.CA).

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IEC 60479-2:1987, Effects of Current Passing Through the Human Body.[2]

IEEE Std 4™-1995, IEEE Standard Techniques for High-Voltage Testing.[3,4]

IEEE Std 80™-2000, IEEE Guide for Safety in AC Substation Grounding.

IEEE Std 516™-2003, IEEE Guide for Maintenance Methods on Energized Power Lines.

IEEE Std 1048™-2003, IEEE Guide for Protective Grounding of Power Lines.

3. Definitions, acronyms, and abbreviations

For the purposes of this document, the following terms and definitions apply. *The Authoritative Dictionary of Standards Terms* [B22] should be referenced for terms not defined in this clause.

3.1 Definitions

3.1.1 ceramic insulator: Insulators made from porcelain, glass, or a general class of rigid material.

3.1.2 cubic meters per second (m^3/s): Volume of water or liquid discharged per second under standard conditions.

3.1.3 equivalent salt-deposit density (ESDD): A measure of contamination level.

3.1.4 insulator: In this guide, IEEE Std 957-2005, this refers to individual insulators and also the external insulating members of other apparatus; e.g., transformer bushings and surge arresters.

3.1.5 non-conducting or non-conductive: Made of a material of high dielectric strength.

3.1.6 overspray: A portion of the water stream that is unintentionally directed away from the device being washed.

3.1.7 polymer (non-ceramic) insulator: Insulators made from polymeric materials.

3.1.8 polyplastic: A synonym for polyethylene-coated, nylon-reinforced hose (used in this case to carry water), usually considered to be non-conductive.

3.1.9 qualified worker: A person qualified to perform various line-work operations, including aerial and groundwork.

NOTE—Refer to IEEE Std 516-2003.[5,6]

3.1.10 skiving: The process of assembling a fitting to a hose, by trimming the outside of a hose to fit the inside dimensions of a fitting.

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[2]IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

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3.1.11 system voltage: Phase-to-phase voltage of the circuit(s). When phase-to-ground voltage is the intention, it should be so noted.

3.1.12 water conductivity: Conductivity (reciprocal of resistivity) of water is expressed in microsimens/centimeters (μS/cm)

3.1.13 water resistivity: Resistivity of water is expressed in ohm-cm (Ω·cm) or ohm-inch (Ω·in).

3.2 Acronyms and abbreviations

ESDD	equivalent salt-deposit density
gal/min	gallons per minute
gal/s	gallons per second
id	inside diameter
kPa	kilopascals, metric unit for pressure
L/s	liters per second
LZ	landing zone
m^3/s	cubic meters per second
PTO	power takeoff
rpm	revolutions per minute
RTV	room temperature vulcanizing

4. Insulators to be cleaned

4.1 Introduction

Line insulators and arresters are made of ceramic and polymeric materials. Cleaning distribution insulators entails different concerns than transmission line insulators due to the lesser voltage involved and the respective clearance distances. The insulator should be washed so that the watersheds just cleaned will maintain adequate insulation. (For example, on vertical insulators the washing would be started at the bottom and work upwards.) One of the main concerns of washing is the potential problem of overspray. When overspray presents a problem, washing from different positions may help, but will take more time and reduce production.

4.2 Transmission line insulators

4.2.1 Ceramic

Porcelain and glass insulators with galvanized hardware are the most common insulators to be cleaned. Any cleaning technique used should not damage or deteriorate the item to be cleaned.

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Ceramic insulators can be cleaned in a number of ways, and they can either be energized or de-energized. The most common methods used are the following:

a) High-pressure water (2750 kPa to 7000 kPa) (400 psi to 1000 psi)

b) Medium-pressure water (2100 kPa to 2750 kPa) (300 psi to 400 psi)

c) Low-pressure water (flood wash) (1400 kPa) (200 psi)

d) Low-pressure water fixed-spray nozzle

e) Compressed air cleaning—corncob and CO_2 pellets

f) Hot wiping (using a live-line tool)

g) Hand cleaning

4.2.2 Polymer

Manufacturers should be consulted prior to cleaning for advice on their respective products and applicability of cleaning methods.

4.2.2.1 General guidelines for water pressure washing

Table 1 shows a general guide for washing different types of polymer insulators with water pressure washing.

Table 1—Water pressure washing for polymer insulators

1. Direct molded units	
Silicone	Low- to high-pressure water washing (1400 kPa to 7000 kPa)
EPDM/EPR	High-pressure water washing (2750 kPa to7000 kPa)
Alloy EPDMs	High-pressure water washing (2750 kPa to 7000 kPa)
Epoxy	High-pressure water washing (2750 kPa to 7000 kPa)
Polymer ceramic	Medium- to high-pressure water washing (2100 kPa to 7000 kPa)
2. Individual weathershed bonded to a polymer sheath or to each other	
Silicone	Low- to high-pressure water washing (1400 kPa to 7000 kPa)
EPDM/EPR	High-pressure water washing (2750 kPa to 7000 kPa)
Alloy EPDMs	High-pressure water washing (2750 kPa to 7000 kPa)
3. Individual weathershed with an unbonded interface	
All compounds	1400 kPa at the pump with a 6 mm nozzle and no closer than 4.6 m
NOTE—For types 1 and 2, the water stream may be directed at any angle to the insulator axis. Type 3 requires the water stream to be directed on the upper (tapered) surface of the weathersheds at an angle no greater than 90° (perpendicular) to the insulator axis.	

NOTE—For English units, see Annex C.

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4.2.2.2 Washing frequency

Polymer insulators that require washing do not require it as often as porcelain or glass insulators. They may be washed if caution is used during the washing procedure along with the manufacturer's approval.

4.2.2.3 Other procedures

Polymer insulators may be cleaned by methods other than water washing.

4.2.2.3.1 De-energized cleaning

If the insulators can be de-energized for cleaning, they may be hand washed with rags or wiping cloths in mild detergent water. This should be followed by a low-pressure flood rinse with clean water to remove any residue. Solvents or harsh abrasives are normally not recommended. Wetting agents or additives can be used to improve the washing action of the cleaning water. Solvents may be used, provided all cleaning residue is removed by the final clean water rinse and only after manufacturer approval.

4.2.2.3.2 Energized cleaning

Compressed air/dry abrasive cleaning—This procedure involves the use of compressed air and dry abrasive cleaning media. The abrasive cleaning compounds often consist of ground corncob mixed with ground walnut or pecan shells.

The actual cleaning process is similar to sandblasting in that a pressurized air stream is used to bombard the insulator surface with abrasive media. After cleaning, the contaminant and abrasive residue remaining on the insulator surfaces are blown off with dry, clean, compressed air.

With proper cleaning media and procedures, virtually any contaminant can be safely removed from the insulator surfaces without the need for area cleanup of the abrasive residue. Abrasive cleaning techniques are not recommended for silicone rubber insulators since they can temporarily destroy the surface hydrophobicity of the polymer.

4.3 Station equipment

4.3.1 Insulators

4.3.1.1 Ceramic

Same as for transmission line insulators.

4.3.1.2 Polymeric

Same as for transmission line insulators.

4.3.2 Bushings

Bushings are made of ceramic or polymeric materials and must be treated with great care. Consideration of pressure and volume and the mechanical support of the bushing are required prior to washing.

4.3.3 Surge arresters

Surge arresters can be made of ceramic or polymeric materials.

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4.3.3.1 Ceramic

Energized washing may impose severe electrical stresses on the surge arresters due to voltage imbalance and should not be performed without the concurrence of the arrester manufacturer.

4.3.3.2 Polymeric

Energized washing of these also imposes severe electrical stresses due to voltage imbalance. Polymer housed distribution arresters should not be exposed to the direct stream of high-pressure washing. Consult the arrester manufacturer for washing recommendations.

4.4 Distribution line equipment

4.4.1 Insulators

4.4.1.1 Porcelain and glass

Same as for transmission line insulators.

4.4.1.2 Polymeric

Same as for transmission line insulators.

4.4.2 Distribution class surge arresters

Polymer housed distribution arresters should not be exposed to the direct stream of high-pressure washing. Consult the arrester manufacturer for washing recommendations.

4.5 Large diameter equipment

Large diameter equipment may require the application of more than one simultaneous water stream from opposite sides of the equipment.

4.6 Greased insulator cleaning

Greased insulators may be cleaned either in the energized or de-energized condition.

If it is possible to de-energize the facilities, the insulators may be cleaned by hand. Simply wipe off the contaminated grease with cloths. If the grease coating has hardened and caked on the insulator, it may be necessary to chip or scrape the coating or use a high-pressure air blast that delivers ground-up corncobs, walnut or pecan shells against the insulator. The air blast should not be directed against one spot for too long as the ground material may damage the porcelain glaze. Residual dust can be blown off with clean air.

If the insulators must be cleaned in the energized state, the air-blast corncob method should be considered. Cleaning equipment with properly insulated wands is available commercially. Solvents can also be used to soften the grease before removal by hand or by high-pressure water spray.

It is well known that alumina trihydrate (ATH) fillers improve the arc resistance of organic polymer systems used for high-voltage insulator applications (silicone grease). An ATH-filled silicone grease has the water repellency of conventional grease but with much improved arc resistance. This permits operation under severe wet contamination conditions such as salt fog without encountering a critical failure condition where

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hot-spot arcing can lead to the fracture of porcelain or glass, or both, insulators. The limitation of the ATH-filled silicone grease is the reduced mobility of the free fluid due to the high filler loading.

ATH-filled silicone grease can be used under severe contamination when conventional silica filled greases have experienced service problems due to hot-spot arcing or flashovers, or both. The method for application and cleaning are the same as for conventional greases.

The application of fresh silicone grease over contaminated silicone grease is not recommended. The contaminated grease must be removed prior to coating a new layer. Simple hand wiping with disposable paper towels, burlap, or porous hand pads is all that is required.

For cleaning silicone grease insulators on energized lines, use of demineralized water spray, at a relatively low pressure of 850 kPa (125 psi) and a high capacity of 3.2 L/s (50 gal/min) is recommended. Removal of silicone grease is relatively simple compared to the removal of petroleum jellies from insulators.

4.7 Resistive glazed insulator cleaning

Resistive glaze (or semiconducting glaze) insulators can be treated the same as ordinary glaze porcelain insulators in all matters concerning cleaning techniques as cleaning will not damage their resistive glaze surface. However, it is unlikely that properly functioning resistive glaze insulators will require cleaning due to their superior contamination performance.

Pressure washing may overwhelm resistive glaze properties so that resistive glaze insulators become as susceptible to accidental flashover as ordinary glaze insulators due to poor washing techniques.

4.8 Room temperature vulcanizing coated ceramic insulator cleaning

When the room temperature vulcanizing (RTV) begins to get contaminated and loses some of its water repellency, it can easily be washed. Some RTV coatings can be high-pressure washed, but there are RTV coatings where low-pressure washing or flooding is recommended. Once clean, the hydrophobicity is restored. If recoating is necessary, the old coating can be removed by cleaning with an abrasive media, such as corn cob. This is simple compared to grease, which requires rags and a solvent; a messy and time-consuming operation. Detergents should not be used. A new top layer can also be achieved by application over existing coating without removal of the existing layer. Some cleaning may be recommended; however, lately, dry cleaning methods for removing the spent RTV coatings are available. However, the new RTV coating may be more effective if the old coating is removed completely and then recoated.

5. Types of contaminants

Exposed insulators are subject to surface dirt deposits to some degree in all operating areas. Most commonly encountered contaminants have little effect on insulator performance as long as the surface is dry. Fog, mist, or light rain usually creates conditions that produce a conducting film on the dirty insulator surface, without washing the impurities from the surface.

A number of types of contaminants have been identified as sources of surface deposits on insulators affecting insulator performance. These contaminants are distinguished primarily by the source of the impurities. Local agricultural, industrial, and geographic conditions determine which are present in the atmosphere. The various types of contaminants identified are: salt, cement/lime, dusts, bird excrement, chemicals, smog (automobile emissions), cooling tower effluents, smoke, organic and ice/snow. Ordinarily, wind and rain provide sufficient washing action to remove most of the common deposits. More than one of

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these contaminants may be deposited on a group of insulators at a particular location. The mix and rates of deposit of these contaminants determine the characteristics of the mixture.

5.1 Salt

In areas near a body of salt water and in areas adjacent to highways, particularly elevated roads, where salt is used to melt snow or ice, substantial salt deposits may result from windblown spray. Such deposits may make it necessary to clean insulators in these areas where long, dry periods are followed by intervals of misty rain or fog.

Salt spray may lead to flashovers and leakage current fires. This condition is common on structures adjacent to high traffic roads, particularly along elevated roadways. Insulators should be cleaned before the mist or fog occurs, not afterward.

Salt will quickly dissolve and wash off in a heavy rain or a stream of water.

5.2 Cement/lime

Insulators located near cement plants, construction sites, and rock quarries may accumulate deposits of cement or lime. These materials may build up a thick crust, which becomes firmly bonded to the insulator surface and may require hand scrubbing. A chemical agent may be needed to remove the cement layers. The dry method of cleaning also has proven quite effective.

5.3 Dusts

The kinds of dust that can be deposited on insulators originate from a wide variety of sources. Some of the types of dust affecting insulator performance are earth dust, fertilizer, metallic dust, coal dust, feedlot dust, and volcanic ash. This is not a complete list, but does cover many dust sources.

5.3.1 Earth

Earth dust can arise from plowed fields, earth moving on construction projects, etc. Various methods of cleaning earth dust are: water washing, compressed air cleaning, and wiping (both hot and hand cleaning).

5.3.2 Fertilizer

Fertilizer dust is emitted from fertilizer plants and from fertilizer application in farming. Fertilizer dust has been known to create a thick coating that high-pressure washing could not remove. In these cases, hand scrubbing or dry washing is needed to clean the insulators. Liquid fertilizer of the urea type is cleaned with water.

5.3.3 Metallic

Metallic dust originates from various mining and mineral handling processes. Metallic dust can be cleaned using compressed air and wiping (hot and hand cleaning).

5.3.4 Coal

Coal mining and coal handling operations and industrial burning of coal are major sources of coal dust. Soot and fly ash resulting from the burning of coal may form compounds that adhere firmly to insulator surfaces and may be removed only with high-pressure washing or compressed air with an abrasive substance. Coal dust can be cleaned by water washing or compressed air or wiping.

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5.3.5 Feedlot

Provender dust and earth dust stirred by animals in large feedlots can settle on nearby insulators in dry weather. This dust is normally removed with water.

5.3.6 Volcanic ash

Volcanic activity can emit large quantities of pollutant into the atmosphere in a short period. Thick layers of volcanic ash accumulate on exposed insulators during and shortly after periods of volcanic activity. This ash is not easily removed unless it is cleaned soon after it is deposited. Water washing or compressed air cleaning or wiping can be used.

5.4 Bird excrement

Insulators located in the vicinity of roosts of birds are subject to contamination by excrement. These deposits are usually washable and are often cleansed by heavy rain, but may present serious problems of system reliability. All the methods, such as water washing, compressed air cleaning, and wiping can be used to clean this contaminant.

5.5 Chemical

Atmospheric pollutants from a wide variety of industrial chemical processes, aerial spraying of agricultural chemicals, and fire-fighting chemicals (borate) are deposited on insulators. The characteristics of these chemical contaminants vary widely. Some chemicals are highly soluble and can be washed easily, while others bond firmly and can be removed only by hand scrubbing.

5.6 Smog (vehicular emission)

In urban areas automobile emissions introduce a significant amount of particulate matter into the environment. In addition, diesel engine emissions from trains particularly affect areas adjacent to rights-of-way. Normally, industrial chemicals are present in areas with heavy smog problems. Resulting insulator contaminants have varying characteristics, depending on the combination of pollutants present. Various methods, such as water washing, compressed air cleaning, or wiping can be used to clean smog.

5.7 Cooling tower effluent

Cooling tower effluent is composed of water vapor and a small amount of dissolved solids. Under normal wind and temperature conditions, cooling tower effluent should quickly disperse and not affect insulator performance. However, under certain weather conditions, it is possible for the effluent to create a localized fog. This fog may moisten dry, dirty insulators, or if the temperature is cold enough, ice glazing on insulators may occur. Either situation can affect the performance of the insulator. Water washing or dry ice cleaning is an effective way to clean cooling tower effluent.

5.8 Smoke

Industrial and agricultural burning or wildfires can, with other compatible conditions (such as moisture and humidity), cause the resulting contamination to accumulate on the insulation. Smoke can be washed using water or dry ice or wiping.

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5.9 Organic

Organic contamination consists of living or dead organisms, or by-products produced by them. Common examples are mold and algae. Wiping and compressed air cleaning and washing can be effective in cleaning.

5.10 Ice/snow

Ice is an electrical insulator if its temperature is less than –2 °C but can cause electrical flashovers if it starts to soften and melt at –1 °C. Heavy ice or snow accumulation on insulators can sometimes be cleaned using preheated water that has a resistivity of more than 50 000 Ω·cm (conductivity less than 20 μS/cm). Generally, a vertical pass to split the ice cover, followed by injection of the hot water stream between the ice and the insulator, can be effective. The high water purity is needed because the resistivity of water decreases by a factor of two as temperature increases from 25 °C to 70 °C.

5.11 Frequency of cleaning

Frequency of cleaning varies depending upon the degree of contamination, the weather conditions, and the particular insulator design. Where frequent washing is required, it is sometimes economical to install either piping systems on towers or permanent fixed-spray nozzle systems for ease in washing.

Insulators should be washed prior to the time of reaching the critical contamination level. This point can be estimated from the following:

a) Past experience on periods between flashovers, or pole fires

b) Allowable equivalent salt-deposited density (ESDD) obtained from de-energized test insulators or from energized insulators

c) Degree of scintillation during damp weather conditions

d) Complaints of radio/television interference

e) Proximity and exposure to the pollution source

f) Type of contaminant, and its rate of buildup on the insulator

g) Weather conditions (it is noted that the danger of flashover and pole fires is particularly great after a long, dry period, either in winter or summer, followed by a light drizzle or fog condition)

h) Sensor insulators that indicate contamination level (to be used for areas of consistent contamination levels or worst-case areas)

6. Methods

The method used for insulator cleaning is dependent on the insulator material, construction, whether or not the line is energized, and the type of containment to be removed.

6.1 Energized

6.1.1 High-pressure water

High-pressure water washing utilizes a narrow stream of water with typical pressures ranging from 2750 kPa to 7000 kPa (400 psi to1000 psi) at the nozzle. Four types of nozzles are most often used with high-pressure water: handheld jet, remote-control jet (pea shooter), fixed spray, and helicopter mounted.

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6.1.1.1 Handheld jet nozzle

The handheld nozzle is the most common type of nozzle used for high-pressure washing. The line worker either climbs the tower or uses an aerial lift to raise the hose and nozzle to the wash position. The line worker may also connect a detachable hose and nozzle to a standpipe permanently installed on the tower.

Substation insulators may also be washed using a handheld nozzle while on the ground or in an aerial basket.

The resistivity/conductivity of the water from the wash truck reservoir should be checked by a resistivity/conductivity meter each time water is added. The wash truck is positioned so that the wash hose will come off the hose reels at the tower leg to be climbed. In this way, the hose does not have to be dragged around the tower.

Some utilities specify wire braid conductive hose to bond the truck to the tower. The continuity of this bonded connection is checked prior to the start of the job. Routinely, all bonding connections should be checked for corrosion and cleaned, as required. Since the wash truck may acquire a relatively high potential, it is important when washing that no person gets on or off the truck and that all persons on the ground are kept away from the truck. Persons on the truck must also avoid reaching out and touching adjacent trees, poles, towers, or other objects. Refer to IEEE Std 516-2003 for more details on grounding.

Some utilities use non-conductive wash hose and do not bond the truck to the tower so that the truck is unlikely to acquire a high potential. However, good practice is to allow no one to get on or off the truck and that all persons on the ground be kept away from the truck during the actual washing operation.

Next, the qualified worker climbs the tower carrying a hand line. The truck driver sends up the hose, gun, and nozzle. The qualified worker bonds the nozzle to the tower steel or pole bond wire. The point is that the qualified worker, the nozzle, and the tower must be at the same potential.

The qualified worker then directs the truck driver to increase the water pressure. If the unit is equipped with a demand throttle, the pressure (revolutions per minute—rpm) will be automatically increased when the gun is opened. The water is directed away from the insulator string until full pressure has been achieved. The line worker on the tower then directs the wash stream at the insulator. The nozzle-to-conductor distance shall not be less than the established minimum wash distance. See Table 4.

Suspension insulator strings are washed by first directing the stream of water at the insulator nearest the energized conductor in such a manner as to take advantage of both the impact and the swirling action of the water to remove deposits. After the bottom insulators in the string are washed, the wash stream is moved up a few units. These units are washed and the stream then is directed on the clean units below to re-rinse them. This process is repeated, moving up a few insulators at a time until the entire string is clean. Failure to re-rinse lower insulators before moving further up the string can lead to flashover. The stream must be moved away from any energized part of the insulators before the water pressure is reduced. Care should be taken to prevent the spray from unduly moistening nearby dirty insulators, particularly in the station.

Deadend insulators must be washed carefully to keep overspray from causing flashover. Begin washing on the downwind end of the insulator string and then work upwind.

It is important that the above procedures and the established wash parameters are strictly adhered to when conducting hot-line washing.

6.1.1.2 Remote-control jet nozzle

The remote-control jet nozzle system consists of a nozzle mounted on a truck-mounted boom. Both the nozzle and the boom are controlled from a console connected to the boom turret. This system permits

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positioning of the water stream when washing is difficult to perform from a tower or station structure (such as for outer phase vee-string insulators on high-voltage lines).

The technique for washing with a remote-control nozzle is very similar to that for the handheld nozzle. The primary difference in the two techniques is that the nozzle positioning is done remotely from an operator's console at the base of the truck boom. A knowledgeable operator is required to position the boom in a location that will provide a good washing angle in addition to maintaining safe working clearances.

6.1.1.3 Fixed-spray nozzle

Fixed-spray nozzle hot-line washing has proven to be effective in preventing sea-salt contamination flashover problems. The wash parameters and equipment should be developed and established for each installation. This is mainly due to various local parameters that influence the washing. Such parameters are precipitation, water resistivity, wind, contamination severity, and design and installation arrangement of the insulators to be washed.

Two basic washing systems are used, as follows:

a) Spray washing for calm wind conditions
b) Water-screen washing for strong wind conditions

For spray washing, the electrical apparatus is divided into groups, and nozzles are firmly fixed on piping arranged around apparatus insulators. The apparatus is washed sequentially from one group to another, according to a preset washing order. Table 2 provides general information on this system.

Table 2—Fixed nozzle washing equipment and usage

Type of nozzle	Spray
Number of nozzles	Multiple
Water pressure	350 kPa to 3000 kPa (50 psi to 430 psi)
Nozzle installation	Permanently installed on steel structure
Wash control	Fixed
Washing coverage	Water envelopes and swamps insulator in one surge
Operation	Eliminates both climbing and special skill requirements for washing
Application	Suitable in areas where washing is frequent (at least once a month) and where tower or station structures are very high
Other features	Piping to nozzle is required for each insulator assembly. Water usually controlled automatically.
Disadvantage	Affected by wind

For water-screen washing, nozzles are installed only on the windward side of the apparatus. Washing water is discharged upwards and carried onto the insulators by the strong winds.

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6.1.1.4 Helicopter-mounted nozzle

This washing method involves the use of a self-contained high-pressure wash system carried aloft by a helicopter. The system is controlled by a wash operator in the aircraft or by the pilot. The helicopter hovers near the insulator string and the operator positions the nozzle to direct the stream at the insulator string.

The actual washing techniques employed are similar to those for washing with the handheld nozzle. A knowledgeable pilot, or pilot/wash operator team, is required to position the aircraft/wash-boom in a location that will provide a good washing angle in addition to maintaining safe working clearances to other phases, tower equipment, and/or obstructions. Three techniques have been employed when using water to wash or clean insulation contamination.

6.1.1.4.1 Fixed nozzle

A fixed nozzle is extended from the helicopter along the path of a runner or guide to outside the direct prop wash. The pilot controls the direction of the water stream by movement of the helicopter. The pilot controls the water stream pump as necessary.

6.1.1.4.2 Movable nozzle on a fixed wand

This system is similar to the fixed nozzle except the single pilot controls a movable nozzle. The helicopter is moved to the general location and the movable nozzle controls the direction of the water stream.

6.1.1.4.3 Fixed nozzle in a movable wand

This method employs a second person to control the direction and availability of the water stream. The helicopter gets to the required general position and then washing is actually controlled by the second person.

Each of the three methods has their advantages and can be used on transmission circuits effectively. The greatest plus for helicopter cleaning is its production and easy access to isolated structures. However, the expense and special equipment required suggest the importance of careful analysis of the cost to benefits before considering everyday use.

6.1.2 Medium-pressure water

The concept of medium-pressure washing has proven to be effective. This system involves many of the same procedures used in the high-pressure handheld and remote-control jet nozzle procedures.

While effective washing is maintained, the advantages are reduced equipment stress and employee fatigue because of the lower operating pressures. Tests indicate that the leakage currents through the water stream using this method are within safe operating limits. The pressures used for this method are in the 2100 kPa to 2750 kPa (300 psi to 400 psi) range.

6.1.3 Low-pressure water (flood wash)

In some circumstances, such as for cleaning power transformer bushings, a fixed nozzle system may be used. The nozzles spray the water in a predirected pattern toward the bushing so as to encompass the entire bushing. Frequent washing is used to prevent any severe build-up of contaminant.

Some transmission towers are fitted with plumbing so as to direct a water stream to deluge the suspension insulators. The piping is generally brought down through the tower to ground level where a tank and pump unit are connected. The frequency of such washing is dictated by the degree of contamination present. The pressure at the ground level pump is usually 1400 kPa (200 psi) with a pump output of 2.5 L/s (40 gal/min)

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per nozzle. The nozzle size, pipe size, and tower height should be considered when selecting pump capacity and pressure.

6.1.4 Low-pressure water fixed-spray nozzle

These systems employ a fixed-spray nozzle system operating at low pressure, typically 350 kPa to 1030 kPa (50 psi to 150 psi). They are used primarily in areas where frequent washing is required. Because of the low pressure and spray nozzle system, the effectiveness in removing nonsoluble contaminants, other than sea salt, is diminished. Fixed-spray nozzle washing has proven to be effective in preventing sea-salt contamination flashover problems. Therefore, most fixed-spray nozzle installations are used in or near seacoast areas, mainly to remove sea-salt contamination. This method of washing is widely used in Japan. This method can also be used for soluble contaminants that are found inland. See Table 3.[7] The wash parameters and equipment must be developed and established for each installation. This is mainly due to various local parameters that influence the washing. Such parameters are precipitation, water resistivity, wind, contamination severity, and design and installation arrangement of the insulators to be washed.

Table 3—Low-pressure spray washing equipment design data

Design data	Automatic spray system	
	275 kV	**400 kV**
Minimum permissible water resistivity	10 000 Ω·cm	20 000 Ω·cm
Water pressure at nozzle	700 kPa	1000 kPa
Type of nozzle	Spray	Spray
Minimum distance from nozzle to live conductor	3.1 m	4.3 m
Number of nozzles per insulator	CB and CT: 6 Others: 4	CB: 8 Others: 6
Quantity of water	CB and CT: 4.7 L/s Others: 3.5 L/s	CB: 7.4 L/s CT: 6.2 L/s Others: 5.5 L/s
Duration of wash (dependent on type of insulator)	25 s	25 s
NOTE 1—CB: circuit breaker; CT: current transformer. NOTE 2—Refer to Fujimura, T., Okayama, M., and Isozaki, T. [B10].		

NOTE—For English units, see Annex C.

6.1.5 Compressed air cleaning

This method of cleaning insulators involves the use of compressed air and an abrasive cleaning compound. This procedure requires an air compressor capable of supplying a minimum of 0.05 m^3/s (110 ft^3/min) (52 L/s) at 850 kPa (125 psi), an air dryer, a pressure blaster, an applicator wand, adequate supply hoses, and cleaning compound. An air dryer should be used between the air compressor and the air blaster to remove moisture from the compressed air.

[7]The numbers in brackets correspond to those of the bibliography in Annex A.

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Commonly used abrasive cleaning compounds consist of ground corncob mixed with ground walnut or pecan shells. In some cases, powdered limestone may be added for increased abrasiveness.

To clean insulators, the cleaning compound is directed onto the insulator surface through a specially designed applicator wand. The wand consists of a hot stick/nozzle combination that allows work to be done on energized systems. This method has been used on energized lines and substations through 500 kV.

The actual cleaning process for this medium is very similar to sandblasting in that a high-pressure stream of air is used to bombard the surface of the specimen to be cleaned with the cleaning medium. By choosing the proper medium, virtually any contaminant can be removed from the insulator surface. Caution shall be exercised to prevent glaze erosion or deterioration to the galvanized hardware.

6.1.5.1 CO_2 pellets (dry ice)

CO_2 pellets are a commonly used nonabrasive component. In the CO_2 process, the pellets of frozen CO_2 strike the surface of the insulator, penetrating through the containment to the insulator surface. The pellet then sublimates into a gas, which blasts the contaminant from the surface. There is no abrasive action to the insulator.

The technique for this method is very similar to the high-pressure water in that the insulators next to the conductor are cleaned first (one or two insulators on each string) of a vee string and then the remainder of the insulators. A full stream of cleaner should be flowing before the stream contacts the conductor, and likewise, a decrease in psi should only be made after leaving the conductor.

6.1.6 Hot wiping (using a live-line tool)

A procedure using hot sticks and a special hammock (usually made from burlap) to clean energized insulators is used on equipment operating at voltages from 4 kV to 69 kV.

The need for cleaning energized strings depends upon the level of contamination and the risk of flashover during washing. This procedure may also be used prior to hot washing to reduce the possibility of flashover. The line worker performing wiping may do this task from a ladder, on the ground, in a bucket truck, or from a steel tower. Two hot sticks are used.

The technique requires one hot stick that is hooked into an eye of the hammock, to be positioned around the insulator or bushing, and to engage a second eyelet in the hammock with the hook of the second hot stick.

When this is accomplished, the porcelain can be cleaned with a seesaw motion. The hot sticks with the hammock shall be kept tight enough so that the eyelet does not drop from the hammock's loop. Generally, cleaning begins adjacent to the energized conductor and moves towards the grounded end of the insulator string.

The hot stick used for this purpose is usually approximately 20 mm (0.75 in) in diameter and 3 m (10 ft) long.[8] The end loop is attached to the stick with a bolt and nut.

Normal care must be taken to observe the safe working distances for the hot sticks, and the critical precaution is to keep the wiping cloths clear of any grounded objects or supports. Good communication and coordination is required between the operators all the time.

One company using this method recommends the following:

a) The hammock material should be 540 g/m^2 weight.

[8] Max. 345 kV—Use appropriate hot stick for higher voltages.

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b) The cleaning hammocks should be cut 460 mm wide by 610 mm in length for 46 kV and 760 mm in width by 910 mm in length for 69 kV post, cap, and pin insulators. A 25 mm hem should be folded on both short ends. Then, 25 mm pleats should be folded. A 3.8 mm diameter iron wire, 305 mm in length, should be threaded through the pleated hem so that the necessary loop and hook may be formed.

NOTE—For English units, see Annex C.

See Figure 1 and Figure 2.

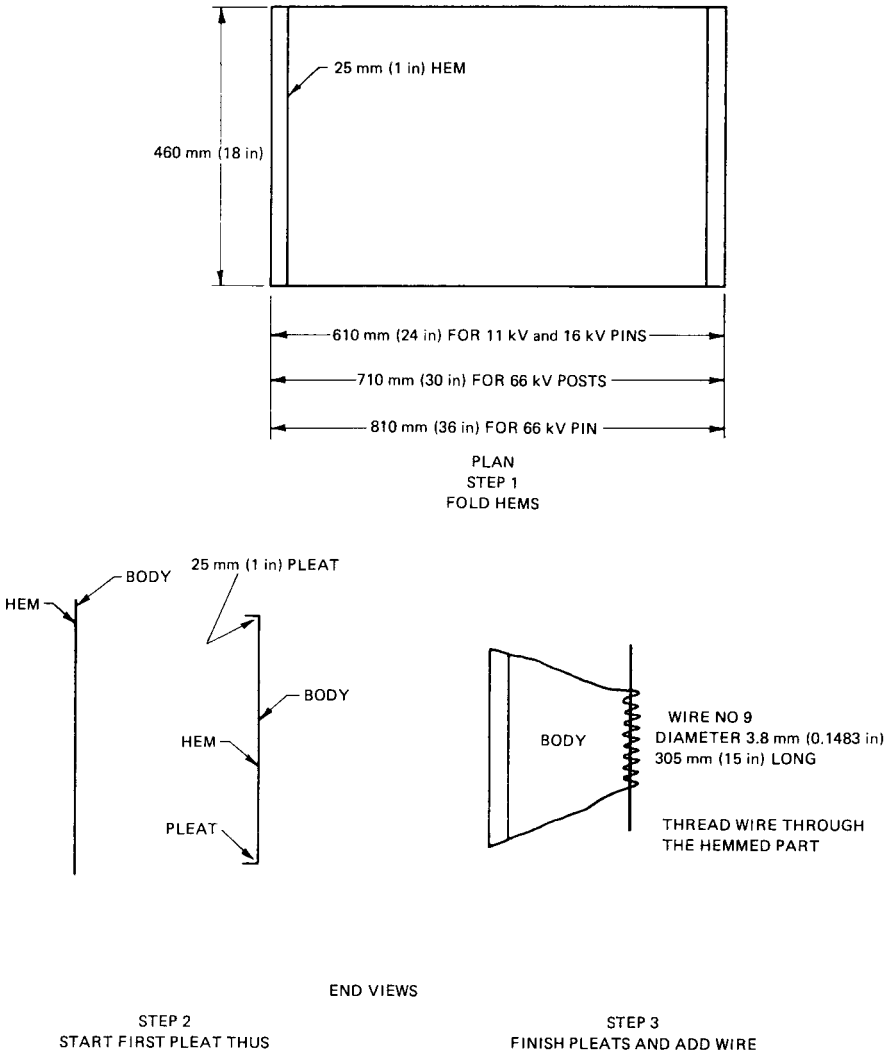


Figure 1—Hot wiping material

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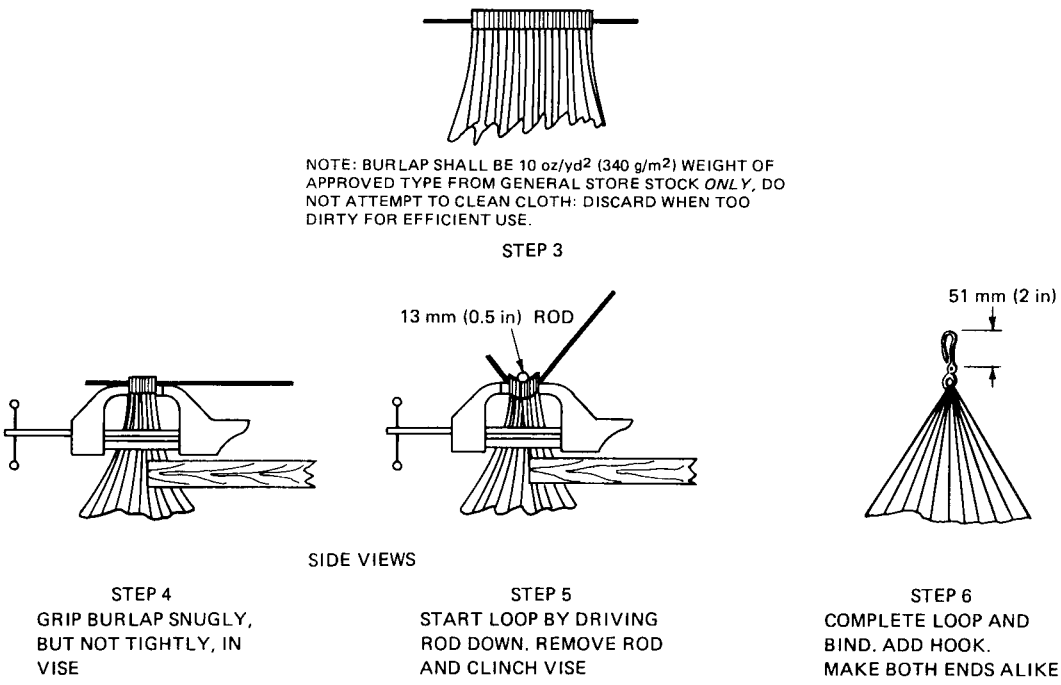


Figure 2—Hot wiping material assembly

6.2 De-energized

All of the methods discussed in 6.1 may also be utilized in addition to hand cleaning, when the facility is de-energized (and grounded). When the system is de-energized (and grounded), the requirements of water resistivity are the same as for an energized system. However, the clearance issue is not there, thereby allowing different washing conditions.

6.2.1 Hand cleaning

Cleaning insulators by hand wiping is thorough and effective, but it is also a tedious, time-consuming, and expensive process that requires equipment outages. Hand wiping is generally used only when washing is impractical because of problems of access by heavy vehicles, height or design of structures, or type of contamination. Hand wiping is normally used on station insulators where high-pressure washing is either impractical due to proximity of energized equipment or ineffective due to hardness of surface deposits.

Some insulators can be cleaned using only soft, dry wiping rags. Additional materials, such as wet or paraffin-soaked cloth, solvents, steel brushes, or steel wool, may be needed for other insulators.

6.2.1.1 Nonabrasive nylon pads

Nonabrasive nylon pads are used when rags and paper towels are ineffective.

6.2.1.2 Steel wool

Steel wool is sometimes used when rags and paper towels or nylon pads are ineffective. Caution shall be exercised to remove all the metal particles left by the steel wool.

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6.2.1.3 Solvents

Solvents may be used to aid the cleaning. Care shall be taken with strong cleaning agents because of fumes or residue. After cleaning, the insulator should be rinsed with clean water to remove residue. For polymeric insulators, in general no solvent can be used, unless advised by the manufacturer.

6.3 Results

Results of efficient insulator cleaning can be judged by the following.

6.3.1 Visible (clean-shiny)

Surface condition of both the top and bottom of the insulator skirts should be visually clean and shiny after the water or solvents have dried.

6.3.2 Insulator vibration (ringing)

Mechanical vibration (ringing) of insulator skirts under impact of high-pressure washing and exhibiting evidence of efficient swirling cleaning action.

6.3.3 Absence of corona

Blue corona discharges extend from the metal cap to the porcelain during energized high-pressure washing and may be heard for a few seconds after completion of cleaning.

If this discharge continues for more than a few seconds, it may indicate incomplete washing of the insulators, in which case the wash stream should be reapplied.

6.3.4 Clarity of runoff

Clarity of the water runoff may also indicate the effectiveness of contamination removal. Clarity of water runoff may be difficult to observe due to distance, sunlight, wearing of sunglasses, etc.

7. Cleaning equipment

7.1 High-pressure water equipment (2750 kPa to 7000 kPa) (400 psi to 1000 psi)

7.1.1 Pump

The pump may be either a centrifugal or positive displacement type.

7.1.1.1 Centrifugal

This pump type utilizes a rotary impeller or series of impellers in 1 to 4 stages and is commonly used in fire fighting applications. Water is drawn from the tank by suction to the first stage; then the pressure is compounded through the remaining stages. A flooded suction is best; however, once the pump is primed, a negative head or draft can be pulled from several feet below the pump. A gear set is directly bolted to the flywheel of the gasoline or diesel power unit, or can be driven from a truck power takeoff (PTO).

A single 4-stage pump may develop up to 7000 kPa (1000 psi) with 0.005 m^3/s or 5 L/s (80 gal/min) discharge and may rotate at a speed up to 9600 rpm. A separate, single-stage centrifugal pump can be run

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from an engine crankshaft to supercharge the main 4-stage pump where high water volume is required. The centrifugal design allows internal slippage when the wash gun or remote monitor is abruptly shut off, cushioning the shock force to hose, fittings, valves, gun, and operator; therefore, no dampers or cushioning devices are required. The pump produces even flow without pulsations. Adequate bearings, steel wear rings, and balanced impellers are required to provide long, trouble-free service.

7.1.1.2 Positive displacement

One or more pistons are utilized to produce high pressure. The pump may be driven by sheaves and vee-belts from an engine-driven PTO, capable of absorbing belt loading, or a chassis-powered PTO, with pulleys of various sizes to match engine rpm to the pump crankshaft rpm required to produce proper flow and pressure.

A suction damper or shock absorber is usually required, together with an exhaust damper and pressure accumulator. An unloading valve in the system is usually utilized for engine/pump cranking to eliminate start-up back pressure.

Piston pumps of this size are available from several manufacturers. Sheave/vee-belt combinations of cog type or multi-vee-type are also available. Unloading valves and accumulators cushion system shock. Total pump/damping and vee-belt drive usually make this package more expensive than the centrifugal system.

7.1.1.3 Power source

Truck engines, separate engines, gasoline or diesel, power the pumps. The engine rpm versus torque curve must match the demand of the pumping system. Gasoline engines operate at higher rpm than diesels, 4- or 6-cylinder engines will develop maximum torque at lower rpm than a V8. These factors must be considered when matching the engine to the pump. Gear set or belt-driven sheave size variations can be used to arrive at a proper match for optimum engine/pump match. The main advantage in using separate engine power is not having to run the motive vehicle engine (often large and expensive) for intermittent pump power. The disadvantage to using a separate engine is the added weight can limit the water carrying capacity of the vehicle as well as add complexity to the system.

PTO (from truck chassis) pumps of centrifugal or piston design producing the discharge and pressure required to support washing at high head and for two-gun, simultaneous use in substations will require 50 kW to 67 kW (68 bhp to 90 bhp). The truck chassis PTO must have the capability to produce this horsepower. A PTO driven from an 8-hole SAE from the opening on the main transmission (manual shift type) or from an automatic transmission with converter lock-up is required for this horsepower. The truck-engine horsepower output and torque must be tailored to the pump rpm and power requirement through the PTO ratio. Speed variation from 60% to 115% of engine speed is usually available through gear set selection. Note that most medium to large gasoline or truck engines are governed as to top rpm; this fact and the best rpm for maximum engine torque should be considered on all-wheel-drive chassis. A full torque (same as output at crankshaft of engine) is usually available from the transfer case of the all-wheel drive. When this PTO is utilized, it must be of the full-oiled type, which guarantees lubrication under sustained speed and load.

Pump clearance and piping availability to the pump are major considerations. Often chassis frame, cross members, or exhaust will interfere with the pump location. Remote pump location can be accomplished by adding a driveline from the PTO pump. This must be, however, a tubular balanced driveline with proper U-joint angles at both ends, due to high rpm required under demand load.

Any of the PTO drives require running the chassis engine to provide water flow and pressure. Usually, the truck engine is very large and very expensive to operate for pump power only. If production cleaning is being done where the vehicle moves from structure to structure and washing is done repetitively, chassis

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PTO power can be effectively utilized. The use of a PTO versus separate engine-driven pump should be carefully considered.

7.1.1.4 Controls

A demand throttle should be considered. This may improve the efficiency for both the engine and operators. This device drops the pump engine rpm to idle when the handheld gun valve is closed. As soon as the trigger on the gun valve is pulled, the pump engine is automatically speeded up to a preset rpm and nozzle pressure.

7.1.2 Tank

7.1.2.1 Type of material

Three basic materials—fiberglass, coated mild steel, or stainless steel—have been used to carry the wash water. For any of these tank types, a rigid, firm base of support must be provided: truck or trailer frame, or steel-aluminum skid. In larger capacity tanks, where bending or rocking occurs, spring loaded mountings must be utilized or damage will occur. A truck or trailer chassis may flex while carrying the load, therefore, the tank and its base or skid must move as the twisting and rocking of the frame occurs. A solid skid or base for the tank is essential; the mounting to the carrier must provide the compensation for the chassis movement.

Fiberglass/plastic type tanks may be limited in capacity. Tanks of 1.9 m^3 (500 gal) or less are most popular. If higher capacity is required, steel tanks should be considered.

Mild steel tanks must be coated inside, primed, and painted outside to prevent rust. It is essential before coating the inside that the entire tank inside be thoroughly sandblasted, then cleaned. All weld flux-mill coating must be removed.

Cleanliness of all joints and welds, including filler dome weldments, inlet and outlet bosses, is essential. An epoxy or similar type coating should then be applied. The coating must be suitable for water immersion.

Tank capacity length, width, and height will govern selection of material, gauge of metal, type of header, and number and location of baffles. In 1.9 m^3 to 4.5 m^3 (500 gal to 1200 gal) mild steel tanks, 10 gauge (3.4 mm) (0.1345 in) heads with 10 gauge (3.4 mm) (0.1345 in) wrap is adequate, again with the proper base. If stainless steel is utilized in 1.9 m^3 to 9.5 m^3 (500 gal to 2500 gal) capacity, 12 gauge (2.7 mm) (0.1046 in) throughout or 12 gauge (2.7 mm) (0.1046 in) heads with 10 gauge (3.4 mm) (0.1345 in) wrap is adequate. Again, baffles and base are important considerations in choosing the thickness of metal required.

7.1.2.2 Capacity

Tanks from 0.19 m^3 to 1.9 m^3 to 9.5 m^3 (50 gal to 500 gal to 2500 gal) have been used for insulator washing. Helicopters to 10-wheel off-highway trucks provide the motive power. Water source, amount of washing to be done, availability of tanker supply vehicles, and type of right-of-way terrain will affect tank and carrier size. For helicopter washing with small onboard tanks, a water supply vehicle is usually provided at the landing zone/staging area.

7.1.2.3 Fill method

Where overhead discharge of water supply is utilized, a top opening type dome is available. This must be a vented design. A filler screen of stainless steel material should be utilized to filter any foreign matter. Access from the ground to the dome is necessary. The dome should be securely fastened before travel to prevent sloshing and water loss.

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When hydrant fill or pressure filling from ground level is used, valving and system plumbing is usually fitted at the rear or curb side of the vehicle. Some washer pumping systems permit using the wash pump with valve selection changes to pull high-volume/low-pressure water from a hydrant or carrier into the tank. A water level indication, a visual sight gauge, or electronic indicator is essential. Modern level systems may be tied electronically to low-level water indicators and engine throttle shutdown systems.

Tank backflow restrictions may be required for portable tanks to meet local codes.

7.1.2.4 Design

Capacity, vehicle dimensions, and terrain to be traversed are important design parameters. A low center of gravity and proper baffling are most important. Tank manufacturers offer a limited number of standard head and intermediate tank baffle configurations.

Round, elliptical, and semi-elliptical tanks are popular types, as are flat, square, or rectangular tanks. Strength, weight, and appearance are all considerations in basic tank design. Liquid highway transports do not experience the same water movement as an off-highway insulator washer. The tank manufacturer must be made aware of the anticipated usage. Openings of adequate size for suction, pressure bleeder return, sight gauge, level probe, and resistivity probe should be provided when the tank is fabricated. A vortex straightener may be provided at the suction outlet boss to improve efficiency.

7.1.3 Piping

Efficient piping is important. Water restriction between the pump and the tip of the nozzle affects the efficiency of the entire wash system. The suction system, pipe, and hose need to be large enough to provide a surplus of flow capacity to the high-pressure pump when it is working at maximum flow and pressure. If 3.75 L/s to 5 L/s (60 gal/min to 80 gal/ min) of water is to be pumped at a maximum usage, 63.5 mm (2.5 in) suction piping and hose should be provided; 38.1 mm (1.5 in) heavy-duty pressure discharge piping is used to the tee and to the hose reels. Valves of minimum 25.4 mm (1.0 in) inside dimension (id) dimension will ensure minimum pressure loss. It is important in ball valves that a clear 25.4 mm (1.0 in) throat be provided; not a valve with 25.4 mm (1.0 in) female threads and 19 mm (0.75 in) throat; 90° elbows, sharp hose bends, union, nipple, and valve cluttered plumbing should be avoided. Pressure lines from the pump should travel to the hose reels or tip monitor in as straight a line as possible. A filter at the outlet of the tank suction or pump inlet, if installed, should be of a monitoring type. If it becomes blocked, an immediate bypass should allow flow around.

NOTE—Some pump manufacturers will not warrant a pump if a filter is placed ahead of the inlet. This is due to cavitation danger.

7.1.4 Hose

7.1.4.1 Type

The insulator cleaning standards of utilities vary, depending on the type of washing and the structure to be cleaned. Both conductive and non-conductive hose are utilized. Fire hoses of non-conductive material and polyplastic nylon reinforced hoses are being utilized where non-conductive practices are utilized. When the practices call for conductive hose, wire braid, rubber covered hoses with stapled couplings are used.

7.1.4.2 Size

Hose from 15.8 mm to 25.4 mm (5/8 in to 1 in) id are used. The larger the id, the less the pressure loss. The larger size hose is heavier, more expensive, requires larger reels, and greater bend radius, etc., but is much more efficient. A short piece of smaller id hose can be attached to the outlet end. A 2.43 m to 3.05 m (8 ft to 10 ft) jumper will cause no measurable pressure drop, and the operator will have more flexibility.

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7.1.4.3 Reel

Live hose reels, or reels with end transfer of water through a live rotary joint, may be utilized. Again, the swivel size should be no smaller than 25.4 mm (1 in) id. The reel can be powered by hand, electrically, or hydraulically. A roller guide for the hose should be provided. All fittings should be the submersible type. A brake is essential to lock the reel where desired. Continual on/off operation will cause hose crawl unless a manual brake is installed and used.

7.1.4.4 Coupling

Safety is most important. Compression type fittings, as specified by the fitting and hose manufacturer, should be used. A qualified craftsperson should make the assembly, carefully checking the hose, inside and outside, skiving if specified, and visually measuring and marking the depth of male hose insert as it passes inside the hose. When the coupling is completed, the outer crimped member must be at the premeasured depth. Non-conductive nylon or plastic hoses should be coupled per the hose and fitting manufacturer's specifications.

7.1.5 Nozzle

7.1.5.1 Handheld

The last item the water passes through is the nozzle. Proper design and finish will produce a good straight stream of water with a minimum of breakup. A flow straightener located ahead of the nozzle changes turbulently rotating water into a straight stream as it enters the nozzle. Orifice sizes vary from 3.2 mm to 7.94 mm (1/8 in to 5/l6 in), varying with distance and water pressure. Effective cleaning is accomplished by the impact of the water, followed by the rinsing of the contaminant from the insulator. Efficient utilization of the water is the objective. A fine polished tip may be difficult to obtain commercially. Many users hand finish and polish their own. Brass or aluminum bodies with steel, stainless steel, ceramic, or metal compounded tips may be used. The nozzle is attached to a handheld wash gun. A trigger opens and closes the water source. A fore-end or handle and bracketing with shoulder pad are added operator features. Pressure drop across gun, weight, cost of manufacture, positive shutoff, and deadman trigger are to be considered when selecting washing guns.

7.1.5.2 Remote/standpipe

Transmission towers can be piped with top-mounted nozzles predirected toward the insulators and line. A pumper/tanker then connects to the standpipe to wash the insulators remotely.

7.1.6 Carrier

7.1.6.1 Trucks

Chassis, from small 4-wheel-drive vehicles to 10-wheel-drive diesels, of 27 216 kg (60 000 lb) are being used. Small all-wheel-drive trucks equipped with water pump only pick up water from tanker trucks or trailers. Medium and heavy trucks pump/engine or PTO equipped may carry the water and accomplish the washing. The truck may also carry a skid-mounted tank pump and aerial manlift to use when cleaning from a basket.

A chassis-mounted boom with a remotely controlled tip monitor is a popular arrangement. Ground-to-tip heights of 19.8 m to 41.1 m (65 ft to 135 ft) are in use. Washing requires many more extensions/retractions than the use of a crane/derrick in line construction or maintenance. Wear and tear require a tough rigid boom that can tolerate the repetitive cycles required in the washing function. Articulated aerial units to 41.1 m (135 ft) are in use. An insulated upper arm and a basket with non-conductive hose that is equipped with a

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handheld gun are used. Existing aerial lift equipment can be used seasonally for washing transmission, distribution, and substation insulators. Skid or trailer wash equipment is also utilized.

7.1.6.2 Trailer

A wash trailer can be towed behind existing truck equipment. Trailer brake actuation, electric vacuum, air, or combinations provide stopping ability and allow towing vehicles with varying brake systems to tow the trailer. The trailer can be towed behind an existing 10.6 m to 19.8 m (35 ft to 65 ft) aerial lift for distribution washing or an existing 27.4 m to 38.1 m (90 ft to 125 ft) lift for transmission. Metal towers can be climbed, with the line worker carrying a hand line up the tower, and then pulling the gun to him/her. Two people can wash from one trailer on high-voltage vee-string requirements if the pump power unit is equipped to produce pressure and flow for two-gun simultaneous operation. Voltages of up to 800 kV are being washed by this method.

Substation washing often requires a vehicle, low in height, with flotation tires to avoid substation gravel disturbance. A short-coupled trailer can be used in a substation, and two-gun cleaning can be accomplished. The throttle can be lowered for flood washing the more delicate apparatus. Used with a boom of 9.1 m to 12.2 m (30 ft to 40 ft), higher bus insulators can be cleaned. The same self-contained trailer can be used in various applications, providing increased vehicle utilization in all the maintenance functions. During dry summer months, the trailer becomes an excellent fire-fighting vehicle.

7.1.6.3 Helicopter

When access to insulators is difficult, rugged, or remote, or when high mobility is required for rapid washing operations over long distances, overhead washing by helicopter is an option. Such aircraft are limited in the amount of wash water they can carry. The pumping system and handheld or guided gun with wand are usually powered with a higher pressure, lower volume system than ground-carried systems. With this self-contained, isolated, and ungrounded system, the spray nozzle can be safely positioned closer to the insulators that are to be cleaned. Considerations have to be made for the structure type and helicopter accessibility before using a helicopter-mounted nozzle.

Most helicopter-mounted cleaning equipment utilizes water at higher pressures, and in turn, a lower volume water flow. This, of course, is compatible with aircraft operation. Typical equipment today uses a two-cylinder gasoline engine to drive a 6895 kPa (1000 psi) output pump or a hydraulically driven pump from a PTO from the helicopter engine. The water tank is lashed in the passenger seat of the helicopter or carried underneath as a load. A 2.06 mm (0.081 in) nozzle is used with this higher output pressure.

Helicopter-mounted cleaning equipment may also utilize a compressed air, dry-type cleaner. The equipment is similar to, but normally smaller in scale, than land-based units.

7.1.7 Water

7.1.7.1 Quality

Water of high resistivity or low conductivity should be utilized in cleaning energized insulators. Rainwater, snowmelt, and steam plant distillate are known in general to have good resistivity characteristics. Constant testing of the water being used is important. Resistivities can quickly change due to temperature. Water of poor resistivity, in the range of 750 Ω·cm to 1000 Ω·cm (295 Ω·in to 394 Ω·in) can be purified by de-ionizing systems or filtering. Minimum water characteristic should be determined based on planned operating practices and expected voltages. A resistivity greater than 1500 Ω·cm (591 Ω·in) is desirable. In freezing conditions, water resistivity should exceed 50 000 Ω·cm (20 000 Ω·in).

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7.1.7.2 Additives

No soaps or detergents should be added to the water. Cleaning is accomplished by the impact of the water and rinsing.

In northern and Arctic climates, no antifreeze or alcohol is added. Flame danger and residual contaminants, and environmental considerations, eliminate their use. Water, warm but not hot, will remove contaminants, and although freezing will occur as the ice or frozen contaminated water melts, contaminants will be flushed away. Ice should not be left bridging the air gaps between insulator sheds.

Polymers, or a polymer-type substance, can be added to the water to focus the water stream more than with water alone. It increases the amount of pressure available at the nozzle and allows for a more effective jet of water farther from the nozzle. It is most effective when used during windy conditions or when wash distances exceed the reach of a normal water stream. To provide for the proper mixture ratio, it is important to follow the manufacturer's guidelines for adding the polymers to the water system. When finished with the polymer mixture, make sure to properly flush the water system before storage.

7.1.7.3 Monitoring

Various continuous testing or monitoring systems are available to measure the resistivity/conductivity of the water used. Whether the characteristics of the water are known or unknown, each tank full or addition should be tested. Minimum standards must be maintained for safety. The water resistivity decreases as water temperature increases. Non-temperature compensated testers should be used. A common practice is to dump water tanks after use, and refill with fresh tested water the next day. Continuous monitoring systems usually require a probe within the tank. Probe (or probes) constantly measures the conductivity of the fluid. A light or audible warning, and pump throttle control, can be integrated into the monitor circuit. Twelve-volt dc actuated systems are preferred to ac industrial devices that require an ac/dc inverter or converter.

7.2 Medium-pressure water equipment (2100 kPa to 2750 kPa) (300 psi to 400 psi)

The equipment used for this system is essentially the same as for high-pressure water.

7.3 Low-pressure water equipment (1400 kPa) (200 psi)

Low-pressure water (flood wash) apparatus is similar to the high-pressure equipment except for less severe service requirements. An automatic or manual repetitive system may be desirable depending upon the degree of contamination and type.

7.4 Compressed air, dry-type cleaner

7.4.1 Pressure

The pressure is generally 850 kPa (125 psi) but may be as high as 1050 kPa (150 psi).

7.4.2 Volume

Cleaning by this method requires an above-average volume of air, up to 1.0 L/s (2.0 ft^3/min) is recommended.

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7.4.3 Dryers

An air dryer is required for use on energized systems. Any effective type should be suitable. Dry air offers many advantages. Improved dielectric quality and less frequent clogging of the cleaning compound are two of the most noteworthy.

7.4.4 Hopper

A commercial pressure blast machine should be satisfactory. Some models have an air-activated vibrator attached, which should improve the mix of the cleaning compound. However, proper premixing of the cleaner may eliminate the need for the vibrator.

7.4.5 Hose

Standard air hoses should be of sufficient size to handle the air volume required. Conductive hose may be used to connect the air compressor to the pressure blaster. Suitable non-conductive hose should be used between the blaster and the applicator wand unless the handle of the wand is grounded, in which case conductive hose may be used.

7.4.6 Nozzle

The nozzle is generally of ceramic material or stainless steel with a special carbide lining to reduce nozzle erosion caused by the cleaning compound. The angle of attachment between the nozzle and the wand is important in controlling the flow of air and cleaning compound over various insulator shapes. Generally, three nozzles have provided the flexibility to clean all insulators. They are: a straight nozzle, a 30° to 45° nozzle, and a 120° nozzle. Protective covers are sometimes used over the nozzles when cleaning on voltages of 34 kV and below, due to the decreased safe working distances.

7.4.7 Wand

The wand must have a dielectric strength suitable for the voltage on which it is being used. Generally, the insulated wand is used for all applications.

7.4.8 Power source

Any satisfactory prime mover for the air compressor will serve. Generally, gasoline or diesel engines are used.

7.4.9 Cleaning materials

Crushed corncobs, powdered limestone, pecan shells, walnut shells, and CO_2 pellets are commonly used cleaning materials. It is important that the cleaning compound clean and not damage the item to be cleaned. Use of limestone must be monitored before long-term application. Use of walnut shells leaves an oily residue, which may have certain advantages. Several of these are abrasive and come in various grades and sizes, which offer flexibility in selecting the proper material for a given cleaning job. CO_2 pellets, which are non-abrasive, turn to gas that blows the contaminant off the insulator upon impact. The high dielectric strength of CO_2 (3.1 kV/mm) (0.122 kV/in) and its fire extinguishing properties allow energized cleaning. CO_2 pellets are presently being used by some utilities to clean energized live front pad-mounted switchgear. Check local regulations for restrictions on use of specific cleaning materials.

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7.5 Fixed spray

The equipment is composed of a water tank, pump and motor, various valves, nozzles, piping system, and control system.

7.5.1 Piping and motor

A centrifugal pump and three-phase induction motor are generally used. The required pump capacity is decided according to the maximum water flow of washing sections.

7.5.2 Nozzles

Nozzles should be of simple, sturdy construction and not easily clogged with foreign bodies. They should be capable of providing a satisfactory cleaning effect, taking strong wind into account. The type of insulator to be washed will determine the cleaning system parameters.

7.5.3 Piping system

Pipes and fittings generally used are made of steel, hot-dip galvanized, inside and outside. They are butt-welded for underground piping and butt-welded, flanged, or screw-jointed for above ground piping. Sizes of pipes are determined by the water flow needs.

7.5.4 Control system

To operate the washing equipment effectively and wash insulators safely, a control system should be provided that checks that the washing equipment is in a normal condition, with water resistivity, water pressure, and water level being satisfactory before washing. Any abnormality in the system after commencing to wash should automatically stop the operation. All the processes, from the decision to start the washing to the completion of the operation, should be programmed in the control system. An automatic pollution monitor can be the control for the system. The sequence of washing should also take into account the wind direction and the amount of contaminants being carried by the wind.

8. Technical considerations for energized cleaning with water

8.1 Leakage current

For the purpose of this guide, leakage current is defined as the current that flows through normally non-conducting elements such as hoses. Refer to IEEE Std 80-2000 and IEC 60479-2:1987 for safe values of let-go current for the average person.

The level of 1 mA is the approximate perception threshold current that a person detects as a slight tingling sensation in his hands or fingers due to current flow. When the nozzle grounding braid is properly grounded, no appreciable leakage current should flow through a person's body during the washing operation. Nevertheless, a person should anticipate the possibility that the nozzle grounding braid can accidentally open or become disconnected. For this reason, leakage current in the wash stream should be limited to 2 mA.

The washing equipment, the wand, the structure, and the washing person should be at the same potential. Refer to IEEE Std 1048-2003 for more details about grounding.

In substations, nozzle operators using handheld nozzles wear rubber boots, rain clothes, and rubber gloves to avoid getting wet. In addition, the wet hose is in direct contact with the ground. The operator has both hands on the nozzle while the stream is contacting energized equipment. It should not be difficult under these

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circumstances to limit the leakage current by adjusting washing distance, pressure, orifice, and water resistivity.

The parameters that influence the leakage current in the wash water stream are as follows:

a) Line voltage
b) Distance from the nozzle tip to the energized parts
c) Water resistivity or conductivity
d) Water pressure
e) Nozzle orifice diameter

Currents exceeding 1 or 2 mA are to be guarded against by the following:

1) Using water that falls within the acceptable range of conductivity or resistivity
2) Replacing worn nozzles
3) Carefully maintaining safe working distance

8.2 Working distance

Table 4—Minimum distance for energized washing[a]

Line voltage	Minimum nozzle-to-conductor distance	Minimum water resistivity	Minimum nozzle pressure	Maximum orifice diameter
(kV)	(m)	(Ω·cm)	(kPa)	(mm)
13 & below	1.82	1300	2758	4.76
13 & below	1.82	1300	2758	6.35
16	2.13	1300	2758	4.76
34.5	2.44	1300	2758	6.35
34.5	2.44	1300	2758	4.76
69	2.74	1300	2758	4.76
69	3.66	1300	2758	6.35
115	3.05	1300	2758	4.76
115	3.96	1300	2758	6.35
230	3.66	1300	2758	4.76
230	4.57	1300	2758	6.35
345	3.92	1300	2758	4.76

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Table 4—Minimum distance for energized washing[a] *(continued)*

Line voltage	Minimum nozzle-to-conductor distance	Minimum water resistivity	Minimum nozzle pressure	Maximum orifice diameter
(kV)	(m)	(Ω·cm)	(kPa)	(mm)
345	5.22	1300	2758	6.35
500	4.27	50 000	5516	6.35
500	6.10	3000	3792	7.94
500 dc	6.10	50 000	5516	6.35
NOTE—The 345 kV distances were interpolated using 230 kV and 500 kV and found to be in line with industry practice.				

[a]The distance is limited by tower dimensions and configuration. Because of the limited nozzle-to-conductor distance, demineralized water with resistivity of 50 000 Ω·cm (19 685Ω·in) or greater can be used.

NOTE—For English units, see Annex C.

Nozzle-to-conductor distance for a given line voltage and nozzle diameter is the most important parameter that influences the leakage current and the washing effectiveness of the water stream. Washing effectiveness and the magnitude of leakage current decrease with increasing nozzle-to-conductor distance. In cases where the wash distance is limited by the tower dimensions, demineralized water can be used.

Table 4 gives minimum distance between the energized parts and the nozzle tip for various line voltages.

8.2.1 Establishing a maximum stream length distance

Everyone involved with cleaning energized insulators understands the need for establishing a minimum stream length distance. Something that many utilities do not consider is establishing a maximum stream length distance. The maximum distance between the nozzle and the insulators being washed is the distance that a high-pressure compact stream can be maintained. The compact stream is more effective in washing contaminants from the insulators and can be directed with better accuracy to avoid wetting adjacent unwashed/energized insulators. Beyond that distance, the stream will break into a spray, which can result in insulators not getting adequately washed, or in the worst-case scenario, flashing over the insulator.

Also, failure to establish a maximum distance can place the worker at risk and affect the reliability of the circuit being washed. When establishing the maximum stream length distance, the following, additional factors need to be considered:

a) Type of insulator to be cleaned
   1) Cap and pin
   2) Post
   3) Ball and socket
b) Insulator configuration
   1) Vertical
   2) Horizontal
c) Stream impact on insulator surface
d) Contamination level on insulator surface
e) Configuration of the wash stream at a given distance

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Each of these factors should be considered in establishing the maximum stream length distance that can be used and still provide a safe and effective cleaning.

Tests proved that insulator cleaning is ineffective when performed from too great a distance, and all that is actually accomplished is a wetting of the surface of the insulator, which can increase the risk of flashover. Everyone who performs energized insulator cleaning using pressurized water must consider establishing a maximum stream length distance. This will help to ensure that an effective wash is achieved and reduce the risk of insulator flashovers.

8.3 Water quality

8.3.1 Water resistivity

This is the insulating value of water. The unit to measure the resistivity of water is the ohm-centimeter or ohm-inch. This is determined by measuring the resistance between opposite faces of a cube of water, 1 cm or 1 in one apart.

Water resistivity or water conductivity is another important parameter that influences the leakage current of the water stream. A low value of water resistivity could lead to insulator flashover or injury during washing.

NOTE—Ohm is a measure of resistance. Ohm-cm is a measure of the resistivity. The higher the reading, the better the quality of water. Microsimens/cm is a measure of conductivity. The lower the reading, the better the quality of water.

Test conductivity with each filling of the tank. If the reading does not fall within the acceptable range, obtain water from another source.

NOTE—To convert ohm-inch into ohm-cm, multiply by 2.540. To convert ohm-cm into ohm-inch, multiply by 0.3937. The following table shows some typical values (here 2.5, not 2.54 is used to convert from Ω·cm to Ω·inch):

Water resistivity/conductivity

Resistivity Ω·cm	Resistivity Ω·in (Ω·cm/2.5)	Conductivity μS/cm (1/Ω·cm*10^6)
100	40	10 000
1 000	400	1 000
1 500	600	667
5 000	2 000	200
10 000	4 000	100
20 000	8 000	50
50 000	20 000	20

Water having a resistivity greater than 1500 Ω·cm (591 Ω·in) is widely used and can usually be obtained from city hydrants. Demineralized water of 50 000 Ω·cm (19 685 Ω·in) or greater resistivity is also used and is usually obtained from steam power plants or from mobile demineralizing equipment.

8.3.2 Water temperature

As the temperature of water increases, its resistivity decreases. In other words, the conductivity increases with the increase of temperature.

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Because the water resistivity changes with temperature, it is necessary to measure resistivity periodically, especially in hot weather.

To prevent water from heating up, the pump must be idled back and the recirculating valve opened when washing is not in progress.

Water that has been in the hose long enough to warm up must be flushed out before washing starts.

8.3.3 Water resistivity measurement

An instrument to measure the resistivity/conductivity of the water is required, since it is very important that the washing crew know the resistance of the water before using it to clean energized insulators, to ensure that the resistivity is sufficiently high.

8.3.3.1 Resistivity meters

Commercial resistivity/conductivity meters are available in portable models, which are utilized for testing of each tank of water before and after filling (before hot washing).

A constant resistivity monitoring system provides continuous metering of the water resistivity while the washer is operating. It consists of a remote probe with a sensor lead from the bottom of the tank outlet and provides for metering and washer control.

NOTE—The tester should be non-temperature compensated.

8.3.3.1.1 Portable handheld

A portable handheld resistivity meter should be utilized for testing the resistivity qualities of water sources before filling the washer tank. Also, wash practices should call for testing of each tank of water after filling, before hot washing, unless the washer is equipped with a constant monitoring system.

A typical tester has a self-contained sample well, a padded unbreakable case, is powered by a battery, and has a battery test and calibration circuit. The meter has a display in ohms per cubic inch or ohms per cubic centimeter with minimum limits highlighted in red and accurate to within ±2% of full scale.

8.3.3.2 Continuous monitor

Hard-mounted solid-state circuitry, with a waterproof high impact case and meter scales as previously described, is utilized. A remote probe with a lead from the tank bottom outlet provides a sensor for the meter and control. A continuous measurement of the water is made while the unit is operating. An operator warning and complete shutdown occurs if the minimum preset resistivity limit is reached.

NOTE—If de-ionized or boiled water of high resistivity is utilized for washing, a dual range meter may be required.

8.4 Water supply

Washing water may be obtained from a municipal supply or other clean source, such as a running stream. Water containing chemicals or salts must not be used. Under no circumstances should detergents be added to the water. Only approved chemicals, such as polymer additives, may be added to the water. The operator must make sure there is sufficient water in the tank to finish the job once it is started.

Each tank of water must be tested even if the water has been taken from a source that previously tested good. The conductivity of all water used for washing insulators must be within the limits.

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A tank of water that has warmed up since it was originally tested must be retested to ensure that it still meets resistivity requirements

8.5 Water pressure

Water pressure is related to the working distance and may be adjusted accordingly. The pressure will decrease as the distance increases, and if the distance is too far, washing will not be effective (refer to 8.2.1). Safe working distances must always be maintained. The cleaning effect is directly related to the water force or impact of the water on the insulators.

High water pressure and a compact stream are required to

a) Perform the best cleaning job with the smallest amount of water.
b) Cut down overspray and hence minimize the flashover of insulators during washing.
c) Ensure that sufficient water can be delivered to extinguish an electrical arc should it develop.

8.6 Nozzles

The size and design of the nozzle orifice affects the size and performance of the water stream, thus affecting the water pressure and leakage current. The nozzles must be inspected daily when in use. If nicks, which would cause the water stream to break into a spray, are observed, the orifice must be rehoned. Worn out nozzles that do not do a satisfactory cleaning job must be repaired.

8.7 Grounding

The body of the truck is insulated from ground by the tires and can thus become a large capacitor. If the truck is not grounded, it is possible that it can build up charge to a dangerously high voltage. Hence, the truck must be grounded while washing is in progress. It is of utmost importance that no human contact be made with the truck to avoid establishing a parallel ground through a person's body.

Adherence of the requirements stated in the preceding subclauses will limit the leakage current to safe limits. Additional protection is provided by placing the washing gun operator in an equipotential zone by bonding and grounding appropriately. Refer to IEEE Std 1048-2003 for additional details.

8.8 Laboratory tests in grounded environments

Table 5 and Table 6 furnish the leakage currents measured in a laboratory environment for various voltage levels and at various distances for different water resistivities. It can be seen that for a given resistivity, and for the same distance, the leakage current increases with an increase in voltage level (Table 5). For the same voltage, the leakage current decreases with an increase in distance (Table 5). The leakage current varies also if the resistivity varies; the higher the resistivity, the lower the leakage current (refer to Table 5 and Table 6). Table 7 gives the leakage currents with no water spray. Table 8 gives flashover voltages with no water spray for various distances, and Table 9 shows the pressure impact for various pressure levels.

— Washing with a hand nozzle in a laboratory using water with a resistivity of 1600 Ω·cm (612 Ω·in) and a pressure of 4688 kPa (667 psi) resulted in leakage currents recorded in microamperes. See Table 5.
— Washing with a hand nozzle in a laboratory using water with a resistivity of 29 000 Ω·cm (11 417 Ω·in) and a pressure of 4688 kPa (667 psi) resulted in leakage currents recorded in micro amperes. See Table 6.
— Applied voltage with no water spray resulted in leakage currents recorded in microamperes. See Table 7.
— Flashover voltages with no water was recorded versus distance. See Table 8.

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Table 5—Leakage currents (μA) for various line voltages for washing with a hand nozzle in a laboratory using water with a resistivity of 1600 Ω·cm and a pressure of 4688 kPa

Distance from tip of nozzle to energized conductor	Line voltage					
m	80 kV	140 kV	180 kV	200 kV	220 kV	250 kV
1.52	41 000	90 000	130 000	145 000	165 000	—
1.83	22 000	61 000	100 000	110 000	—	150 000
2.13	19 000	25 000	45 000	85 000	—	112 000

NOTE—For English units for Table 5, Table 6, Table 7, and Table 8, see Annex C.

Table 6—Leakage currents (μA) for various line voltages for washing with a hand nozzle in a laboratory using water with a resistivity of 29 000 Ω·cm and a pressure of 4688 kPa

Distance from tip of nozzle to energized conductor	Line voltage					
m	80 kV	140 kV	180 kV	200 kV	220 kV	250 kV
1.52	1600	4100	5400	6200	6600	—
1.83	910	1300	2800	3600	—	5200
2.13	640	1200	1600	2700	—	4900
2.44	560	—	—	—	—	—
3.05	450	880	1000	4000	—	5000

Table 7—Leakage currents (μA) for various line voltages with no water spray

Distance from tip of nozzle to energized conductor	Line voltage				
m	140 kV	180 kV	200 kV	220 kV	250 kV
1.52	620	110	1350	1550	1700
1.83	380	680	900	1000	1350
2.13	330	590	780	880	1100

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Table 8—Flashover voltages with no water was recorded versus distance from tip of nozzle to conductor

kV	m
226	0.91
280	1.22
336	1.52
376	1.83
420	2.13
460	2.44
468	2.74
488	3.05

8.8.1 Water pressure performance

Various pressure tests have been conducted using 45.5 m (150 ft) of 25.4 mm (1 in) hose with a 3.03 m (10 ft) of 19.05 mm (3/4 in) leader. See Table 9.

Table 9—Water-pressure performance for various pressures using 45.5 m of 25.4 mm hose with a 3.03 m of 19.05 mm leader

Desired pressure	Nozzle	Pump pressure	Impact	Distance
kPa	mm	kPa	kg	m
3795	6.35	5175	10.8	9.1
2760		3450	9.07	
3795	6.35	6210		
2760		6210		
2070	8.0	4140	11.34	
2070	6.35	3450	13.6	

NOTE—For English units, see Annex C.

8.8.2 Wet and dry flashover values

The following figures show graphs of laboratory work depicting wet and dry flashover values for different gap lengths and for different resistivities. For example:

a) Figure 3 shows for 4137 kPa at 2.43 m at 2450 Ω·cm
b) Figure 4 shows for 4481 kPa at 3.04 m at 2450 Ω·cm
c) Figure 5 shows for 20 685 kPa at 3.04 m at 2450 Ω·cm
d) Figure 6 shows for 20 685 kPa at 3.81 m at 2450 Ω·cm

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e) Figure 7 shows for 20 685 kPa at 3.81 m at 60 000 Ω·cm

f) Figure 8 shows for 20 685 kPa at 1.52 m at 60 000 Ω·cm

g) Figure 9 shows for 20 685 kPa at 1.52 m at 1240 Ω·cm

h) Figure 10 shows for composite using different nozzles and water resistance

NOTE—For English units, see Annex C.

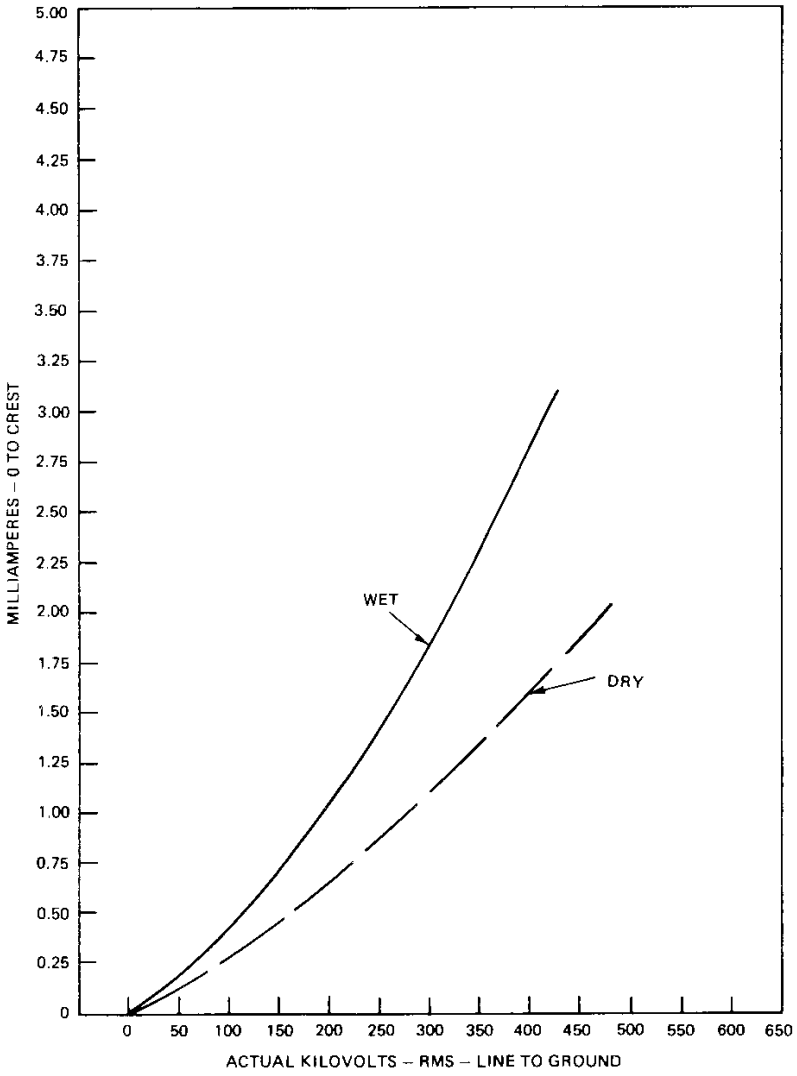


Figure 3—Wet and dry flashover for a 2.43 m (96 in) gap with 4137 kPa (600 psi) and 2450 Ω·cm (966 Ω·in) water

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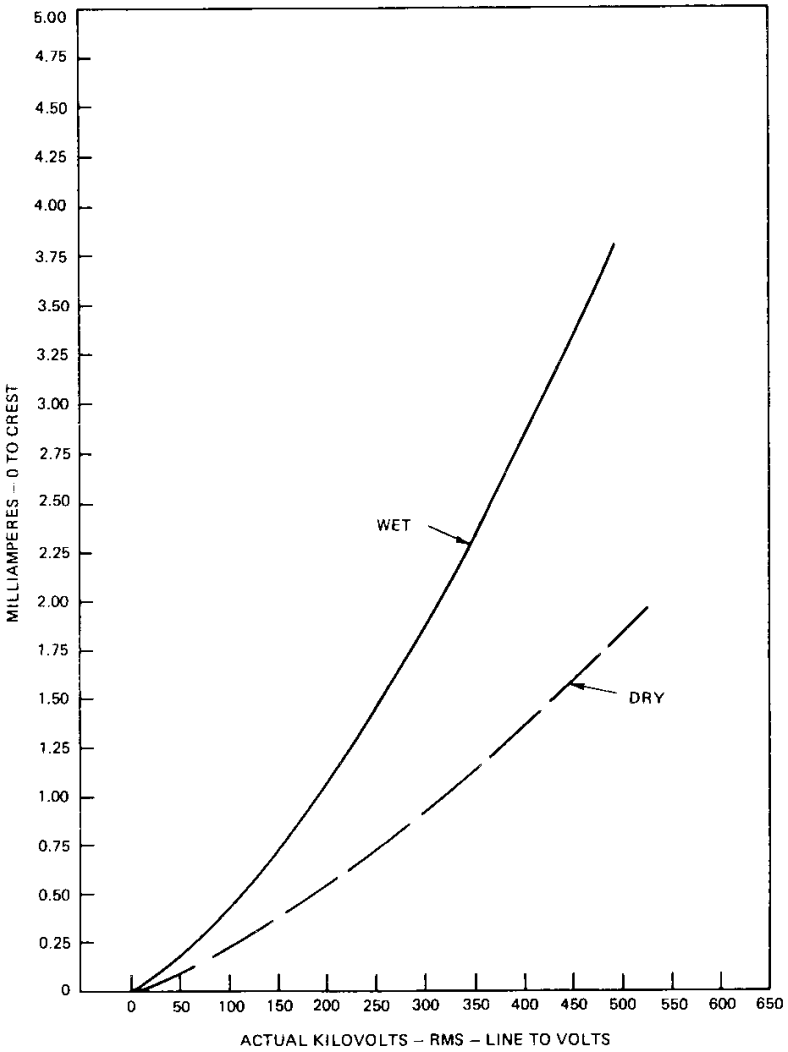


Figure 4—Wet and dry flashover values for a 3.04 m (120 in) gap with 4481 kPa (650 psi) and 2450 Ω·cm (966 Ω·in) water

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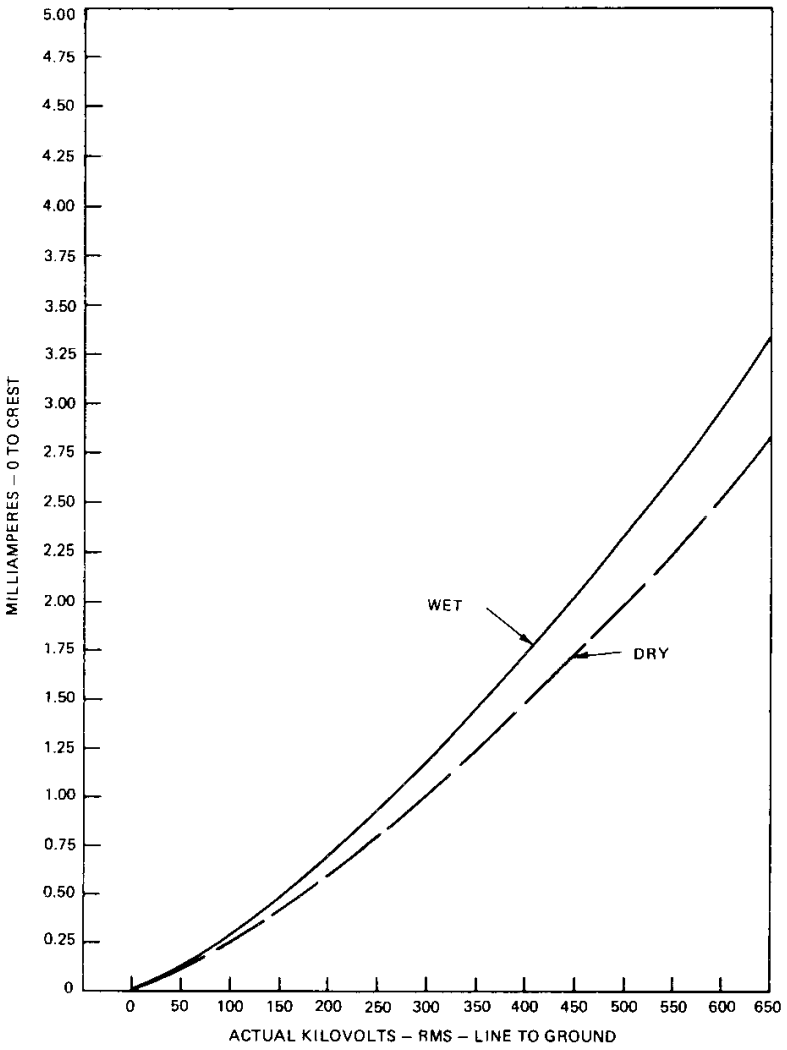


Figure 5—Wet and dry flashover values for a 3.04 m (120 in) gap with 20 685 kPa (3000 psi) and 2450 Ω·cm (966 Ω·in) water

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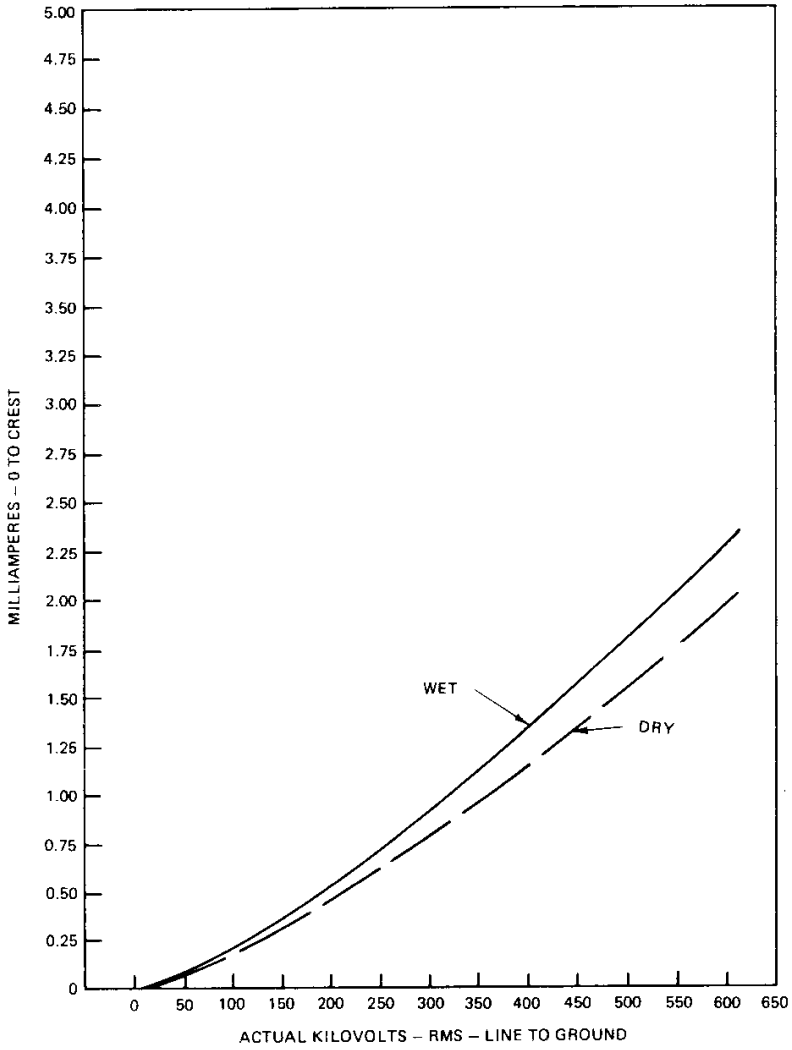


Figure 6—Wet and dry flashover values for a 3.81 m (150 in) gap with 20 685 kPa (3000 psi) and 2450 Ω·cm (966 Ω·in) water

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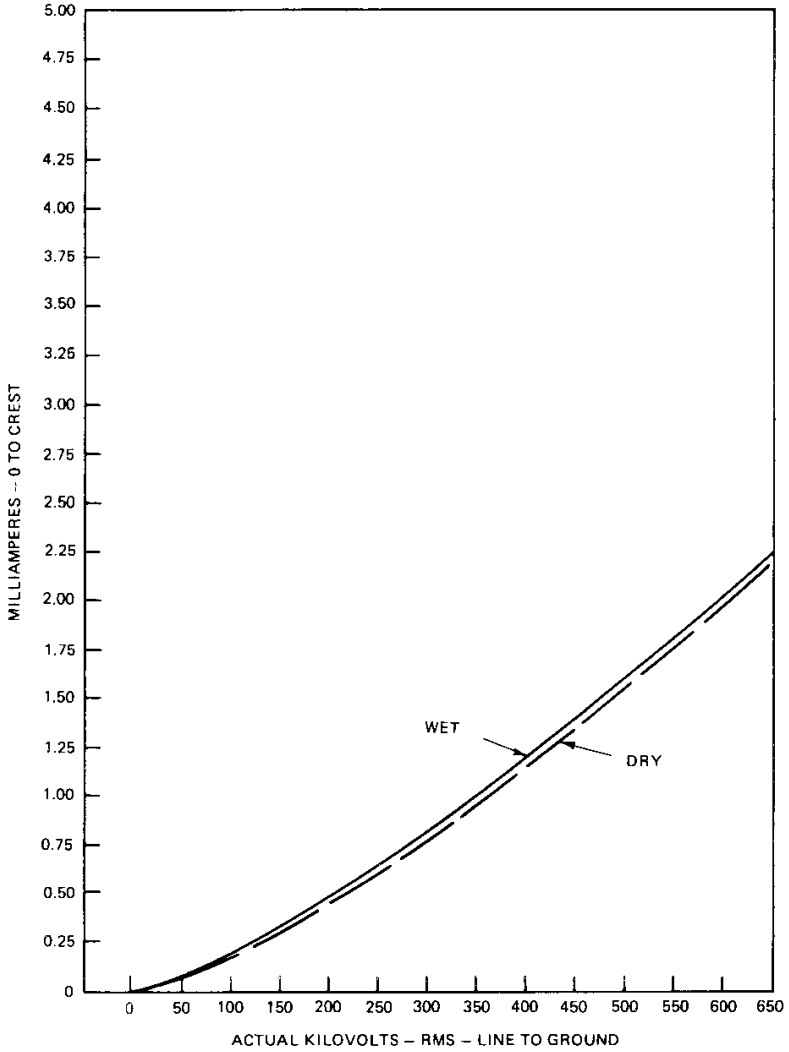


Figure 7—Wet and dry flashover values for a 3.81 m (150 in) gap with 20 685 kPa (3000 psi) and 60 000 Ω·cm (23 622 Ω·in) water

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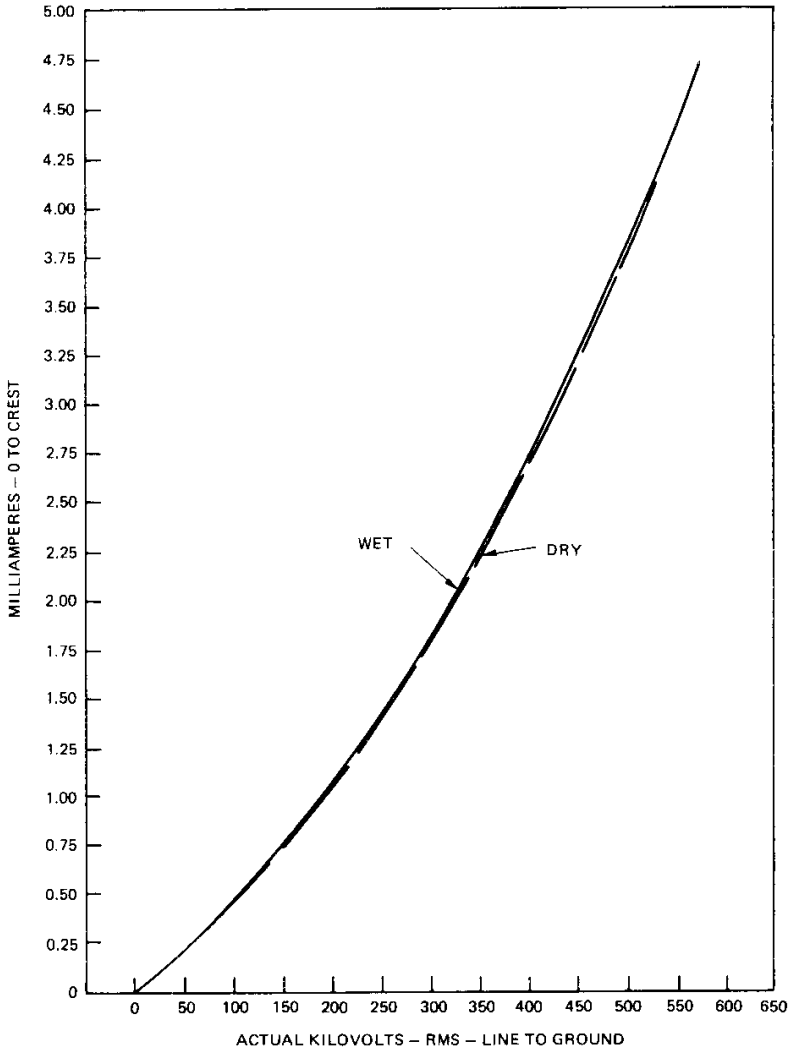


Figure 8—Wet and dry flashover values for a 1.52 m (60 in) gap with 20 685 kPa (3000 psi) and 60 000 Ω·cm (23 622 Ω·in) water

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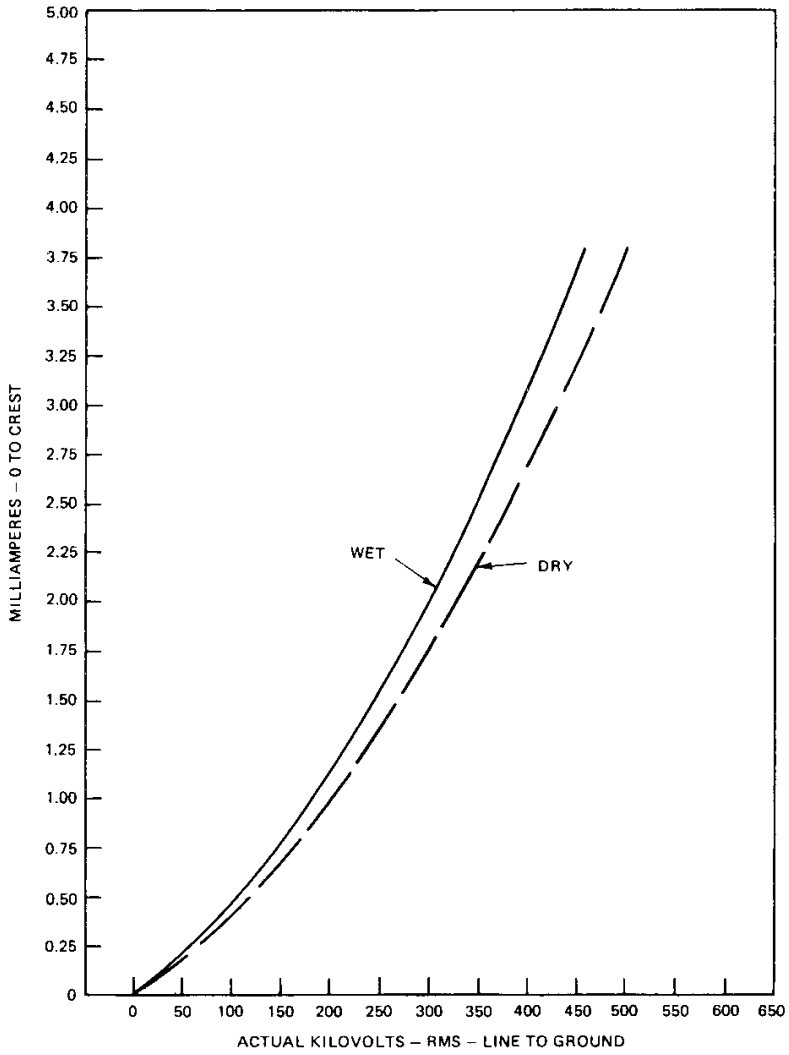


Figure 9—Wet and dry flashover values for a 1.52 m (60 in) gap with 20 685 kPa (3000 psi) and 1240 Ω·cm (488 Ω·in) water

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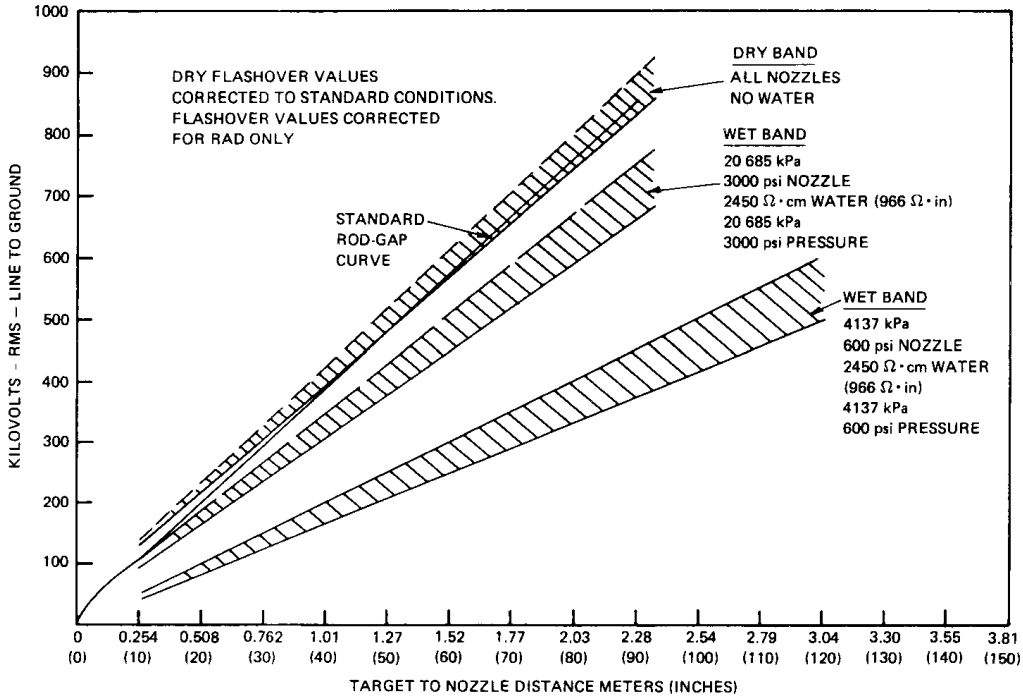


Figure 10—60 Hz dry and wet air gap flashover bands using different nozzles and water resistance

NOTE—For English units for Figure 10, see Annex C.

8.9 Fixed nozzle

Performance of hot-line washing with fixed nozzles is affected by such factors as water volume, stream size, force, water resistivity, and wind condition. Other factors are design and mounting arrangement of the insulators. Therefore, it is valuable to perform an experimental study on the electrical characteristics covering the particular conditions expected in a given situation.

8.9.1 Quantity of wash water

When the water physical variables (WPV—volume, stream size, and force) are low, washing is not effective, and the withstand voltage remains low. As the WPV increases, withstand voltage rises. Then, as the WPV is further increased, water starts to bridge the sheds of insulators and the withstand voltage decreases. An experimental study, supplemented by manufacturer's data, should help in determining the optimum quantity of water.

8.9.2 Effect of wind

Even when the appropriate WPV is used, water spraying may lose its efficiency under a strong wind. It may therefore be necessary to develop a spray nozzle that can ensure high washing withstand voltage under a strong wind. A proper combination of jet nozzles and spray nozzles, used widely in Japan, may be a solution.

The jet nozzle is more suited to high-voltage systems because of lesser wind effect and long spray range. The spray nozzle is suited for medium-voltage systems.

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8.9.3 Water resistivity

Withstand voltage decreases as the water resistivity is lowered and shows a marked decrease when the specific resistivity of the water falls below 1500 Ω·cm (591 Ω·in).

8.10 Helicopter-mounted nozzle

Because this wash system is self-contained, isolated, and ungrounded, the spray nozzle can be safely positioned very close to the insulators to be cleaned. Performance of helicopter-mounted wash systems is directly influenced by the proximity of the nozzle to the target. But, as can be seen for other high-pressure water systems, performance is also influenced by such factors as water resistivity, water volume, and wind conditions. Care must still be taken to maintain safe working distances to other parts of the helicopter, including conductive and non-conductive parts of the heliwash operation.

8.10.1 Water resistivity

Leakage current through the water stream to the wash equipment, aircraft, and crew is not a concern for isolated and ungrounded heliwash operations. However, a low value of water resistivity could lead to insulator flashovers during washing. The following minimum water resistivities are suggested:

a) 230 kV and below 1300 Ω·cm (512 Ω·in)

b) Above 230 kV 2600 Ω·cm (1024 Ω·in)

8.10.2 Quantity of wash water

The amount of wash water carried onboard the helicopter is limited by the capabilities of the aircraft. Therefore, heliwash systems output a lower volume of water by operating at higher water pressures (usually about 6895 kPa—1000 psi), and utilizing smaller jet nozzle orifices [usually 3.2 mm (1/8 in) or less]. In combination with the close proximity of the nozzle to the wash target, this produces a highly effective and efficient wash stream blast at the contaminants.

8.10.3 Effect of wind

In general, any high-pressure water spraying method will lose its effectiveness and efficiency under windy conditions. But, heliwash spraying will remain effective and efficient if the helicopter can continue to maneuver within a few feet of the wash target. However, if obstructions or other right-of-way congestion prevents such proximity, the wind may break up the wash stream. Further, if the wind is strong and/or gusty, the pilot may decide that safe flight operations are not possible.

9. Industry practices

9.1 General industry practices

The following are suggested work practices based on many years of successful and safe operation in live-line washing:

a) The nozzle should be bonded to whatever the operator is standing on to ensure the gun and operator are at the same potential.

b) The cleaning media must be brought to full-nozzle pressure before it is directed to the insulation.

c) In general, warm water has a lower resistivity than cold water. The initial stream should be directed away from the energized equipment until the warm water of lower resistivity is cleared from the

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hose line and pipes. The resistivity monitoring equipment should be used when available to determine safe operating levels.

d) Any adjustments of the pump controls should be made with water turned off or the stream directed away from the energized equipment.

e) Either the cleaning equipment should be grounded or care should be taken to ensure that workers and public stay clear of the equipment.

f) Whenever practicable, it is best to clean with the direction of the wind, that is, spray in the same direction as the wind. Overspray to adjacent insulators/parts should be monitored and avoided. Overspray cannot be prevented, but it can be managed. Prior to directing a wash stream at an insulator, the worker must determine if the angle that they intend to wash from will allow overspray to wet the surface of energized insulators that have not been cleaned. If it does, then they should wash from another angle or wash the dirty insulators that the overspray would land on, before washing this insulator.

g) To reduce the risk of a circuit interruption, insulators, crossarms, and hardware should be inspected prior to the cleaning program.

h) Suspension-type insulators: Direct the solid stream to the lowest insulator first and move progressively upward on the string, periodically returning to the lower units to wash off drip from higher units. On horizontal units, begin at the conductor and work toward the structure, taking into consideration an alternate method if the wind direction is with the direction of the stream.

i) Stacked insulators: Clean from the lower insulator upwards, returning to the lower units to clean off residue from the higher units.

j) Pin or post type insulators: The stream should be directed to the underside of the insulator and up towards the conductor. If using water, caution must be exercised when wetting of crossarms occurs. The wetting of crossarms can increase leakage currents and lead to fires. It may be necessary to direct additional water to the arm if burning is initiated.

k) Damaged insulation should not be cleaned.

l) On over-build construction, clean lower level insulators first.

m) If a sizable arc begins when cleaning insulation that supports energized conductors, keep the stream into the arc. In some instances the arc may be extinguished. Damage from the arc can be kept to a minimum in this manner.

n) When cleaning in stations, care shall be taken in choosing the direction from which equipment will be cleaned. Equipment in a water overspray area may become partially wetted, giving some risk of flashover.

o) The hose operator should consider protective equipment to prevent possible inhaling of dust or possible eye injury. This is especially important when using dry cleaners.

p) Corona discharges may extend from the metal cap to the porcelain during energized high-pressure water washing and may be heard for a few seconds after completion. If this discharge continues, it may indicate incomplete washing, in which case the wash stream should be reapplied.

q) When cleaning any facilities, individual company grounding rules should apply.

r) Use of two nozzles is preferred, especially when washing big size equipment.

s) If the insulator column is long, for example, insulator strings for 230 kV and above, they can be washed in sections, for effective cleaning.

t) Results of efficient insulator cleaning can be judged by the following:

   1) Visible surface condition—The surface condition of both the top and bottom of the insulator skirts should be visually clean and shiny after the water has dried.

   2) Insulator vibration—Mechanical vibration (ringing) of insulator skirts under the impact of high-pressure washing and exhibiting evidence of efficient, swirling, cleaning action.

   3) Absence of corona arcing or tracking—Leakage current discharges are not present.

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4) Clarity of runoff— Clarity of the water runoff may also indicate the effectiveness of contamination removal. Clarity of water runoff may be difficult to observe due to distance, wearing of shaded safety glasses, etc.

u) Flashovers during live-line washing can be minimized by the following:

1) Using high water pressure and a compact stream

2) Preventing polluted wash water from being sprayed over unwashed, dirty insulators

3) Avoiding partial wetting of unwashed insulators

v) The equipment used to clean insulators should be designed for this purpose.

w) For de-energized work, individual company grounding practices should apply.

x) Tools and equipment shall be inspected prior to each use and any found with defects shall be taken out of service or repaired before being used.

9.2 Individual company standards/rules

Each individual company should establish rules and operating practices.

9.2.1 Working positions

Each company has rules and regulations. The minimum approach distance established by occupational safety authorities is the minimum distance recommended at any time. In addition to the minimum approach distance to an energized conductor, the operator should be positioned in a favorable location, whether in an aerial device, on a structure, or on the ground for safe working.

9.2.2 Helicopter

Prior to the start of any heliwash operations, the operating voltage of the line and the physical dimensions of the structures, phase spacing, helicopter, and wash-boom shall be determined. Verify that the helicopter, including the wash rig, has the physical clearance to position the wash-boom in the work position, while maintaining safe working distances from all phases and objects at a different potential than the phases to be washed. Care must be taken to ensure that the helicopter is positioned so that the rotor blades and tail rotor will not come into physical contact with any components of the structure, conductors, overhead ground wire, or insulator strings of the line to be washed, an adjacent tower line, or any other obstruction near the right-of-way. The pilot shall never position the tail rotor between phase or ground wires. Physical and electrical clearance shall be reviewed prior to positioning the main rotor between vertical phase conductors.

All heliwash operations should be conducted using the crew loop concept; however, ultimate responsibility for flight safety lies with the pilot in command. A flight following system should be in place for all heliwash operations

Several of the suggested work practices in 9.1 are not appropriate for heliwash operations, such as items e), q), and r). The following are suggested work practices based on years of successful and safe operation in live-line work from helicopters:

a) In addition to the nozzle being bonded to the platform or frame that the wash operator occupies, the platform shall be connected electrically to the fuselage of the helicopter. All equipment installed on the platform, including the water pump, gas engine, fuel tank, and water tank, must be electrically bonded to each other and the platform. All these bonds shall be checked before use each day.

b) A safety conference or tailboard briefing shall be held with all crew members prior to the beginning of heliwash operations each day. The safety conference should include a review of appropriate safety rules, wash procedures to be used, and applicable safety distances for the voltage to be washed.

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c) During the wash, the operator and the pilot shall maintain voice contact and work as a team. The pilot shall maintain radio communications with the ground support personnel at the landing zone (LZ). The ground support personnel shall maintain communications with the switching center having jurisdiction over the lines being washed.

d) The pilot, in consultation with the wash operator, shall be responsible for all decisions regarding safe flying conditions.

e) The wash operator shall be fastened to the helicopter or work platform by an approved safety harness and lanyard.

f) Insulating and working clearances shall be maintained as described in IEEE Std 516-2003, 7.2.

g) The pilot/wash operator shall not approach the energized line in a manner that would short-out any insulating system. When making inadvertent contact and during arcing, maintain safe working distances from other phase potential and ground.

h) The wash-boom shall not be released except when it is in the stowed/locked position.

i) The wash stream is not to be directed at personnel.

j) Ground personnel should not stand near tower footings of the line being washed.

k) All helicopter and wash equipment, including platforms, shall conform to appropriate civil aviation authority and have proper certification.

9.2.2.1 Landing zone

An integral part of the safety of overall heliwash operations includes the following suggested work practices at the LZ:

a) Ground support personnel shall always obtain permission from the pilot before approaching or departing from the helicopter, which shall always be done from a position in front of the aircraft, and never from an uphill slope.

b) All fuel hose, water hose, grounding lines, fire extinguishers, containers, and other equipment and vehicles will be kept forward of the helicopter tail section.

c) Personnel shall not stand on vehicles or equipment while the helicopter is taking off or landing.

d) Equipment must be kept below shoulder height.

e) Consider ways of personnel to protect their eyes by keeping well clear of the LZ, turning their backs to the aircraft, or wearing face shields.

f) Refueling operations shall comply with occupational safety authorities and civil aviation authorities requirements. Smoking is not permitted in the LZ.

g) Rotor blades should be flat pitched during ground running to reduce the movement of debris.

h) The LZ shall be secure at all times to prevent unauthorized entry. Special attention should be directed toward children, bicyclists, joggers, and pets.

i) LZ sites should be clear of obstructions and relatively level; hilltops and ridge locations are preferred.

j) The tail rotor is unprotected. Every effort shall be made when setting up landing zones to position the helicopter so that all personnel and equipment are forward of the helicopter cabin. Movement of LZ personnel rear of the cabin section while the rotors are turning is strictly forbidden, except for trained, authorized personnel.

k) All landing sites shall, at a minimum, conform to the requirements of a “basic helicopter landing zone” as described in civil aviation authorities regulations.

l) Extreme care should be taken when working around a helicopter with turning rotors. Careful examination of hazardous areas within the LZ should be pointed out and monitored by all personnel (i.e., approaching from hills or jumping off trucks, slopes, rocks, holes, etc.).

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9.2.2.2 Training

All personnel must have satisfactorily completed a formal training course of instruction and practice, which includes work rules, procedures, wash equipment operation, safety practices, and governmental regulations (civil aviation authorities and occupational safety authorities). This includes the operation of the helicopter, fuel handling, and LZ general safety.

9.2.2.2.1 Pilot

The pilot shall have the proper license and/or endorsements for the type of helicopter being used and the work being performed in accordance with the applicable government regulations and safe flight practices. The pilot shall be adequately trained and familiar with the particular helicopter to be used and prepared for flying conditions, and shall be fully trained on minimum distance requirements for live-line work. The pilot should have the proper training and minimum flight time as required by civil aviation authorities or other applicable government regulations.

9.2.2.2.2 Aerial wash equipment operator

The aerial wash equipment operator must be thoroughly trained and familiar with the particular helicopter and with the washing procedures and techniques to be used. The operator shall be trained in the inspection, handling, and care of the wash equipment and shall be fully trained on the minimum distance requirements for live-line work.

9.2.2.2.3 Ground support crew members

All ground-support crew members should be under the responsibility of a designated ground coordinator/ safety officer, who controls the LZ, fuel transfer, flight following system, and communications. All ground crew personnel shall know how to use the communications equipment, and if required by the type of radio being used, a least one member must have a permit issued by the appropriate governmental agency. They shall be trained in the inspection, handling, and care of the tools and equipment to be used (water tankers, fuel pumps, wash rig, etc.). They shall be thoroughly familiar with LZ safety practices, fuel handling, and emergency response procedures, including the operation of fire extinguishers.

9.3 Public/public relations

When insulator cleaning has some impact on members of the public, they should be notified/considered. A public relations trained person should be involved.

9.4 Limitations

Factors limiting safe, economic, and effective insulator cleaning are: weather, system loading, long stream length distance, and the type of contaminants present. These factors may either eliminate the cleaning of particular insulators, or influence when the particular insulators can be cleaned, or determine which method can be used to clean the insulators.

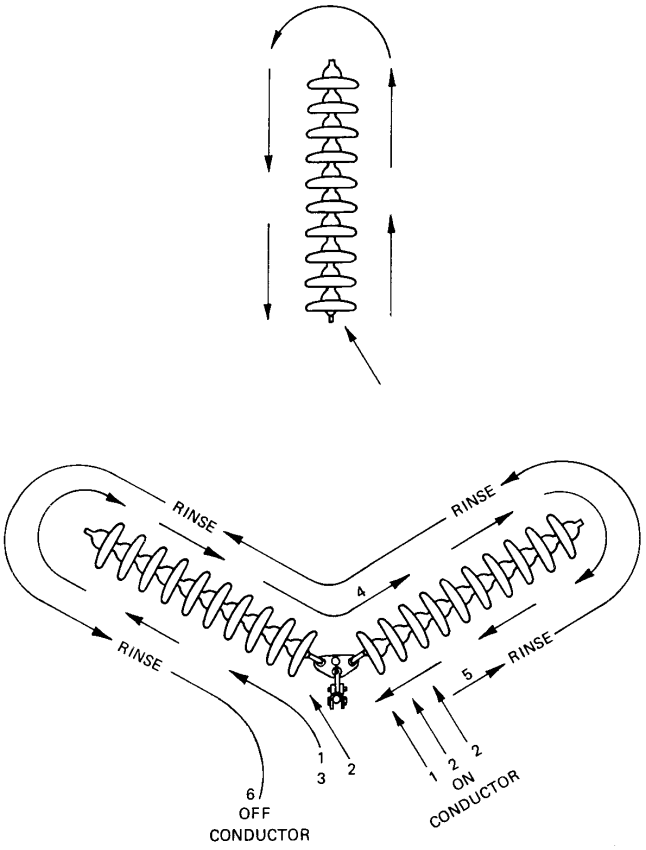
Weather conditions limit when each of the methods of insulator cleaning may be applied. If the wind is strong enough to prevent accurate aiming of water or dry cleaning materials, or if the wind disperses the stream and significantly reduces the impact on the insulator, these methods should not be used. Compressed air using dry cleaning cannot be effectively performed when humidity is high because the moisture content of the material will be high. High humidity causes the dry cleaning material to clump together, which usually causes an erratic flow of the material.

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Pressure washing insulators can become ineffective if the stream length distances are too long. The effectiveness of the stream length distance can vary depending on the type of nozzle, size of nozzle orifice, and nozzle pressure used. When the wash stream is too long, the impact pressure can be reduced enough to eliminate any cleaning action and only accomplish a wetting of the insulator surface, which can lead to insulator flashover. Establishing a maximum stream length distance, based on the variables mentioned, can ensure that an effective cleaning is being performed and eliminate an insulator flashover.

Figure 11 shows an example of washing steps for vertical and vee-string insulators.



Step 1. Always contact conductor first with full pressure water stream.

Step 2. Move up string slightly off center.

Step 3. Move down string slightly off center.

Step 4. Repeat steps 2 and 3 as a rinse.

Step 5. Move off conductor with full pressure water stream.

Step 1. Contact conductor first with full pressure water stream.

Step 2. Clean one of three insulators on both vee strings.

Step 3. Move up string slightly off center and back down to conductor.

Step 4. Move up other string slightly off center and back down to conductor.

Step 5. Rinse (repeat steps 2 and 3).

Step 6. Move off conductor with full pressure water stream.

Figure 11—Washing steps for vertical and vee-string insulators

The types of contaminants present on the insulator surface can influence the cleaning method that should be used. Some contaminants, such as bird excrement, can become very conductive when wet. For contaminants that become conductive when wet, the high-pressure wash or flooding method should not be used on energized lines. The high-pressure wash and flooding methods are most effective when used to clean soluble contaminants. Adhesive insoluble deposits may limit the effectiveness of water cleaning methods. These types of deposits and extremely stubborn compounds may constrain the cleaning methods to either hand cleaning with chemical agents and scrubbing or use of the compressed air, dry cleaning method. Hand cleaning is an expensive procedure. Only by experience with a particular contaminant can the most effective and economical cleaning process be determined.

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10. Summary

The following tables summarize the insulator cleaning methods and use (Table 10), the list of contaminants and the various methods to be considered to clean them (Table 11), and the list of grounding rules adopted in practice.

Table 10—Methods and use

Method	Energized	De-energized	Uses	Clause
High-pressure water				6.1.1
Fixed-spray system	Yes	Yes	Installed permanently on structure (where frequent washing is required)	6.1.1.3
Helicopter	Yes	Yes	Inaccessible locations and fastest method for multiple sites	6.1.1.4
Remote-control nozzle	Yes	Yes	Where safe working distance is a concern or difficult to wash from a structure	6.1.1.2
Handheld nozzle	Yes	Yes	Most common and least expensive for smaller jobs, can be used at most sites	6.1.1.1
Medium-pressure water			Less worker fatigue with medium pressure and higher production	6.1.2
Remote control nozzle	Yes	Yes	Same as high pressure	6.1.1.2
Handheld nozzle	Yes	Yes	Same as high pressure	6.1.1.1
Low-pressure water				6.1.3
Fixed-spray system	Yes	Yes	Cleaning transformer bushings and sea-salt spray problems	6.1.4
Compressed air dry cleaning			Similar to sandblasting, used to remove heavy contaminants	6.1.5
Corncob/walnut shell	Yes	Yes	Abrasive particles that are ground up, remove heavy contaminants	6.1.5
Limestone, powdered	Yes	Yes	An additive to the corncob and shells mixture for increased abrasion	6.1.5
CO_2 pellets	Yes	Yes	No abrasive action to insulators	6.1.5.1
Hot wiping	Yes	Yes	Used when special equipment is not available or prior to hot washing to reduce flashovers, accomplished with hot sticks	6.1.6
Hand cleaning			A thorough and effective method, when outages are occurring	6.2.1
Steel wool/nylon pads	No	Yes	Access to the insulating device is difficult	6.2.1.1 6.2.1.2
Solvents	No	Yes	Solvents are used to aid the cleaning	6.2.1.3

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Table 11—Contaminant types and washing types

Contaminant	Water washing		Compressed air dry cleaning		Wiping	
	Flood/ low pressure	High pressure	Corncob w/nut shell	CO_2 pellets	Hot wiping	Hand wiping
Salt	√	√				√
Cement/lime			√	√	√	√
Earth dust	√	√	√	√	√	√
Fertilizer dust	√	√	√	√	√	√
Metallic dust			√	√	√	√
Coal dust	√	√	√	√	√	√
Volcanic ash	√	√	√	√	√	√
Bird excrement	√	√	√	√	√	√
Chemical	√		√	√		√
Smog (vehicular)	√	√	√	√	√	√
Cooling tower effluent	√	√	√	√		
Smoke/coal soot	√	√	√	√	√	√
Organic	√	√	√	√	√	√
Ice/snow		√	√			√
Petroleum/grease			√	√	√	√

10.1 Grounding

When washing insulators on steel towers, or when washing insulators of pole structures on lines over 44 kV, the pump, motor, and tank assembly should be grounded to a steel tower or structure that is known to be grounded. Another low-resistance ground may be used if no permanent ground is available.

The spray gun should be grounded by means of a flexible cable not less than #4 AGW copper in size.

If the spray gun is operated from a steel structure or tower, it should be grounded to the steel structure.

If operated from a truck, an insulated aerial device with bucket, or aerial ladder mounted on a truck, the spray gun should be grounded to the same electrode as the truck frame.

If working from the ground, the operator should stand on a ground mat, so that the hands and feet will be at the same potential. The ground mat should also be connected to a grounded steel structure or other low-resistance ground. Rubber gloves are not required because there is no potential difference between the hose/ nozzle and the operator, when all are bonded together.

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The tank, pump, motor assembly, and truck frame should be bonded together and the truck frame grounded as follows:

When washing pin type insulators on wood pole lines along roadways, installation of a dragging chain is sufficient to drain off normal static charge. However, under these circumstances, persons on the ground should be prevented from contacting the ungrounded vehicle during washing operations. Portable truck barriers can be used to warn and/or prevent persons from making vehicle contact during washing operations.

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Annex A

(informative)

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Annex B

(informative)

Maintenance of ceramic insulators after cleaning

B.1 Silicone protective coating for high-voltage insulators

Grease like silicone coating compounds have been used successfully as protective coatings of porcelain and glass insulators in electrical maintenance for over 25 years. All forms of present insulator greases prevent formation of a water film because of their water-repellent, low surface energy characteristics. Service experience with silicones has shown that when they maintain their water repellency, they provide protection of the insulator by breaking up water filming. However, extended exposure to sparking, ultraviolet radiation, water erosion, or particulate contamination will reduce the water repellency of the grease. When water repellency of the grease is lost, leakage currents and dry-band discharges may result in decomposition of the grease, forming a depressed path in the coating. These paths act as collection sites for moisture, leading to concentrated currents forming arcs. This path or valley can thus lengthen on the insulator surface with time. Under high intensity arcs on a relatively thin silicone coat, channeled tracks may develop in the grease, resulting in local hot spots on the insulator surface. If the temperature of the track gets hot enough, the glass or porcelain insulator may fracture.

Channeled arcing in a greased polymer insulator may also lead to tracking on the insulator. Therefore, greasing of composite insulators should not be done without first consulting the insulator manufacturer.

Contrary to the belief that all silicone compounds are similar, large differences exist in the types of fluids, fillers, and coupling agents used. This means that there will be large differences in consistency of compounds, their ability to build heavy layers of varying stability, and their performance under severe high-voltage outdoor conditions.

Utilities, therefore, should select silicone compounds for the various weather and service conditions of the insulators and bushings exposed to polluting atmospheres.

The effectiveness of the silicone grease coating is dependent upon the proper thickness and the uniformity. The requirements for protection differ widely according to location and environment, and govern the choice of thickness. This means that each utility may have adopted their own application practices for insulator maintenance. For example, nonabsorbent contaminants such as metallic particles require less compound or fluid than an absorbent particle such as fertilizer, if the rate of pollution is similar.

To adequately maintain protection from pollution over a long period of time, a 1.6 mm (1/16 in) to 3.2 mm (1/8 in) thick thixotropic coating of silicone compound is required. In practice, it has been found that coatings vary considerably and often nominal 3.2 mm (1/8 in) thick coatings are found to be less than 0.8 mm (1/22 in) thick, with spots having little or no compound. These thin spots can be sources for dry-band arcing and premature flashover. Table B.1 gives typical quantities of conventional silicone grease required to coat a specific insulator.

Silicone greases are normally applied to insulators by hand, brush, or spray. Hand coatings can be applied with a soft cotton glove or with a rag; brush coatings should be applied with a brush having stiff bristles. If necessary, the sprayable greases can be dispersed further in solvent to produce consistencies for dip coating.

The silicone grease dispersions can be sprayed with airless pumps having compression ratio of at least 26:1. A reversible nozzle can be used on the spray gun for quick cleaning if the orifice becomes plugged. A

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0.46 mm (0.018 in) to 0.66 mm (0.026 in) nozzle with a fan angle from 15° to 65° may be used, depending on the size and shape of the insulators to be coated.

A hot-stick spray gun, designed specifically for energized compound application, is often used.

If the following insulators were coated with a 1.59 mm (1/16 in) coat of compound, each insulator would require the amount of compound listed in Table B.1.

Table B.1—Typical quantities of silicone grease required to coat a specific insulator

Description	Area	Amount of compound required
	m^2	kg
13 kV one-piece pin type	0.07	0.10
34.5 kV line-post insulator	0.22	0.34
Standard 0.254 m (10 in) suspension unit	0.17	0.27
Smog type 0.254 m (10 in) suspension unit	0.23	0.35
34.5 kV pin-cap apparatus insulator	0.39	0.62
69 kV pin-cap unit used in two-unit stacks	0.46	0.74
High-voltage pin-cap apparatus unit	0.72	1.16
69 kV bushing	0.85	1.36
138 kV bushing	1.99	3.18
230 kV bushing	4.59	7.26

NOTE—For English units, see Annex C.

The nozzle can be adjusted through 360° in any plane so the spray can be directed in any direction. An all-directional swivel is mounted at the base of the stick to prevent long lengths of hose from interfering with maneuverability. The swivel has a quick change coupling for changing to hand guns or for easy removal of the feeder hose. Electrical tests on the stick and the feeder hose filled with solid silicone mixture indicate that the equipment is more than adequate for 230 kV. The hot-stick spray gun is rated at 100 kV/0.30 m (1 ft).

Coatings applied by spraying can lose up to 50% of their original thickness due to solvent evaporation and the escape of air that has been trapped during application. A 3.18 mm (1/8 in) thick initial coating, for example, will plate out to approximately 1.59 mm (1/16 in). To compensate for this loss, a heavier coating must be applied.

Actual measurements at utilities have shown that visual observations are often misleading no matter how the coating is applied. Usually coatings are much thinner than they appear to be, especially in areas difficult to reach. To avoid sections that are inadequately coated, accurate measurements should be made periodically with a step gauge or other measuring device. Colored or pigmented coatings facilitate control of thickness.

Thin spots in the silicone insulator coating are more rapidly saturated with particles than thicker areas. When this happens, the insulator surface loses its water-repellent properties and local arcing may develop. As a result of excessive sparking, the silicone fluid is decomposed to leave the silica filler exposed. These areas

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show up as white or light colored patches on the insulators. In turn, the exposure of water-absorbent silica will locally increase surface currents and cause more severe arcing and so-called hot spots. To avoid this phenomenon, apply a homogeneous, even coating, and periodically check the water repellency and development of light colored spots on the insulators. This should be done under conditions of rain, fog, or water spray. If excessive audible, visual, or measurable conditions of leakage currents exist, the coating is near the end of its useful life.

The application of fresh silicone compound over contaminated silicone material is not recommended; reapplication over dirt-saturated, wet compound is usually disastrous. In an emergency, silicone fluid sprays can be used to reestablish a highly resistant surface. Over-coating should be done with caution.

When problems have developed with the silicone compounds, the causes can often be traced to improper application or to the attempt to use the materials beyond the technical limits of their useful service life. When problems occur, three questions immediately arise:

a) Has the compound been applied properly?

b) Has the free fluid in the coating been used up by heavy coatings of contaminants?

c) Have maintenance personnel somehow missed a scheduled removal and replacement of compound?

Careful study of the problems and past experience can lead both to improved methods and, when relayed to compound manufacturers, to better materials.

B.2 Silicone RTV coatings as protective coatings for high-voltage insulators

Increasingly, RTV silicone coatings are being used to prevent flashover on porcelain insulators and bushings. These coatings are designed to replace silicone grease and water washing. When properly selected and applied, these coatings will last ten or more years without maintenance. Because they are an advanced technology engineering material, their application requires rigorous attention to detail.

The various RTV coatings differ greatly in their ability to prevent leakage current and flashover. Coating composition is the key to their performance. Coatings that loose their hydrophobicity have a short life. These coatings become ineffective in a short time and fail to prevent flashover. Properly selected coatings, which maintain their hydrophobicity, have a long life in preventing flashover.

RTV coatings also differ greatly in their application. After performance, ease of application is the most important consideration of these coatings, greatly affecting their cost of installation. Typically, the cost of labor ranges from 50% to 70% of the total cost of an application project. Therefore, coating systems that are easier and faster to apply represent significant cost savings.

A comprehensive coating specification is critical to ensuring a successful application project. It should provide all of the essential information to describe the job, identify the materials and methods to be used, establish quality control and milestone to determine the suitability of a contractor for the job. A model specification is provided for guidance as the first step in a coating project.

B.2.1 Selection

RTV coatings that are commercially available vary significantly in solids content. A coating with a higher percentage of solids may initially appear to be a better value, but thicker coatings pose the following problems.

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B.2.1.1 Pot life

Thicker coatings tend to “skin-over” more quickly. This necessitates the use of airless equipment or maintaining a purge with dry nitrogen. Shorter pot life creates problems with material drying inside hoses and guns, and the formation of skin inside the pot, which will plug nozzles.

B.2.1.2 Material preparation

Thicker coatings usually need to be thinned with a solvent to facilitate spraying and prolong pot life. In the field, this is time-consuming and requires the use of hazardous solvents. In addition, field application is not conducive to careful measurement of additives, which means that every pot used has a different consistency.

B.2.1.3 Flowability

Thicker coatings generally have reduced self-leveling properties. This means that drips and runs will remain on the coating, and it will be more difficult to maintain the thickness within the specified range. Furthermore, there is a noticeable tendency for thicker coatings to produce an “orange peel” type surface texture. This is caused by particles of coating curing before they impinge the insulator surface (dry spray).

B.2.2 Application

After performance, ease of application is the second most important characteristic of an RTV coating project. Application considerations include film build, pot life, surface preparation, and material preparation. This factor can significantly impact the cost and duration of an application project.

B.2.2.1 Surface preparation

Most coating applicators agree that surface preparation is the most important element in a coating project. Silicone RTV is surprisingly undemanding in this respect. Surfaces must be clean and free of oil, dust, or moisture, but blasting is usually not required. Most surface preparation consists of high-pressure water washing followed by hand wiping with an isopropyl alcohol.

Insulators contaminated with cement-like material must be cleaned using a dry abrasive cleaner such as crushed corncob or walnut shells mixed with lime powder.

Greased insulators are very difficult to clean. Once the bulk of the grease has been removed using a dry abrasive cleaner or by hand wiping, the surface must be hand wiped clean using a solvent such as naphtha to remove the residual film of grease. The surface must be free of even a film of oil.

B.2.2.2 Material preparation

Material preparation refers to the preparation of the coating material for the application equipment at hand. This usually means mixing of solid material that has settled, which is necessary particularly if the coating material has been kept in storage for some time. Thick coatings, which may appear to be a much better value, must be thinned with a solvent to facilitate spraying. In the field, thinning is time-consuming and requires the use of hazardous solvents. Furthermore, field application is not very conducive to careful measurement of additives, which means that every pot used has a different consistency. Therefore, it is best to specify a coating that is supplied ready-to-use and only requires simple mixing of settled material.

B.2.2.3 Film build

Film build properties dictate the maximum thickness that can be attained in a single pass using spray equipment and, therefore, have a major impact on the time and cost of a coating project. Material viscosity and

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sag characteristics and the surface finish of the substrate affect film build. Sag is affected by the adhesion and skinning characteristics of the RTV silicone rubber, the type of carrier solvent, and the ambient temperature and humidity conditions. Because these coatings are normally applied to glazed porcelain, sag is the most important material property.

The type of solvent controls the length of time it takes the material to cure. The best solvent in current use is 1,1,1 trichloroethane. Experience has shown that coating systems using this solvent cure 30% faster than naphtha-based coating systems. This means that subsequent coats can be applied more quickly in order to attain the recommended coating thickness of 15 mil to 20 mil. The cost of a typical application breaks down evenly between material and labor. A quick curing coating system represents significant cost saving.

B.2.2.4 Equipment

RTV silicone rubber coatings can be applied with a brush, conventional air spray, and airless spray equipment.

For small projects involving a few insulators, brushing is the most economical method of application. However, it is very difficult to apply these systems quickly or uniformly by this method. A foam rubber type of brush gives a smoother surface than a conventional bristle brush.

Conventional air spray equipment injects air into the material before it exits the gun. Deposition rates are generally lower than with airless systems, but the guns allow for easy adjustment of spray patterns and flow. Because these coatings are usually applied to complex geometrical shapes, and because material loss should be minimized to reduce cost, these are the best systems for general use.

Spray equipment manufacturers have introduced conventional guns that reduce overspray significantly. Generally described as “high-volume, low-pressure” guns, this type of equipment is ideally suited for use with RTV silicone rubber coatings.

Application equipment should be dedicated to silicone coatings. Other coating materials may leave residues, which may contaminate silicone. Pumps, hoses, and guns must be flushed with solvent following use.

All fittings for pumps and guns should have 100% stainless steel or brass. In addition, all hoses should be non-conductive when used in power station environments.

Airless spray equipment avoids the problems associated with pot life in conventional air spray equipment. As well, airless systems can be used on hot sticks for energized application. However, spray patterns and volume cannot be easily controlled. This type of equipment is best suited for situations where overspray is not a concern and speed of application is very important.

B.2.2.5 Energized application

Coating systems that are dispersed in nonflammable solvents may be applied to energized equipment. This must be done under strict supervision and performed only by experienced live-line crews. It should be noted that energized application does not permit thickness measurement, and material loss is much higher than with conventional application.

B.2.2.6 Inspection

There are just two nondestructive tests that can be performed on RTV coatings to verify thickness, as follows:

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a) *Wet film gauge:* Wet film gauges give a reading on thickness as applied. To determine the dry film thickness, subtract the percentage of solvent. For example, 10 mil of wet material at 50% solids would provide 5 mil of cured coating. Applicators typically take frequent wet film readings.

b) *Ultrasonic thickness gauge:* Ultrasonic thickness gauges will read the thickness of cured silicone coating on porcelain surfaces. These gauges must be calibrated and checked prior to use.

Visual inspection will indicate any overspray or dry spray problems.

B.2.3 Specification

A comprehensive coating specification is critical to ensuring a successful application project. A model specification is provided in this subclause.

B.2.3.1 Preliminary

Prior to the start of work, the owner should provide the following:

a) A detailed written document establishing all of the owner safety requirements on the job site.

b) A comprehensive schedule showing exactly when specific insulators or bushings will be available for coating.

c) A detailed written document describing all of the owner environmental requirements on the job site.

B.2.3.2 Scope of work

The contractor should be responsible for the following:

a) Removal of any contamination, silicone grease, or non-silicone coating on all exposed surfaces. Blasting with high-pressure water, walnut shells, dry ice, or catalyst is permitted. Each component must be hand wiped using isopropyl alcohol.

b) Masking of critical areas, such as mechanical switches.

c) Application of coating to suitably prepared components. (Owner should provide a detailed description of components to be coated, including component type, voltage rating, and quantity.)

B.2.3.3 Coating material

The material should be delivered to the job site in their original unopened containers with proper labels attached. The label information should include such data as: material name, unit size, batch number, and date of manufacture. Product data, material safety data and product certification sheets should be submitted at the time of shipment of the material. The material should consist of an RTV silicone rubber not to exceed 50% solids suspended in a quick evaporating solvent such as 1,1,1 trichloroethane. The material should be stored in a secure, dry location. The temperature shall not exceed 100 °F.

B.2.3.4 Inventory control

An inventory log should be maintained showing material name, batch number, and date of manufacture. The log should be completed daily to show the depletion of material. The coating material should be used in accordance with the manufacturers' most recent published instructions without being thinned, diluted, or modified, except as called for in these instructions, or with the concurrence of the owner.

B.2.3.5 Environmental control

Coating work should not be performed during precipitation or when the dew point exceeds the manufacturer's recommendations. The contractors must ensure that the coating is applied to dry surfaces

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only. Compressed air should be free of oil, water, or other contaminants. Oil and water separators or filters should be installed in the air supply. The contractor should submit a list of all of the equipment considered essential to maintain the projected work schedule.

B.2.3.6 Coating application

Thinning of coating product should be performed only under supervision and using only solvents approved by the manufacturer. Thinning should be performed using standard beakers, and records shall be kept of each batch that is thinned. When possible, thinning is to be avoided. Coating should be applied using the appropriate method allowed by the manufacturer. This includes brushing (foam rubber brush) and spraying using conventional or airless systems. Coating should be applied to an average thickness or 15 mil. In no case should the coating be less than 10 mil.

B.2.3.7 Inspection

Coating should be measured using wet film thickness gauges during application. Fully cured coating (24 hours or longer) should be checked using a properly calibrated ultrasonic thickness tester.

B.2.3.8 Repair

Any coating areas not meeting thickness requirements should be recoated.

B.2.3.9 Clean-up

Any overspray posing a potential problem (for example, on mechanical equipment) should be removed. The contractor should remove all materials, such as coating and solvent containers, and application equipment from the work site.

B.3 Basic materials and equipment used for spraying silicone compound

B.3.1 Commercial hot-stick spraying equipment

Commercial hot-stick spraying equipment consists of the following:

a) Insulated spray stick is equipped with an all-direction, reversible cleaning, tungsten carbide nozzle with a precision high-pressure valve and actuator. A double swivel hose connection permits universal stick positioning for all types of coating applications. The 2.44 m (8 ft) fiberglass sticks are assembled with toolmaker quality, anodized aluminum hardware, and are tested in accordance with the industry standard at 100 000 V for each 0.305 m (1 ft) of length for a period of 300 s (5 min) after assembly and with silicone grease mixture in the stick.

b) Sticks are furnished with a rigid plastic shipping/carrying case, which is foam cushioned internally for maximum handling protection for the precision stick assembly.

c) Insulating stick extension is of tested fiberglass and adds to effective stick length, at handle end, to improve access to remote insulator surfaces.

d) Pressure with 689.5 kPa (100 psi) air pressure. An adequate air supply for insulator coating service is approximately 1.888 L/s (4 ft^3/min) at 413.7 kPa (60 psi) pressure.

e) Pressurizer assembly includes air distribution manifold, air pressure regulator, air pressure gauge, coating material strainer, bleed valve, connect coupling, and 18.93 L (5 gal) reservoir for material to be sprayed.

f) 7.62 m (25 ft) 6.35 mm (1/4 in) insulating hydraulic hose equipped with quick-connect couplings and caps.

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g) 15.24 m (50 ft) 9.35 mm (3/8 in) insulating hydraulic hose equipped with quick-connect couplings and caps.

NOTE—9.35 mm (3/8 in) hose is recommended for over 7.62 m (25 ft) from pressurizer to spray stick.

h) Air-driven agitator and mixer assembly complete with throttle valve and connecting hose-mounts on pressurizer assembly.

i) Hand spray gun with roto-clean nozzle.

j) Portable air compressor capable of delivering 3.304 L/s (7 ft^3/min) of air at 689.5 kPa (100 psi).

k) Typical silicone compound.

l) Mixture to spray-approximately equal parts of solvent and silicone compound 2.839 L (3 qt) of solvent and 4.536 kg (10 lb) of silicone, by volume or just thin enough to ensure continuous flow of the mixture to the pump.

m) Silicone is also available in pressurized 0.47 L (16 oz) cans and 0.24 L (8 oz) squeeze tubes for emergency use.

B.3.2 Conventional application systems

Conventional application systems offer better control and minimal overspray. These systems are recommended for de-energized application. Typical equipment consists of the following:

a) High-volume, low-pressure gun with a 11.7 mm (0.46 in) nozzle

b) Air-driven agitator and mixer assembly on 7.57 L (2 gal) or 18.93 L (5 gal) pump (25:1 ratio)

c) Portable compressor capable of delivering 690 kPa (100 psi) air pressure

d) Insulating hydraulic material hose 9.35 mm (3/8 in)

e) Insulating hydraulic air hose 6.35 mm (1/4 in)

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Annex C

(informative)

English units

Table C.1—Water pressure washing for polymeric insulators psi (see Table 1)

1. Direct molded units	
Silicone	Low- to high-pressure water washing 200 psi to 1000 psi
EPDM/EPR	High-pressure water washing 400 psi to 1000 psi
Alloy EPDMs	High-pressure water washing 400 psi to 1000 psi
Epoxy	High-pressure water washing 400 psi to 1000 psi
Polymer ceramic	Medium- to high-pressure water washing 300 psi to 1000 psi
2. Individual weathershed bonded to a polymer sheath or to each other	
Silicone	Low- to high-pressure water washing 200 psi to 1000 psi
EPDM/EPR	High-pressure water washing 400 psi to 1000 psi
Alloy EPDMs	High-pressure water washing 400 psi to 1000 psi
3. Individual weathershed with an unbonded interface	
All compounds	200 psi, at the pump with a 1/4 in nozzle and no closer than 15 ft
NOTE—For types 1 and 2, the water stream may be directed at any angle to the insulator axis. Type 3 requires the water stream to be directed on the upper (tapered) surface of the weathersheds at an angle no greater than 90° (perpendicular) to the insulator axis.	

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Table C.2—Low-pressure spray washing equipment design data (feet, inches, and pounds) (see Table 3)

Design data	Automatic spray system	
	275 kV	400 kV
Minimum permissible water resistivity	3937 Ω·in	7874 Ω·in
Water pressure at nozzle	100 psi	150 psi
Type of nozzle	Spray	Spray
Minimum distance from nozzle to live conductor	122 in	170 in
Number of nozzles per insulator	CB and CT: 6 Others: 4	CB: 8 Others: 6
Quantity of water	CB and CT: 1.24 gal/s Others: 0.92 gal/s	CB: 1.96 gal/s CT: 1.64 gal/s Others: 1.45 gal/s
Duration of wash (dependent on type of insulator)	25 s	25 s

NOTE 1—CB: circuit breaker; CT: current transformer.

NOTE 2—Refer to Fujimura, T., Okayama, M., and Isozaki, T. [B10].

See 6.1.6 and Figure 1 and Figure 2.

a) The hammock should material be 10 oz/yd^2 weight

b) The cleaning hammocks should be cut 18 in wide by 2 in length for 46 kV and 3 in width by 36 in length for 69 kV post, cap, and pin insulators. A 1 in hem should be folded on both short ends. Then, 1 in pleats should be folded. A #9 diameter iron wire, 12 in length, should be threaded through the pleated hem so that the necessary loop and hook may be formed.

Table C.3—Minimum distance for energized washing (feet, inches, and pounds) (see Table 4)

Line voltage	Minimum nozzle-to-conductor distance	Minimum water resistivity	Minimum nozzle pressure	Maximum orifice diameter
kV	ft	Ω·in	psi	in
13 & below	6	512	400	3/16
13 & below	6	512	400	1/4
16	7	512	400	3/16
34.5	8	512	400	1/4
34.5	8	512	400	3/16
69	9	512	400	3/16

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Table C.3—Minimum distance for energized washing (feet, inches, and pounds) (see Table 4) *(continued)*

Line voltage	Minimum nozzle-to-conductor distance	Minimum water resistivity	Minimum nozzle pressure	Maximum orifice diameter
kV	ft	Ω·in	psi	in
69	12	512	400	1/4
115	10	512	400	3/16
115	13	512	400	1/4
230	12	512	400	3/16
230	15	512	400	1/4
345	13	512	400	3/16
345	17	512	400	1/4
500	14[a]	19 685	800	1/4
500	20	11 81	550	5/16
500 dc	20[a]	19 685	800	1/4

[a]The distance is limited by tower dimensions and configuration. Because of the limited nozzle-to-conductor distance, demineralized water with resistivity of 50 000 Ω·cm (19 685 Ω·in) or greater can be used.

Table C.4—Leakage currents (μA) for various line voltages for washing with a hand nozzle in a laboratory using water with a resistivity of 612 Ω·in and a pressure or 580 psi (see Table 5)

Distance from tip of nozzle to energized conductor	Line voltage					
ft	80 kV	140 kV	180 kV	200 kV	220 kV	250 kV
5	41 000	90 000	130 000	145 000	165 000	—
6	22 000	61 000	100 000	110 000	—	150 000
7	19 000	25 000	45 000	85 000	—	112 000

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Table C.5—Leakage currents (μA) for various line voltages for washing with a hand nozzle in a laboratory using water with a resistivity of 11 417 Ω·in and a pressure of 580 psi (see Table 6)

Distance from tip of nozzle to energized conductor	Line voltage					
ft	80 kV	140 kV	180 kV	200 kV	220 kV	250 kV
5	1600	4100	5400	6200	6.600	—
6	910	1300	2800	3600	—	5200
7	640	1200	1600	2700	—	4900
8	560	—	—	—	—	—
10	450	880	1000	4000	—	5000

Table C.6—Leakage currents (μA) for various line voltages with no water spray (see Table 7)

Distance from tip of nozzle to energized conductor	Line voltage				
ft	140 kV	180 kV	200 kV	220 kV	250 kV
5	620	110	1350	1550	1700
6	380	680	900	1000	1350
7	330	590	780	880	1100

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Table C.7—Flashover voltages with no water was recorded versus distance from tip of nozzle to conductor (see Table 8)

kV	ft
226	3
280	4
336	5
376	6
420	7
460	8
468	9
488	10

Table C.8—Water-pressure performance for various pressures using 150 ft of 1 in hose with a 10 ft of 3/4 in leader (see Table 9)

Desired pressure	Nozzle	Pump pressure	Impact	Distance
psi	in	psi	lb	ft
550	0.25	750	24	30
400		500	20	
550	0.25	900		
400		900		
300	0.3125	600	25	
300	0.25	500	30	

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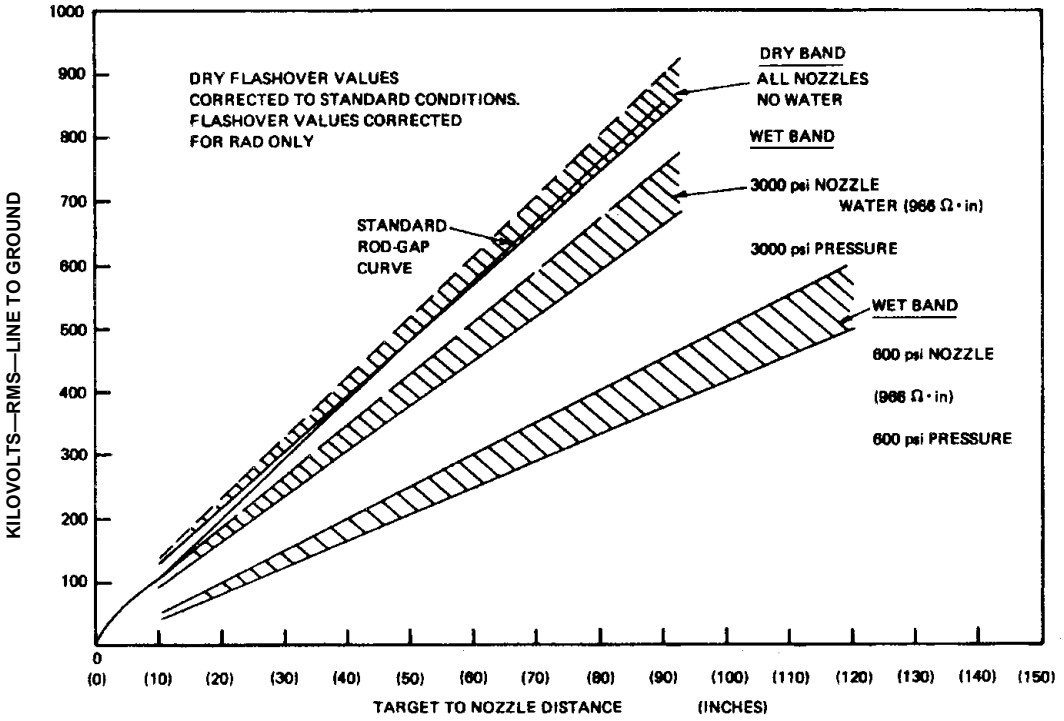


Figure C.1—60 Hz dry and wet air gap flashover (see Figure 10)

Table C.9—Typical quantities of silicone grease required to coat a specific insulator (see Table B.1)

Description	Area	Amount of compound required
	ft^2	lb-oz
13 kV one-piece pin type	0.70	0-3.6
34.5 kV line-post insulator	2.32	0-12.1
Standard 0.254 m (10 in) suspension unit	1.82	0-9.5
Smog type 0.254 m (10 in) suspension unit	2.47	0-12.5
34.5 kV pin-cap apparatus insulator	4.24	1-6.0
69 kV pin-cap unit used in two-unit stacks	4.96	1-10.0
High-voltage pin-cap apparatus unit	7.73	2-9.0
69 kV bushing	9.1	3-0
138 kV bushing	21.4	7-0
230 kV bushing	49.4	16-0

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C.1 Dry flashover values (see 8.8.2)

The following figures show graphs of laboratory work depicting wet and dry flashover values for different gap lengths and for different resistivities. For example:

a) Figure 3 shows for 600 psi at 96 in at 964 Ω·in
b) Figure 4 shows for 650 psi at 120 in at 964 Ω·in
c) Figure 5 shows for 3000 psi at 120 3/8 in at 964 Ω·in
d) Figure 6 shows for 3000 psi at 150 in at 964 Ω·in
e) Figure 7 shows for 3000 psi at 150 in at 23 622 Ω·in
f) Figure 8 shows for 3000 psi at 60 in at 23 622 Ω·in
g) Figure 9 shows for 3000 psi at 60 in at 488 Ω·in
h) Figure 10 shows for composite using different nozzles and water resistance

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