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IEEE Guide for Cleaning Insulators

Sponsor

Engineering in Safety, Maintenance, and Operation of Lines (ESMOL) Subcommittee
of the
Transmission and Distribution Committee
of the
IEEE Power Engineering Society

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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 957-1995, 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 the cleaning of insulators. The information for this guide was drawn from electric utilities, suppliers, universities, related industries, 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 have required newer and more 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(s). It is also thought to be of value to those with an existing program.

This guide was prepared by the Work Methods Working Group of the Engineering in Safety, Maintenance, and Operation of Lines (ESMOL) Subcommittee of the Transmission and Distribution Committee of the IEEE Power Engineering Society. At the time this guide was approved, the task group had the following membership:

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IEEE Guide for Cleaning Insulators

1. Overview

1.1 Scope

This guide for cleaning insulators documents the procedures used for cleaning contaminated electrical insulators (excluding nuclear, toxic, and hazardous chemical contaminants) of all types, using various equipment and techniques.

Because of the great variety of conditions, practices, electrical system designs, and contamination possibilities, this guide describes a number of approaches to insulator cleaning on power systems. The IEEE makes no representation or warranty as to the adequacy, accuracy, economy, or safety of this guide. When determining whether or not, and/or how, to use the information in this guide, all factors shall be considered with regard to the specific situation(s).

1.2 Purpose

This guide presents information on the equipment needed and the methods that can be used when cleaning contaminated insulators. The methods or equipment, or both, presented are not intended to prescribe specific procedures, but to show 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. References

This guide shall be used in conjunction with the following publications:

IEEE Std 4-1995, IEEE Standard Techniques for High-Voltage Testing.[1]

IEEE Std 516-1995, IEEE Guide for Maintenance Methods on Energized Power Lines.[2]

IEC 479-2 (1987), Effects of current on human beings and livestock, part 2: Special aspects. Chapter 4: Effects of alternating current with frequencies above 100 Hz. Chapter 5: Effects of special waveforms of current. Chapter 6: Effects of unidirectional single impulse currents of short duration.[3]

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[1] As this standard goes to press, IEEE Std 4-1995 is approved but not yet published. The draft standard is, however, available from the IEEE. Anticipated publication date is September 1995. Contact the IEEE Standards Department at 1 (908) 562-3800 for status information.

[2] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

[3] IEC publications are available from IEC Sales Department, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse. IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

3. Definitions

3.1 Terms

3.1.1 ceramic insulator: Insulators made from porcelain or 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 kilopascal (kPa): Metric unit for water or air pressure.

3.1.5 line worker: A person qualified to perform various work operations on electric transmission or distribution, including on the ground or from aerial devices.

3.1.6 nonceramic insulator: Insulators made from polymer materials.

3.1.7 nonconducting: Made of a material of high dielectric strength.

3.1.8 nonconductive: *See:* **nonconducting.**

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

3.1.10 polyplastic: A synonym for polyethylene-coated, nylon-reinforced hose, usually considered to be nonconductive. (In terms of this guide, the hose is used to carry water.)

3.1.11 skiving: 1) The process of assembling a fitting to a hose. 2) The process of trimming outside of a hose to fit the inside dimensions of a fitting.

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

3.1.13 water resistivity: Resistance of water is expressed in Ωcm or Ωin.

3.2 Acronyms and symbols

3.2.1 ESDD: Acronym for equivalent salt-deposit density. *See also:* **3.1.3.**

3.2.2 gal/min: Symbol for gallons per minute.

3.2.3 gal/s: Symbol for gallons per second.

3.2.4 id: Acronym for inside diameter.

3.2.5 kPa: Symbol for kilopascals. *See also:* **3.1.4.**

3.2.6 L/s: Symbol for liters per second.

3.2.7 m^3/s: Symbol for cubic meters per second. *See also:* **3.1.2**.

3.2.8 pto: Acronym for power takeoff.

3.2.9 r/min Symbol for revolutions per minute (rpm).

3.2.10 RTV: Acronym for room temperature vulcanizing.

4. Application

This guide is intended to present a reference source of methods and equipment presently used for safe cleaning of insulators, which should be considered as cleaning practices when reviewed by utilities. Safety considerations are presented throughout the guide in the application of safe and efficient methods and equipment. Criteria for the voltage versus washing distance requirements are under consideration and will be added to future revisions of this guide.

When using this guide, it should be noted that the term “insulator(s)” is used in a general sense to describe individual insulators and also the external insulating members of other apparatus (e.g., transformer bushings and surge arresters).

5. Methods

The method used for insulator cleaning is dependent on the insulator material, construction, whether or not the line is energized, and on the type of contaminant to be removed [B11].[4] Additional methods currently under development will be covered in future revisions of this guide.

5.1 Energized

5.1.1 High-pressure water

High-pressure water washing utilizes a narrow stream of water with typical pressures ranging from 2750–6900 kPa (400–1000 psi) at the nozzle. Four types of nozzles are most often used with high-pressure water: hand-held jet, remote-control jet (pea shooter), fixed-spray, and helicopter mounted.

5.1.1.1 Hand-held jet nozzle

The hand-held 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 connect a detachable hose and nozzle to a standpipe permanently installed on the tower.

Substation insulators may also be washed by qualified workers using a hand-held nozzle while on the ground or in an aerial basket.

5.1.1.2 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 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).

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[4] The numbers in brackets preceded by the letter B correspond to those in the bibliography in clause 16.

5.1.1.3 Fixed-spray nozzle

Two basic washing systems are used.

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 1 provides general information on this system.

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.

Table 1—Fixed-nozzle washing equipment and usage

Type of nozzle	Spray
Number of nozzles	Multiple
Water pressure	350–3000 kPa (50–430 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 usage is usually controlled automatically.
Disadvantage	Affected by wind

5.1.1.4 Helicopter mounted nozzle

This washing method involves the use of a self-contained high-pressure wash system borne by a helicopter. The system is controlled by a wash operator or by the pilot. The helicopter hovers in place with the nozzle positioned to direct the water stream.

5.1.2 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 hand-held and remote-control jet nozzle procedures.

While effective washing is maintained, the advantages are reduced equipment demands, less employee fatigue than with the high-pressure method, and increased production. Decreased leakage current through the water stream was evident as the method was tested. The pressures used for this method are in the 2070–2760 kPa (300–400 psi) range.

5.1.3 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 also piped to direct a water stream to flood 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 1380 kPa (200 psi) with a pump output of 2.524 L/s (40 gal/m) per nozzle. The nozzle size, pipe size, and tower height should be considered when selecting pump capacity and pressure.

5.1.4 Low-pressure water fixed-spray nozzle

Low-pressure washing employs a fixed-spray nozzle system operating at low pressure, typically 350–1030 kPa (5–150 psi). These systems are used primarily in areas where frequent washing is required. Because of the low pressure and spray nozzle system, the effectiveness in removing contaminants, other than sea salt, is diminished. Therefore, most fixed-spray nozzle installations are used in or near sea coast areas, mainly to remove sea salt contamination. This method can be used for contaminants that are found inland. See table 2.

Table 2—Low-pressure spray washing equipment design data

Design data	Automatic spray system	
	275 kV	**400 kV**
Minimum permissible water resistivity (Ωcm)	10 000 Ωcm (3937 Ωin)	20 000 Ωcm (7874 Ωin)
Water pressure at nozzle	700 kPa (100 psi)	1000 kPa (150 psi)
Type of nozzle	Spray	Spray
Minimum distance from nozzle to live conductor	3.1 m (122 in)	4.3 m (170 in)
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 (1.24 gal/s) Others: 3.5 L/s (0.92 gal/s)	CB: 7.4 L/s (1.96 gal/s) CT: 6.2 L/s (1.64 gal/s) Others: 5.5 L/s (1.45 gal/s)
Duration of wash (dependent on type of insulator)	25 s	25 s

CB: circuit breaker
CT: current transformer
NOTE—[B8] summarizes work of Fijimura, Orayama, and Isozaki.

5.1.5 Compressed air-dry cleaning

This method of cleaning insulators involves the use of compressed air and a dry cleaning compound. This procedure requires an air compressor capable of supplying a minimum of 0.052 m^3/s (110 ft^3/min) at 860 kPa (125 psi), an air dryer, a pressure blaster, an applicator wand, adequate supply hoses, and cleaning compound.

Commonly used abrasive cleaning compounds consist of ground corn cob 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 dry cleaners 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.

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 contaminant 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.

An air dryer should be used between the air compressor and the air blaster to remove moisture from the compressed air.

5.1.6 Wiping (hot cleaning)

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

The need for hot cleaning 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 the hot cleaning may do this task from a ladder, on the ground, in a bucket truck, or from a steel tower.

The technique requires one hot stick, which 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 ends at the tower.

The hot stick used for this purpose is usually approximately 19 mm (0.75 in) in diameter and 3050 mm (10 ft) long.[5] The end loop is attached to the stick with a bolt and nut.

One company using this method recommends the following:

a) The hammock material be 540 g/m^2 weight (10 oz/yd^2).
b) The cleaning hammocks should be cut 460 mm (18 in) wide by 610 mm (24 in) in length for 46 kV and 760 mm (30 in) in width by 910 mm (36 in) in length for 69 kV post, cap and pin insulators. A 25 mm (1 in) hem should be folded on both short ends. Then, 25 mm (1 in) pleats should be folded. A 3.8 mm diameter (#9) iron wire, 305 mm (12 in) in length, should be threaded through the pleated hem so that the necessary loop and hook may be formed.

See figures 1 and 2.

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

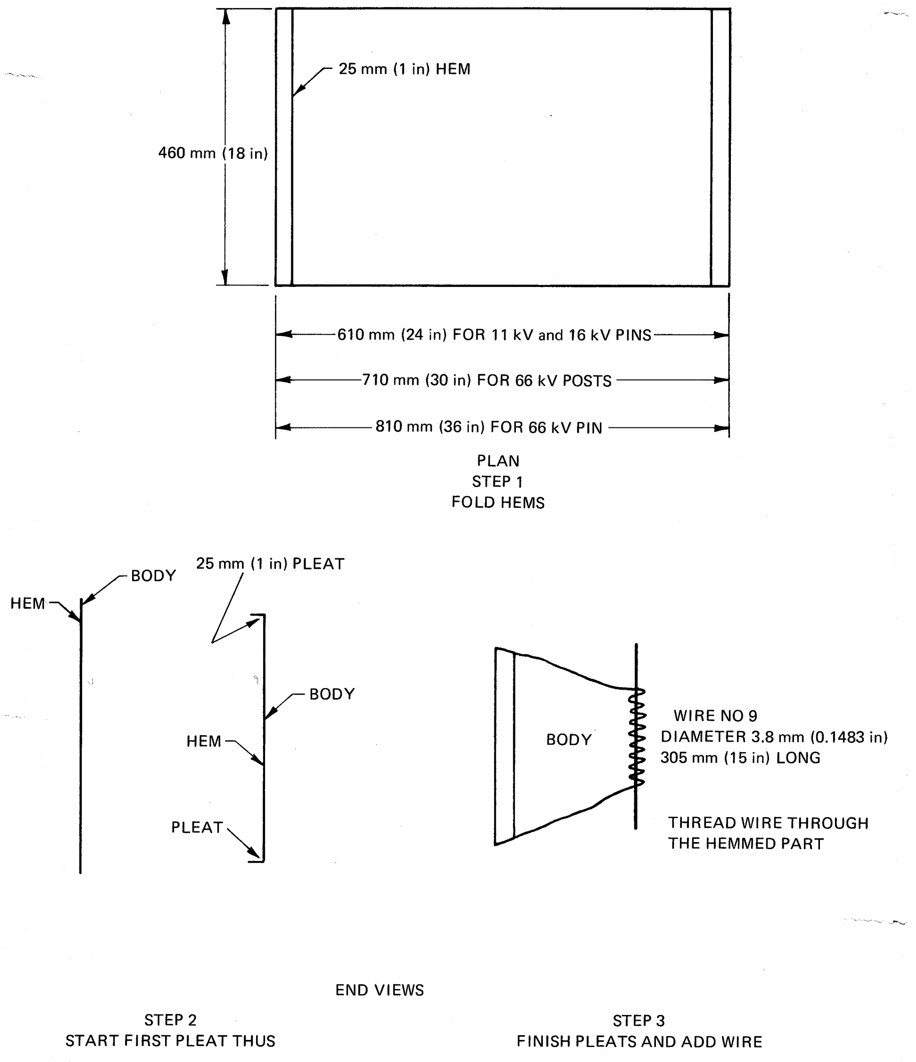


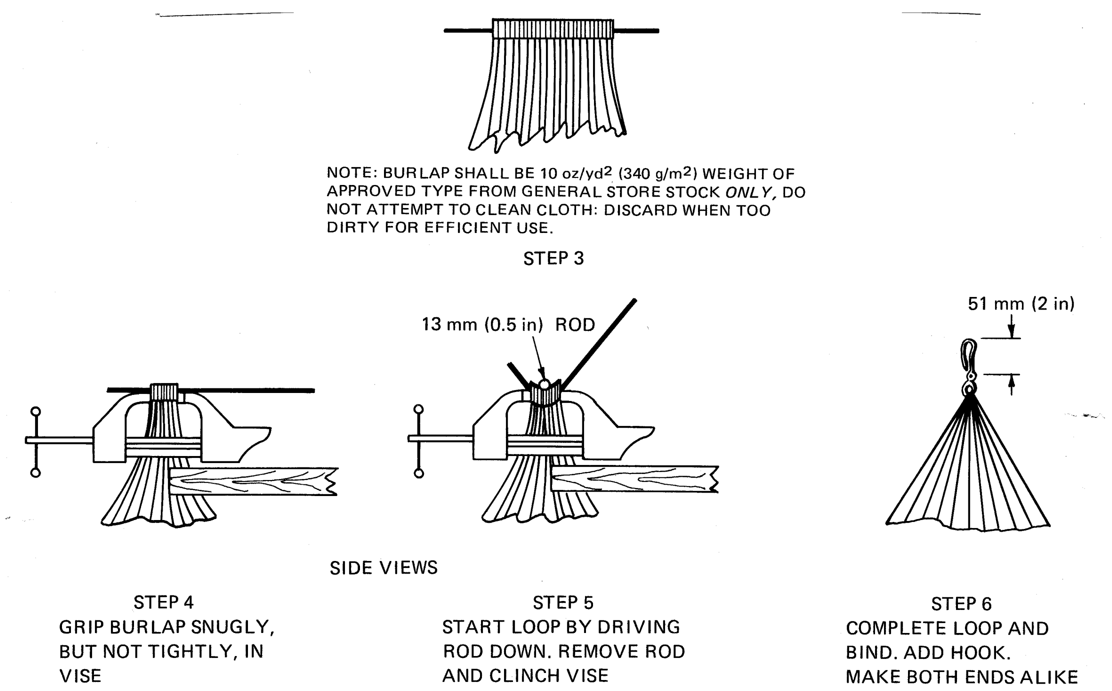
Figure 1—Hot wiping material

5.2 De-energized

All of the methods discussed in 5.1 may also be utilized in addition to the hand cleaning and low-pressure water methods discussed below if the facility is de-energized.

5.2.1 Hand cleaning

Cleaning insulators by hand wiping is thorough and effective, but 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. The



NOTE: BURLAP SHALL BE 10 oz/yd^2 (340 g/m^2) WEIGHT OF APPROVED TYPE FROM GENERAL STORE STOCK *ONLY,* DO NOT ATTEMPT TO CLEAN CLOTH: DISCARD WHEN TOO DIRTY FOR EFFICIENT USE.

STEP 3

STEP 4
GRIP BURLAP SNUGLY, BUT NOT TIGHTLY, IN VISE

STEP 5
START LOOP BY DRIVING ROD DOWN. REMOVE ROD AND CLINCH VISE

STEP 6
COMPLETE LOOP AND BIND. ADD HOOK.
MAKE BOTH ENDS ALIKE

Figure 2—Hot wiping material assembly

line worker carries a personal grounding device, necessary rags, steel wool, etc., safety and body belts, and an adjustable safety life line, if required.

5.2.1.1 Steel wool/nonabrasive nylon pads

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

5.2.1.2 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.

6. Cleaning equipment

6.1 High-pressure water equipment

6.1.1 Pump

6.1.1.1 Type

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

a) *Centrifugal.* This pump type utilizes a rotary impeller or series of impellers in one to four 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 four-stage pump may develop up to 6900 kPa (1000 psi) with 0.005 m^3/s or 5.05 L/s (80 gal/min) discharge and may rotate at a speed up to 9600 r/min. A separate, single-stage centrifugal pump can be run from an engine crankshaft or from opening two pto's to supercharge the main four-stage pump where high water volume is required. An engine with the capacity of 70–90 bhp (52–67 kW) may be required to power this pump. 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.

b) *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. In one such system, an oil-filled crankcase is utilized. 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. Flows of 0.004–0.006 m^3/s or 3.8–5.7 L/s with pressures to 6900 kPa (1000 psi) are nominal for two gun simultaneous washing operation.

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.

6.1.1.2 Power source

a) Truck engines (separate engines, either gasoline or diesel) power the pumps. The engine rpm torque curve shall match the demand of the pumping system. Gasoline engines operate at higher rpm than diesels; four- or six-cylinder engines will develop maximum torque at lower rpm than a V8. These factors shall be considered when matching the engine to the pump. Gear set or belt-driven sheave size variations can be used to arrive at 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 that the added weight can limit the water carrying capacity of the vehicle as well as add complexity to the system.

b) Power takeoff (pto) (from truck chassis) pumps of centrifugal or piston design producing the L/s (gal/min) and kPa (psi) required to support washing at high head and for two-gun, simultaneous, use in substations will require 50–67 kW (68–90 bhp). The truck chassis pto shall have the capability to produce this horsepower. A pto driven from an eight-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 shall be tailored to the pump rpm and power requirement through the pto ratio. Speed variation from 60–115% 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 revolutions per minute. This fact, and the best revolutions per minute (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 shall 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 pto pump. However, due to the high rpm required under demand load, this shall be a tubular balanced driveline with proper U-joint angles at both ends.

Any of the pto drives described here require running the chassis engine to provide water flow and pressure. Usually, the truck engine is too large and too expensive to operate for pump power only. If production cleaning is being done where the vehicle moves structure to structure and washing is done repetitively, chassis pto power can be effectively utilized. The use of a pto versus separate engine-driven pump should be carefully considered.

c) A demand throttle should be considered for use as a control. This may improve the efficiency for both the engine and operators. This device drops the pump engine rpm to idle when the hand-held 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.

6.1.2 Tank

6.1.2.1 Material types

Three basic materials have been used to carry the wash water: fiberglass, coated mild steel, or stainless steel. For any of the above tank types, a rigid, firm base of support, such as a truck or trailer frame or steel-aluminum skid, shall be provided. In larger capacity tanks, where bending or rocking occurs, spring-loaded mountings shall be utilized or damage will occur. 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 shall 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 shall be coated inside and primed and painted outside to prevent rust. Before coating the inside, it is essential that the entire inside of the tank be thoroughly sandblasted and then cleaned. All weld flux-mill coating shall 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 by qualified personnel. The coating shall 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 1.9–4.5 m^3 (500–1200 gal) mild steel tanks, 10 gauge (3.4 mm or 0.1345 in) heads with 10 gauge (3.4 mm or 0.1345 in) wrap is adequate, again with the proper base. If stainless steel is utilized in 1.9–9.5 m^3 (500–2500 gal) capacity, 12 gauge (2.7 mm or 0.1046 in) throughout or 12 gauge (2.7 mm or 0.1046 in) heads with 10 gauge (3.4 mm or 1345 in) wrap is adequate. Again, baffles and base are important considerations in choosing the thickness of metal required.

6.1.2.2 Capacity

Tanks from 0.19–1.9–9.5 m^3 (50–500–2500 gal) have been used for insulator washing. Helicopters to ten-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, all will affect tank and carrier size. For helicopter washing with small on-board tanks, a water supply vehicle is usually provided at the landing zone/staging area.

6.1.2.3 Fill method

Where overhead discharge of water supply is utilized, a top opening type dome is available. This shall 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.

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 back-flow restrictions may be required for portable tanks to meet local codes.

6.1.2.4 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 shall 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.

6.1.3 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 3.75–5 L/s (60–80 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) 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 1.9 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 by-pass should allow flow around.

NOTE—Due to cavitation danger, some pump manufacturers will not warrant a pump if a filter is placed ahead of the inlet.

6.1.4 Hose

6.1.4.1 Type

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

6.1.4.2 Size

Hose from 15.8–25.4 mm (0.625–1.0 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 2.43–3.05 m (8–10 ft) jumper will cause no measurable pressure drop, and the operator will have more flexibility.

6.1.4.3 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 either 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.

6.1.4.4 Coupling

Safety is most important. Compression type fittings, as specified by the fitting and hose manufacturer, should be used. A qualified crafts person 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 shall be at the premeasured depth. Nonconductive nylon or plastic hoses should be coupled per the hose and fitting manufacturer's specifications.

6.1.5 Nozzle

6.1.5.1 Hand held

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 break-up. 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 3.2–7.94 mm (0.125–0.3125 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 hand-held 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.

6.1.5.2 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.

6.1.6 Carrier

6.1.6.1 Trucks

Chassis, from small four-wheel drive vehicles to ten-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 19.8–41.1 m (65–135 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 nonconductive hose that is equipped with a hand-held gun is used. Existing user manlift equipment can be used seasonally for washing both transmission, distribution, and substation insulators. Skid or trailer wash equipment is also utilized.

6.1.6.2 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 10.6–19.8 m (35–65 ft) aerial lift for distribution washing or an existing 27.4–38.1 m (90–125 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 himself or herself. Two people can wash from one trailer on HV 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 9.1–12.2 m (30–40 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.

6.1.6.3 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 hand-held 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.

6.1.7 Water

6.1.7.1 Quality

Water of high resistivity or low conductivity should be utilized in cleaning energized insulators. Rain water, snow melt, 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 750–1000 Ωcm (295–394 Ωin) can be purified by deionizing systems or filtering. Minimum water characteristic should be determined based on planned operating practices and expected voltages. A resistivity greater than 1500 Ωcm (591 Ωin) is desirable.

6.1.7.2 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. Warm (not hot) water 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.

6.1.7.3 Monitoring

Portable and continuous testing or monitoring systems are available. Hand-held, solid-state testers are most common. Whether the characteristics of the water are known or unknown, each tank full or addition should be tested. Minimum standards shall be maintained for safety. The water resistivity decreases as water temperature increases. Nontemperature compensated testers should be used. A common practice is to dump water tanks, partially filled at the end of the wash day, and refill with fresh tested water the next day. Continuous monitoring systems usually require a probe within the tank. The 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.

6.2 Low-pressure water

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.

6.3 Compressed air—dry type cleaner

6.3.1 Pressure

The pressure is generally 862 kPa (125 psi) but may be as high as 1034 kPa (150 psi).

6.3.2 Volume

Cleaning by this method requires an above-average volume of air [up to 0.95 L/s (2.0 ft^3/min) is recommended].

6.3.3 Dryers

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

6.3.4 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.

6.3.5 Hose

Standard air hoses of sufficient size to handle the air volume required are satisfactory. Conductive hose may be used to connect the air compressor to the pressure blaster. Suitable nonconductive 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.

6.3.6 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: straight nozzle, 30–45° nozzle, and 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.

6.3.7 Wand

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

6.3.8 Power source

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

6.3.9 Cleaning materials

Crushed corn cobs, powdered limestone, pecan shells, walnut shells, and CO_2 pellets are commonly used cleaning materials. Combinations of these materials can be used effectively. It is important that the cleaning compound clean, and not damage, the item to be cleaned. Use of limestone shall 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 again offer flexibility in selecting the proper material for a given cleaning job. CO_2 pellets, which are nonabrasive, turn to gas that blows the contaminate off the insulator upon impact. The high dielectric strength of CO_2 (3.1 kV/mm) and its fire extinguishing properties allow energized cleaning. CO_2 pellets are presently being used by some utilities to clean energized live front padmounted switchgear.

6.4 Helicopters

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 used 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. The equipment used with the helicopter may vary as the function of the helicopter is to provide access to the item to be cleaned.

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.

Several techniques utilize different equipment to direct the cleaning medium.

a) A permanent nozzle on an extended boom is mounted in the same alignment as the helicopter runner. The nozzle may be outboard of the rotor blades. The spray is directed by the pilot of the helicopter. This equipment generally uses a higher volume and reduced water pressure similar to the flood wash.
b) A nozzle that may be rotated is mounted on the helicopter runner and controlled by the aircraft pilot.
c) A manual nozzle is controlled or operated by a second crew member. The equipment for this manual nozzle is the same as for the rotating nozzle technique. The boom is of light metal and normally extends outboard of the aircraft blades.

6.5 Medium-pressure water

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

6.6 Fixed spray

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

6.6.1 Piping and motor

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

6.6.2 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.

6.6.3 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.

6.6.4 Control system

To operate the washing equipment effectively and wash insulators safely, a control system should be provided which 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.

7. Types of contaminant

Exposed insulators are subject to surface dirt deposition 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 create the condition that produces a conducting film on the dirty insulator surface without washing the impurities from the surface.

Eight types of contaminants have been identified as sources of surface deposits on insulators that affect the insulator performance.

- Salt
- Cement/lime
- Dust
- Defecation
- Chemical
- Smog (vehicular emissions)
- Cooling tower effluent
- Smoke

These contaminants are distinguished primarily by the source of the impurities. Local agricultural, industrial, and geographical conditions determine which contaminants are present in the atmosphere. Ordinarily, wind and rain provide sufficient washing action to remove most of the common deposits.

More than one of 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.

7.1 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 wind-blown 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 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.

7.2 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.

7.3 Dust

The types 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.

7.3.1 Earth

Earth dust can arise from plowed fields, earth moving on construction projects, etc.

7.3.2 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.

7.3.3 Metallic

Metallic dust originates from various mining and mineral handling processes.

7.3.4 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.

7.3.5 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.

7.3.6 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.

7.4 Defecation

Insulators located in the vicinity of roosts of birds are subject to contamination by defecation. These deposits are usually washable and are often cleansed by heavy rain, but may present serious problems of system reliability.

7.5 Chemical

Atmospheric pollutants from a wide variety of industrial chemical processes and 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.

7.6 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 effect areas adjacent to rights-of-ways. Normally, industrial chemicals are present in areas with heavy smog problems. Resulting insulator contaminants have varying characteristics, depending on the combination of pollutants present.

7.7 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.

7.8 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.

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 nonconducting elements such as hoses. Safe values of let-go current for the average person are given in IEC 479-2 (however, 8–9 mA is believed to be a safe value for the average male).[6]

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, one must 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.

If possible, the wash operator's hands and feet should be at the same electrical potential. When washing from a tower, this is accomplished by the structure.

In substations, nozzle operators using hand-held 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. Under these circumstances, it should not be difficult 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 nozzle-conductor distance, water resistivity, water pressure, and nozzle orifice diameter (see table 3).

8.1.1 Working distance

Nozzle to conductor distance 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.

8.1.2 Water resistivity

Water resistivity 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.

8.1.2.1 General

The unit of resistivity is the ohm-centimeter or ohm-inch, and is equal to the resistance between opposite faces of a cube of water one centimeter or 1 in on a side.

$$R = \rho\frac{L}{A}$$

where

R is resistance of water, W
L is separation of electrodes
A is cross-sectional area of water
ρ is resistivity, a constant that is a characteristic of the water under test

NOTE—To convert Ωin to Ωcm, multiply by 2.540. To convert Ωcm to Ωin, multiply by 0.3937.

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[6] Information on references can be found in clause 2.

Table 3—Parameters for energized washing

Line voltage	Minimum nozzle to conductor distance		Minimum water resistivity		Minimum nozzle pressure		Maximum orifice diameter	
(kV)	m	ft	Ωcm	Ωin	kPa	psi	mm	in
13	1.82	6	1300	512	2758	400	4.76	0.1875
13	2.74	9	1300	512	2758	400	6.35	0.25
16	2.13	7	1300	512	2758	400	4.76	0.1875
34.5	2.44	8	1300	512	2758	400	6.35	0.25
34.5	2.44	8	1300	512	2758	400	4.76	0.1875
69	2.74	9	1300	512	2758	400	4.76	0.1875
69	3.66	12	1300	512	2758	400	6.35	0.25
115	3.05	10	1300	512	2758	400	4.76	0.1875
115	3.96	13	1300	512	2758	400	6.35	0.25
230	3.66	12	1300	512	2758	400	4.76	0.1875
230	4.57	15	1300	512	2758	400	6.35	0.25
500	4.27	14[1]	50 000	19 685	5516	800	6.35	0.25
500	6.10	20	3000	1181	3792	550	7.94	0.3125
400 dc	6.10	20[1]	50 000	19 685	5516	800	6.35	0.25

[1] The distance is limited by tower dimensions and configuration. Because of the limited nozzle to conductor distance, demineralized water with resistivity of 50 000 Ωcm (19 685 Ωin) or greater can be used.

Water having a resistivity greater than 1500 Ωcm (491 Ωin) is widely used and can usually be obtained from city hydrants. Demineralized water of 50 000 Ωcm (19 685 Ωin) or greater resistivity is also used and is usually obtained from steam power plants or from mobile demineralizing equipment. The resistivity of water varies inversely with temperature; that is, as the temperature of water increases, its resistivity decreases.

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

8.1.2.2 Measurement

An instrument to measure the resistivity of the water is required because 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).

8.1.2.3 Resistivity meters

Commercial resistivity meters are available in portable models, which are utilized for the testing of each tank of water after filling (before hot washing) unless the washer is equipped with a constant monitoring system.

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. A continuous resistivity measurement of the water is made while the unit is operating, providing operator warning and a complete shutdown if a minimum preset resistivity limit is reached.

NOTE—The tester should be nontemperature compensated.

a) *Portable hand-held.* A portable hand-held resistivity meter can 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, and 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 9 V battery, and has a battery test and calibration circuit. The meter has a display in either ohms per cubic centimeter or ohms per cubic inch with minimum limits highlighted in red and accurate to within ± 2% of full scale.

   Other uses for this tester include monitoring of boiler and cooling tower water, purification equipment, deionizers, stills, and reverse osmosis equipment.

b) *Continuous monitor.* Hard mounted, solid-state circuitry, with a waterproof high impact case and meter scales as described above is utilized. A remote probe with lead from tank bottom outlet provides sensor for 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. The device is powered from a 12 V direct-current automotive source.

NOTE—If deionized or boiler water of high resistivity is utilized for washing, a dual range meter may be required.

8.1.3 Water pressure

Water pressure is related to the working distance and may be adjusted accordingly—that is, a lower pressure may be used with an increased distance (safe working distances shall always be maintained). The cleaning effect is directly related to the water force or impact of the water on the insulators.

8.1.4 Nozzle orifice

The size and design of the nozzle orifice affect the makeup (size and performance) of the water stream. The nozzle orifice more nearly follows the water pressure concerns, but interrelates to each of the other three parameters.

8.1.5 Typical specifications

For nozzle pressures of a selected utility, see figure 3.

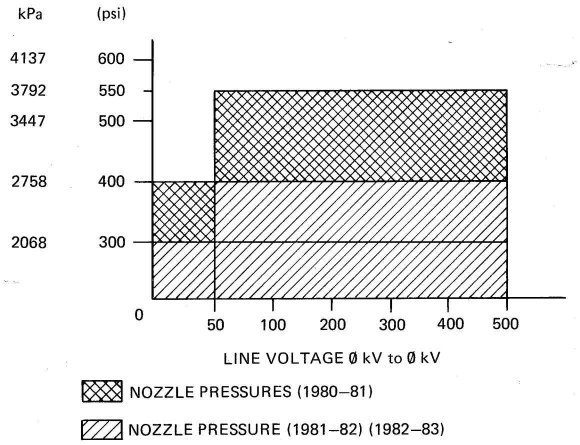

Figure 3—Nozzle pressures of a selected utility

For washing distances for a 5.95 mm nozzle, see table 4.

Table 4—Washing distance for a 5.95 mm (0.234375 in) nozzle

Line voltage	m	ft
4–kV	2.13	7
13–kV	3.05	10
24–kV	3.66	12
71–115 kV	4.57	15
230 kV	4.57	15
500 kV	6.10	20

8.2 Tests in grounded environments

a) Washing with a hand nozzle in a laboratory using water with a resistivity of 1600 Ωcm (612 Ωin) and a pressure of 4688 kPa (580 psi) resulted in leakage currents recorded in microamperes (see table 5).

Table 5—Distance from tip of nozzle to energized conductor (leakage current in microamperes)

m	ft	80 kV	140 kV	180 kV	200 kV	220 kV	250 kV
1.52	5	41 000	90 000	130 000	145 000	165 000	—
1.83	6	22 000	61 000	100 000	110 000	—	150 000
2.13	7	19 000	25 000	45 000	85 000	—	112 000

b) Washing with a hand nozzle in a laboratory using water with a resistivity of 29 000 Ωcm (11 417 Ωin) and a pressure of 4688 kPa (580 psi) resulted in leakage currents recorded in microamperes (see table 6).

Table 6—Distance from tip to nozzle to energized conductor (leakage current in microamperes)

m	ft	80 kV	140 kV	180 kV	200 kV	220 kV	250 kV
1.52	5	1600	4100	5400	6200	6600	—
1.83	6	910	1300	2800	3600	—	5200
2.13	7	640	1200	1600	2700	—	4900
2.44	8	560	—	—	—	—	—
3.05	10	450	880	1000	4000	—	5000

c) Applied voltage with no water spray resulted in leakage currents recorded in microamperes (see table 7).

Table 7—Distance from tip of nozzle to conductor (leakage current in microamperes)

m	ft	80 kV	140 kV	180 kV	200 kV	220 kV	250 kV
1.52	5	—	620	110	1350	1550	1700
1.83	6	—	380	680	900	1000	1350
2.13	7	—	330	590	780	880	1100

d) Flashover with no water voltages recorded versus distance (see table 8).

Table 8—Distance from tip of nozzle to conductor

m	ft	kV
0.91	3	226
1.22	4	280
1.52	5	336
1.83	6	376
2.13	7	420
2.44	8	460
2.74	9	468
3.05	10	488

e) For 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 (0.75 in) leader (see table 9).

Table 9—Water-pressure performance

Desired pressure	Nozzle	Pump pressure	Impact	Distance
3791 kPa (550 psi)	6.35 mm (0.25 in)	5171 kPa (750 psi)	10.8 kg (24 lb)	9.1 m (30 ft)
2758 kPa (440 psi)		3447 kPa (500 psi)	9.07 kg (20 lb)	
3792 kPa (550 psi)	2–6.35 mm (1.25 in)	6205 kPa (900 psi)		
2758 kPa (400 psi)		4826 kPa (900 psi)		
2068 kPa (300 psi)	8.0 mm (0.3125 in)	4137 kPa (600 psi)	11.34 kg (25 lb)	
2068 kPa (300 psi)	6.35 mm (0.25 in)	3447 kPa (500 psi)	13.6 kg (30 lb)	

f) The following graphs of laboratory work depict wet and dry flashover values for different gap lengths.

Figure 4. 4137 kPa (600 psi) at 2.43 m (96 in)
Figure 5. 4481 kPa (650 psi) at 3.04 m (120 in)
Figure 6. 20 685 kPa (3000 psi) at 3.04 m (120.375 in)
Figure 7. 20 685 kPa (3000 psi) at 3.81 m (150 in)
Figure 8. 20 685 kPa (3000 psi) at 3.81 m (150 in)
Figure 9. 20 685 kPa (3000 psi) at 1.52 m (60 in)
Figure 10. 20 685 kPa (3000 psi) at 1.52 m (60 in)
Figure 11. Composite

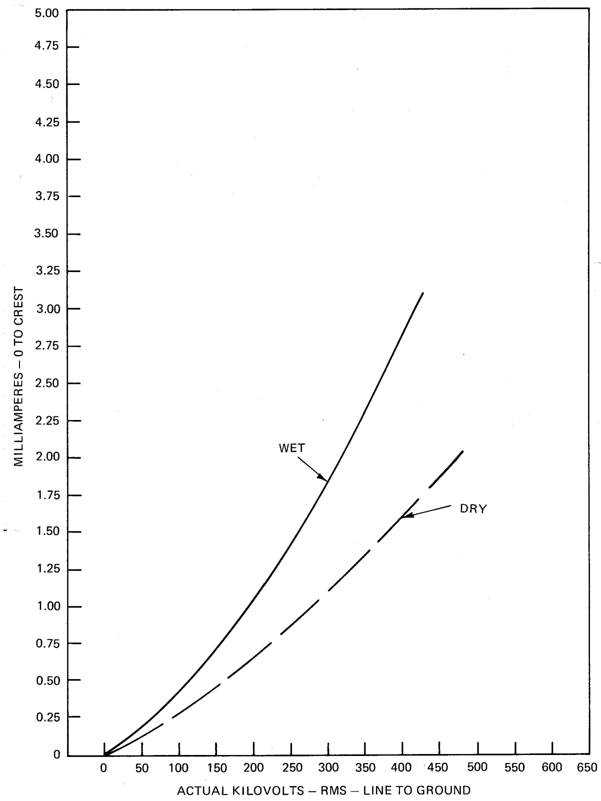

Figure 4—Wet and dry flashover for a 2.43 m (96 in) gap value with 4137 kPA (600 psi) and 2450 Ωcm (966 Ωin) water

8.3 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.

8.3.1 Quantity of wash water

When the water physical variable (WPV)[7] is 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.

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[7] Water physical variables (WPV) are volume, stream size, and force.

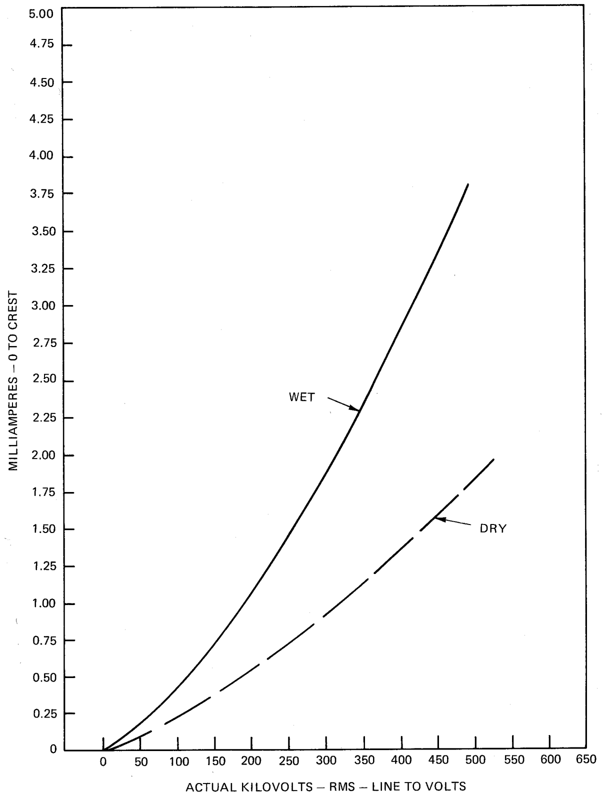


Figure 5—Wet and dry flashover values for a 3.04 m (120 in) gap with 4481 kPA (650 psi) and 2450 Ωcm (966 Ωin) water

8.3.2 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.

8.3.3 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 Ωcm (591 Ωin).

8.3.4 Washing interval

It is necessary to establish a proper washing interval so as not to cause a flashover accident during hot line washing. The insulator should be washed before the predetermined limit of contamination level is reached. The indication of when washing should begin can be found by monitoring the contaminant accumulation on pilot insulators by measuring the equivalent salt density deposit (ESDD).

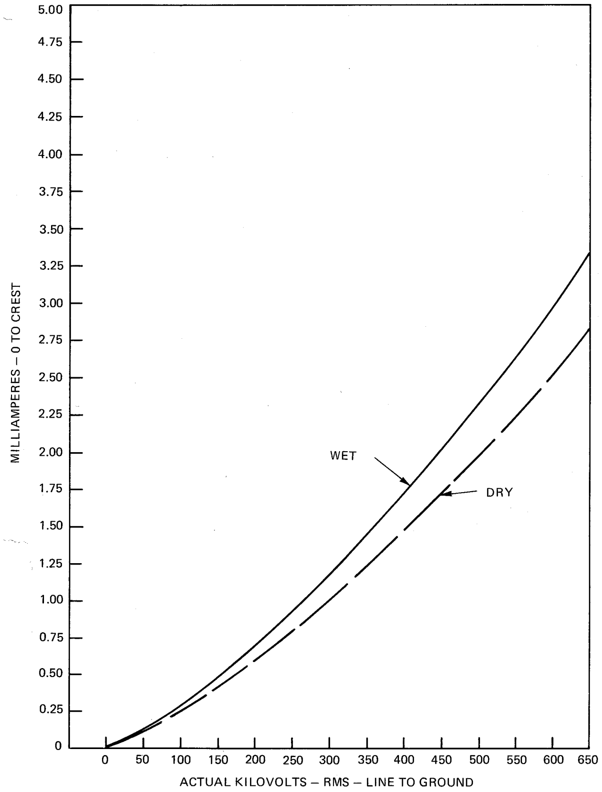


Figure 6—Wet and dry flashover values for a 3.04 m (120 in) gap with 20 685 kPa (3000 psi) and 2450 Ωcm (966 Ωin) water

8.4 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 are 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 shall still be taken to maintain safe working distances to other parts of the helicopter, including conductive and nonconductive parts of the heliwash operation.

8.4.1 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:

≤ 230 kV: 1300 Ωcm (512 Ωin)
> 230 kV: 2600 Ωcm (1024 Ωin)

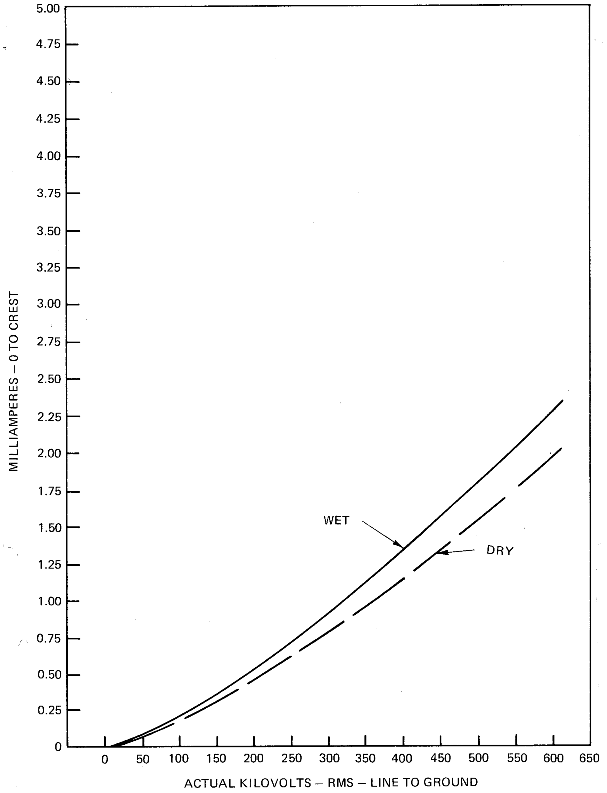


Figure 7—Wet and dry flashover values for a 3.81 m (150 in) gap with 20 685 kPa (3000 psi) and 2450 Ωcm (966 Ωin) water

8.4.2 Quantity of wash water

The amount of wash water carried on-board 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 of 0.125 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.

8.4.3 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.

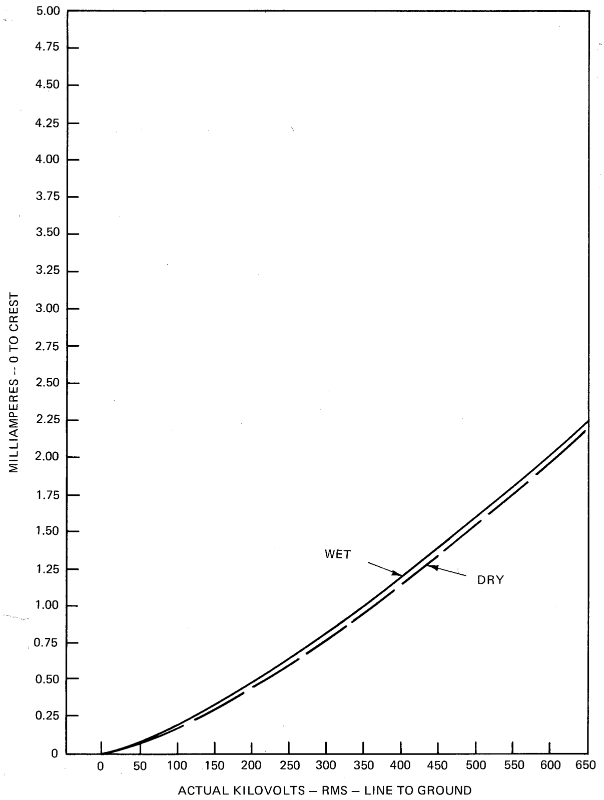


Figure 8—Wet and dry flashover values for a 3.81 m (150 in) gap with 20 685 kPa (3000 psi) and 60 000 Ωcm (23 622 Ωin) water

9. Insulators to be cleaned

9.1 Introduction

Line insulators and arresters are made of ceramic and nonceramic materials. Distribution insulators entail different concerns than transmission line insulators due to the lesser voltage involved and the respective clearance distances of the pole framing. One of the main concerns of washing is the potential problem of over spray. This is tempered somewhat by the reduced nozzle to insulator distance. A much lower water pressure may be feasible for low voltage, even to the point of almost a flooding. The water then would be directed to the whole pole or area of a pole. When over-spray presents a problem, washing from different positions may help, but will take more time and reduce production (see [B10]).

9.2 Transmission line insulators

9.2.1 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.

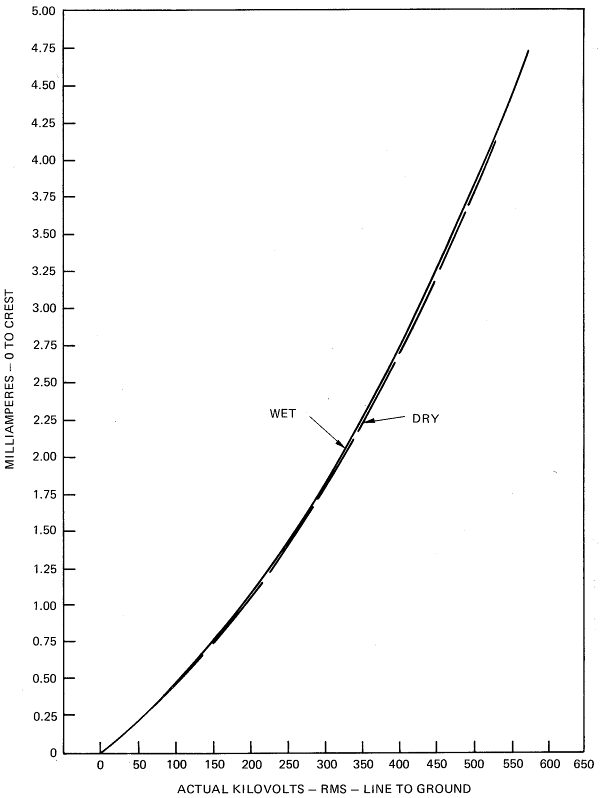


Figure 9—Wet and dry flashover values for a 1.52 m (60 in) gap with 20 685 kPa (3000 psi) and 60 000 Ωcm (23 622 Ωin) water

9.2.2 Nonceramic

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

9.2.2.1 General guidelines for water pressure washing

a) Individual weathersheds bonded to a polymer sheath or to each other with an unbonded interface.
   Silicone: Low to high-pressure water washing
   EPDM/EPR: High-pressure water washing
   Alloy EPDMs: High-pressure water washing
b) Direct molded units.
   Silicone: Low to high-pressure water washing
   EPDM/EPR: High-pressure water washing
   Alloy EPDMs: High-pressure water washing
   Epoxy: High-pressure water washing
   Polymer ceramic: Medium to high-pressure water washing
c) Individual weathersheds with an unbonded interface.
   All compounds: 200 psi at the pump with a 6 mm (0.25 in) nozzle and no closer than 4.6 m (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 degrees (perpendicular) to the insulator axis.

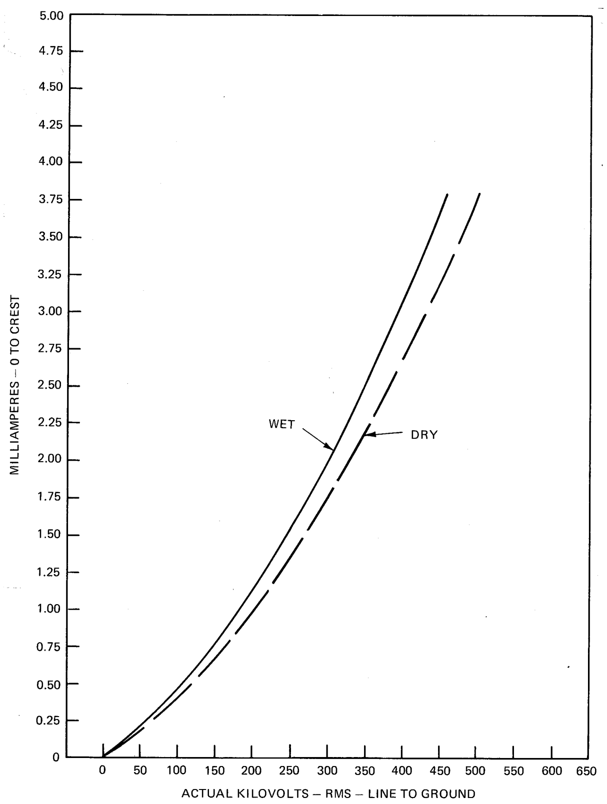


Figure 10—Wet and dry flashover values for a 1.52 m (60 in) gap with 20 685 kPa (3000 psi) and 1240 Ωcm (488 Ωin) water

9.2.2.2 Procedure

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.

9.2.2.3 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.

9.2.2.4 Other procedures

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

a) *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 are removed by the final clean water rinse and only after manufacturer approval.

b) *Energized cleaning.* Compressed air/dry abrasive cleaning involves the use of compressed air and dry abrasive cleaning media. The abrasive cleaning compounds often consist of ground corn cob mixed with ground walnut or pecan shells. Powdered silica or lime may be added to the compound or used alone to increase abrasiveness.

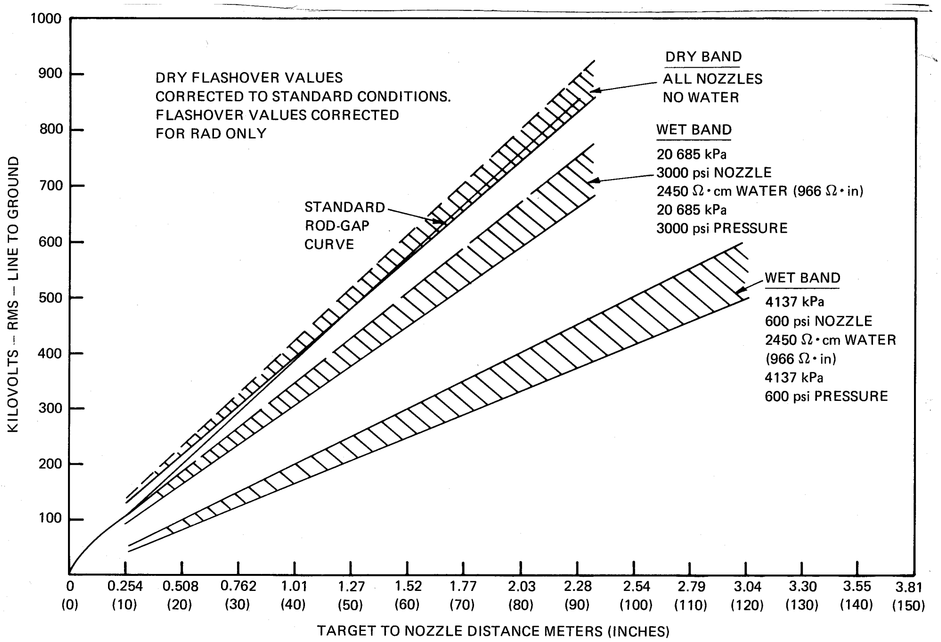


Figure 11—60 Hz dry and wet air gap flashover bands using different nozzles and water resistance

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.

9.3 Station equipment

9.3.1 Insulators

9.3.1.1 Ceramic

Same as for transmission line insulators.

9.3.1.2 Nonceramic

Same as for transmission line insulators.

9.3.2 Bushings

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

9.3.3 Surge arresters

Surge arresters can be made of ceramic or nonceramic materials.

9.3.3.1 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.

9.3.3.2 Nonceramic

Energized washing of nonceramic surge arrestors 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.

9.4 Distribution line equipment

9.4.1 Insulators

9.4.1.1 Ceramic and glass

Same as for transmission line insulators.

9.4.1.2 Nonceramic

Same as for transmission line insulators.

9.4.2 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.

9.5 Large diameter equipment

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

10. Techniques

10.1 Energized

10.1.1 High-pressure water

10.1.1.1 Hand-held nozzle

The resistivity of water from the wash truck reservoir should be checked by a portable resistance meter each time water is added. The wash truck should be 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 and 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 shall also avoid reaching out and touching adjacent trees, poles, towers, or other objects.

Some utilities use nonconductive 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 not allow anyone to get on or off the truck and to keep all persons on the ground away from the truck during the actual washing operation.

Next, the line worker should climb the tower carrying a hand line. The truck driver should send up the hose, gun, and nozzle. The line worker should bond the nozzle to the tower steel or pole bond wire.

The line worker should then direct the truck driver to increase the water pressure. If the unit is equipped with a demand throttle, the pressure (revolution per minute) 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 should then direct the wash stream at the insulator. The nozzle to conductor distance shall not be less than the established minimum wash distance (see tables 3 and 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 should be moved up a few units. After these units are washed, the stream should be directed on the clean units below to rerinse them. This process should be repeated, moving up a few insulators at a time until the entire string is clean. Failure to rerinse lower insulators before moving further up the string can lead to flashover. The stream shall be moved away from any energized part of 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.

Dead-end insulators shall 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.

10.1.1.2 Remote-control nozzle

The technique for washing with a remote-control nozzle is very similar to that for the hand-held 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.

10.1.1.3 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.

10.1.2 Compressed air cleaning

The technique for this method is very similar to that for high-pressure washing. The insulators next to the conductor are cleaned first (one or two insulators on each string of a vee string). Then, the remainder of the insulators are cleaned, moving away from the conductor. 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.

10.1.3 Hot wiping

Normal care shall be taken to observe the safe working distances for the hot sticks. The critical precaution is to keep the wiping cloths clear of any grounded objects or supports. When two sticks are used, good communication and coordination is required between operators.

10.1.4 Helicopter

The actual washing techniques employed are similar to those for washing with the hand-held 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.

10.1.4.1 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.

10.1.4.2 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.

10.1.4.3 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 have 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.

10.2 De-energized

All of the techniques discussed in 10.1 can be utilized when the facility is de-energized. In addition, hand cleaning and low-pressure water technique described elsewhere may be used. When the system is de-energized, the requirements of water resistivity and clearances are relaxed, thereby allowing different washing conditions.

10.2.1 Low-pressure water fixed-spray nozzle

Fixed-spray-nozzle washing has proven to be effective in preventing sea-salt contamination flashover problems. This method of washing is used widely in Japan.

The wash parameters and equipment shall 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.

10.2.2 Hand cleaning

The techniques required for hand wiping are dependent upon the nature of the surface deposits to be removed. Some insulators can be cleaned by 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.

10.3 Results

Results of efficient insulator cleaning can be judged by

a) *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.

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

c) *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.

d) *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.

10.4 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

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 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)

11. Safety

11.1 Individual company standards/rules

Each individual company should establish rules and operating practices.

11.1.1 Working positions

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

11.1.1.1 Helicopter

a) 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.
b) It shall be verified 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.
c) Care shall 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.
d) 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.
e) All heliwash operations should be conducted using the crew loop concept. However, ultimate responsibility for flight safety lies with the pilot in command.
f) A flight following system should be in place for all heliwash operations.

11.2 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 shall 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 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 practical, cleaning should be done with the direction of the wind (i.e., spray in same direction as the wind). Overspray to adjacent insulators/parts should be monitored and avoided.
g) To reduce the risk of a circuit interruption, insulators, crossarms, and hardware should be inspected prior to the cleaning program.
h) With suspension-type insulators, the solid stream should be directed to the lowest insulator first, moved progressively upward on the string, and periodically returned to the lower units to wash off drip from higher units. On horizontal units, the stream should be directed first at the conductor and worked towards the structure (taking into consideration an alternate method if the wind direction is with the direction of the stream).
i) With stacked insulators, cleaning should be done from the lower insulator upwards, with periodic returns to the lower units to clean off residue from the higher units.
j) With pin or post type insulators, the solid stream should be directed to the underside of the insulator and up towards the conductor. If using water, caution shall be exercised when wetting of cross arms.

The wetting of cross arms 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, lower level insulators should be cleaned first.
m) If a sizable arc begins when cleaning insulation that supports energized conductors, the stream should be kept into any arc that may develop. 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) The hose operator should not stand on the same wood pole supporting the insulation to be cleaned unless it is a single pole structure.
q) 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.
r) When cleaning any facilities, individual company grounding rules should apply.

11.2.1 Helicopter

Several of the suggested work practices in 11.2, including b), c), e), p) and r), are not appropriate for heliwash operations. 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, water tank, shall 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.
c) During the wash, the operator and the pilot shall maintain communications (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 516-1995, subclause 6.3.
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.

11.2.1.1 Landing zone

An integral part of the safety of overall heliwash operations includes the following suggested work practices at the landing zone (LZ).

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

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

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

d) Since the tail rotor is unprotected, when setting up landing zones, every effort shall be made 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.

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

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

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

h) Equipment shall be kept below shoulder height.

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

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

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

l) Extreme care should be taken when working around a helicopter with turning rotors. Extreme caution should be exercised when working for the first time on an LZ. 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.).

11.2.1.2 Training

All personnel shall 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 landing zone general safety.

a) *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. The pilot 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.

b) *Aerial wash equipment operator.* The aerial wash equipment operator shall 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. The operator shall be fully trained on the minimum distance requirements for live-line work.

c) *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 shall 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.

11.3 Equipment

The following should apply:

a) The equipment used to clean insulators should be designed for this purpose.
b) Grounding—For de-energized work, individual company practices should apply.
c) Helicopter—All helicopter and wash equipment, including platforms, shall conform to appropriate civil aviation authority (i.e., Federal Aviation Administration) and have proper certification.
d) 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.

11.4 Public

In the process of cleaning insulators, all factors shall be considered [not only the employee(s) involved, but also the public].

12. Public relations

When insulator cleaning has some impact on members of the public, trained public relations personnel should be involved.

13. Limitations

Factors limiting safe, economic, and effective insulator cleaning are weather, system loading, and the type of contaminants present. These factors may either eliminate the cleaning of particular insulators, influence when the particular insulators can be cleaned, or determine which method can be used to cleanse 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 compressed air propelled dry cleaning materials, 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-moisture content usually causes an erratic flow of the material.

The type of contaminant often limits which cleaning method can be effectively and economically applied. Soluble dirts can be easily washed so either flood or high-pressure washing may be used. Adhesive insoluble deposits may limit the effectiveness of washing techniques. Extremely stubborn compounds may constrain cleaning methods to hand scrubbing with chemical agents. This is the most expensive procedure. Only by experience with a particular contaminant can the most effective and economical cleaning process be determined.

14. Greased insulator cleaning

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. The contaminant grease should be wiped off 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 corn cobs, or walnut or pecan shells, against the insulator. The air blast should not be directed against one spot too long as the ground material can 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 corn-cob 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. An ATH-filled silicone grease has the water repellency of a 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 hot spot arcing can lead to 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.

15. Individual company practices

Representative practices followed by specific utilities are described below. Note that these are presented only as examples.

15.1 East coast utility

15.1.1 Insulator washing on energized facilities 0–230 kV

15.1.1.1 Introduction

Laboratory and field tests have proven that pole top fires and insulator flashovers can be reduced by washing contamination from the insulators. The washing of insulators with the line energized by means of a high-pressure hose, spray gun, and high-pressure pump has been tested; and the method is now used on voltages from 0–230 kV phase-to-phase.

The following safety and operating procedures and equipment requirements serve as a guide concerning the methods to be used.

15.1.1.2 Equipment insulator washing

Power sprayers are trailer and truck mounted with 10.97 m (36 ft) aerial lift respectively. These pumps are powered by air-cooled engines, generator, and starter. The pumps are equipped with high-pressure packing and modified automatic controller. The capacity ratings of the pumps area as shown in table 10.

Table 10—Capacity ratings of typical pump

Engine	Pressure	L/s (gal/min)	Tank cap
VG4D	6895 kPa (1000 psi)	1.577 (25)	1893 L (500 gal)
V465D	6895 kPa (1000 psi)	3.155 (50)	3028 L (800 gal)

Guns have been modified to accommodate hydro-type nozzle and tips. Tip openings range from 2.4–6.35 mm (0.09375–0.25 in). A typical gun and tip combination is Spraymaster No. LCP354C with a No. TR-204 tip.

15.1.1.3 Hose

30.48–0.01275 m (100 ft–0.5 in) and 30.48–0.01905 m (100 ft–0.75 in) nylon reinforced high-pressure nonconductive hose complete with fittings. Hose is stored on electric or manual rewind reel installed with shut-off valve.

15.1.1.4 Water pressure

Water pressure at the pump should be adjusted to produce, as quickly as possible, a complete stream at contact with the energized part without bringing the nozzle closer than the safe working clearances. The water stream shall always be at full pressure before contact is made with energized conductor.

NOTE—A pressure of 6895 kPa (1000 psi) at the pump should deliver approximately 6205 kPa (900 psi) at the nozzle, which is sufficient to produce a complete stream extended approximately 6.10 m (20 ft) on a calm day. It has been found that good results can be obtained by washing at a distance of 2.44 m (8 ft) to 3.05 m (10 ft).

15.1.1.5 Grounding

When washing insulators from steel towers, or when washing insulators from pole structures, the pump (truck and trailer bonded together) assembly should be grounded in accordance with established procedures, using as an electrode the steel tower, structure ground lead that is grounded, or the common neutral. Anchor rods also can be acceptable.

a) The spray gun should be grounded by means of a grounding cable when washing from wood structures.
b) The spray gun should be grounded to the steel structure by means of a grounding cable when washing from steel towers.
c) If washing from an insulated aerial lift on circuits energized at 40 kV or below, the spray gun, truck, or pump do not have to be grounded. The water hose shall be isolated from the boom by stand-off insulators.
d) If washing from an insulated aerial lift on circuits energized at 46 kV or above, the towing vehicle (truck) and pump should be bonded together and grounded in accordance with established procedures. The water hose should be isolated from the boom as described in item c).
e) If the operator is working from the ground (earth), he should position himself so as not to make body contact with the hose or spray nozzle. The spray nozzle and pump should be grounded in a manner so that the nozzle and pump will be of the same potential.

15.1.1.6 Avoiding flashovers

a) When damp, a dirty insulator is likely to flashover. Avoid partially wetting an insulator with spray before the solid stream is applied. Hose stream should be applied as follows:
b) The water should be brought to the full nozzle pressure required before it is directed toward the insulator. Direct stream away from insulator before reducing pressure.
c) For suspension type insulator, direct the solid stream to the insulator attached to the conductor first, and then progressively upward on the string of insulators.
d) The polymer suspension insulators, or other similar units, should not be washed by this high-pressure method at any time, except on advice and guidance of the manufacturer.
e) Where an insulator string has broken units, washing should not be undertaken on that string with the circuit energized. This will reduce the possibility of flashovers. Only strings that have no broken units should be washed. Damaged polymer or post insulators should not be energized.
f) Stacked insulators (stacked-type insulators) on airbreak switches, etc., should be washed so that the watersheds just cleaned will maintain adequate insulation. For example, on vertical insulators, the washing would be started on the bottom and worked upwards.

g) For pin type insulators, the solid stream should be directed at the underside of the insulator. The insulators on a pole or structure should be washed in the order least likely to cause the wetting of unwashed insulators.
h) Whenever practical, surge arresters should be removed from service prior to washing or washed according to the manufacturer's recommendations and the applicable safe practices. Whenever practical, line transformers, including arrester leads, should be disconnected and de-energized prior to washing.
i) Line reclosers, sectionalizers, and oil or vacuum switches should be completely removed from service before being washed.
j) Wafer-type cable terminations should be washed with extreme care, and then only if absolutely necessary. The water stream should be directed at the termination from a point slightly above the pot head to prevent spreading of the wafers. The water stream should not be directed so as to provide an upward force on the wafers.
k) Care should be taken in washing fuse cutouts to direct the water stream from such a direction as to prevent forcing open the cutout barrel.

15.1.1.7 Corona discharge

Usually, blue corona discharges can extend from the metal to the porcelain during the washing and may be heard for a few seconds after completion. If this continues for more than a few seconds, it may indicate incomplete washing of the insulator, in which case the stream should be applied again.

15.1.1.8 Water supply

Water to be used for washing insulators shall be obtained from a municipal supply or other clear source. In these cases, it is expected that the resistivity would be measured and within the limits established within the company. Water containing excessive chemicals or salts shall not be used, and under no circumstances shall chemicals of any kind be added to the water, unless approved by the individual company for the specific application.

15.1.1.9 Additional precautions

In addition to the foregoing, the following precautions should be taken:

a) All company safety rules should be observed.
b) All personnel should stay clear of the spray-gun operator during washing operation. The nozzle should be kept under control and never pointed toward another person.
c) At the end of each washing cycle, at each washing location, the pressure should be relieved from the hose and nozzle by closing the cut-off valve at the pump and discharging the hose.
d) Any adjustment of the pump controls should be made with the water turned off or the stream directed so as not to create a hazard for personnel or property.
e) Care should be exercised in observance of defective hardware, rotten wood, etc., before attempting to wash.
f) When washing, care should be taken in choosing the direction from which equipment will be washed to avoid causing flashovers on equipment in the overshoot area. Wind is a definite factor.

15.2 West coast utility

The larger 7.938 mm (0.3125 in) nozzle is used under windy conditions for a better washing action, but not under calm conditions to conserve water. See table 11.

Eye-protection goggles with a no. 2 shade color shall be used during hot-washing.

Table 11—Safety precaution specifications

Voltage	Length of stream		Distance	
	m	ft	m	ft
kV (phase-to-phase)	6.35 mm[1]	0.25 in[1]	7.938 mm nozzle	0.3125 in nozzle
4–12 kV	2.134	7	3.048	10
13–23 kV	3.048	10	3.962	13
24–70 kV	3.658	12	4.572	15
71–115 kV	4.572	15	5.486	18
230 kV	4.572	15	6.096	20
500 kV	6.096	20	6.096	20

[1] Also 5.953 mm (0.234375 in) nozzle

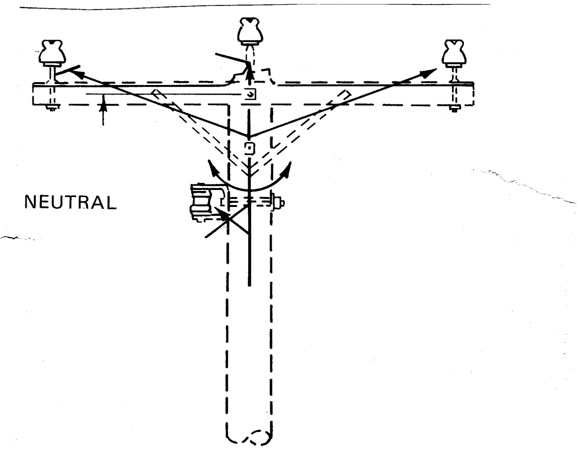
— *Grounding.* When washing from the steel structure that supports the insulators being hot-washed, the washing operator should ground the nozzle and gun valve to the structure to bleed off any current flow through the stream. The wash trailer (unit) is not grounded.

Where possible, the washing operator should take advantage of the shielding provided by the structural members by washing from inside the cage or from the side.

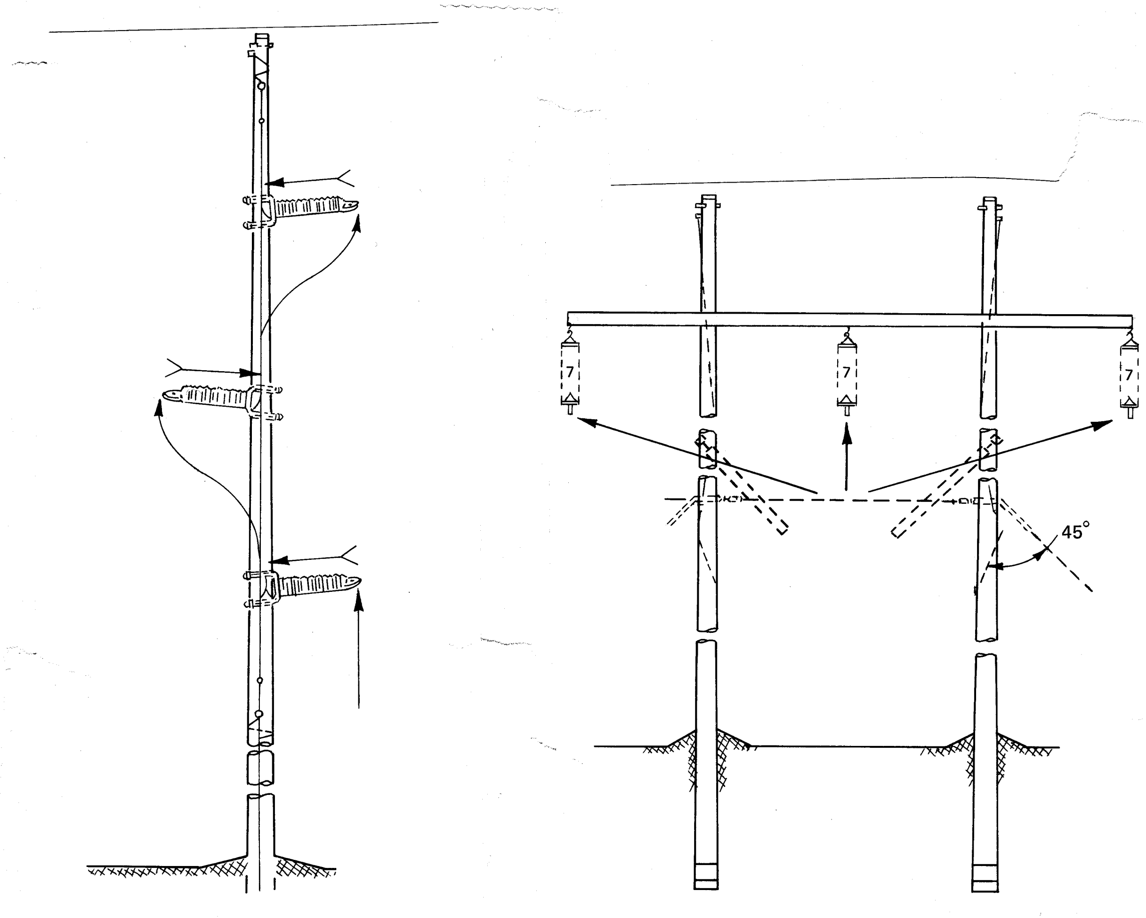
The nozzle shall not be allowed to project beyond the plane of the tower steel.

— *Washing techniques.* The insulator should always be washed at the lowest point on a structure on the downwind side first. If possible, it should be washed from the bottom level to the top level, starting on the downwind side at each level. Finally, all washed insulation should be rinsed at the lower levels to remove any dripping dirty water.

A steel braided hose is used to avoid separate grounding of a hand-held nozzle (the washing equipment is grounded). The use of the steel braided hose was adopted only after tests of fault conditions determined it (hose) to be safe.



a) Wash up pole from neutral (include braces) and up under insulators.



b) Wash from conductor to pole when wind conditions (including direction) so indicate.

c) Wash from conductor to arm end of insulator string.

Figure 12—East coast utility examples

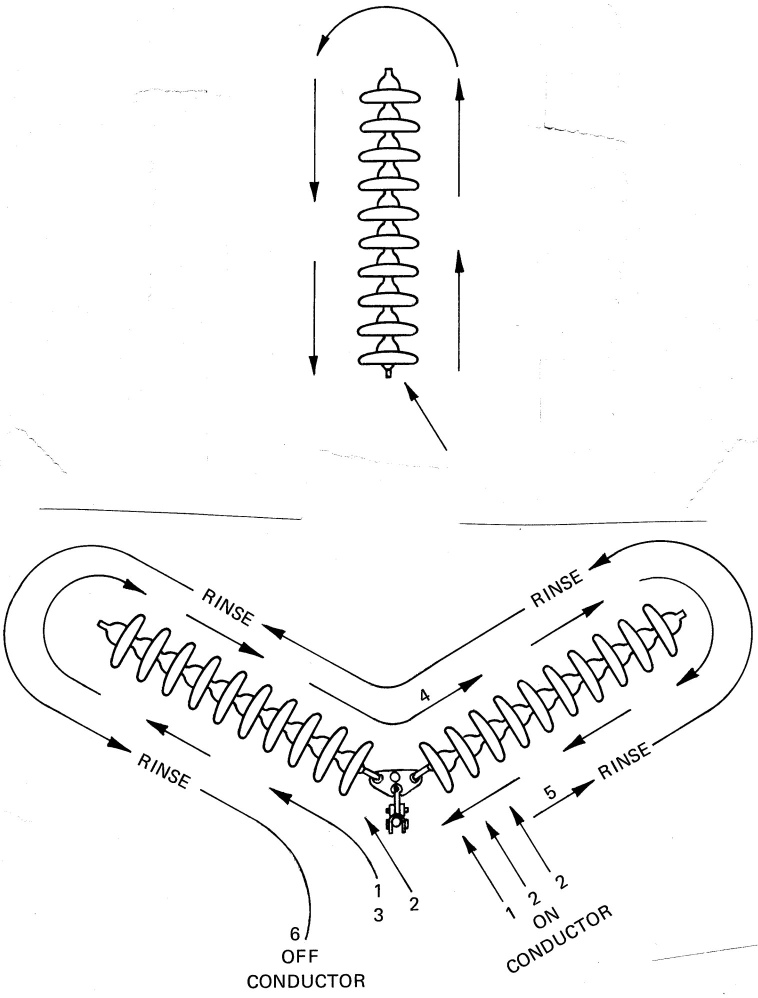


Figure 13—Washing steps for vertical and vee-string insulators

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Annex
Maintenance of insulators after cleaning

(normative)

A.1 Silicone protective coating for high-voltage insulators

Greaselike 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 its 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 (0.0625 in) to 3.2 mm (0.125 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 (0.5 in) thick coatings are found to be less than 0.8 mm (0.045 in) thick, with spots having little or no compound. These thin spots can be sources for dry-band arcing and premature flashover. Table 12 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 a 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 0.46 mm (0.018 in) to 0.66 mm (0.026 in) nozzle with a fan angle from 15–65° 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.

Table A1—Typical quantities of silicone grease required to coat a specific insulator

If the following insulators were coated with a 1.59 mm (0.0625 in) coat of compound, each insulator would require the amount of compound listed below

Insulator type (Ohio Brass catalog no.)	Description	Area		Amount of compound required	
		m^2	ft^2	kg	lb oz
38149	13 kV one-piece pin type	0.07	0.70	0.10	0–3.6
37630	34.5 kV line-post insulator	0.22	2.32	0.34	0–12.1
32440	Standard 0.254 m (10 in) suspension unit	0.17	1.82	0.27	0–9.5
35230	Smog-type 0.254E-01 m (10 in) suspension unit	0.23	2.47	0.35	0–12.5
37734	34.5 kV pin-cap apparatus insulator	0.39	4.24	0.62	1–6.0
37769	69 kV pin-cap unit used in two-unit stacks	0.46	4.96	0.74	1–10.0
31152	High voltage pin-cap apparatus unit	0.72	7.73	1.16	2–9.0
	69 kV bushing	0.85	9.1	1.36	3–0
	138 kV bushing	1.99	21.4	3.18	7–0
	230 kV bushing	4.59	49.4	7.26	16–0

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 hotstick 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 (0.125 in) thick initial coating, for example, will plate out to approximately 1.59 mm (0.0625 in). To compensate for this loss, a heavier coating shall be applied.

Actual measurements at utilities have shown that visual observations are often misleading no matter how the coating is applied. Coatings usually 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 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, a homogeneous, even coating should be applied, and the water-repellency and development of light colored spots on the insulators should be checked periodically. 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 re-establish 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.

- Has the compound been applied properly?
- Has the free fluid in the coating been used up by heavy coatings of contaminants?
- Have maintenance personnel somehow missed a scheduled removal and replacement of compound?

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

A.2 Silicone RTV coatings as protective coatings for HV insulators

Increasingly, room temperature vulcanizing (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 10 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 that 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 50–70% 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, and establish quality control and milestones 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.

A.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 problems, as follows.

A.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.

A.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.

A.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).

A.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.

A.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 shall 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 shall be cleaned using a dry abrasive cleaner such as crushed corn cob 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 shall be hand wiped clean, using a solvent such as naphtha, to remove the residual film of grease. The surface shall be free of even a film of oil.

A.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 much better value, shall 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.

A.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. Film build is affected by material viscosity and sag characteristics and the surface finish of the substrate. 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 trichloro-ethane. 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 15–20 mil. The cost of a typical application breaks down evenly between material and labor. A quick-curing coating system represents significant cost saving.

A.2.2.4 Equipment

RTV silicone rubber coatings can be applied with brush and 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 inject 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 significantly reduce over-spray. 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 that may contaminate silicone. Pumps, hoses, and guns shall 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 nonconductive 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 over-spray is not a concern and speed of application is very important.

A.2.2.5 Energized application

Coating systems that are dispersed in nonflammable solvents may be applied to energized equipment. This shall 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.

A.2.2.6 Inspection

Only two nondestructive tests, as follows, can be performed on RTV coatings to verify thickness.

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 shall be calibrated and checked prior to use.

Visual inspection will indicate any over-spray or dry spray problems.

A.2.3 Specification

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

A.2.3.1 Preliminary

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

a) Detailed written document establishing all of the owner safety requirements on the job site
b) Comprehensive schedule showing exactly when specific insulators or bushings will be available for coating
c) Detailed written document describing all of the owner environmental requirements on the job site

A.2.3.2 Scope of work

The contractor should be responsible for the following:

a) Removal of any contamination, silicone grease, or nonsilicone coating on all exposed surfaces. Blasting with high-pressure water, walnut shells, dry ice, or catalyst is permitted. Each component shall 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.)

A.2.3.3 Coating material

The material(s) should be delivered to the job site in its original unopened container(s) with proper labels attached. The label information should include data such as material name, unit size, batch number, and date of manufacture. Product data, material safety date, 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 trichloro-ethane. The material should be stored in a secure dry location. The temperature shall not exceed 38° C (100° F).

A.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 manufacturer’s most recent published instructions, without being thinned, diluted, or modified, except as called for in these instructions, or with the concurrence of the owner.

A.2.3.5 Environmental control

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

A.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 the conventional or airless systems]. Coating should be applied to an average thickness or 15 mil. In no cases should the coating be less than 10 mil.

A.2.3.7 Inspection

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

A.2.3.8 Repair

Any coating areas not meeting thickness requirements should be recoated.

A.2.3.9 Cleanup

Any over-spray 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.

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

a) Parke-Thompson hot-stick spraying equipment. This equipment consists of the following:
   1) 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 (ft) of length for a period of 300 s (5 min) after assembly and with silicone grease mixture in the stick. Sticks are furnished with a rigid plastic shipping/carrying case, which is foam cushioned internally for maximum handling protection for the precision stick assembly.
   2) Insulating stick extension is of tested fiberglass and adds to effective stick length at the handle end to improve access to remote insulator surfaces.
   3) Pressurizer is an air powered, hydraulic pumping unit capable of providing up to 17 240 kPa (2500 psi) spraying 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.
   4) Pressurizer assembly that 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.
   5) 7.62 m–6.35 mm (25 ft–0.25 in) insulating hydraulic hose equipped with quick-connect couplings and caps.
   6) 15.24 m–9.35 mm (50 ft–0.375 in) insulating hydraulic hose equipped with quick-connect couplings and caps.

      NOTE—9.53 mm (0.5 in) hose is recommended for over 7.62 m (25 ft) from pressurizer to spray stick.

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

b) Alemite hand-spray gun with roto-clean nozzle.

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

d) Typical silicone compound: Dow-Corning no. 5, GE no. 620, or GE no. 635.

e) 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.

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

f) Conventional application systems, offering better control and minimal overspray, are recommended for de-energized application. Typical equipment consists of the following:
   - Graco high volume, low-pressure gun with a 0.046 nozzle
   - Air driven agitator and mixer assembly on 2 gal or 5 gal pump (25:1 ratio)
   - Portable compressor capable of delivering 100 psi air pressure
   - Insulating hydraulic material hose (0.375 in)
   - Insulating hydraulic air hose (0.25 in)