

IEEE Guide for Installation, Maintenance, and Operation of Irrigation Equipment Located Near or Under Power Lines

IEEE Power and Energy Society

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IEEE Guide for Installation, Maintenance, and Operation of Irrigation Equipment Located Near or Under Power Lines

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Transmission and Distribution Committee of
the
IEEE Power and Energy Society

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Abstract: Industry practices and guidelines for installation, maintenance, and operation of irrigation equipment near or under power lines as they pertain to minimum distance to energized conductors and proper grounding to help minimize nuisance shocks are presented in this guide. A variety of conditions in general terms is covered in this guide. Specific recommendations are made for the type of irrigation systems and power line parameters most commonly found.

Keywords: farm irrigation systems, IEEE 1542™, irrigation, irrigation systems, sprinklers

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

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Kevin Edmonds	Marc Patterson	Jack Varner
		Mike Warntjes

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Introduction

This introduction is not part of IEEE Std 1542-2018, IEEE Guide for Installation, Maintenance, and Operation of Irrigation Equipment Located Near or Under Power Lines.

The guide is intended for designers, installers, and operators of the irrigation equipment, as well as electric power utilities whose lines are located near or above the irrigation systems. General information is provided on installation, maintenance, and operation of irrigation equipment as it relates to safety due to the presence of electric power lines. The following parameters are considered:

- a) Distance to energized conductors during installation
- b) Proper grounding to help minimize nuisance shocks
- c) Distance between irrigation nozzle and power line conductors during operation of the irrigation system

The recommended minimum conductor-to-nozzle distance is based on the maximum allowable body leakage current of 5 mA rms and field tests conducted by the Nebraska Public Power District and the USDA Agricultural Research Service, University of Nebraska.

Because of the great variety of conditions, practices, electrical system designs, types of irrigation systems, water conductivity, and ground resistance values, this guide covers these variables only in general terms. However, specific recommendations are made for the type of irrigation system and power line parameters that are most representative in the industry. The IEEE makes no representation or warranty as to the adequacy or accuracy of the information in this guide or as to economy, or safety issues associated with the use 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).

This material is intended to provide a helpful reference for those seeking information on common industry practices so they may consider the experience of others in developing or modifying their own practices.

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IEEE Guide for Installation, Maintenance, and Operation of Irrigation Equipment Located Near or Under Power Lines

1. Overview

1.1 Scope

The guide is based on industry practices and presents guidelines for installation, maintenance, and operation of above ground irrigation equipment near or under power lines as they pertain to minimum distance to energized conductors and proper grounding to help minimize nuisance shocks. The guide covers a variety of conditions in general terms. Specific recommendations are made for the type of irrigation systems and power line parameters most commonly found. This guide does not cover transferred potentials and currents.

1.2 Purpose

The guide is intended for designers, installers, and operators of the irrigation equipment, as well as electric power utilities whose lines are located near or above the irrigation systems. General information is provided on installation, maintenance, and operation of irrigation equipment as it relates to safety due to the presence of electric power lines. The following parameters are considered:

- a) Distance to energized conductors during installation
- b) Proper grounding to help minimize nuisance shocks
- c) Distance between irrigation nozzle and power line conductors during operation of the irrigation system

The recommended minimum conductor-to-nozzle distance is based on the maximum allowable body leakage current of 5 mA rms and field tests conducted by the Nebraska Public Power District and the USDA Agricultural Research Service, University of Nebraska [B3]¹.

Because of the great variety of conditions, practices, electrical system designs, types of irrigation systems, water conductivity, and ground-resistance values, this guide covers these variables only in general terms. However, specific recommendations are made for the type of irrigation system and power line parameters that are most representative in the industry. The IEEE makes no representation or warranty as to the adequacy or accuracy of the information in this guide or as to economy, or safety issues associated with the use 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).

¹The numbers in brackets correspond to those of the bibliography in [Annex D](#).

This material is intended to provide a helpful reference for those seeking information on common industry practices so they may consider the experience of others in developing or modifying their own practices.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

Accredited Standards Committee C2, National Electrical Safety Code® (NESC®).²

3. Definitions

For the purposes of this document, the following terms and definitions apply. The IEEE Standards Dictionary Online should be consulted for terms not defined in this clause.³

ground resistance: The resistance of the irrigation system to earth, determined by a grounding electrode or by the contact of the irrigation equipment with the earth, or both.

irrigation equipment: Structures, pipes, nozzles, valves, etc., that support, convey, direct, and/or control water or other equipment in an irrigation system.

irrigation system: An arrangement of equipment including a water supply that is assembled to systematically apply irrigation to an area.

nuisance shock: An electric shock from a steady-state or a discharge current for which a person would consider the sensation to be a mild irritant if it were to occur repeatedly. Syn: annoyance shock, secondary shock

reference heights: Assumed height above ground of a metal object (i.e., sprinkler height).

water spray: water broken up into minute droplets.

water stream: electrically continuous column of water.

4. Application

This guide presents a reference source for the operation of irrigation systems located near or under electric power lines to reduce safety risks. The distances between the power line conductors and water spray nozzles that are given in this guide are based on commonly used body resistance values and other parameters that are representative of typical conditions and methods. For conditions where the values of parameters such as water resistivity, system ground resistance, and/or body resistance differ from those used here, the value of the power-line-conductor-to-nozzle distance can be determined using the equations and plots provided in this guide.

²The NESC is available from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

³IEEE Standards Dictionary Online is available at: <http://dictionary.ieee.org>.

5. Types of irrigation systems

5.1 General

From the many types of sprinkler irrigation systems, the ones of concern for this guide are those that travel or can be transported under power lines. Those systems include side roll, boom, hand move, traveler, center pivot, corner pivot, and lateral move. [Table 1](#) is a summary of irrigation equipment and water stream heights. The following sections describe the different types of irrigation systems.

Table 1—Typical heights of irrigation systems. (For estimating purposes only. Actual values depend on manufacturer and model of irrigation system, and terrain of application.)

Irrigation equipment	Equipment height		Stream height	
	m	ft	m	ft
Side roll	2	6.5	N/A	N/A
Boom	6	20	N/A	N/A
Hand move	1.5	4	4	13
Traveler	4	13	12	40
Center pivot (corner pivot)	6	20	10	33
Lateral move	4.5	15	N/A	N/A

5.2 Side roll

For a side roll sprinkler system, the supply pipe is mounted on wheels with the pipe as the axle. The system is moved by rotating the pipeline through engine power. The approximate wheel diameters range from 1 m (3.5 ft) to 2 m (6.5 ft) depending on the height of the crop irrigated. These systems are found mostly in the western United States.

5.3 Boom

Boom sprinklers are cantilevered pipes (laterally) mounted on a stand. The laterals rotate about the stand by the jet action of the nozzles. The laterals are lowered for transport. The approximate height of the booms ranges from 3 m (10 ft) to 6 m (20 ft).

5.4 Hand move

Hand move sprinklers are moved by uncoupling, picking up, and moving sections (laterally) of the pipeline with the hands, requiring no tools. Each section can range between 6 m (20 ft) and 12 m (40 ft) in length. A rotating sprinkler head is attached atop a vertical riser pipe. The riser is typically 0.30 m (1 ft) to 1.5 m (4 ft) in height. The water trajectory from the nozzle can reach heights of 4 m (13 ft).

5.5 Traveler

A traveler sprinkler consists of a chassis that carries a large volume sprinkler. The chassis is pulled across the field by a cable or supply hose. Approximate nozzle height is 3 m (10 ft) to 4 m (13 ft), but the water trajectory from the nozzle can reach heights of 10 m (33 ft) to 12 m (40 ft).

5.6 Center pivot

A center pivot is an automated irrigation system consisting of a pipeline with sprinklers supported by a number of self-supported towers that all travel in unison in concentric paths about a fixed pivot point. The water

is supplied at the pivot point and flows outward. The last pipeline span is cantilevered from the last tower. Cantilever supports are about 6 m (20 ft) high. Many center pivots have a large volume sprinkler on the outer end to water an additional area. The end of the pipeline is approximately 4.5 m (15 ft) high. However, on hilly terrain, the end of the pipeline can range between 3 m (10 ft) and 6 m (20 ft) above the ground. Also, there are low profile pivots where the height is approximately 2 m (6.5 ft). Water stream trajectory could be as high as 10 m (33 ft).

5.7 Corner pivot

A corner pivot is a center pivot with additional spans and other equipment that allows the overall radius to increase in relation to field boundaries. The pipeline end will have a large volume sprinkler like a center pivot.

5.8 Lateral move

A lateral move system is an automated irrigation machine consisting of a sprinkler line supported by a number of self-propelled towers. The entire unit moves in a generally straight path and irrigates a generally rectangular area. Sometimes it is called a "linear move." This system is only used on flat fields so the pipeline is a constant height above the ground of approximately 4.5 m (15 ft) or less depending upon the wheel sizes.

6. Installation and maintenance

6.1 General

The following guidelines are suggested for handling pipes or other long pieces of metallic equipment:

- a) To help minimize the occurrence of nuisance shocks or electrical contact with power line conductors, the unloading of pipe sections from a vehicle or trailer should be done at least 15.24 m (50 ft) away horizontally from the nearest conductor.
- b) The pipe and other large objects should always be carried in a horizontal position to avoid contact or coming within flashover and/or sparkover distance of the overhead conductors.
- c) Construction of irrigation systems directly under transmission lines should be avoided.

Water should not be sprayed on powerline structures, poles or other facilities. This can cause premature deterioration of the power line facilities. Residue from sprayed fertilizer can cause contamination of the power line facilities and lead to their misoperation or deterioration.

6.2 Distance to energized conductors

When working near power lines and performing such tasks as handling metal irrigation pipes or installing or maintaining irrigation equipment, one should always maintain a minimum safe distance to energized conductors; in the United States this is specified by OSHA[B2].

The height of power line conductors above ground can change significantly depending on the electrical load (amount of power) being transmitted and air temperature. For example, for a 366 m (1200 ft) long span, the height of conductors above ground can change by as much as 5.49 m (18 ft). For this reason, it is necessary for the installer to call the electric utility to obtain guidelines on line heights during the time when working under overhead transmission lines. In much of the United States, the National Electrical Safety Code® (NESC®) (Accredited Standards Committee C2) provides minimum distances between overhead lines and objects on the right-of-way. Many utilities use clearance requirements specified in the NESC for other installations (i.e., antennas, signs, etc.).⁴

⁴Information on references can be found in [Clause 2](#).

6.3 Protection from nuisance shocks

Metallic parts of irrigation systems located near or under power lines can become a potential shock hazard. This potential hazard can be reduced or eliminated with grounding and bonding of the equipment.

The center pivot irrigation system is used as an example to illustrate what steps are necessary to reduce or eliminate the nuisance shock. First, to eliminate electric charge buildup, the pivot point should provide a good electrical ground for the sprinkler system. However, this electrical ground does not eliminate the shock hazard caused by inductive coupling between the transmission line and the sprinkler pipe. For this reason, the following precautions should be observed:

- a) Personnel should not touch the sprinkler pipe or its supporting structures when in operation under, parallel to, or near a transmission line.
- b) If possible, maintenance work should be done with the center pivot system oriented perpendicular with respect to the transmission line.
- c) If perpendicular orientation of the center pivot system is not practical, the pipe where the maintenance is performed should be grounded (connected to a ground rod). Also, each disjointed length of the system should be grounded on both sides of the coupling before it is decoupled.
- d) Pipe sections closest to a transmission line should be installed last and removed first to reduce potential hazard time.

7. Operation of irrigation equipment

7.1 General

This clause deals with operation of the irrigation equipment when the water stream is near or spraying the power line energized conductors (wires). It is best to avoid working on or maintaining irrigation equipment near power lines when the sprinkler is operating.

There are two significant safety concerns that need to be addressed. First is the concern of an electric fault in case the water stream should come very near or make contact with energized line conductors. The second concern deals with the capacitive coupling, in which case there might be sufficient leakage current in the water spray to cause nuisance shocks.

Both of these problems are addressed. The probability of an electric fault can be reduced or eliminated by dispersing the water stream into a spray. The magnitude of the leakage current can be controlled by maintaining certain minimum distances (clearances) between the line conductor and the irrigation nozzle. This clause deals primarily with establishing the minimum conductor to nozzle clearances.

7.2 Distance from metal frame of irrigation equipment

The metal frame of any irrigation equipment should stay a safe distance from any power line. In the US, many utilities use the distances specified in the NESC for distances to signs, billboards and other installations.

7.3 Operating guidelines for Irrigation Systems

The following are general operating guidelines:

- a) Irrigation systems should be operated at distances sufficient to avoid direct contact between the water stream and conductors.

- b) A solid and continuous stream of water should never be directed at or near the energized line conductors.
- c) Test results (see [Annex A](#)) and operating experience in the industry indicate that direct water spray contact with power line conductors is permissible when irrigation nozzles have discharge characteristics that cause water stream breakup due to normal water turbulence and nozzle or system design. Once the water stream has been broken up and becomes a spray, the probability of line conductor to nozzle flashover and/or sparkover is greatly reduced or eliminated [[B3](#)].

Some of the other factors that need consideration are conductor-to-nozzle distance, water conductivity, water pressure, nozzle size and type, wind speed, ground and irrigation system resistance, total and body leakage current, and other considerations. When these factors are unknown, a conservative approach would be to model the water as a continuous stream of water and require a clearance equal to that between the power line and the metal frame of the irrigation equipment.

The equation developed in [[B3](#)] is used for calculating the conductor-to-nozzle distances. [Figure A.1](#) shows the system configuration without the presence of a body to create a resistive current path to ground through the body. [Figure A.2](#) shows the same system with the presence of a body (located in the worst place in the circuit) to create a resistive current path to ground through the body. The crest voltage due to the leakage current through a known resistance was used to calculate the crest leakage current through the water stream. The current through the water stream (I_T) can be expressed in terms of a nominal 1.0 kV rms line-to-neutral (L-N) voltage and a conductivity of 1000 $\mu\text{S}/\text{cm}$. This normalized crest leakage current I_{nc} is defined as follows in [Equation \(1\)](#):

$$I_{nc} = 1000 I_P \frac{(R_G = R_P)}{R_G \text{ kV } \sigma_w} \quad (1)$$

where

I_{nc}	is the crest leakage current in milliamperes normalized to 1.0 kV rms line-to-neutral and 1000 $\mu\text{S}/\text{cm}$
I_P	is the allowable body current in milliamperes crest (7.07 mA)
R_P	is the body resistance, ohms
R_G	is the irrigation system ground resistance, ohms
kV_{L-N}	is the rms line-to-neutral voltage in kilovolts of the power line $(\sqrt{V_{LL}} \cdot 3)$
σ_w	is the water conductivity in microsiemens/centimeter

The normalized crest current data versus line-to-nozzle distance is plotted in [Figure 1](#), [Figure 2](#), and [Figure 3](#), for various nozzle diameter sizes and types. Therefore, if the normalized crest leakage current (I_{nc}) is calculated from [Equation \(1\)](#), then the minimum line-to-nozzle distance for a specific nozzle size can be obtained directly from the plots in [Figure 1](#), [Figure 2](#), and [Figure 3](#). An example can be found in [Annex C](#).

[Table 2](#) gives conductor-to-nozzle clearances for water spray where the irrigation system resistance (R_G) is 10 Ω , body current (I_P) is 5 mA rms (7.07 mA crest), and body resistance (R_P) is 1500 Ω .⁵ Water conductivity is 1200 $\mu\text{S}/\text{cm}$ and water pressure is 552 kPa (80 psi). Values apply for water spray so that the water stream is

broken up with no solid and continuous stream. Quantities are as shown in [Figure 4](#).

In [Table 3](#), the body resistance (R_P) has been reduced from 1500 Ω to 1000 Ω . There is more information in [Annex B](#) on how to choose the appropriate body resistance.

⁵Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

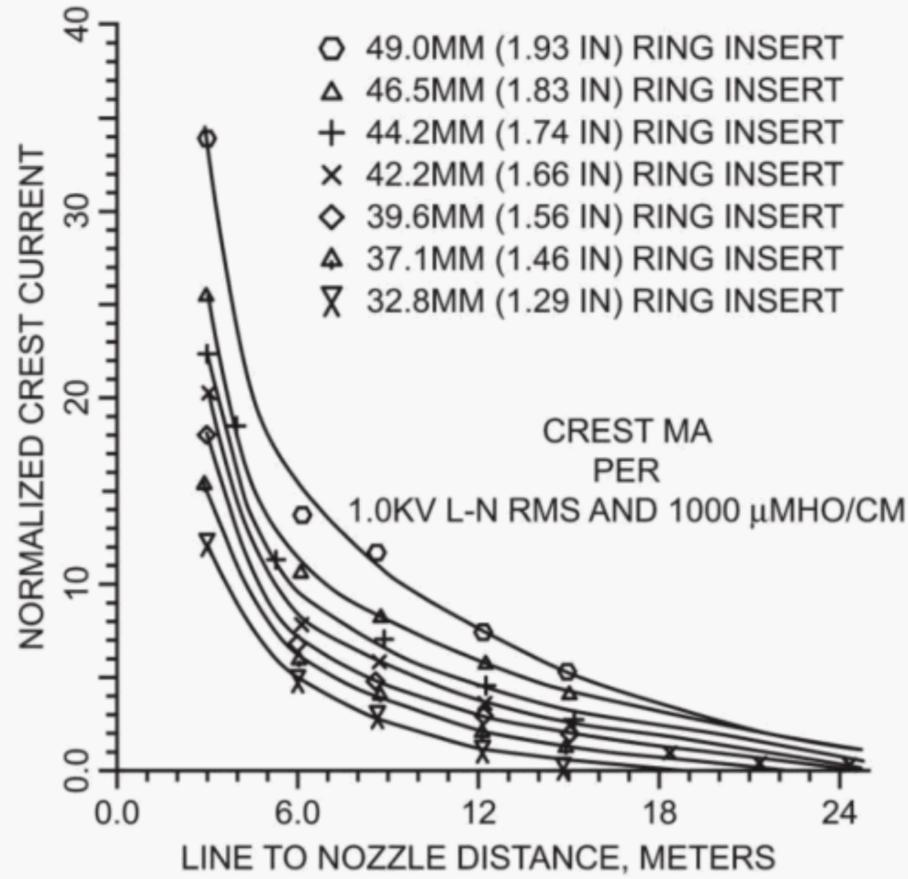


Figure 1—Normalized crest leakage current for 200 series ring nozzles at distances and nozzle sizes and types shown. Nozzle pressure 552 kPa (80 psi) [B3]

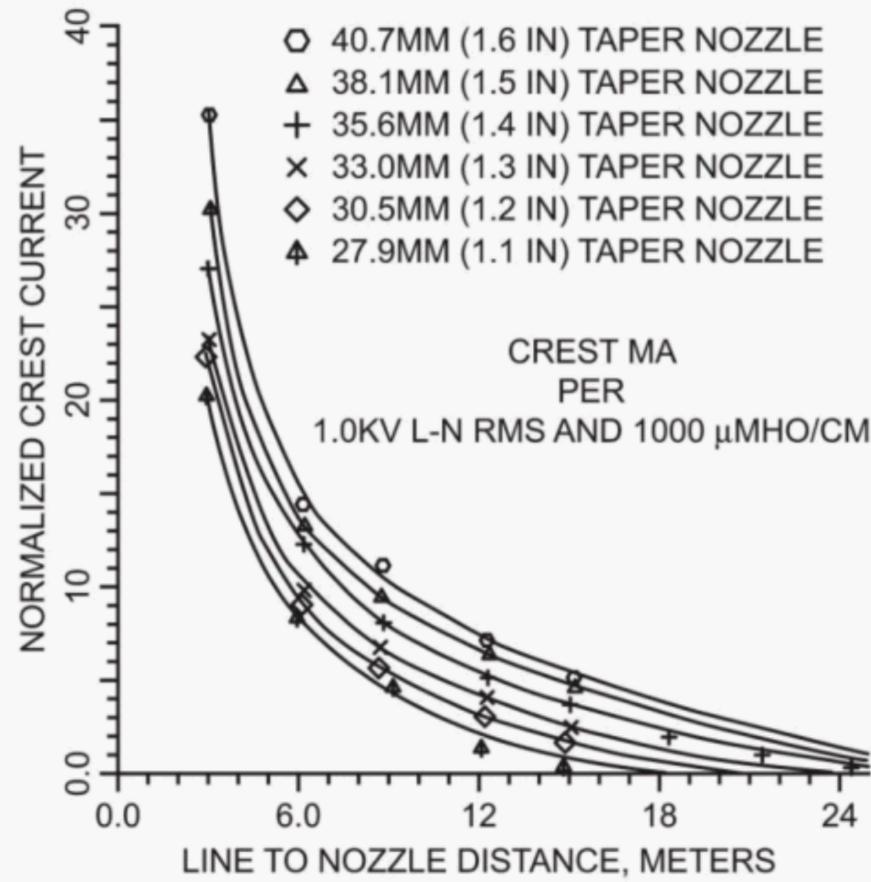


Figure 2—Normalized crest leakage current for 200 series taper nozzles at distances and nozzle sizes and types shown. Nozzle pressure 552 kPa (80 psi) [B3]

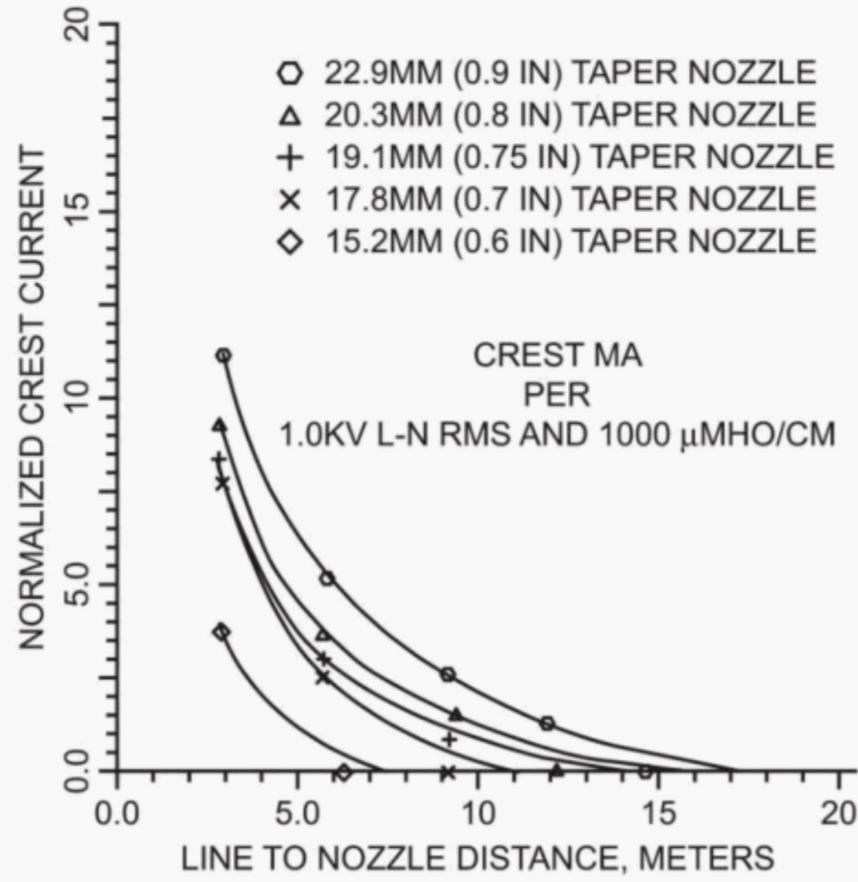


Figure 3—Normalized crest leakage current for 100 series taper nozzles at distances and nozzle sizes and types shown. Nozzle pressure 552 kPa (80 psi) [B3]

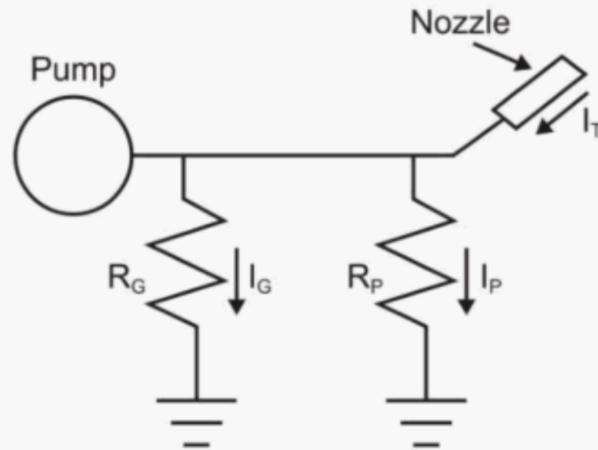


Figure 4—The schematic representation used in the calculation of the values in Table 2 and Table 3

Table 2—Minimum conductor-to-nozzle distance for water spray with body resistance of 1500 Ω^a

Nozzle diameter		Power line voltage (kV rms, line-to-line)													
		115 kV		138 kV		161 kV		230 kV		345 kV		500 kV		765 kV	
mm	in	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft
19.1	0.8	3.66 ^c	12.0	3.66 ^c	12.0	3.66 ^c	12.0	3.66 ^c	12.0	4.7	15.4	6.4	21.0	7.8	25.6
22.9	0.9	3.66 ^c	12.0	3.66 ^c	12.8	5.2	17.1	6.9	22.6	9.2	30.2	9.2	30.2	10.7	35.1
27.9	1.1	4.20	13.8	5.0	16.4	7.3	24.0	9.2	30.2	11.2	36.7	11.2	36.7	12.6	41.3
35.6	1.4	5.69	18.7	7.0	22.9	10.7	35.1	13.8	45.3	17.3	56.8	17.3	56.8	19.7	64.6
40.7	1.6	6.19	20.3	8.8	28.9	13.4	44.0	17.3	56.8	21.0	68.9	21.0	68.9	22.9	75.1
49.0 ^b	1.9	6.19	20.3	9.0	29.5	13.4	44.0	16.7	54.8	19.9	65.3	19.9	65.3	22.1	72.5

^aFor power lines below 115 kV, the minimum conductor-to-nozzle distance shall be 3.1 m. For water spray, the water stream is broken up so there is no solid and continuous stream.

^bRing insert.

^cLimited by regulations [B1], [B2].

Table 3—Minimum conductor-to-nozzle distance for water spray with body resistance of 1000 Ω^a

Nozzle diameter		Power line voltage (kV rms, line-to-line)													
		115 kV		138 kV		161 kV		230 kV		345 kV		500 kV		765 kV	
mm	in	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft
19.1	0.8	3.66 ^c	12	3.66 ^c	12	3.8	12.5	4.7	15.4	6.3	20.7	7.9	25.9	9.3	30.5
22.9	0.9	3.7	12.1	4.7	15.4	5.2	17.1	7	23.0	9	29.5	10.8	35.4	12.3	40.4
27.9	1.1	5.8	19.0	6.8	22.3	7.6	24.9	9.2	30.2	11.1	36.4	12.7	41.7	13.4	44.0
35.6	1.4	8.1	26.6	9.7	31.8	11.2	36.7	13.9	45.6	17.2	56.4	19.8	65.0	20.2	66.3
40.7	1.6	10.2	33.5	12	39.4	14.2	46.6	17.4	57.1	20.9	68.6	23.0	75.5	24.4	80.1
49.0 ^b	1.9	10.4	34.1	12.3	40.4	13.9	45.6	16.7	54.8	19.8	65.0	22.2	72.8	24.0	78.7

^aFor power lines below 115 kV, the minimum conductor-to-nozzle distance shall be 3.1 m. For water spray, the water stream is broken up so there is no solid and continuous stream.

^bRing insert.

^cLimited by regulations [B1], [B2].

Annex A

(informative)

Discussion of historical studies on irrigation systems near transmission lines

The Starr, et al., (BPA/TVA) [B5] and Ewy, et al., (Nebraska) [B3] investigations represented the major and perhaps the most useful studies of power line effects on irrigation systems. A discussion of these two studies can be found in this Annex. Several other studies have focused on insulator washing where special equipment is used. Also, the insulator washing procedure is under control of the electric utility. The system operating conditions during irrigation including the nozzle design are very different in comparison to washing insulators. Therefore, the operating guidelines developed for insulator washing applications cannot be directly adopted for irrigation near power lines.

In determining the minimum conductor-to-nozzle distances, the industry accepted allowable maximum body current of 5.0 mA rms (7.07 mA crest) and a body resistance of 1500 Ω was used.

A.1 Historical material BPA and Nebraska results

Based on test results reported in 1969, the Bonneville Power Administration (BPA) [B5] was perhaps the first organization to establish guidelines recommending minimum line-conductor-to-nozzle distance for a range of nozzle sizes and transmission line voltages up to 550 kV (ac). The study was primarily directed toward the measurement of electrical current through the water stream between the energized conductor and the nozzle. They also investigated the possibility of flashover caused by a solid water stream between the live conductor and tower and between two line conductors. The Nebraska Public Power District [B3] reported their test results in 1981. The study included new large irrigation sprinklers and their application on center pivots and traveler irrigation systems. Data was also obtained for lower power line voltages than the BPA/TVA tests, covering 115 kV and 12.5 kV lines.

Based on their test results and BPA test data, the authors of the Nebraska [B3] paper have suggested an equation

that can be used to calculate the line-conductor-to-nozzle distance for any power line voltage and a selected

allowable body current. According to the Nebraska authors, the compatibility of irrigation system and power

lines as determined by allowable water stream currents will depend upon the assumptions or measurements

made pertaining to the water conductivity, irrigation system grounding, body resistance, and allowable level of body current. The maximum normalized allowable level of the total water stream current (I_T) can be

determined in order to establish which nozzle size at a specific line-conductor-to-nozzle distance will limit the

body current to an allowable level for specified safety criterion. The equation for the normalized total water stream current (I_{nc}) was derived by the authors [B3] and has been used in this guide as [Equation \(1\)](#).

The major difference between the Nebraska and BPA results can be explained by how the conductor-to-nozzle distances are established. BPA used the total water stream current, as shown in [Figure A.1](#), where $I_T = I_G$. On

the other hand, Nebraska in addition to the irrigation system grounding resistance (R_G) also introduced the—

body resistance (R_P) of a person in contact with parts of the irrigation system as shown in [Figure A.2](#), where

$I_T = I_G + I_P$. Nebraska used the body current I_P rather than the total water stream current I_T , for

establishing
the conductor-to-nozzle distances. The Nebraska approach can illustrate the value of bonding from
irrigation
equipment to the interconnected neutral impedance of the electric supply to a pump, if available.

For the same conditions, where the R_G is about 10Ω ⁶, and where the body resistance R_P is 1500Ω , there will be a significant difference between the conductor-to-nozzle distances determined by BPA and Nebraska

⁶Characteristics of soil varies significantly, 10Ω may not be conservative in all cases.

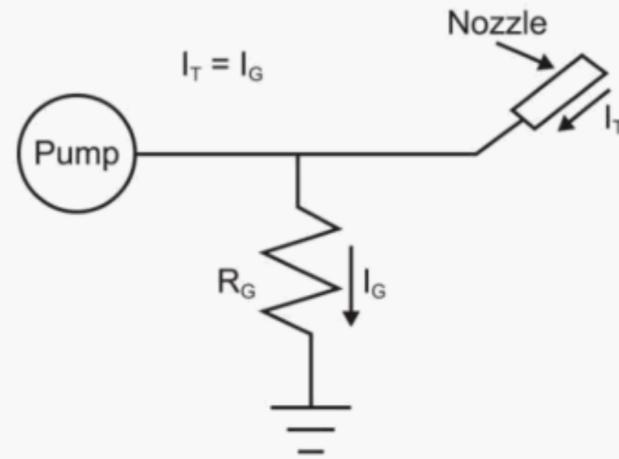


Figure A.1—Model for calculation of leakage current without body resistance

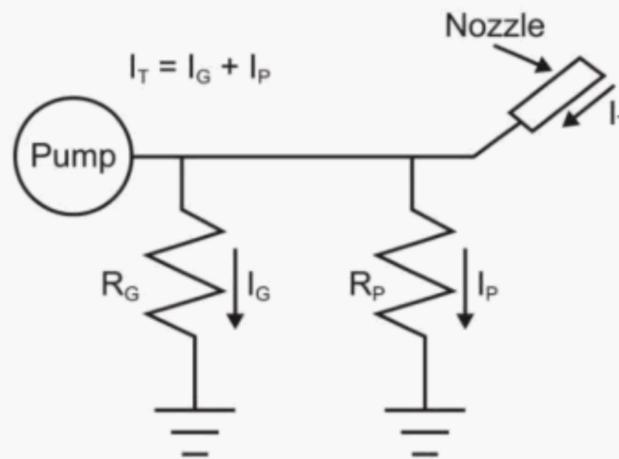


Figure A.2—Model for calculation of leakage current with body resistance

approaches. This is illustrated in [Table A.1](#) for a case study on 345 kV line. The BPA data came from Table 10 of [\[B5\]](#), where $I_T = 2$ mA crest. The Nebraska results were calculated using the normalized current [Equation \(1\)](#) for body current $I_P = 2$ mA crest and $I_P = 7.07$ mA crest. For about the same nozzle sizes, the Nebraska results give much smaller conductor-to-nozzle distances than BPA. For example, for a nozzle size of 49 mm (1.93 in), BPA requires 39.6 m (130 ft) whereas the Nebraska distance values are 25 m (82 ft) for 2 mA and 16.7 m (54.8 ft) for 7.07 mA.

Table A.1—Minimum conductor-to-nozzle distances for water spray comparison of Nebraska [B3] versus BPA [B5] studies at 345 kV

Nozzle diameter				Conductor-to-nozzle distance					
				Nebraska study				BPA study	
NEB		BPA		Inc = 1.2, IP = 2 mA crest		Inc = 4.26, IP = 7.07 mA crest		IT = 2 mA crest	
mm	in	mm	in	m	ft	m	ft	m	ft
19.1	0.8	19.1	0.8	9.5	31.2	4.7	15.4	16.8	55.1
22.9	0.9	22.2	0.9	7.4	24.3	12.1	39.7	22.5	73.8
		25.4	1.0	—	—	—	—	19.8	65.0
27.9	1.1	28.6	1.1	14	45.9	9.2	30.2	24.4	80.1
35.6	1.4	34.9	1.4	22.3	73.2	13.8	45.3	29	95.1
40.7	1.6	41.3	1.6	25	82.0	17.3	56.8	30.5	100.1
49	1.9	49.2	1.9	25	82.0	16.7	54.8	39.6	129.9
Nebraska study						BPA study			
Body resistance, $R_P = 1500 \Omega$						Total current in the nozzle, $I_T = 2 \text{ mA crest}$			
System ground resistance, $R_G = 10 \Omega$						Water conductivity, $\sigma_w = 1170 \mu\text{S/cm}$			
Water conductivity, $\sigma_w = 1200 \mu\text{S/cm}$						Water pressure = 552 kPa (80 psi)			
Body current, IP = 2 mA crest, 7.07 mA crest									
Water pressure = 552 kPa (80 psi)									

In determining the minimum conductor-to-nozzle distances, a body current of 5.0 mA rms (7.07 mA crest) and body resistance of 1500Ω are used in Table A.2 to calculate the Nebraska conductor-to-nozzle distances and to compare them with BPA measured values for transmission line voltages from 115 kV to 765 kV. Similar to the 345 kV results in Table A.2 show that the Nebraska conductor-to-nozzle distances are significantly smaller for the 115 kV to 500 kV range than BPA distances.

Table A.2—Minimum conductor-to-nozzle distances for water spray comparison of Nebraska [B3] versus BPA [B5] studies at 345 kV

Nozzle diameter		Conductor-to-nozzle distance																													
		115 kV						230 kV						345 kV						500 kV						765 kV					
		NEB		BPA		NEB		BPA		NEB		BPA		NEB		BPA		NEB		BPA		NEB		BPA							
mm	in	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft	m	ft								
19.1	0.8			12.2	40.0	3.7	12.1	13.7	44.9	4.9	16.1	16.8	55.1	6.4	21.0	18.3	60.0	6.4	21.0	18.3	60.0	7.9	25.9								
22.2	0.9	7.4	24.3	16.8	55.1	5.2	17.1	18.3	60.0	7	23.0	18.3	60.0	9.4	30.8	19.8	65.0	9.4	30.8	19.8	65.0	10.7	35.1								
25.4	1.0	—	—	18.3	60.0			19.8	65.0			19.8	65.0			21.3	69.9			21.3											
27.9	1.1	4.3	14.1			7.3	24.0			9.4	30.8			11.3	37.1			11.3	37.1			12.8	42.0								
31.8	1.3			21.3	69.9			22.9	75.1			24.4	80.1			25.9	85.0			25.9											
34.9	1.4	5.8	19.0	24.4	80.1	10.7	35.1	27.4	89.9	14	45.9	29	95.1	17.4	57.1	30.5	100.1	17.4	57.1	30.5	100.1	19.8	65.0								
41.3	1.6	6.4	21.0	27.4	89.9	13.4	44.0	29	95.1	17.4	57.1	30.5	100.1	21	68.9	33.5	109.9	21	68.9	33.5	109.9	22.9	75.1								
49.2	1.9	6.4 ^a	21 ^a	35.1	115.2	13.4 ^a	44.0 ^a	36.6	120.1	16.8 ^a	55.1 ^a	39.6	129.9	20.1 ^a	65.9 ^a	42.7	140.1	20.1 ^a	65.9 ^a	42.7	140.1	22.3 ^a	73.2 ^a								
<i>Nebraska study</i>																															
Body resistance, RP = 1500 Ω																															
System ground resistance, RG = 10 Ω																															
Water conductivity, σw = 1200 μS/cm																															
Body current, IP = 7.07 mA crest																															
Water pressure = 552 kPa (80 psi)																															
Taper nozzles																															
<i>BPA study</i>																															
Total current in the nozzle, IT = 2 mA crest																															
Water conductivity, σw = 1170 μS/cm																															
Water pressure = 552 kPa (80 psi)																															

^aRing insert in the nozzle

Annex B

(informative)

Significance of parameters

The results in [Table 2](#) and [Table 3](#) were based on parameters such as irrigation system ground resistance, water conductivity, type of nozzle, and allowable body currents that are typical on most center pivot and on grounded traveler irrigation systems. Changing these parameters may have significant influence on the conductor-to-nozzle distance.

B.1 Water pressure

From the reported data, the leakage current measurements for water pressures between 414 kPa (60 psi) and 689 kPa (100 psi) were within the range of testing accuracy. It is concluded that there is no significant effect on leakage current for this water pressure range. [\[B3\]](#)

B.2 Water conductivity

The impurities in the water increase water conductivity. For a given conductor-to-nozzle distance, power line voltage and stream size, the leakage current will be proportional to the conductivity of the water stream. Water pumped from underground sources may have higher conductivity than the surface water. Values of 200 $\mu\text{S}/\text{cm}$ to 300 $\mu\text{S}/\text{cm}$ are considered as low conductivity whereas those of 1000 $\mu\text{S}/\text{cm}$ and above represent high conductivity. For typical irrigation systems, the water conductivity is about 1200 $\mu\text{S}/\text{cm}$.

An operator adding fertilizer or manure to the irrigation water will often have conductivity measurements available to optimize nutrient delivery. Properties of types of manure are provided at the following website: <https://www.gov.mb.ca/agriculture/environment/nutrient-management/pubs/properties-of-manure.pdf>. The addition of fertilizer will have a lesser effect on water conductivity for water with high conductivity than for water with low conductivity.

Where measured values are not available, conservative estimates can be used. A conductivity above 6000 $\mu\text{S}/\text{cm}$ can begin to stunt growth in some plants; a conductivity above 12000 $\mu\text{S}/\text{cm}$ can be damaging to irrigation equipment [\[B4\]](#).

B.2 Water stream

The degree of water stream dispersion has a profound effect on the electrical conductivity of the water stream. If the stream is solid with no water dispersion, a contact with a line conductor most likely will cause a high leakage current and an electrical fault. On the other hand, when the stream is dispersed, broken up and becomes a spray, it can contact energized conductors with low probability of causing a fault. Hence the water spray current can be controlled by maintaining certain conductor-to-nozzle distances. For all applications of irrigation systems near or under power lines where a water stream can contact the power line, the water stream must be of the spray type. A better solution is to change the nozzle trajectory so the water stream does not contact the power line. Solid water streams cannot be permitted to contact the power line. In an irrigation system, any obstruction or discontinuity in pipes, hoses, or the nozzle will cause water turbulence and the breakup of water stream. Also, a ring insert in the nozzle will cause water stream breakup.

B.3 Ground resistance and body resistance

The ground resistance of the irrigation system constitutes a very important safety factor during its operation near power lines. The resistance of the irrigation system to ground (R_G) and the resistance of the person to ground (body resistance R_P) will determine how much current will flow in R_P and R_G . With the body resistance of 1500 Ω , it is important to maintain a very low irrigation system resistance below 10 Ω . In the Nebraska study [B3], it was found that grounding will keep both the center pivot and traveler irrigation systems resistance to ground at an acceptably low value. Thus, it is necessary for all irrigation systems operating near or under power lines to be grounded. The R_G value of 10 Ω used in Table 2 and Table 3 can be assumed as representative of grounded irrigation systems. However, if values of irrigation system ground resistance for a given installation are higher than 10 Ω , then the conductor-to-nozzle clearances can be calculated by the method given in Equation (1). Table B.1 illustrates how the conductor-to-nozzle clearance for a 345 kV line is affected by changing the irrigation system ground resistance (R_G) from 10 Ω to 100 Ω for various nozzle diameters.

A number of utilities have used 1500 Ω as a representative value for body resistance (R_P), and Table 2 was based on this assumption. However, there are others that may choose to use another value of body resistance. Accepted range of body resistance for various applications and circumstances has been between 500 Ω and 5000 Ω . Low values of body resistance can significantly increase the conductor-to-nozzle clearances. For example, reducing the body resistance from 1500 Ω to 1000 Ω will increase the conductor-to-nozzle clearance between 1.1 to 1.7 times depending on the size of the nozzle. From safety and economic points of view, it may be more practical to take precautions (using rubber gloves and rubber footwear) to maintain higher body resistance than to deal with greater conductor-to-nozzle clearances.

Table B.1—Minimum conductor-to-nozzle distances for water spray on a 345 kV line to ground resistance (R_G) values between 10 Ω and 100 Ω												
System resistance R_G (Ω)	Nozzle diameter											
	19.5 mm/ 0.8 in		22.9 mm/ 0.9 in		27.9 mm/ 1.1 in		35.6 mm/ 1.4 in		40.6 mm/ 1.6 in		49.0 mm/ 1.9 in	
	m	ft										
10	4.7	15.4	6.9	22.6	9.2	30.2	13.8	45.3	17.3	56.8	16.7	54.8
20	7.4	24.3	10.3	33.8	12.1	39.7	19.0	62.3	22.5	73.8	21.8	71.5
30	8.9	29.2	11.7	38.4	13.7	44.9	21.6	70.9	24.5	80.4	24.0	78.7
40	10.1	33.1	13.0	42.7	14.3	46.9	22.4	73.5	25.0	82.0	25.0	82.0
50	10.5	34.4	13.5	44.3	15.3	50.2	23.8	78.1	25.8	84.6	26.3	86.3
60	11.0	36.1	14.0	45.9	15.6	51.2	23.9	78.4	26.0	85.3	26.5	86.9
70	11.3	37.1	14.3	46.9	15.9	52.2	24.1	79.1	26.2	86.0	26.9	88.3
80	11.6	38.1	14.6	47.9	16.1	52.8	24.3	79.7	26.4	86.6	27.1	88.9
90	11.9	39.0	15.0	49.2	16.3	53.5	24.6	80.7	26.6	87.3	27.5	90.2
100	12.1	39.7	15.3	50.2	16.5	54.1	24.9	81.7	26.8	87.9	27.8	91.2

Annex C

(informative)

Example of conductor-to-nozzle distance calculation

According to [B3], the compatibility of irrigation systems and power lines as determined by allowable water stream currents will depend upon the assumptions or measurements made pertaining to the water conductivity, irrigation system grounding, body resistance, and allowable level of body current. The normalized allowable level of the total water stream current (I_T) can be determined in order to establish which nozzle size at a specific line-conductor-to-nozzle distance will limit the body current to an allowable level for specified safety criterion. The equation for the normalized total water stream current (I_{nc}) was derived in [B3] and used in this guide as Equation (1).

This example shows how the authors of reference [B3] publication have used Equation (1) and Figure 1, Figure 2, and Figure 3 to obtain conductor-to-nozzle clearances. Assuming that $R_P = 1500 \Omega$, $R_G = 10 \Omega$, $\sigma_w = 1650 \mu\text{S}/\text{cm}$, and $I_P = 7.07 \text{ mA crest}$, the normalized crest current I_{nc} can be calculated during spraying of 345 kV power line conductors for the worst case, which would be during maximum conductor sag typically at a 1.0 p.u. voltage (199 kV_{L-N}).

$$I_{nc} = 1000 \times 7.07 \times (1500 + 10) / (10 \times 199 \times 1650) = 3.25 \text{ mA}$$

Referring to Figure 3, the conductor-to-nozzle distance at which $I_{nc} = 3.25 \text{ mA crest}$ for a 23 mm taper nozzle is 8.2 m. As shown in Figure C.1, if the minimum conductor height is 9.1 m and the nozzle height is 4.6 m, the water stream from a 24° nozzle will be able to reach the conductor. On flat terrain with a 24° nozzle trajectory, the minimum conductor-to-nozzle water stream distance physically attainable is 11.1 m $[(9.1 - 4.6) / \sin 24^\circ]$. Since the actual conductor-to-nozzle distance of 11.1 m is greater than 8.2 m, which is the distance based on I_P of 7.07 mA crest, the installation is acceptable. However, in general, it is also necessary to check if the actual conductor-to-nozzle distance meets the minimum requirements of 6.2 and safety policies and codes such as the National NESC or other.

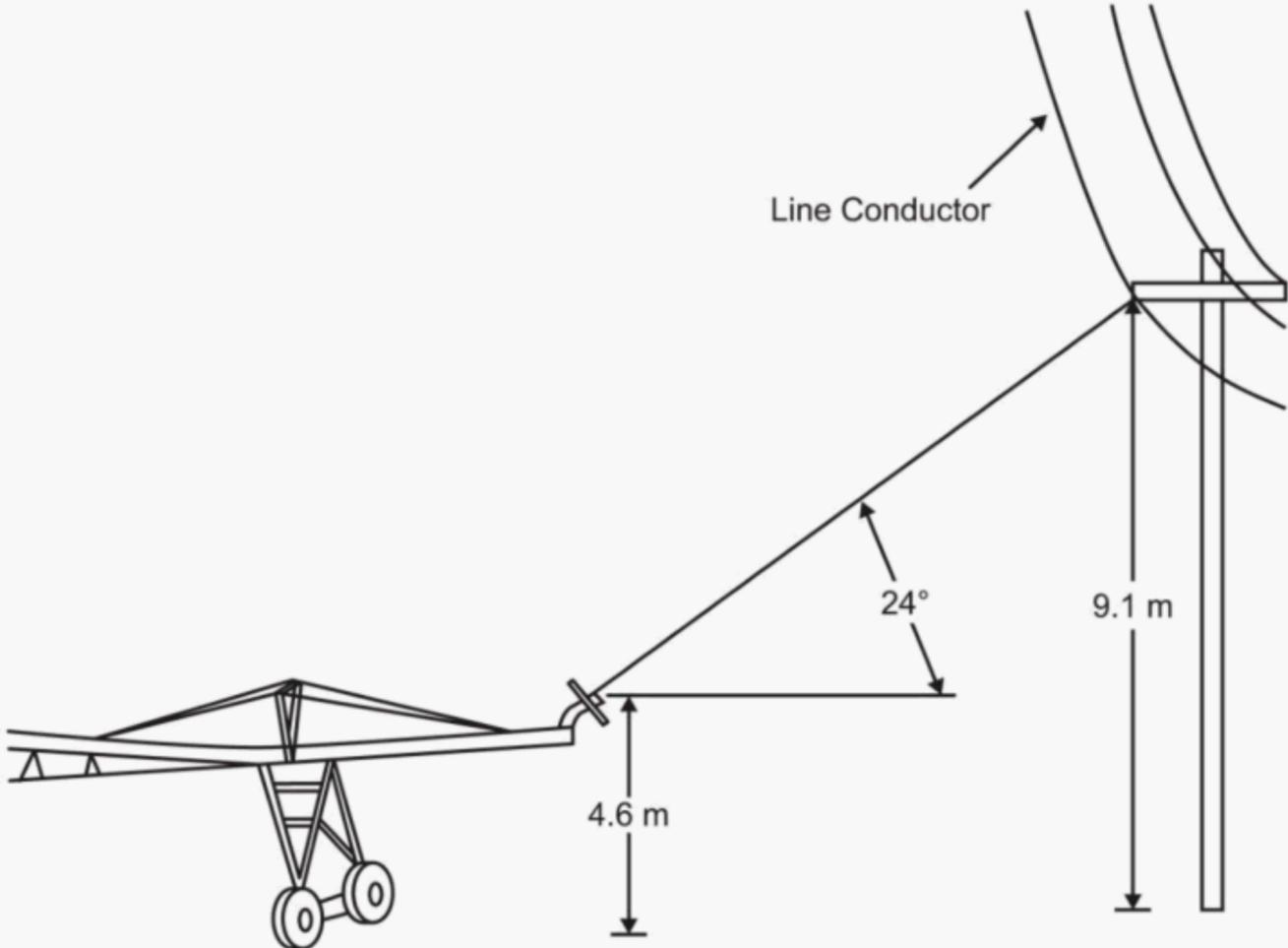


Figure C.1—Example of conductor-to-nozzle distance calculation

Annex D

Bibliography

Bibliographical references are resources that provide additional or helpful material but do not need to be understood or used to implement this standard. Reference to these resources is made for informational use only.

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[B2] 29CFR1926, OSHA Safety and Health Regulations for Construction—Subpart K: Electrical.

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