

IEEE Guide for Installation Methods for Generating Station Cables

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IEEE Power Engineering Society**

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Abstract: Installation methods to improve cable installation practices in generating stations are provided. These include cable lubrication methods, conduit-cable pulling charts, pull rope selection criteria, pulling attachment methods, and alternative methods to traditional cable pulling tension monitoring. This guide supplements IEEE Std 422-1986 and IEEE Std 690-1984, which provide specific cable installation limits. This guide may also be of benefit to cable pulling crews in commercial and industrial facilities when similar cable types and raceways are used.

Keywords: cable lubrication techniques, cable pullback, cable pullby, cable pulling tension limiting methods, conduit-cable pulling charts, pull rope attachment methods, pull rope selection criteria

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Introduction

(This introduction is not a part of IEEE Std 1185-1994, IEEE Guide for Installation Methods for Generating Station Cables.)

Construction of generating stations involves the installation of a large number of cables in conduits, trays, and duct banks. The majority of these cables are unshielded. Except in duct banks, where water may be present, there is usually no continuous ground plane on the outside of the cable insulation to allow effective post-installation voltage testing of the cable.

Since the effectiveness of post-installation testing of cable is limited, more emphasis should be placed on the method of installing the cable. IEEE Std 422-1986, IEEE Guide for the Design and Installation of Cable Systems in Power Generating Stations, and IEEE Std 690-1984, IEEE Standard for the Design and Installation of Cable Systems for Class IE Circuits in Nuclear Power Generating Stations, provide recommended cable installation limits, e.g., allowable conductor strength, sidewall bearing pressure, pulling tension equations, etc. In many situations, detailed installation methods are needed to complement these installation limits. These include cable lubrication methods, conduit-cable pulling charts, pull rope selection criteria, pulling attachment methods, and alternative methods to traditional cable pulling tension monitoring.

Improved installation methods are also expected to increase confidence in the ability of the installed cable to function in the accident environments of power generating stations.

Monitoring pulling tensions is an effective approach to ensuring that the cable pulling limits, such as sidewall bearing pressure and conductor strength, are not exceeded. However, for many cable pulls the setup time to monitor the tension is prohibitive. Most of the cable pulls are manual pulls. When a manual cable pull in conduit is made, the dynamometer reading has to be adjusted after measuring various angles. Due to the complexity of this process, manual cable pulls are seldom monitored. This guide introduces the use of conduit-cable pulling charts and other methods as alternatives to direct monitoring of the pulling tensions.

Cable pullby is a common practice in the industry though not addressed in either cable manufacturer literature or existing industry standards. Some utilities have reported damage to the existing cables in the conduits when pulling cables into conduits that already contain cables, i.e., cable pullbys. Monitoring the pulling tensions may not prevent this cable damage, since the damage can occur from the pull rope as the pull rope or cable passes over existing cables. Instead of prohibiting the practice of cable pullbys, installation methods with modifying restrictions are provided to control the process. However, it should be recognized that this is a risky procedure and damaged cables or questionable conditions can result from such pullby operations.

AEIC G5-90, Underground Extruded Power Cable Pulling Guide, will complement this guide for long power cable pulls through duct bank systems and should be considered as an additional reference source. Work is in progress under IEEE P971, Guide for Distribution Cable Installation Methods in Duct Systems.

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IEEE Guide for Installation Methods for Generating Station Cables

1. Overview

1.1 Scope

This guide provides installation methods to improve cable installation practices in generating stations. Some specific limits in cable installation are covered in IEEE Std 422-1986¹ and IEEE Std 690-1984 and are not within the scope of this guide.

This guide may also be of benefit to cable pulling crews in commercial and industrial facilities when similar cable types and raceways are used.

1.2 Purpose

The purpose of this guide is to improve cable pulling practices in generating stations by:

- a) Establishing alternative methods of limiting and monitoring cable pulling tensions to prevent cable damage from excessive pulling tension
- b) Introducing the use of cable pull charts that address cable pulling limits including sidewall bearing pressure, and relationship of conduit length and total conduit bends
- c) Establishing safe guidelines for pulling cables into conduits containing cables (pullbys)
- d) Providing practical guidance in lubrication techniques, pull rope attachment methods, and pull rope selection
- e) Facilitating good conduit system layout to permit the safe installation of cables in most raceways without the need for difficult monitoring or costly, rigorous calculations

2. References

This guide shall be used in conjunction with the following references.

ANSI/NEMA WC 55-1992 (ICEA S-82-552), Instrumentation Cables and Thermocouple Wire.²

ANSI/NEMA WC 57-1990 (ICEA S-73-532), Standard for Control Cables.

¹Information on references can be found in clause 2.

²NEMA publications are available from the National Electrical Manufacturers Association, 2101 L Street NW, Washington, DC 20037, USA.

ANSI/NFPA 70-1993, National Electrical Code (NEC).³

IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).⁴

IEEE Std 400-1991, IEEE Guide for Making High-Direct-Voltage Tests on Power Cable Systems in the Field (ANSI).

IEEE Std 422-1986, IEEE Guide for the Design and Installation of Cable Systems in Power Generating Stations (ANSI).

IEEE Std 690-1984, IEEE Standard for the Design and Installation of Cable Systems for Class IE Circuits in Nuclear Power Generating Stations (ANSI).

NEMA WC 3-1992 (ICEA S-19-81), Rubber Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

NEMA WC 5-1992 (ICEA S-61-402), Thermoplastic-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

NEMA WC 7-1993 (ICEA S-66-524), Cross-Linked-Thermosetting-Polyethylene-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

NEMA WC 8-1993 (ICEA S-68-516), Ethylene-Propylene-Rubber Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

3. Definitions

The following definitions are provided to describe terms used in this guide. For definitions of other terms, see IEEE Std 100-1992.

3.1 break link: A weak section of rope connected between the cable pulling attachment and the pull rope that is intended to break when the pulling tension exceeds a certain limit.

3.2 cable pullback: The pulling of one or more cables out of a conduit system for the express purpose of repulling the cables into the same conduit.

NOTE—Cable pullback is normally performed to allow relocation of a portion of a conduit system or to avoid pullbys during the installation of additional cables.

3.3 cable pullby: The pulling of cable(s) into a conduit that already contains one or more cables.

3.4 control cable: Cable used in a control function application, e.g., interconnection of control switches, indicating lights, relays, solenoids, etc. Generally the cable construction is 600 V or 1000 V, single or multiple conductors, typically in wire sizes 14 AWG (2.08 mm²), 12 AWG (3.31 mm²), 10 AWG (5.26 mm²), 9 AWG (6.63 mm²), or 8 AWG (8.37 mm²).

3.5 critical jamming ratio: The ratio of conduit diameter (D) to cable diameter (d) that could result in the cable wedging or jamming in the conduit during the cable pull.

³ANSI/NFPA publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA, and also from Publications Sales, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, USA.

⁴IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

3.6 galloping: The sudden surging and stopping action of cables during high-tension pulls when excessive stretching occurs in the pull rope.

3.7 instrument cable: Cable used for instrument applications where the cable construction is generally 300 V, twisted pairs or triads, in wire sizes 16 AWG (1.31 mm²) or 18 AWG (0.823 mm²). For the purposes of this document, coaxial, triaxial, and fiber optic cables are not considered instrument cable because of differences in cable installation limits.

3.8 low-voltage power cable: Cable designed to supply power to utilization devices of the plant auxiliary system, operated at 600 V or 2000 V in sizes ranging from 14 AWG (2.08 mm²) to 2000 kcmil (1010.0 mm²).

3.9 lubricant: Any material applied on the cable or into a conduit to reduce friction and hence tension during cable pulling operations.

3.10 luff: Pulling additional cable out of the conduit, using a split grip or mare's tail, to be used to facilitate terminating, racking, etc.

3.11 medium-voltage power cable: Cable designed to supply power to utilization devices of the plant auxiliary system, operated at 5000–46 000 V in sizes ranging from 8 AWG (8.37 mm²) to 2000 kcmil (1010.0 mm²).

3.12 power cable: Cable used to supply power to plant auxiliary system devices. The classifications for power cable are: low voltage and medium voltage.

3.13 pull rope: A rope, attached to the cable, that is used to pull the cable through the conduit system. Syn: bull rope; pull line.

4. Conduit-cable pulling charts

4.1 General

The majority of generating station cable pulls in conduit systems are manual pulls. Monitoring the pull tensions for manual pulls is difficult and unreliable. The traditional guidance given to pulling crews is to limit the pull to no more than three or four 90° conduit bends between pull points. Experience has shown that excessive cable tensions may occur unless limits are also established for the conduit length.

A preferred approach is to use conduit-cable pulling charts in conjunction with proper cable installation methods. The use of these charts eliminates the need on many cable pulls to explicitly monitor pull tension or provide a written record for comparing allowable and actual measured pulling tensions. The conduit-cable pulling charts address the cable pulling limits outlined in IEEE Std 422-1986 and IEEE Std 690-1984. This includes allowable conductor strength, sidewall bearing pressure, and jacket strength limits. Cable jamming is not addressed in the pulling charts and should be checked separately as discussed in 4.2 item e).

The conduit-cable pulling charts may also be used as guides in establishing the maximum distance between pull points during the layout of the conduit systems. This ensures that an appropriate number of pull points are installed.

4.2 Cable types and raceway configurations

The maximum effective conduit length shown in the conduit-cable pulling charts depends on conduit size and cable type. The conduit-cable pulling charts in tables 3 through 14 are based on the following conditions:

- a) The radius of conduit bends are assumed to be equal to or greater than those specified in the National Electrical Code (NEC) (ANSI/NFPA 70-1993) table 346-10 Exception "Radius of Conduit Bends (inches)."
- b) The cable constructions are assumed to conform to one of the following:
 - 1) ANSI/NEMA WC 55-1992 (ICEA-S-82-552)
 - 2) ANSI/NEMA WC 57-1990 (ICEA-S-73-532)
 - 3) NEMA WC 3-1992 (ICEA-S-19-81)
 - 4) NEMA WC 5-1992 (ICEA-S-61-402)
 - 5) NEMA WC 7-1993 (ICEA-S-66-524)
 - 6) NEMA WC 8-1993 (ICEA-S-68-516)

Smallest conductor sizes for the various cable types are: two pair 18 AWG (0.823 mm^2) for instrument cable, single conductor 14 AWG (2.08 mm^2) for control cable, and single conductor 12 AWG (3.31 mm^2) for low-voltage power cable. Conductor material is copper. The cable outer sheath is not armored or lead sheathed. Cable pulling calculations are necessary for armored or lead sheathed cables.

- c) The cable sidewall bearing pressure (SWBP) limits vary with cable construction and cable supplier. Charts for two different SWBP limits were developed. In the absence of specific cable manufacturer SWBP data, charts for control and power cable using SWBP = 500 lbf/ft (7297 N/m) of bend radius and instrument cable using SWBP = 300 lbf/ft (4378 N/m) of bend radius should be used.
- d) Conduit-cable fill does not exceed the NEC fill limits of 53% for one cable, 3% for two cables, or 40% for three or more cables.
- e) The ratio of conduit diameter (D) and cable diameter (d), for a pull of three cables of equal size, does not fall into the critical jamming ratio D/d between 2.8 and 3.1 (see IEEE Std 422-1986).

When three cables are pulled into a conduit, it is possible for the center cable to be forced between the two outer cables while being pulled around a bend if the D/d ratio approaches a value of 3.0. Up to a ratio of 2.5, the cables are constrained into a triangular configuration. However, as the value approaches 3.0, jamming of the cables could occur, and the cables could freeze in the conduit, causing serious cable damage. To allow for tolerances in cable and conduit sizes and for ovalness in the conduit at a bend, the D/d ratios between 2.8 and 3.1 should be avoided.

- f) The proper cable lubrication techniques as discussed in clause 7 are followed. Charts for two values of effective coefficient of friction (K') were developed (0.35 and 0.5). The effective coefficient of friction is the coefficient of friction multiplied by the weight correction factor. The coefficient of friction varies with cable jacket material, conduit material, and length of conduit. In the absence of test data, charts based on $K' = 0.5$ should be used. Technical papers [B2]⁵, [B4], and [B5] should be used to obtain the coefficient of friction and the weight correction factor.
- g) The limitations given for pullbys in clause 9 are adhered to.
- h) The lead cable puller stops the pull if abrupt and unexpected change in pulling resistance is encountered.

4.3 Use of conduit-cable pulling charts

The maximum effective conduit length given in the conduit-cable pulling charts presented in tables 3 through 14 should be used as a limitation in cable pulling. If the conditions of the pull are not consistent with

⁵The numbers in brackets correspond to those in the bibliography in clause 11.

the assumptions described in 4.2, or the effective conduit length exceeds the maximum effective conduit length shown in the charts, specific analysis or monitoring of the cable pulling tensions should be made using the pulling tension equations given in IEEE Std 422-1986 or IEEE Std 690-1984.

If control and power cables are pulled together in the same conduit, the pulling charts for power cable should be used.

In order to use the charts, the distance between pull points has to be measured. If some of the conduit sections are not horizontal, an effective conduit length has to be developed. The effective conduit length and the total degrees of angle in the pull are compared to the charts. The effective conduit length is developed as shown in table 1.

Field measurements in congested areas of a generating plant can be difficult. Some latitude in the accuracy of the measurement of the conduit length and total degrees of bend is permitted. Conduit length measurements should be within 2% and total conduit angle measurements should be within 15°. The slope adjustment factor (SAF) can be taken from either equation (1) or from table 2 for specific combinations of effective coefficient of friction and slope angles. SAF, for use in table 1, adjusts the measured length of sloped sections of conduits to arrive at an effective conduit length.

$$SAF = \frac{\sin \theta + K' \cos \theta}{K'} \quad (1)$$

where

- SAF* is the slope adjustment factor, used in table 1
 θ is the angle (in degrees) of the slope from horizontal
 K' is the effective coefficient of friction

Table 1—Development of effective conduit length—Chart comparison

Type of conduit section	Effective conduit length
Horizontal conduit	As measured
Conduit sweep	Need not be included
Vertical conduit—Up	As measured multiplied by: 2 for $K' = 0.5$ and 2.9 for $K' = 0.35$
Vertical conduit—Down	Not included; $L = 0$
Slope—Down	As measured
Slope—Up	As measured multiplied by <i>SAF</i> from equation (1) or table 2

Table 2—Slope adjustment factor (SAF)

Slope angle (°)	Effective coefficient of friction (K')	
	0.5	0.35
15	1.5	1.7
30	1.9	2.3
45	2.1	2.7
60	2.2	2.9

4.4 Bend correction adjustment

The conduit-cable pulling charts are based upon all of the conduit bends located at the end of the cable pull. This results in conservative values. If the conduit bends are distributed throughout the conduit section, as is typical, then the user may consider one of the following:

- a) Performing a detailed cable pulling calculation using the pulling equations listed in IEEE Std 422-1986 or IEEE Std 690-1984. Many computer software programs are available to perform this calculation. This is the recommended approach.
- b) Applying bend correction (BendCorr) adjustment factors to the maximum effective conduit length shown in the charts. These adjustment factors are discussed in annex C.

4.5 Examples

Examples illustrating the use of the conduit-cable pulling charts are included in annex A.

4.6 Methodology

The conduit-cable pulling charts are influenced by cable construction, allowable cable fill in conduits, coefficient of friction, location and number of conduit bends, radius of conduit elbows, and SWBP. Some may find it desirable to develop new charts using project-specific information. The methodology used to develop the conduit-cable pulling charts is presented in annex B.

4.7 Pulling tension

Maximum allowable pulling tensions (MAPT) have been provided in the charts to aid in selecting rope size, pulling machine capacity, pull rope attachment method, and number of workers for manual pulls. In most cases actual tension will be significantly less than the maximum values in the charts. This is due to the conservative basis used in developing the maximum effective conduit lengths. Using MAPT from the charts, equation (2) can be used to arrive at a projected pulling tension (PPT). The BendCorr factor in equation (2) can be obtained from tables C.1 and C.2, or conservatively assumed to be equal to 1.

$$PPT = MAPT \cdot \frac{L'}{L} \cdot \frac{Fill'}{Fill} \cdot BendCorr \quad (2)$$

where

<i>PPT</i>	is the projected pulling tension, lbf (N)
<i>MAPT</i>	is the maximum allowable pulling tension, lbf (N) (from tables 3 through 14)
<i>L'</i>	is the effective conduit length, ft (m)
<i>L</i>	is the maximum length of conduit, ft (m) (from tables 3 through 14)
<i>BendCorr</i>	is the distribution of conduit bends. This varies from 0.25 to 1, decreasing as the conduit bends are located at the front of the pull (see tables C.1 and C.2)
<i>Fill'</i>	is the percentage of cable fill of conduit after the cable pull
<i>Fill</i>	is the chart maximum conduit-cable fill, which is 40%

Table 3a—Control cable—Conduit-cable pulling chart
SWBP = 500 lbf/ft and $K' = 0.5$

Conduit size (in)	Maximum effective conduit length (ft)						Maximum allowable pulling tension (lbf)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
0.75	935	631	288	131	89	60	66
1.0	754	509	232	106	71	48	132
1.5	483	326	149	68	46	31	310
2.0	327	221	101	46	31	21	353
2.5	251	169	77	35	24	16	386
3.0	200	135	62	28	19	13	478
3.5	173	117	53	24	16	11	551
4.0	142	96	44	20	13	9	583
5.0	138	93	43	19	13	9	895
6.0	120	81	37	17	11	8	1124
NOTE—Minimum one single conductor 14 AWG or one multiple conductor 14 AWG conductor size.							

Table 3b—Control cable—Conduit-cable pulling chart
SWBP = 7297 N/m and $K' = 0.5$

Conduit size (cm)	Maximum effective conduit length (m)						Maximum allowable pulling tension (N)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
1.9	284.9	192.4	87.7	40.0	27.0	18.2	293.6
2.5	229.8	155.2	70.7	32.2	21.8	14.7	587.1
3.8	147.1	99.3	45.3	20.7	13.9	9.4	1379.8
5.1	99.7	67.3	30.7	14.0	9.4	6.4	1569.3
6.4	76.5	51.7	23.6	10.7	7.3	4.9	1717.4
7.6	61.0	41.2	18.8	8.6	5.8	3.9	2125.3
8.9	52.6	35.5	16.2	7.4	5.0	3.4	2451.3
10.2	43.2	29.2	13.3	6.1	4.1	2.8	2592.3
12.7	42.1	28.5	13.0	5.9	4.0	2.7	3980.5
15.2	36.7	24.8	11.3	5.1	3.5	2.3	4999.6
NOTE—Minimum one single conductor 2.08 mm ² or one multiple conductor 2.08 mm ² conductor size.							