AMERICAN TRANSMISSION COMPANY®	**Criteria**	Department:	Asset Management
		Document No:	**CR-0062 v06**
Title: **UNDERGROUND TRANSMISSION LINE AMPACITY RATINGS**		Issue Date:	12-28-2012
		Previous Date:	05-24-2010

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1.0 Scope

1.1 This document provides American Transmission Company's (ATC) underground transmission line conductor steady-state current capacity ratings criteria for use in planning, operations, and design.

1.2 This document does not consider system stability, voltage limits, operating economies, or capacity limits of substation equipment all of which could otherwise limit or affect the ampacity of a transmission line.

1.3 In summary, this criteria document includes permissible continuous current ratings for normal and emergency conditions during spring, summer, fall, and winter seasons.

2.0 Introduction

2.1 The electrical ampacity rating of an underground transmission line is dependent upon the material characteristics of the installed cable system and upon the surrounding subsurface environments ability to dissipate the cable generated heat. This document specifies maximum cable conductor temperatures, based on industry standards and manufacturer's recommendations, to be used in designing new underground lines and determining ampere ratings of existing lines. For underground transmission lines, this document Includes:

2.1.1 Ampacity ratings criteria for normal and emergency conditions during spring, summer, fall and winter seasons.

2.1.2 Ampacity ratings criteria for additional durations consistent with Operations' needs and as readily available.

2.1.3 Explanation or documentation of methods, formulas, standards, sources and assumptions used in determining the ampacity ratings.

2.1.4 Qualification of any differences in ratings calculation methodology based on:

2.1.4.1 Cable system age or vintage
2.1.4.2 Maintenance history, condition. etc.
2.1.4.3 Pre-loading levels

2.1.5 Explanation of any special applications exceptions to the standard criteria in this document.

2.2 This document provides for a consistent methodology for determining ratings for underground and submarine cable systems. This document does not attempt to establish ampacities for specific cable types and sizes in that there are numerous installation conditions that must be considered to determine the ampacity of any one cable segment.

2.3 This document also adopts the ratings and/or guidelines from the founding utilities for conductor ampacity ratings of underground transmission lines. The founding utilities ratings documents establish the ATC ratings for the respective facilities and consists of the following:

2.3.1 The ampacity rating criteria for many Milwaukee area 138 kV high pressure fluid filled (HPFF) cable circuits as documented in the WE Reference Manual, "Underground Transmission Line Circuit Ampacities." The document is located on the ATC file server in the "SELD folder" for reference purposes. The associated WE rating methodology is documented in Appendix A. Periodic engineering review or modification to these circuits may initiate an engineering ratings analysis and application of the methodology used for new circuits.

2.3.2 Ratings for the solid dielectric system that were formally part of the Alliant Energy System, which are based on recommendations of the manufacturer who designed and installed the systems.

2.3.3 Other specialized underground cable systems, such as submarine and tunnel systems, are evaluated on a case-by-case basis, using engineering consultants and cable manufacturer's recommendations and industry standards.

3.0 References

3.1 The following documents were used in the development of this methodology.

3.1.1 AEIC CG1, Guide for Establishing the Maximum Operating Temperatures of Impregnated Paper and Laminated Paper Polypropylene Insulated Cables (3rd Edition)

3.1.2 AEIC CG6, Guide for Establishing the Maximum Operating Temperatures of Extruded Dielectric Insulated Shielded Power Cables (2nd Edition)

3.1.3 AEIC CS2, Specifications for Impregnated Paper and Laminated Paper Polypropylene Insulated Cables High-Pressure Pipe-Type (6th Edition)

3.1.4 AEIC CS9, Specification for Extruded Insulation Power Cable and Their Accessories Rated Above 45 KV Through 345 kV (1st Edition)

3.1.5 ATC Criteria CR-0061; Overhead Transmission Line Ampacity Ratings

3.1.6 ATC Criteria CR-0063; Substation Equipment Ampacity Ratings

3.1.7 ATC Procedure PR-0285, Facility Ratings

3.1.8 ATC Operating Procedure TOP-20-GN-000034, EMS Facility Seasonal Limit Transition

3.1.9 EPRI Technical Report TR-108919, Soil Thermal Properties Manual for Underground Power Transmission, Nov. 1997

3.1.10 EPRI Technical Report, TR-109205, Deep Cable Ampacities, Guidelines for Calculating Ampacities of Cables Installed by Guided Boring, December 1997

3.1.11 EPRI Underground Transmission Systems Reference Book, 2006 Edition

3.1.12 EPRI UTWorkstation UTW Software, Version 6.2

3.1.13 IEC 60287, Parts 1-3 Electric Cables – Calculation of Current Ratings

3.1.14 IEC 60853, Parts 2&3 Calculation of the Cyclic and Emergency Current Rating of Cables

3.1.15 IEEE 442-1981 Guide for Soil Thermal Resistivity Measurements

3.1.16 IEEE 835-1994 Standard Power Cable Ampacity Tables

3.1.17 Neher-McGrath, AIEE Transactions on Power Apparatus and Systems, Vol. 76, October 1957, “The Calculation of Temperature Rise and Load Capability of Cable Systems”

3.1.18 National Electric Safety Code (NESC), ANSI-C2, as adopted by the respective state code

3.1.19 NERC Reliability Standard FAC-008-3, Facility Ratings

3.1.20 Wisconsin Electric Power Company, Reference Manual, Document No. 25-130, dated 02/01, Underground Transmission Line Circuit Ampacities.

4.0 Definitions

The bolded definitions are from the NERC Glossary of Terms.

4.1 Ambient Soil (Water) Temperature: The nominal temperature of the soils (or waters) surrounding the subsurface cable system.

4.2 Ampacity: The current carrying capacity of a conductor or circuit. This value is given in Amperes and is a rating for each phase cable of a three-phase circuit. This value may also be listed using apparent power (Mega-Volt-Amperes or MVA) based on the nominal system voltage.

$$\mathrm{MVA} = \frac{\sqrt{3}(\mathrm{kV})(\mathrm{amps})}{1000}$$

4.3 Cable System: The cable system includes the cable and associated accessories along with the surrounding subsurface environment that impacts the thermal performance of the installed cable, including but not limited to duct or pipe, backfill materials, soils, casings, external heat sources, etc.

4.4 **Emergency Rating**: The rating as defined by the equipment owner that specifies the level of electrical loading or output, usually expressed in megawatts (MW) or Mvar or other appropriate units, that a system, facility, or element can support, produce, or withstand for a finite period. The rating assumes acceptable loss of equipment life or other physical or safety limitations for the equipment involved.

4.5 **Normal Rating**: The rating as defined by the equipment owner that specifies the level of electrical loading, usually expressed in megawatts (MW) or other appropriate units that a system, facility, or element can support or withstand through the daily demand cycles without loss of equipment life.

4.6 Seasonal Periods: ATC uses four (4) seasons (Spring, Summer, Fall and Winter) as described in Operating Procedure TOP-20-GN-000034, EMS Facility Seasonal Limit Transition.

4.7 SELD: ATC’s Substation Equipment and Line Database (SELD) is the primary computer application for maintaining ratings data.

4.8 Steady-State Load: A theoretical condition with constant electrical current; electrical load.

4.9 Transient Load: A theoretical condition with a fluctuating electrical current (electrical load). Due to the thermal inertia of equipment and conductors, the associated increase or decrease in the equipment or conductor temperature lags the associated change in loading.

5.0 Cable System Rating

5.1 General:

5.1.1 The rating for underground cable circuits are based on IEC-60287, IEC-60853 and Neher-McGrath cable rating methodologies. Cable ratings shall be determined using an industry accepted modeling program. Acceptable cable rating programs are EPRI ACE, EPRI UTW, CYME CymCap and USAmp. Although these programs may not provide identical results, the comparable results are acceptable for rating purposes.

5.1.2 Historical ratings methodologies from previous owners may also be as they utilized the applicable standards, manufacturer information and calculation methods that were available when the circuits were constructed. The performance history of these circuits supports continued use of these ratings.

5.1.3 Different construction, installation and environmental conditions along cable section will result in different ratings. The ratings for a cable section shall be that of the most limiting situation along the entire length of the cable section.

5.1.4 Cable accessories, such as terminators and splice joints, are designed to operate at emergency temperatures of 105ºC or higher. Cable accessories are assumed to not be a limiting component within the respective cable system.

5.2 Normal Rating:

5.2.1 The normal (steady state) cable ampacity is calculated for normal operating conditions with an average daily load factor and a maximum normal conductor operating temperature, as indicated in Table 1. These cable normal temperatures are based on industry standards as outlined in AEIC publications CG1 and CG6.

5.2.2 The maximum cable operating temperatures as indicted in Table 1 shall be used unless age, condition or past loading conditions indicate that deterioration of the cable insulation and/or covering may have occurred, then a lower maximum operating temperature shall be used.

5.2.3 The normal rating for cable systems are considered under continuous operation without any interruptions, transient affects and are independent of time.

Table 1 – Cable Temperature Limits[1]

Cable / Insulation Type	**Maximum Conductor Temperature**		
	Normal Operation	Emergency Operation	
		≤ 100 Hrs.	> 100 Hrs.
EPR, Extruded Dielectric	90ºC (194ºF)	105ºC (221ºF)	105ºC (221ºF)
XLPE, Extruded Dielectric	90 ºC (194ºF)	105ºC (221ºF)	105ºC (221ºF)
Low Pressure Self-Contained (LPSC)	85 ºC (185ºF)	105ºC (221ºF)	100ºC (212ºF)
Med Pressure Self-Contained (MPSC)	85 ºC (185ºF)	105ºC (221ºF)	100ºC (212ºF)
High Pressure Fluid Filled (HPFF), Mfd.<1967	70 ºC (158ºF)	90ºC (194ºF) [2]	90 ºC (194ºF) [2]
High Pressure Fluid Filled (HPFF), Mfd.≥1967	85 ºC (185ºF)	105ºC (221ºF) [2]	100ºC (212ºF) [2]
High Pressure Gas Filled (HPGF)	85 ºC (185ºF)	105ºC (221ºF) [2]	100ºC (212ºF) [2]

5.3 Emergency Rating:

5.3.1 The emergency ampacity is calculated for transient operating conditions with a 100% load factor and a maximum emergency conductor operating temperature, as indicated in Table 1. These cable emergency temperatures are based on industry standards as outlined in AEIC publications CG1 and CG6.

5.3.2 The long thermal time constant associated with underground cables allows them to have higher emergency ampacity ratings for short durations, as compared to overhead lines. The nominal time constant for underground cables is 50-150 hours and that of overhead lines is 20-30 minutes.

5.3.3 In determining the emergency (transient) ampacity rating of a cable system, the pre-contingency conductor temperature and the loss factor must be know. The calculation of cable emergency ampacity depends on the thermal inertia of the cable along with the thermal conductivity of the cables and the surrounding environment.

5.3.4 Long-term emergency (transient) for a cable system assume that the cable emergency loading duration is limited. The maximum cable emergency loading durations are listed in Table 2. These cable emergency periods are based on industry standards as outlined in AEIC publications CG1 and CG6.

Table 2 – Maximum Cable Emergency Durations[3]

Cable / Insulation Type	**Emergency Operating Temperature** (ºC)	**Any One Emergency Period** (Hrs.)	**Any One 12-Month Period** (Hrs.)	**Average per Year Over Cable Life** (Hrs.)
Extruded Dielectric (XLPE & EPR)	105	216	216	72
Low & Med. Pressure Self-Contained Fluid Filled (LPSC & MPSC)	105	100	100	20
	100	300	300	60
High Pressure Pipe-Type, Fluid & Gas Filled (HPFF & HPGF)	105	100	100	20
	100	300	300	60

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[1] Maximum cable normal and emergency temperatures are industry accepted values as referenced in AEIC Guides CG1 and CG6, Guides for Establishing the Maximum Operating Temperatures of Paper Insulated and Extruded Cables respectively.

[2] The maximum emergency temperatures may be used for ampacity calculations when adequate knowledge of the thermal characteristics of the cable environment is available. In the absence of adequate thermal characteristics, the emergency temperatures shall be reduced by 10 ºC.

[3] Maximum cable emergency durations are derived from industry standards AEIC Guides CG1 and CG6, Guides for Establishing the Maximum Operating Temperatures of Paper Insulated and Extruded Cables respectively.

5.4 Operations Support

5.4.1 The ATC Operations Department may require additional rating information beyond that available in conventional EMS systems. Generally, EMS systems allow only for display of data associated with a normal and emergency rating.

5.4.5 The ATC EMS will display normal and emergency (2-hour) limits for the operating period. The normal rating assumes a load factor of 75%, unless noted otherwise within the SELD ratings. The emergency rating assumes that the cable pre-load was at 100% of the normal rating.

5.4.6 Other longer period contingency ratings may be established for various operational situations.

5.5 Planning Support: ATC Planning will use ratings ≤ 8-hour emergency rating (100% normal pre-load condition) for transmission planning studies that evaluate the future needs of the transmission system. Midwest Independent Service Operator (MISO) will use ratings ≤ 8-hour emergency rating (100% pre-load condition) for transmission service sales transactions and direction.[4]

5.6 Loading Periods:

5.6.1 Asset Planning & Engineering may develop, maintain, and distribute a loading table for specific underground lines. The loading table will reflect the most limiting portion of the respective underground line. These emergency loading tables will be available through SELD.

5.6.2 SELD includes ratings for the normal and emergency operating periods and is shared with MISO for underground facilities. The loading tables provide Planning and Operations with additional information that is more specifically useful to their functions

5.6.3 Normal Rating: The normal rating of an underground transmission line is the most limiting portion the line at the cables maximum normal conductor operating temperature. It is indicative of an indefinite or continuous loading period.

5.6.4 Emergency Rating: The emergency rating of an underground transmission line is based upon the most limiting portion of the line at the cables maximum emergency operating temperature. The emergency rating may be based upon achieving the emergency operating temperature within 2 hours or 100 hours (Wisconsin Electric methodology).

5.6.4.1 30 Minutes: An operator may use a 30-minute limit under circumstances where contingency overloads can be mitigated within 30 minutes.

5.6.4.2 2 Hours (ATC Standard Emergency Rating): The standard emergency limitation period for cable system operation is based on the 2-hour rating with a 100% preload (normal) condition.

If a contingency would cause an underground line to reach the 2-hour limit, the operator develops a mitigation strategy to reduce the line to 2-hour limit for the initial 2-hour period and to the normal limit thereafter, should the contingency occur.

5.6.4.3 8 Hours: An 8-hour limit allows ATC Operators to utilize a longer term loading limit of the underground line, during a longer duration contingency situation, such as the routine maintenance on an adjacent facility.

5.6.4.4 24 Hour: A 24-hour limit allows ATC Operators to utilize a longer term loading limit of the underground line. Generally, the 24-hour limits are for information during operation following the loss of system facilities for which mitigation is expected to take up to a day or for operation of radial and/or limited source networks where load within a geographical area has the highest influence on the underground line loading.

5.6.4.5 100 Hour: A 100-hour limit allows ATC Operators to utilize a longer term loading limit of the underground line. Generally, the 100-hour limits are for information during operation following the loss of system facilities, such as a transformer or overhead transmission line, to allow for its mitigation. The Wisconsin Electric legacy emergency ratings are based upon a 100 hour emergency rating.

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[4] Such ratings will be used in interaction with any other entities honoring ATC facilities in making transmission service decisions.

5.6.4.6 Greater than 100 hours: Allows for Operators to utilize a longer term loading limit for the underground line, frequently associated with the loss of an adjacent underground line. Many pressurized underground lines must be operated at a lower maximum emergency conductor temperature for emergency periods longer than 100 hours, refer to Table 1. Time intervals of 300 and 768 hours are frequently used for these emergency loading periods.

6.0 Operating Conditions

6.1 Load/loss Factor

6.1.1 Load Factor provides a measure of the variation in load over a period of time, is generally cyclic and measured over a typical daily cycle. The load factor rating depends only on the load shape and is independent of the magnitude of the current itself.

6.1.1.1 Load factor is the ratio of the average load over a 24 hour period to that of the peak loading during that 24 hour period. Load factors are generally readily available or can be readily calculated from historic system load data. Seasonal or annual load factors may be used as appropriate for the specific cable section.

6.1.1.2 Load factors are not used directly in determining a cable rating, but can be used to approximate the associated loss factor.

6.1.1.3 Assume 75% load factor for normal ratings, unless system studies and or review of historic cable circuit loading indicate that a higher load factor is appropriate for the specific cable line circuit. Generally, the load factor used will be in increments of 5%.

6.1.1.4 Emergency (transient) ratings for cable systems are commonly calculated using 100% load factor (LF).

This is assumption that is built into most cable rating programs. As cable rating programs are enhanced to allow for a load factor of less than 100% for emergency loading conditions, an appropriate LF shall be used for emergency ratings for 24 hours or longer.

Where possible, a typical LF of 90% shall be used for emergency ratings of 24 hours or longer, with a 100% LF used for emergency ratings less than 24 hour duration. Historic loadings and/or systems studies may show that other emergency LF would be appropriate for specific cable sections, however the long term emergency LF shall never be less than that used for the normal rating LF.

6.1.2 Loss Factor is used in the calculation of the cable rating and can be approximated from the load factor rating. Loss factor is the ratio of the average power loss in the cable to that of the peak-load power loss.

6.1.2.1 An empirical formula developed for transmission cable systems to approximate the loss factor to the load factor is:

$$\text{Loss Factor} = 0.3(\text{Load Factor}) + 0.7(\text{Load Factor})^2$$

6.1.2.2 The loss factor accounts for ohmic losses in the conductor, dielectric losses in the insulation, and circulating and eddy currents losses in the surrounding shield, pipe, metallic duct and/or casing.

6.1.2.3 Cable losses generate heat in the cable system which must be dissipated. The ability of cable system and the surrounding environment to dissipate this loss generated heat ultimately determine the cable rating.

6.2 Conductor Temperature

6.2.1 Conductor temperatures for cable systems are determined by industry standards as outlined in AEIC CG1 and CG6 for extruded and impregnated paper type cables respectively.

6.2.2 Maximum normal and emergency cable operating temperatures are for the hottest portion of the cable system at any time. Maximum cable temperatures used by ATC are summarized in Table 1.

6.2.3 The maximum allowable temperature of the cable can be reduced to account for age and condition of specific cable systems. High pressure paper insulated cables manufactured prior to 1967 have reduced operating temperatures due to manufacturing methods used and insulating technology available at that time.

6.3 Preload

6.3.1 The pre-load condition is the conductor temperature or load level prior to the occurrence of an emergency (contingency) loading period on the cable. The cable pre-load combined with the thermal response time of the cable and surrounding environment, are factors in determining the emergency rating of the cable system.

6.3.2 The ATC EMS will display a 2-hour emergency rating limit for the operating period using a 100% preload assumption. A 100% preload assumes that prior to the emergency period the cable is operating at the rated normal current and temperature rating.

6.3.3 Other lower pre-loading conditions may be used to obtain higher short term emergency load ratings for a cable and will be evaluated on a case-by-case basis as needed.

7.0 Cable Parameters

7.1 Cable parameters are frequently available from cable cross section or cable detail drawings provided by the cable manufacturer, usually showing the cable construction, materials and dimensions.

7.2 Type of cable system must be accounted for in determining the cable rating.

7.2.1 The cable system type will generally be high-pressure fluid or gas filled pipe-type (HPFF or HPGF), self-contained fluid filled (SCFF) or solid dielectric insulated (XPLE or EPR).

7.2.2 SCFF, XLPE and EPR cable system can be installed in concrete encased duct banks, in direct buried duct(s) or cable direct buried in the soils.

7.2.3 Most cables are single-conductor, with a few being three-conductor cables. Pipe-type systems are modeled as a three-conductor installation, although there are three individual cables within the pipe.

7.3 Conductor

7.3.1 Conductor material will be either copper or aluminum

7.3.2 Conductor size indicates the cross-sectional area of the conductor and is generally indicated in ASTM “circular mil” (kcmil) sizes. The conductor size may also be in IEC square millimeters (mm^2) and must be accounted within the ratings methodology used or converted to kcmil as appropriate.

Conductor size conversion: 1 mm^2 = 1.974 kcmil

7.3.3 The conductor type refers to how the individual conductor stands are arranged or configured to form the total cable conductor. The conductor type (configuration) affects the overall conductor diameter and the AC resistance (especially for large sizes). Conductor types that are generally encountered are as follows;

7.3.3.1 Concentric (round) conductor – Individual strands are laid in un-compressed or un-compacted concentric layers and are generally not used in high-voltage cables.

7.3.3.2 Compressed (round) conductor – The outer layers deliberately flattened (or died-down) to create a smoother outer surface. The inner layers are lightly compressed and the strands are circular in shape.

7.3.3.3 Compacted (round) conductor – This has highly compressed concentric layers throughout the conductor, with the strands become compacted into keystone to rectangular shapes.

7.3.3.4 Compact segmental (Milliken) conductor – Groups of sector-shaped (pie-shaped) stands, spiraled together with each segment insulated from each other and generally consists of 4 or 5 segments. Segmental conductors are often used for conductor sizes greater than 1250 kcmil and results in a lower AC resistance.

7.3.3.5 Hollow-core compressed or compact segmental – A specially design compressed or segmental type conductor laid over an open spiral central tube. The central tube allows for passage of the dielectric fluid in self-contained fluid filled (SCFF) cables.

7.3.3.6 Conci conductor – Conductor in which the individual strands are flat, trapezoidal or keystone shaped strands that maximize the compaction of the overall conductor material. Conci conductor types can be used within segmental and/or hollow-core types of conductors.

7.4 Insulation

7.4.1 Insulation material are of the following general types:

7.4.1.1 Extruded dielectric insulation, also referred to as solid dielectric, is either cross-linked polyethylene (XPLE) or ethylene-propylene rubber (EPR).

7.4.1.2 Impregnated paper insulation is laminated layers of insulating paper or a composite paper-polypropylene (LPP) that is impregnated with a dielectric fluid. Impregnated paper insulation is used for both high-pressure fluid-filled or gas-filled pipe-type (HPFF or HPGF) and self-contained fluid-filled (SCFF) cables.

7.4.1.3 Where other types of uncommon insulating materials are used for cable, the manufacturer's insulation parameters shall be used.

7.4.2 Thickness of the insulation material will vary and is dependent on the cable design voltage.

7.4.3 Insulation properties of the cable insulation that are required in the cable modeling are the thermal resistivity (rho), dielectric constant and the dissipation factor. When the insulation properties are not readily known or available from the manufacturer data, the typical values in Table 3 shall be used.

Table 3 – Cable Insulation Parameters[5]

Insulation Material (Type of Cable System)	**Thermal Resistivity (^{o}C-cm/W)**	**Dielectric Constant**	**Dissipation Factor**
XLPE	350	2.3	0.0005
EPR	450	3.0	0.0035
Impregnated Paper (HPFF)	550	3.5	0.0025
Impregnated Paper (SCGF)	500	3.5	0.0030
Impregnated Paper (SCFF)	500	3.5	0.0025
Laminated Paper-Poly, LLP (HPFF)	600	2.7	0.0008

7.5 Shield layers are provided on either side of the cable insulation, constructed of conductive or semi-conductive material.

7.5.1 Conductor shields are between the conductor and the insulation layer. The thickness of the conductor shield is sometimes required within the rating program.

7.5.2 Insulator shields are between the insulation layer and the outer cable sheath/jacket layers. The insulation shield may consist of a combination of metallic or non-metallic materials that need to be modeled appropriately for the respective cable design.

7.5.3 High-pressure fluid-filled or gas-filled pipe-type (HPFF or HPGF) cables will have skid wires over a metallic sheath tape. The skid wires must be modeled with the material type and dimensional parameters.

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[5] Cable insulation properties are based on references in the EPRI Underground Transmission Systems Reference Book, 2006 Edition.

7.6 Sheath and Jacket

7.6.1 Cable sheath may consist of copper tape, corrugated copper or a lead layer that will carry unbalance, circulating and ground fault currents in addition to providing a moisture barrier. The sheath material, type construction and dimensional parameters must be modeled appropriately for the respective cable design.

Table 4 - Cable System Material Thermal Resistivities[6]

Type of Cable System Material	Thermal Resistivity (ºC-cm/W)
Jacket	
Polyethhylene (LLDPE, MDPE & HDPE)	350
Polyvinyl Chloride (PVC)	400
Neoprene	400
Conduit, Duct and Casing	
Polyvinyl Chloride (PVC)	400
Polyethhylene (PE)	250
Concrete	75
Steel, uncoated	10
Fiber	480
Transite	200
Asbestos	20
Eathernware	120
Pipe Coating	
Somastic	100
Pritek/X-Tex-coat*	350
FBE with Abrasion Resistant Overlay (ABO)	100
Coal Tar	500
Polyvinyl Chloride (PVC)	400
Polyethhylene (PE)	350
Neoprene	400

* Polymer modified asphalt or butyl rubber base with polyethhylene (PE) topcoat

7.6.1.1 Extruded (XPLE & EPR) cables may have a sheath design that also has supplementary copper wires helically arranged under the metallic layer/tape to enhance the sheath current carrying capability.

7.6.1.2 Extruded (XPLE & EPR) and self-contained fluid-filled (SCFF) cables will have a jacket that provides thermal resistivity (rho) to the cables ability to conduct internally generated heat away from the cable. The thermal resistivity of the jacket material must be accounted for in the cable-rating model, and is dependent on the type of jacket material and jacket thickness. If a specific value of the jacket thermal resistivity is not available from the manufactures data, typical values as shown in Table 4 shall be used.

7.6.2 Sheath bonding methods must be modeled for extruded (XLPE or EPR) and self-contained fluid-filled (SCFF) cables to account to sheath current losses. In high-pressure fluid-filled or gas-filled pipe-type (HPFF or HPGF) cables, the shield/skid wires are considered to be in continual contact with the steel pipe they are encased in and are accounted for accordingly within the respective rating program. Sheath bonding methods are as follows;

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[6] The typical thermal resistivity of cable materials are based on references from the EPRI Underground Transmission Systems Reference Book, 2006 Edition and EPRI Technical Report TR-109205, Guidelines for Calculating Ampacities of Cables Installed by Guided Boring, Dec. 1997.

7.6.2.1 Multiple-Point Grounding: The individual cable sheaths are bonded together and connected to ground at multiple points, as a minimum at both ends. This creates closed current loops for circulating currents to flow creating additional heat within the cable, which in turn can reduce of cable capacity by up to 30%.

7.6.2.2 Single-Point Bonding: The three individual cable sheaths are bonded together and connected to ground at a single point, often at one end of the circuit for shorter cable length and possibly at a midpoint for moderate length cables.

7.6.2.3 Cross Bonding: The cable sheath over the entire cable length of the cable is divided into equal length sections, in groups of three. Between each of these sections, the sheath of an individual cable is connected to the sheath of an adjacent phase cable, to create sheath transpositions. In creating the sheath transpositions over the entire length of the cable, the overall sheath current approach zero. This method of reducing the sheath circulating currents is typically used for longer lengths of extruded and SCFF cable.

8.0 Installation Geometry

8.1 The thermal interaction of cables, ducts, pipes, backfill, native soils, etc. are a major factors in dissipating the heat generated within the cable system, which ultimately determines the cable rating. The relative locations of these items and their thermal properties must be accounted for within the cable-rating program. The type of construction geometry are generally obtained from cable installation cross section(s) and profiles of the cable installation (or similar) detail.

8.1.1 The thermal resistivity (rho) of the native soils in the area need to be determined. The soil moisture content has a significant effect on soil thermal resistivity. The soil thermal resistivity should generally be that typical during dry periods for the respective area. Cable systems at depths 4 foot or deeper generally will have at least 1% soil moisture content during dry periods.

8.1.2 Soil thermal resistivity (rho) varies significantly between different types of soil and is best determined from geothermal analysis of the soils at intervals along the cable route.

8.1.2.1 If a geothermal study is not available, a review of the types of soils along the cable route shall be done. For each of the soil types identified, a conservative thermal resistivity value is assigned, as provided in Table 5.

8.1.2.1 In cases were specific soils parameters can not be determined, thermal resistivity (rho) of 100 °C-cm/W or greater shall be used.

Table 5 – Soil Thermal Resistivities[7]

Soils / Backfill Type	Thermal Resistivity (ºC-cm/W)	
	Moderately Dry, 5% Moisture	Dry, 1% Moisture
Lake/River Bottom, Organic Silt	100 (>50% moisture)	300+
Soft Organic Clay	250	350
Clay	150	230
Silt	120	200
Silty Sand	80	140
Uniform Sand	70	200
Sandy (well graded) Gravel	55	100
Thermal (well graded) Sand	50	90
Stone Screening	50	75
Concrete (no air entrainment)	60	80
Flowable (thermal) Backfill / Grout	45	65

8.1.2.2

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[7] The conservative soil Thermal resistivity values derived from data in EPRI Underground Transmission Systems Reference Book, 2006 Edition and EPRI Technical Report TR-108919, Soil Thermal Properties Manual for Underground Power Transmission, Nov. 1997.

8.1.3 As a general rule, for similar installation conditions, a deeper cable installation will result in a reduced cable rating. When determining the most restrictive rating for a cable section, for a specific installation/configuration situation (e.g. 3 by 3 duct bank under a road, etc.), use the deepest location to determine the most limiting cable rating.

8.2 Direct Buried Cable – Extruded (XLPE & EPR) and self-contained fluid-filled (SCFF) cables and/or the conduits (in which the cables are installed) can be buried directly in soil. Installation is generally in a trench with thermal and natural materials used as backfills. The following parameters shall be modeled within the cable ratings program:

8.2.1 The cable configuration is generally in a flat configuration, with triangular and various other cross-section configurations also being used. The spacing, depth and relative location of the individual cables are required.

8.2.2 The trench dimensions, width and depth, along with backfill levels are required. Most ratings programs will model two types of backfill material in a trench, with the top backfill layer being similar to the native (undisturbed) soils. If a concrete protective cap is installed over the lower thermal backfill layer, it may have to be considered to be part of the thermal backfill layer.

8.2.3 Typical thermal resistivity (rho) values for commonly used backfill and native soils are tabulated in Table 5.

8.2.4 Multiple cable circuits in the trench must be identified in the rating model, to account for the mutual heating effects on the surrounding environment. Generally, cable circuits separated by at least 10 feet have negligible mutual heating effect.

8.3 Duct Bank Installations - Extruded (XLPE & EPR) and self-contained fluid-filled (SCFF) cables are frequently installed in a duct system consisting of conduits made of PVC, transite or fiber, encased in concrete within a trench or a larger boring. The following parameters shall be modeled within the cable ratings program:

8.3.1 The concrete encasement around the duct has a relatively low thermal resistivity (rho) which increases the cable ampacity. Duct bank installations however have dead air space within the conduits resulting in reduced ampacity ratings compared to direct buried cables, due to the increased in the effective overall thermal resistivity (rho). Conduit material, size, spacing, configuration and relative location are required as inputs into the rating program.

8.3.2 The trench dimensions, width and depth, along with backfill levels above and around the duct bank. Most ratings programs will model two types of backfill material in a trench, with the top backfill layer being similar to the native (undisturbed) soils.

8.3.3 Typical thermal resistivity values (rho) for commonly used duct bank and backfill material are tabulated in Table 5.

8.3.4 Multiple cable circuits or sets of cables in the same duct bank must be identified in the rating model, to account for the mutual heating effects within the duct bank and on the surrounding environment.

8.4 Pipe-type Cable – High-pressure fluid-filled or gas-filled pipe-type (HPFF or HPGF) cables are installed in a coated steel pipe normally buried directly in the ground. The following parameters shall be modeled within the cable ratings program:

8.4.1 The size of the pipe and pipe coating material and coating thickness are required, along with whether the pipe is filled with fluid or gas.

8.4.2 Typical thermal resistivity values (rho) for commonly used pipe coating and backfill are tabulated in Table 4 and Table 5 respectively.

8.4.3 The trench dimensions, width and depth, along with backfill levels above and around the pipe. Most ratings programs will model two types of backfill material in a trench, with the top backfill layer being similar to the native (undisturbed) soils and surface conditions.

8.4.4 Multiple pipes in the trench must be identified because of the mutual heating effects on the surrounding environment. Generally, cable circuits separated by at least 10 feet have negligible mutual heating effect.

8.5 Casings are often required as part of an installation where the cable passes under railroads, streets, highways or other underground utilities to provide structural support and/or protection. These casings are often filled with a flowable fill or grout to improve the thermal properties and the ends seals to prevent dryout. Casing may reduce the cable rating by as much as 10% and therefore the following parameters are required within the cable ratings program:

8.5.1 Steel casing will experience induced current losses, which creates additional local heating, resulting in a reduced cable rating. Casing dimensions and casing fill thermal resistivity (rho) are needed. The typical thermal resistivity (rho) values for typical fill/grout materials are tabulated in Table 5.

8.5.2 Non-metallic casing materials will have a different thermal performance than the inner cable system and the surrounding soils. Casing material, dimensions and casing fill thermal resistivity (rho) are needed. The typical thermal resistivity (rho) values for casing materials are tabulated in Table 4.

8.5.3 When a duct bank package or multiple pipes are installed in a casing the conduits/pipes are often installed in a circular configuration using special duct spacers. The conduit/pipe configuration shall be modeled appropriately.

8.6 Trenchless installations consist of horizontal directional drilling (HDD), plowing, jack-and–bore, and micro-tunneling. HDD and plowing techniques may include a casing for a single cable or cable circuit. Jack-and–bore, and micro-tunneling methods generally install a large casing within which multiple cable, ducts and/or pipes are installed. Many trenchless installations will result in the installed cable, duct or casing being in direct contact with the native soil or with a minimal flowable grout as an interface to the native soils. Consult the appropriate installation details and model appropriately.

8.7 Tunnel installations of cable system within ATC seldom occur. When encountered they will be handled on a case-by-case basis, but it may be appropriate to model them as basically an in-air installation with little to no airflow, with an elevated ambient air temperature.

9.0 Ambient Environment

9.1 Underground environment in general:

9.1.1 The ambient sub-surface temperatures condition as shown in Table 6 - Typical Ambient Temperatures for Cable Applications apply for rating calculations according to the respective season. Application of these ratings outside of the seasonal periods listed herein may be appropriate if actual or predicted conditions are different.

9.1.2 ATC uses four (4) seasonal rating periods: Summer, Fall, Winter and Spring as described in ATC Operating Procedure TOP-20-GN-000034, EMS Facility Seasonal Limit Transition.

9.1.3 The ambient earth surrounding the underground cable systems dissipate the heat generated within transmission cables. Heat is largely dissipated upward through the soil to the atmosphere. The soils ability to dissipate heat is inversely related to the thermal resistance of the soil (rho) and the depth of the soil cover.

9.1.4 Soil compositions and depth of burial vary along the route of the cable. An accurate geothermal study of the soils in the most limiting section of the cable is one of the governing elements in the ampacity calculation of the cable. During construction, use of special low resistance backfill and shallow bury depths generally allow for higher cable ampacity.

9.2 Seasonal Soil Temperatures

9.2.1 Earth temperatures change seasonally largely due to seasonal changes of the air temperature and solar radiation. Earth temperature profiles have a time lag, as compared to that of the average air temperatures, by 30-45 days at depths of 3-5 foot, with the time lag increasing with increased depth. As a result of this lag in maximum earth temperature, the end of the summer season is about the same as that at the beginning of the fall season, allowing seasons to be combined for rating analysis purposes. Similar maximum seasonal temperatures occur at the beginning of the winter season and the end of the spring season allowing them to be combined for rating analysis purposes.

9.3 Soil temperatures experience less variation in seasonal temperature as depth increases and become relatively constant at depths greater than 20 feet

9.3.1 Earth temperatures between 0’ and 20’ are indicated in 5 foot increments for ease of application with a general exponentially shaped temperature distribution. The resulting typical ambient temperatures for cable applications for various depths and seasons within the ATC system are as indicated in Table 6.

9.3.2 The temperatures reflected in Table 6 are representative of those typical in the upper mid-western region of the United States.

9.3.3 A geological survey of year round temperatures of the earth surrounding a specific underground (or underwater) cable system can provide a more accurate indication of the ambient earth temperature.

9.4 Shallow (≤5’) earth temperatures under paved areas (i.e. streets and parking lots) will have approximately 3ºC warmer maximum temperatures during the Summer/Fall season than areas in grassy and otherwise protected area and are reflected in Table 6. During the late Winter and early Spring months these same paved area tend to be cleared of snow, allowing the cold to penetrate further into the earth creating lower minimum earth temperatures, but does not substantially change the maximum soil temperature for the Winter/Spring seasons.

Table 6 – Typical Ambient Temperatures for Cable Applications

Cable Location (Ft. below grade)	**Summer & Fall**		**Winter & Spring**	
	General	**Pavement /Street**	**General**	**Pavement /Street**
	ºC (°F)		ºC (°F)	
0 - 5	22 (72)	25 (77)	13 (56)	13 (56)
5$^+$ - 10	18 (64)	20 (68)	12 (54)	12 (54)
10$^+$ - 15	15 (59)	16 (61)	12 (54)	12 (54)
15$^+$ - 20	13 (55)	13 (56)	11 (52)	11 (52)
>20	11 (52)	11 (52)	11 (52)	11 (52)

9.5 In some situations, temperatures other than those indicated in Table 6 will need to be used on a case-by-case basis to account for specific local conditions. For site specific locations, where actual average earth temperatures are documented, those ambient earth temperatures can be used in lieu of the typical temperatures in Table 6.

9.6 Cables installed in or under water:

9.6.1 Cables installed under water need to be evaluated on a case-by-case basis, for the specific cable ambient seasonal temperatures. Depth of burial (or not buried) below the bed of the water will cause ambient variation. A study of the seasonal water temperatures, along with burial material and depth, will aid in using the appropriate ambient temperatures.

9.6.2 Where cables are installed under water, in submarine applications, shallow cable installations (laid on bottom to 5’ deep) should use an ambient temperature that is similar to that of the water immediately above the cable. For submarine cables buried more than 5 foot in depth the ambient water/earth temperatures approaches that of a deep (>20’) land based cable installation.

9.7 Cables in pipe and ducts in air (above grade) shall have the same ambient temperatures as those used for substation equipment applications. “In Air” cable applications (e.g. risers and conduits attached to bridge, etc.) shall use ambient temperatures of 32.2ºC (90ºF) for summer, 15.6 ºC (60ºF) for fall and spring and -1.1ºC (30ºF) for winter seasons. Appropriate wind and solar conditions shall be applied to the in-air cable installation (i.e. conduit attached under a bridge deck may need to consider wind but not solar effects).

10.0 External Heat Sources

10.1 External heat sources may be from an adjacent cable system, steam pipe/tunnel, etc. that raises the ambient soils temperature in the area of the cable system. This reduces the cables ability to dissipate its heat through the soils to the atmosphere. External heat sources that cross the cable system and have reasonable separation, additional insulation of heat external source or additional thermal backfills can often be ignored.

10.2 External heat sources could reduce the ampacity by up to 10-20%. Accounting for these heat sources is therefore necessary and is done by considering the following parameters of the nearby heat source.

10.3 Parallel heat sources modeling within the cable rating program often require the following:

10.3.1 The amount of heat dissipated by the parallel or crossing heat source in (W/m) or it's maximum temperature.

10.3.2 The size and location of the heat source relative to the cable being rated.

10.3.3 The angle between the heat source and the cable (the more parallel the heat source and cable, the larger the influence of the heat source on the cable being rated).

10.3.4 Heat sources external to the cable system are often identified from construction or as-built drawings.

11.0 Revision Information

11.1 ATC's Asset Planning and Engineering will be responsible for all revisions to this procedure

11.2 This Criterion will be reviewed in accordance with review requirement in GD-480, Document Control. The review is performed to ensure the Criteria remains current and meets any new or revised NERC Standard.

Version	Author	Date	Section	Description
01	S. Newton	03-27-2007	All	Reformatted and replaces former Operating Procedure 03-01.
02	R. Kluge	10-22-2007	All	Revisions to enhance rating criteria and addressing NERC Reliability Standards.
03	R. Knapwurst	09-05-2008	All	Major re-write of underground rating criteria
04	R. Knapwurst	10-06-2009	3, 7-12 & Appendix B	Title changes, add temperature reference, add Sec. 6 to Appendix B, various minor clarifications & updates. Annual review as required by NERC Stds.
05	R. Knapwurst	05-24-2010	5, 9 and Appendix A	Removed season definition, added season comment to Ambient Conditions Section, other minor corrections / changes. Annual review as required by NERC Standards.
06	R. Knapwurst	12-28-2012	1, 3-9 & Appendix	Added 30-minute limit, made various minor clarifications, updates & formatting changes and Revised Appendix A to include methodology only and removed Appendix B.

Appendix A – Wisconsin Electric Power Company Reference Manual, "Underground Transmission Line Circuit Ampacities"

WISCONSIN ELECTRIC POWER COMPANY

REFERENCE MANUAL	PREPARED BY: M. Smalley	DOCUMENT NO.: 25-130
	ISSUED BY: DO/ESE/Application Support	DATE: Feb. 2001
SUBJECT: UNDERGROUND TRANSMISSION LINE CIRCUIT AMPACITIES		

PURPOSE

This document lists the ampacities of all 138 kV High Pressure Fluid Filled (HPFF or Pipe-Type) cable circuits on the Wisconsin Electric System. It also provides the basis to be used for future underground transmission circuit rating calculations.

DEFINITIONS

A. Ampacity

The current carrying capacity of a conductor or circuit. This value is given in Amperes and is a rating for each phase cable of a three-phase circuit. This value may also be listed using apparent power (Mega-Volt-Amperes or MVA) based on the nominal system voltage.

B. Summer Normal (May 1 to November 30)

The Summer Normal (S.N.) rating of a circuit is calculated using the summer ambient Earth temperature (20°C) and the normal conductor temperature (70°C for cables installed prior to 1967 and 85°C for cables installed in 1967 and later).

C. Summer Emergency (May 1 to November 30)

The Summer Emergency (S.E.) rating of a circuit is calculated using the summer ambient Earth temperature (20°C) and the emergency conductor temperature (90°C for cables installed prior to 1967 and 105°C for cables installed in 1967 and later).

D. Winter Normal (December 1 to April 30)

The Winter Normal (W.N.) rating of a circuit is calculated using the winter ambient Earth temperature (5°C) and the normal conductor temperature (70°C for cables installed prior to 1967 and 85°C for cables installed in 1967 and later).

E. Winter Emergency (December 1 to April 30)

The Winter Emergency (W.E.) rating of a circuit is calculated using the winter ambient Earth temperature (5°C) and the emergency conductor temperature (90°C for cables installed prior to 1967 and 105°C for cables installed in 1967 and later).

ASSUMPTIONS

Underground Transmission Ampacity calculations are based on the following assumptions:

1. Thermal resistivity of native earth is 90 C°-cm/W. This assumption is based on recommended industry practices. This value should be confirmed with a thermal study of the line route.
2. Thermal resistivity of controlled backfill (thermal sand) is 90 C°-cm/W.
3. Trench dimensions are as shown in figure 1 for single circuit installations (24" X 60") and as shown in figure 2 for double circuit installations (48" X 60"). Historically, ampacities have not been derated in areas where the pipe is buried deeper than normal for relatively short distances.
4. Daily load factor is 75%.
5. Emergency ratings apply to periods of not more than 100 hours in duration (elapsed time) with a maximum of one emergency period in any 12 months and a maximum of 0.2 emergency periods per year averaged over the life of the cable.
6. Power system frequency is 60 Hz.
7. Thermal resistivity of paper insulation is 600 C°-cm/W.
8. Dielectric Constants are 3.5 PU for paper and 2.7 PU for laminated paper-polypropylene.
9. Dissipation factors are 0.23 PU for paper and 0.07 PU for laminated paper-polypropylene.
10. Thermal resistivity of the pipe coating is 400 C°-cm/W.
11. Emergency dissipation factors are 1.15 times the dissipation factor of the cable at the normal maximum continuous operating temperature.

AMPACITIES

Normal Installations

The ampacities of Wisconsin Electric's 138 kV HPFF cable systems in standard trenches (Figures 1 and 2) are shown in Table 1.

River Crossings

Ampacities at river crossings may be less than ampacities of normal installations due to the increased thermal resistivity from the cables to the atmosphere. Some ampacities listed in Table 1 are derated for river crossings. However, a lower ambient earth temperature may be present below a riverbed resulting in a higher circuit rating at the river crossing. In addition, flowing water may carry heat away from the circuit resulting in a higher circuit rating at the river crossing. Therefore, ampacities for river crossings are to be reviewed on a case-by-case basis.

Deep Installations

Ampacities for circuits with depths of burial greater than shown in Figures 1 and 2 will be less than those of normal installations. This is due to the increased thermal resistivity from the cables to the atmosphere. Typically, when a circuit is buried deeper than normal for relatively short distances, the circuit has not been de-rated.

Paralleling of Heat Sources

Ampacities of cables paralleling heat sources (e.g. a steam main, high-pressure gas main, or other electrical circuit) will be less than those of normal installations. The increased heat near the cable reduces the amount of heat that can be transferred from the cable through the soil to the atmosphere. The de-rating factor for a paralleling of a heat source will be higher than the de-rating factor for a crossing of a similar heat source.

Crossings of Heat Sources

Ampacities of cables at the crossings of heat sources (e.g. a steam main, high-pressure gas main, or other electrical circuit) will be less than those of normal installations. The increased heat near the cable reduces the amount of heat that can be transferred from the cable through the soil to the atmosphere. The de-rating factor for a crossing of a heat source will be less than the de-rating factor for a paralleling of a similar heat source. This is due to heat being transferred longitudinally along the conductor.

Tunnels

Ampacities of cables installed in air within tunnels are subjected to the higher thermal resistivity of air that surrounds the circuit. In a tunnel, the flow of air is restricted when compared to the flow of air and heat transfer available outdoors (e.g. at a riser). Tunnel ampacities are to be calculated on a case-by-case basis.

Terminations

The ampacity of a cable termination is higher than the ampacity of the cable itself.

METHODOLOGY

The method used to determine the circuit ratings of existing underground transmission lines is detailed in reference three. Calculations for existing circuits were performed by hand. Ampacity calculations for future circuits will be calculated using a computer program (e.g. the Underground Transmission Workstation by the Electric Power Research Institute, CYMCAP by Cyme International, or USAMP by Underground Systems Inc.).

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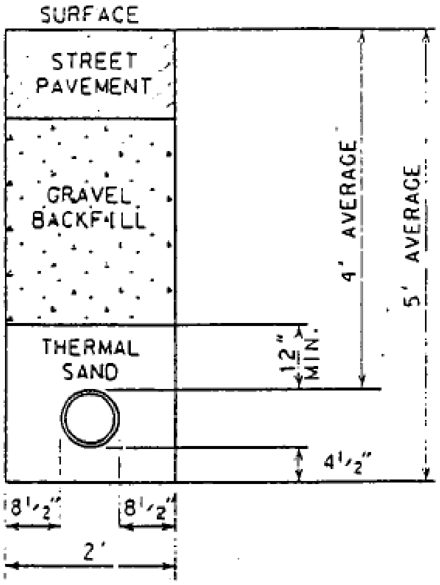
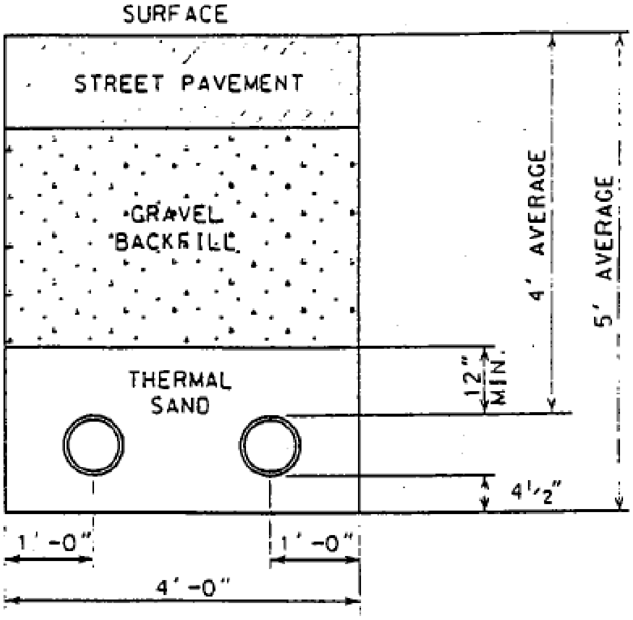


NOTE: WHERE TRENCH IS IN AN UNPAVED AREA. THE AVERAGE DEPTH WILL BE 5 FEET.

FIGURE 1 - Typical Single Circuit Installation



NOTE: WHERE TRENCH IS IN AN UNPAVED AREA. THE AVERAGE DEPTH WILL BE 5 FEET.

FIGURE 2 - Typical Double Circuit Installation