AMERICAN TRANSMISSION COMPANY ®	Criteria	Department:	Asset Management
		Document No:	CR-0062 v05
Title: UNDERGROUND TRANSMISSION LINE AMPACITY RATINGS		Issue Date:	05-24-2010
		Previous Date:	10-06-2009

Table of Contents

1.0 Scope 2
2.0 Introduction 2
3.0 References 3
4.0 Definitions 4
5.0 Cable System Rating 4
6.0 Operating Conditions 7
7.0 Cable Parameters 8
8.0 Installation Geometry 11
9.0 Ambient Environment 14
10.0 External Heat Sources 15
11.0 Revision Information 16
Appendix A – Wisconsin Electric Power Company Reference Manual, "Underground Transmission Line Circuit Ampacities" 17
Appendix B - City of Madison Pipe-Type Ampacity Upgrade Final Report 25

Approved By: Andrew Dolan Signed original on file	**Author:** Ron Knapwurst

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. This document does not address dynamic or real-time ratings.

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 specific manufacturer or 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 138 kV High Pressure Fluid Filled cable circuits that were formally a part of the Wisconsin Electric System, Attachment A. Note the original document has been revised to show line number changes (shown as strikeout of original name, followed by new line number in italic) and lines/line segments no longer in service or cable replaced (strikeout of original data). New lines and/or replace cable data has not been added to the original document.

2.3.2 Consultant rating recommendations for the 138 kV High Pressure Fluid Filled cable circuits that were formally a part of the Madison Gas and Electric System, Attachment B. ATC ratings for these cable circuits is based on Table 5-11 of Attachment B.

2.3.3 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.

2.3.4 Other underground systems are evaluated on a case-by-case basis, using engineering consultant and cable manufacturer's recommendations and industry standards.

3.0 References

3.1 The latest revisions of the following documents shall be applied when not specifically addressed in this document. If there is any apparent contradiction or ambiguity among these documents and this criteria document, this criteria document shall take precedence and the issue should be brought to the attention of Asset Planning & Engineering for resolution before application.

3.1.1 AEIC CG1-96 Guide for Establishing the Maximum Operating Temperatures of Impregnated Paper and Laminated Paper Polypropylene Insulated Cables (3^{rd} Edition)

3.1.2 AEIC CG6-05 Guide for Establishing the Maximum Operating Temperatures of Extruded Dielectric Insulated Shielded Power Cables (2^{nd} Edition)

3.1.3 AEIC CS2-97 Specifications for Impregnated Paper and Laminated Paper Polypropylene Insulated Cables High-Pressure Pipe-Type (6^{th} Edition)

3.1.4 AEIC CS9-06 Specification for Extruded Insulation Power Cable and Their Accessories Rated Above 45 KV Through 345 kV (1^{st} 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 Guide GD-0480, Document Control

3.1.8 ATC Procedure PR-0285, Facility Ratings

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

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

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

3.1.12 EPRI Underground Transmission Systems Reference Book, 2006 Edition

3.1.13 EPRI UTWorkstation ACE Software, Version 4.0

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

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

3.1.16 IEEE 442-1981 Guide for Soil Thermal Resistivity Measurements

3.1.17 IEEE 835-1994 Standard Power Cable Ampacity Tables

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

3.1.19 NERC Reliability Standard FAC-008-1, Facility Ratings Methodology

3.1.20 NERC Reliability Standard FAC-009-1, Establish and Communicate Facility Ratings

3.1.21 Illinois Administrative Code Title 83, Chapter I: Illinois Commerce Commission, Part 305 Construction Of Electric Power And Communication Lines

3.1.22 Michigan Public Service Commission Administrative Rule R460.813

3.1.23 National Electric Safety Code (NESC), C2 – 2007

3.1.24 Wisconsin Administrative Code, Wisconsin State Electrical Code, Volume 1, Chapter PSC 114

3.2 The following appendices are ratings documents for founding utilities underground facilities with the respective ratings and/or guidelines:

3.2.1 Appendix A – Wisconsin Electric Power Company Reference Manual "Underground Transmission Line Circuit Ampacities" (Document No. 25-130), dated 02/01.

3.2.2 Appendix B - American Transmission Company, City of Madison Pipe-Type Ampacity Upgrade Final Report, October 2002

4.0 Definitions

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 Normal Current Rating: The normal current rating is a continuous operating limit for the cable system without exceeding normal allowable maximum conductor temperatures that would otherwise result in degradation or loss of effective equipment life. Normal ratings apply for any loading duration greater than 2 hours, unless other longer emergency durations are indicated.

4.5 Emergency Current Rating: The ATC standard emergency current rating is a limit for an unplanned, temporary event (operating contingency) having duration of less than 2 hours per occurrence. Under an emergency event, a certain amount of life loss is likely and permitted.

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. In some cases where the seasonal high temperatures are similar, seasons will be combined for ratings publication purposes (e.g. Winter/Spring and Summer/Fall for underground cable systems).

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

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

4.9 Transient Loading: The continual increasing or decreasing of 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 ATC's underground cable circuits are based on IEC-60287, IEC-60287 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, USAmp,

5.1.2 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.

5.1.3 Cable accessories, such as terminators and splice joints, are typically designed to operate at emergency temperatures of 105ºC or higher. Cable accessories assumed to not 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 ratings for shorter 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 contingency ratings for a cable system assume that the cable contingency loading duration is limited in length. The maximum cable contingency loading durations are listed in Table 2. These cable emergency periods are based on industry standards as outlined in AEIC publications CG1 and CG6.

[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.

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

5.4 Operations Support

5.4.1 The 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.

5.4.2 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 was at 100% of the normal rating.

5.4.3 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 preload 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% preload 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 ATC-owned 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 While SELD models include ratings for the standard normal/emergency rating criteria that is shared with MISO and others, 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: At the end of any single emergency loading period, the underground line overload will be mitigated to the normal underground line rating, within the respective emergency loading period.

5.6.4.1 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. It is generally accepted practice that, through a combination of system topology changes, Transmission Load Relief (TLR), or other actions, an underground line overload will be mitigated to the normal rating within 2 hours.

[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.

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

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. This is the basis for developing a typical System Operating Limit (SOL); meaning that if no mitigation strategy exists for the line, the system will not be operated such that the line would exceed this limit upon the contingency. Action needs to be taken, including TLR or development of such a mitigation plan.

5.6.4.2 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.

5.6.4.3 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.

5.6.4.4 100 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.

5.6.4.5 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. Period of 300 and 768 hour periods 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, generally measured over a daily cycle. The cyclic 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 an increment of 5%.

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

This is a very conservative 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 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 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 issued on a case-by case basis an 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 at least 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 installations, 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 a 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" (EPR).

7.4.1.2 Impregnated paper insulation is laminated layers of insulating paper or a laminated 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 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 (°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 model appropriately for the respective cable design.

7.5.3 High-pressure fluid-filled or gas-filled pipe-type (HPFF or HPGF) cable will have skid wires over a metallic sheath tape, all of which must be modeled by material type and dimensional parameters.

7.6 Sheath and Jacket

7.6.1 Cable sheath may consist of metallic tape, corrugated copper or aluminum 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.

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 form 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 insulation 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;

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, which in turn can reduction of cable ampacity by up to 30%.

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

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

7.6.3 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.

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

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 usually 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 needs to be determined. The soil moisture content has a significant affect 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.

[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.

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. If a geothermal study is not available, a study of the types of soils along the route need to be determined and then conservative thermal resistivity values assigned for that type of soil should be used, as provided in Table 5. In cases were specific soils parameters can not be determined, thermal resistivity (rho) of 100 ^{o}C-cm/W or greater shall be used.

8.1.3 As a general rule, for similar installation conditions, a deeper cable installation will result in a lower 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 for that rating.

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

8.2 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 arrangements also being used. The spacing, depth and relative location of the individual cables are required.

8.2.1 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 on top of the lower thermal backfill layer, it may have to be considered to be part of that backfill layer.

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

8.2.3 Multiple cable circuits in the trench need to be identified to account for the mutual heating effects on the surrounding environment. Generally cable circuits separated by at least 10 feet have little 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 larger boring. The following parameters shall be modeled within the cable ratings program:

[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.

8.3.1 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 increase in the 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 need to be identified 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 need to be identified because of the mutual heating effects on the surrounding environment. Generally, cable circuits separated by at least 10 feet have little 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 casings 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, and should 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 or may not 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: Spring, Summer, Fall, and Winter 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 The ambient soil and or underwater Seasons as described in Section 6.2.

9.2.2 Earth temperatures change seasonally largely due to seasonal changes of the air temperature and solar radiation. Earth temperature profiles time lag that of the average air temperatures by 30-45 days for 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. These combined Summer/Fall and Winter/Spring seasons are reflected in Table 6.

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		ºC	
0 - 5	22	25	13	13
5^+ - 10	18	20	12	12
10^+ - 15	15	16	12	12
15^+ - 20	13	13	11	11
20^+	11	11	11	11

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 that cables ambient seasonal temperatures. Depth of burial (or not buried) below the bottom 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 overhead or substation 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 spring/fall and -1.1ºC (30ºF) for winter seasons. Appropriate wind and solar conditions applied to the respective 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 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 Document Review

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.

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.

<u>AMPACITIES</u>

<u>Normal Installations</u>

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

<u>River Crossings</u>

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.

<u>Deep Installations</u>

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.

<u>Paralleling of Heat Sources</u>

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.

<u>Crossings of Heat Sources</u>

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.

<u>Tunnels</u>

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.).

REFERENCES

1. EPRI (1992), "Underground Transmission Reference Book", EPRI TR-101670, Research Project 7909-01, Report 1992.
2. Anders, G. J. (1997), *Ratings of Electric Power Cables*, New Jersey: IEEE Press.
3. Nehr, J. H., and McGrath, M. H. (Oct. 1957), "The calculation of the temperature rise and load capability of cable systems," AIEE Trans., vol. 76, part 3, pp. 752-772.
4. IEC Standard 287 (1982), "Calculation of the continuous current rating of cables (100% load factor)," 2nd. ed., 3rd amendment, 1993.
5. AEIC CS2-90 (1990), "Specification for impregnated paper and laminated paper polypropylene insulated cable, high pressure pipe type."
6. EPRI (1997), "Soil thermal properties manual for underground power transmission," EPRI TR-108819, Report November 1997.
7. Nehr, J. H. (1964), "The transient temperature rise of buried power cable systems," IEEE Trans. power app. Syst., vol. PAS-83, pp. 102-111.
8. EPRI, Underground Transmission Workstation - Alternative Cable Evaluation (computer program), V 3.0.

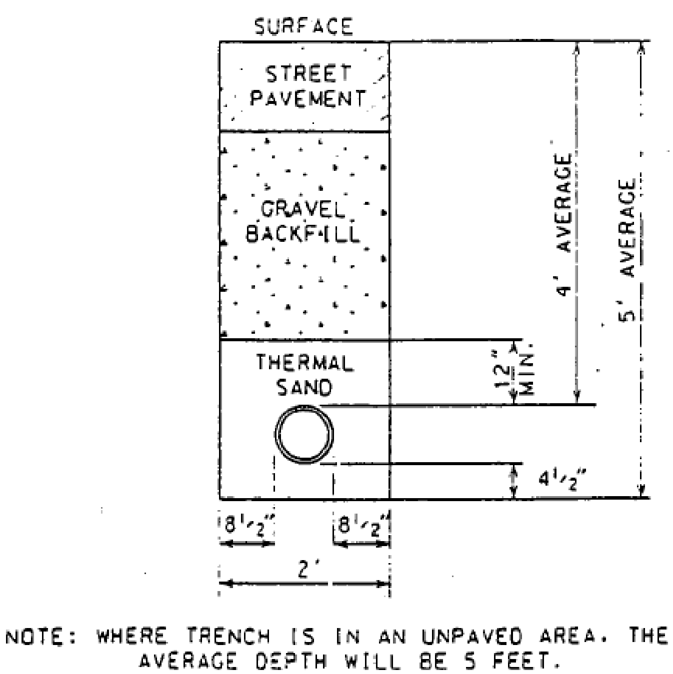
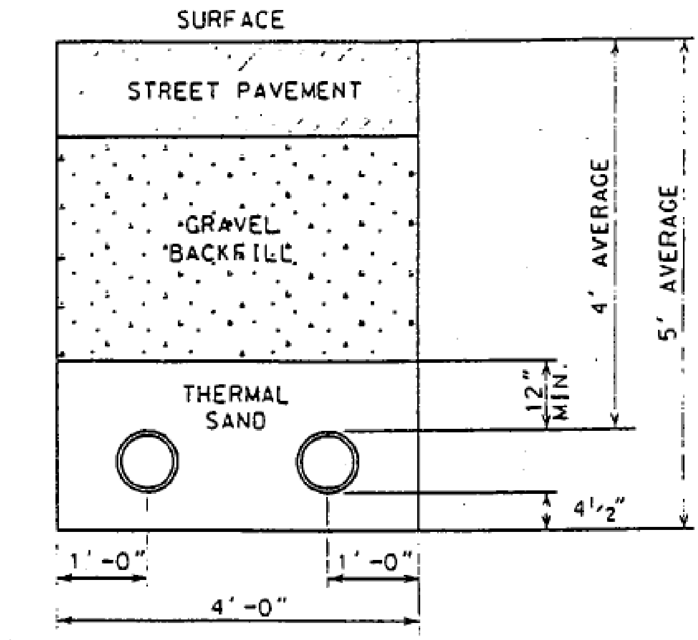


FIGURE 1 - Typical Single Circuit Installation



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

FIGURE 2 - Typical Double Circuit Installation

TABLE 1 – LOAD CAPABILITY
138 KV HPFF PIPE-TYPE CABLES[9]

Line	Year Energized	Terminals	Conductor Size (KCM)[8]	Rating in AMPS/MVA[1]			
				S.N.	S.E.	W.N.	W.E.
KK301 *NMAG21*	1967 Seg. A 1976 Seg. B	Valley - *Montana* - Dewey ~~Valley~~ *Montana* – Dewey	1250 CR[10] 1250 CR	836/200 836/200	941/225 941/225	941/225 941/225	1046/250 1046/250
~~KK302~~ *KK311*	1967 *Seg. B*	Valley - Harbor	1250 CR[10]	836/200	941/225	941/225	1046/250
KK314[4,13] KK324[13]	1971 *Seg. A* ~~1981~~ Seg. A 1981 Seg. B	Valley - Haymarket Valley - Everett *(Replaced)* Valley - Everett (Both Lines in Service)	1250 CR ~~1750 CS[10]~~ 2000 CS	644/154 ~~790/189~~ 790/189	732/175 ~~899/215~~ 899/215	732/175 ~~899/215~~ 899/215	820/196 ~~1004/240~~ 1004/240
KK314[5,13] KK324[13]	1971 ~~1981~~ Seg. A 1981 Seg. B	Valley - Haymarket Valley – Everett *(Replaced)* Valley - Everett (One Line in Service)	1250 CR ~~1750 CS[10]~~ 2000 CS	753/180 ~~920/220~~ 920/220	853/204 ~~1037/248~~ 1037/248	853/204 ~~1037/248~~ 1037/248	954/228 ~~1163/278~~ 1163/278
KK321	1968 Seg. A 1980 Seg. B	Valley - Park Hill Valley - Park Hill	1250 CR[10] 1250 CR	836/200	941/225	941/225	1046/250
KK823	1969	Lincoln – Allerton *(51 St)*	1250 CR[10]	836/200	941/225	941/225	1046/250
~~KK911[13]~~ *893K21[13]* KK5053[13]	1976 1956	(Both Lines in Service) Lincoln - 43 Lincoln – 43	1250 CCR[10] 1000 CTS[10]	744/178 673/161	836/200 786/188	836/200 786/188	899/215 882/211
~~KK911[13]~~ *893K21[13]* KK5053[13]	1976 1956	(One Line in Service) Lincoln - 43 Lincoln – 43	1250 CCR[10] 1000 CTS[10]	836/200 774/185	941/225 903/216	941/225 903/216	1045/250 1016/243
893K51 848	1967 Seg. ~~A~~ *B* 1976 Seg. ~~B~~ *C*	Norwich - Dewey Norwich – 01-8033M	1250 CR 1250 CR	836/200 836/200	941/225 941/225	941/225 941/225	1046/250 1046/250
848[13]	1959 Seg. ~~A~~ *B & D*	01-8033M - 74-002M, 74-003M - 2941M	1000 CS[10]	656/157	774/185	774/185	870/208
	1975 Seg. ~~B~~ *C*	74-002M - 74-003M, 2941M -Harbor (WE)	1250 CS	744/178	837/200	837/200	900/215
893K11[13]	1959 Seg. ~~A~~*B*	Russel Term-92-8006M, 74-003M-2941M	1000 CS[10]	656/157	774/185	74/185	870/208
	1992 Seg. ~~B~~*D*	92-8006M-74-003M, 2941M-Harbor (WE) (Both Lines in Service.)	1250 CS	744/198	837/200	837/200	900/215

TABLE 1 – LOAD CAPABILITY (Cont'd.)
138 KV HPFF PIPE-TYPE CABLES[9]

Line	Year Energized	Terminals	Conductor Size (KCM)[8]	Rating in AMPS/MVA[1]			
				S.N.	S.E.	W.N.	W.E.
848[13]	1959 Seg. ~~A~~ *B & D*	01-8033M - 74-002M, 74-003M - 2941M	1000 CS[10]	757/181	891/213	891/213	1000/239
	1975 Seg. ~~B~~ *C*	74-002M - 74-003M, 2941M -Harbor (WE)	1250 CS	837/200	941/225	941/225	1046/250
893K11[13]	1959 Seg. ~~A~~*B*	Russel Term-92-8006M, 74-003M-2941M	1000 CS[10]	757/181	891/213	891/213	1000/239
	1992 Seg. ~~B~~*D*	92-8006M-74-003M, 2941M-Harbor (WE) (One Line in Service)	1250 CS	837/200	941/225	941/225	1046/250
~~KK3441~~	~~1969~~	~~Granville~~ *(De-Energized)*	~~1500 CS[11]~~	~~928/222~~	~~1046/250~~	~~1046/250~~	~~1146/274~~
~~KK3451~~	~~1969~~	~~Granville~~ *(De-Energized)*	~~1500 CS[11]~~	~~928/222~~	~~1046/250~~	~~1046/250~~	~~1146/274~~
KK3462[14]	1969	Granville *(to Granville Riser)*	1500 CS[11]	921/220	1137/272	1027/245	1195/285
KK3611L	1976 Seg. A	Center - Fiebrantz	1250 CR	836/200	941/225	941/225	1045/250
KK3611M	1971	Cornell - Fiebrantz	1250 CR	836/200	941/225	941/225	1046/250
KK3632	1977	Humboldt-Shorewood	2000 CS[10]	1096/262	1247/298	1247/298	1372/328
KK4843	~~1949~~ Seg. A[2] 1976 Seg. B	28 – Center *(Replace)d* 28 - Center	~~500 CO[7]~~ 1250 CR	~~451/108~~ 836/200	~~531/127~~ 941/225	~~531/127~~ 941/225	~~581/139~~ 1046/250
KK5042[6]	1971 Seg. A 1981 Seg. B 1981 Seg. C	28 - Everett 28 - Everett[3] 28 - Everett	1250 CR 1250 CR 2000 CS	836/200 836/200 836/200	941/225 941/225 941/225	941/225 941/225 941/225	1046/250 1046/250 1046/250
KK5044	1958 *Seg. A*	Bluemound - 96th	600 CRO[7,11]	422/101	489/117	489/117	548/131
KK5055	1970	Bluemound - 96th	1250 CR[11]	502/120	560/134	560/134	615/147
KK5063	1975	O'Connor - Walker	1250 CR	836/200	941/225	941/225	1046/250
KK16504	1971 Seg. ~~A~~ *C* 1981 Seg. B 1981 Seg. ~~C~~ *A*	Haymarket-Everett Haymarket-Everett Haymarket-Everett	1250 CR 1250 CR 2000 CS[3]	836/200 836/200 836/200	941/225 941/225 941/225	941/225 941/225 941/225	1046/250 1046/250 1046/250
KK61441[13] KK61452[13]	1972 1972	Range Line Range Line (Both Lines in Service)	1250 CR 1250 CR	744/178 744/178	836/200 836/200	836/200 836/200	899/215 899/215

TABLE 1 – LOAD CAPABILITY (Cont'd.)
138 KV HPFF PIPE-TYPE CABLES[9]

Line	Year Energized	Terminals	Conductor Size (KCM)[8]	Rating in AMPS/MVA[1]			
				S.N.	S.E.	W.N.	W.E.
KK61441[13] KK61452[13]	1972 1972	Range Line Range Line (One Line in Service)	1250 CR 1250 CR	836/200 836/200	941/225 941/225	941/225 941/225	1046/250 1046/250
KK61442-2	1977 Seg. A 1992 Seg. B	Glendale-Custer Glendale-Custer	2000 CS[10] 2000 CS	1096/262 1096/262	1247/298 1247/298	1247/298 1247/298	1372//328 1372/328
KK61442-3	1992	Glendale-Custer	2000 CS[10]	1096/262	1247/298	1247/298	1372/328
KK61443	1960	Cornell - Sidney	500 CR[10]	477/114	560/134	560/134	623/149
KK61453[14]	1969	Granville *(to Granville Riser)*	1500 CS[11]	921/220	1137/272	1027/245	1195/285
KK62831	1977 Seg. A 1992 Seg. B	Shorewood-Glendale Shorewood-Glendale	1250 CR 1250[12]	836/200 836/200	941/225 941/225	941/225 941/225	1046/250 1046/250

TABLE 1 NOTES:

1. Refer to the ASSUMPTIONS section for all related assumptions.

2. The segments of all lines are in series. Therefore, the actual circuit rating is based on the rating of the segment with the lowest ampacity. Refer to the 138 kV underground transmission route maps (distributed by the transmission maintenance engineer) for locations of the line segments.

3. Cables in the vicinity of Everett were intentionally oversized in order to realize these ratings. The rating of the segment with the lowest ampacity is assumed.

4. Ratings may be increased to 189 MVA (791 Amps), 215 MVA (900 Amps), 215 MVA (900 Amps), 240 MVA (1004 Amps) if the cables across the Menomonee River are replaced.

5. Ratings may be increased to 200 MVA (837 Amps), 225 MVA (941 Amps), 225 MVA (941 Amps), 250 MVA (1046 Amps), if the cables across the Menomonee River are replaced.

6. Formerly KK4861 prior to retirement of Parkhill Substation bus section 6 in 1996.

7. Former gas compression cable

8. Cable construction abbreviations are as follows:

CR – Compact Round
CS – Compact Segmental
CCR – Compressed, Concentric Round
CTS – Crushed, Triangular Segmental
CO – Compressed Oval
CRO – Crushed Oval

9. Ampacities listed in Table 1 are based on calculations performed prior to issuance of this ERM. Therefore, the assumptions listed in this ERM may not have been incorporated in the listed ratings. However, similar (but not identical) ratings will result if the assumptions in this document are used to determine the circuit rating.

10. This line segment contains a river crossing.

11. This line segment contains pipe in air within a tunnel.

12. Cable construction (compact round, compressed round, or compact segmental) is unknown.

13. The two circuits listed were constructed within the same trench. When both circuits are in service, the heat generated from each circuit is cumulatively higher than if only one circuit is in service. Therefore, two ratings are given.

14. Refer to *Appendix A* for continuous emergency ratings for this circuit versus time.

APPENDIX A

Continuous Time in Hours	Summer in Amps	Winter in Amps
10	1270	1300
20	1230	1280
30	1195	1250
40	1175	1225
50	1155	1210
60	1140	1195
70	1135	1180
80	1125	1175
90	1120	1165
100	1100	1155
Continuous	1050	1125

Appendix B - City of Madison Pipe-Type Ampacity Upgrade Final Report

American Transmission Company

City of Madison Pipe Type Upgrade Final Ampacity Report

October 2002

FOR INFORMATION CONTACT:
Power Engineers
Dennis Johnson, Project Engineer
Rich Mues, Project Manager
Reference Project No. 150036-02

1.0 INTRODUCTION

The American Transmission Company (ATC) has a number of high-pressure fluid-filled (HPFF) cable circuits in the downtown Madison area. ATC has identified these circuits as possibly needing to be upgraded to meet the future needs of the downtown area. ATC requested POWER Engineers perform a system analysis to determine the existing load capacity and the various ways that the circuits could be upgraded to increase the load capacity.

The analysis consisted of reviewing the existing circuit information, determining the largest conductor that could be installed in the existing pipe, calculating the steady state and emergency ampacity ratings for the existing circuits operated in a static, circulation or refrigeration configuration, and calculating the steady state and emergency ampacity for the maximum conductor size in the existing pipe operated in a static configuration.

2.0 CIRCUITS ANALYZED

ATC identified six different circuit configurations that POWER was to evaluate. Table 1 identifies the circuit arrangement cases that were analyzed.

Case	Circuit	Nom Pipe Size (in)	Volts (kV)	Conductor Size (kcmil)
A	Double Circuit Blount to Commercial Riser Blount to Gateway	 6 6	 138 69	 1500 AL 1500 AL
B	Double Circuit Blount to East Campus Blount to East Campus	5 5	69 69	650 CU 650 CU
C	Single Circuit Blount to Lakeside	5	69	650 CU
D	Double Circuit East Campus to Blount East Campus to Lakeside	5 5	69 69	800 CU 800 CU
E	Single Circuit East Campus to Walnut #1	5	69	1250 AL
F	Single Circuit East Campus to Walnut #2	6	69	1750 CU

Note: Case F considers the new circuit between East Campus and Walnut.

3.0 APPROACH

The overall approach to this project is summarized below.

1. ATC provided POWER with the initial information on the conductor size and pipe size for each circuit to be investigated. From this information, a maximum conductor size for each pipe size and voltage class was determined.
2. POWER prepared a table of steady state and emergency ampacities based on general assumptions for the existing static circuits and the maximum conductor sizes for each pipe size.
3. ATC provided the plan and profile for each circuit and additional design information. The design parameters were different than the assumed values, so POWER recalculated the steady state and emergency ampacities based on the information provided.
4. POWER contracted with USI to calculate the circulation and refrigeration ratings for the East Campus to Blount circuits. USI also provided cost estimates for adding the circulation and/or refrigeration for the existing circuits.
5. POWER presented the results of the study and ATC requested additional ampacities be performed to show the sensitivity to the earth environment and the emergency time duration and conductor temperature for the existing cable circuits.
6. POWER contracted with Geotherm to perform soil thermal tests along the existing circuit routes to determine the thermal characteristics of the existing backfill. From this information, POWER performed additional ampacity based on the results of these tests.
7. Based on the results of the soil thermal tests, POWER performed ampacity calculations to determine the ampacity rating for the new Walnut to East Campus HPFF circuit.

4.0 CABLE SYSTEM DESIGN

One of the major advantages of pipe-type cable systems is the ability to increase the capacity of the circuit. This may be accomplished by one of three methods. Each method is briefly described below.

•**Increase conductor size**

Increasing the cable size is only possible if the cable pipe is large enough to accommodate a larger conductor. A minimum clearance of about 0.5 in. is needed between the top of the three cables and the pipe. This clearance is necessary due to the likelihood of the pipe not being perfectly round in the bends. The pipe tends to become oval when bent. Increasing the cable size provides a larger conductor and thereby allow for an increase in capacity.

•**Provide slow circulation**

Slow circulation may be added to a pipe-type cable system if there are two parallel circuits or an additional return pipe. Circulation pumps are added at the pumping plant to facilitate the slow circulation. The circulation of the dielectric fluid eliminates “hot spots” along the route by moving the fluid to other areas along the route that are cooler. These “hot spots” typically occur at the deepest locations along the route. One of the disadvantages of using another cable pipe for the return is that if one of the cable circuits fails that pipe cannot be used as a return path since it will need to be opened to repair the cable or pipe.

•**Provide circulation and refrigeration**
This method will provide the greatest increase in capacity, but it is very expensive. Since circulation is required, the same prerequisites exist as for the slow circulation and in addition a refrigeration system is needed. The dielectric fluid is circulated through the refrigeration system to be cooled and then sent into the cable pipes.

4.1 STEADY STATE AMPACITY CALCULATIONS

Cable ampacity is affected by many parameters, some inherent to the cable design and voltage and others as a function of the installation configuration end environment. Ampacity calculations are generally based on the well known procedure described by Neher and McGrath. This requires solving the equivalent thermal circuit. The components of the thermal circuit – heat sources, thermal resistances, and thermal capacitances - are analogous to electrical components modeled by Ohm’s Law. Like Ohm’s Law where current flowing through an electrical resistance causes a voltage drop or voltage rise, heating flowing through a thermal resistance causes a temperature drop or temperature rise.

Heat sources include the resistance losses from the conductor, cable sheath and the dielectric heating in the insulation. The thermal resistances impede the heat from escaping to ambient earth and ultimately to ambient air and thus raise the temperature of the conductor during loading. The thermal capacitance’s account for the thermal time constants of the various cable layers and earth such that load cycling does not immediately change the cable temperature.

Although there is some control over design aspects of the cable, the insulation thickness, maximum conductor operating temperature and other parameters are controlled by the type of cable system selected, system voltage, load requirements and cable size. These parameters are fixed by the design. However, the cable environment can vary greatly along the circuit route. The following parameters are considered, when determining the load carrying capability of an existing or proposed cable system.

- •Burial depth – deeper burial depths generally reduce ampacity
- •Spacing between cable phases and other circuits – increased spacing decreases mutual heating, improving ampacity.
- •Backfill material – special low thermal resistivity backfill around the cables or conduits can improve overall ampacity. The units for thermal resistivity is o C-cm/W, however commonly referred to as the “rho” value.
- •External heat sources (steam mains, etc.) – external heating from other sources can reduce ampacity as a function of the heat output and proximity to the cables.
- •In-situ soil thermal resistivity – perhaps the most important parameter, high native thermal resistivity can greatly reduce ampacity
- •Soil ambient temperature – increased ambient soil temperature can reduce the available temperature rise from circuit load, thus reducing ampacity.
- •Load factor – the average daily loading, a low load factor results in a higher ampacity.

Because of these factors, it is important to characterize the cable route in detail in order to accurately calculate the loading capability of a particular cable circuit.

4.2 EMERGENCY AMPACITY CALCULATIONS

One benefit to installing underground cable is the cables ability to operate at higher temperatures for short periods of time. This is possible due to the thermal capacitance of each individual cable. Since this calculation is highly temperature and time dependent it is very important to establish the following parameters.

- •Pre-emergency load condition. If unknown, assume 100%.
- •Maximum operating temperature. AEIC CS7 allows a paper cable to operate at 105˚C up to 100 hours and 100˚C up to 300 hours.

The larger the conductor temperature difference and the shorter the emergency duration, the higher the emergency ampacity will be.

5.0 SYSTEM ANALYSIS

POWER used the following typical parameters to calculate the ampacities for the existing cables.

Ambient Soil Temp:	25˚C
Native Soil Thermal Resistivity:	90 rho
Backfill Thermal Resistivity:	70 rho
Depth to Bottom of Duct bank:	12’
Pipe size (ID):	
5”	5.047 in
6”	6.125 in
Load Factor:	75%
Steady State Conductor Temperature:	85˚C

Table 5-2
Continuous Ampacities for Existing Cables

Case	Circuit	Nom Pipe Size (in)	Volts (kv)	Conductor size (kcmil)	Normal Ampacity Rating (amps)
A	Double Circuit				
	Blount to Commercial Riser	6	138	1500 AL	708
	Blount to Gateway	6	69	1500 AL	777
B	Double Circuit				
	Blount to East Campus	5	69	650 CU	641
	Blount to East Campus	5	69	650 CU	641
C	Single Circuit				
	Blount to Lakeside	5	69	650 CU	745
D	Double Circuit				
	East Campus to Blount	5	69	800 CU	706
	East Campus to Lakeside	5	69	800 CU	706
E	Single Circuit				
	East Campus to Walnut #1	5	69	1250 AL	821

Table 5-4
ATC continuous ampacity ratings, which are currently being used to operate the system

Case	Circuit	Nom Pipe Size (in)	Volts (kv)	Conductor size (kcmil)	Normal Ampacity Rating (amps)
A	Double Circuit				
	Blount to Commercial Riser	6	138	1500 AL	775
	Blount to Gateway	6	69	1500 AL	775
B	Double Circuit				
	Blount to East Campus	5	69	650 CU	568
	Blount to East Campus	5	69	650 CU	568
C	Single Circuit				
	Blount to Lakeside	5	69	650 CU	622
D	Double Circuit				
	East Campus to Blount	5	69	800 CU	568
	East Campus to Lakeside	5	69	800 CU	568
E	Single Circuit				
	East Campus to Walnut #1	5	69	1250 AL	765

It was evident that different parameters were used to calculate the existing ampacity ratings. Together with additional information provided by ATC, POWER determined that the following parameters were used to determine the above rating for the cable circuits.

Ambient Soil Temp:	25˚C
Native Soil Thermal Resistivity:	90 rho
Backfill Thermal Resistivity:	90 rho
Depth to Bottom of Ductbank:	4’
Pipe size (ID):	
5”	5.047 in
6”	6.125 in
Load Factor:	75%
Steady State Conductor Temperature:	75˚C
Emergency Conductor Temperature:	90˚C
Emergency Duration	300 hours

It is significant to note that the maximum allowable steady state and emergency conductor temperatures identified in the ATC information is ten degrees lower than the value (85˚C) indicated in POWER’s preliminary calculations and commonly utilized in the industry. AEIC CS2-97 notes that the maximum allowable steady state and emergency conductor temperature should be reduced by ten degrees if the overall thermal characteristics of the cable environment are unknown.

Based on the above parameters, POWER recalculated the continuous and emergency ampacities to try and verify the original current calculations. Table 5-5 summarizes the results of these calculations.

Table 5-5
Continuous Ratings for Existing Cables
(4 foot depth)

Case	Circuit	Nom Pipe Size (in)	Volts (kv)	Conductor size (kcmil)	Normal Ampacity Rating (amps)	Emerg. Ampacity Rating (amps)
A	Double Circuit					
	Blount to Commercial Riser	6	138	1500 AL	680	743
	Blount to Gateway	6	69	1500 AL	738	800
B	Double Circuit					
	Blount to East Campus	5	69	650 CU	602	661
	Blount to East Campus	5	69	650 CU	602	661
C	Single Circuit					
	Blount to Lakeside	5	69	650 CU	640	685
D	Double Circuit					
	East Campus to Blount	5	69	800 CU	665	726
	East Campus to Lakeside	5	69	800 CU	665	726
E	Single Circuit					
	East Campus to Walnut #1	5	69	1250 AL	701	759

After review of the plan and profiles that were also provided by ATC, it was determined that the four foot burial depth that was assumed in the original calculations was incorrect and should have been twelve feet. Based on this new assumption, POWER recalculated the ampacities for the circuits assuming a twelve-foot burial depth. Table 5-6 summarizes the results.

Table 5-6
Continuous Ratings for Existing Cables
(12 foot depth)

Table	5-8			Table	5-8	
Ampacity	Results			Ampacity	Results	
For	varying	Thermal	Resistivities	For	varying	Thermal
Table	5-8			Table	5-8	
Ampacity	Results			Ampacity	Results	
For	varying	Thermal	Resistivities	For	varying	Thermal

The following table and graph illustrates the sensitivity of the ampacity to the varying soil thermal characteristics.

Table 5-8
Ampacity Results
For varying Thermal Resistivities

Case	Circuit	70 rho	80 rho	90 rho	100 rho	110 rho
A	Double Circuit					
	Blount to Commercial Riser	619	586	556	530	507
	Blount to Gateway	678	643	613	586	563
B	Double Circuit					
	Blount to East Campus Blount to East Campus	563	538	516	496	478
C	Single Circuit					
	Blount to Lakeside	628	604	582	563	545
D	Double Circuit					
	East Campus to Blount East Campus to Lakeside	620	591	566	544	523
E	Single Circuit					
	East Campus to Walnut #1	686	655	628	604	582

The following table summarizes the emergency ampacities as a function of duration and time.

Table 5-9
Emergency Ampacity Results
For varying Temperature and Duration

Case	Route Description	95˚C 24 hrs	100˚C 24 hrs	95˚C 100 hrs	100˚C 300 hrs	105˚C 100 hrs	90˚C 300 hrs
A	Double Circuit						
	Blount to Commercial Riser	964	1074	884	763	984	683
	Blount to Gateway	1026	1143	945	822	1055	739
B	Double Circuit						
	Blount to East Campus	848	940	804	686	886	619
	Blount to East Campus	848	940	804	686	886	619
C	Single Circuit						
	Blount to Lakeside	894	977	859	737	939	673
D	Double Circuit						
	East Campus to Blount	931	1033	877	752	968	678
	East Campus to Lakeside	931	1033	877	752	968	678
E	Single Circuit						
	East Campus to Walnut #1	965	1061	913	795	1004	725

It was evident with all the various parameters and the potential cost, that it would be important to determine the soil thermal characteristics surrounding the existing cable pipes. POWER contracted with Geotherm to perform the necessary tests. The thermal sand exhibited good thermal properties at high moisture content. However, there appears to be some areas where the moisture content was poor and could eventually dry out due to the heating of the cable. Based on the results of the thermal study, the following parameters where established.

Ambient Soil Temp:	25˚C
Native Soil Thermal Resistivity:	90 rho
Backfill Thermal Resistivity (A):	50 rho
Backfill Thermal Resistivity (B-F):	170 rho
Depth to Bottom of Ductbank:	4’ and 12’
Pipe size (ID):	
5”	5.047 in
6”	6.125 in
Load Factor:	75%
Steady State Conductor Temperature:	85˚C
Emergency Conductor Temperature:	100˚C
Emergency Duration	300 hours

Based on the above parameters, POWER recalculated the continuous and emergency ampacities to try and determine the appropriate ampacity rating for the existing circuits. Tables 5-10 and 5-11 summarize the results of the ampacity calculations for the depths of 4 foot and 12 foot, respectively.

Table 5-10
Continuous Ratings for Existing Cables
(4 foot depth)

Case	Circuit	Normal Ampacity Rating (amps)	24 hrs Emerg. Ampacity Rating (amps)	300 hrs Emerg. Ampacity Rating (amps)
A	Double Circuit			
	Blount to Commercial Riser	805	1157	850
	Blount to Gateway	873	1238	917
B	Double Circuit			
	Blount to East Campus	581	805	635
	Blount to East Campus	581	805	635
C	Single Circuit			
	Blount to Lakeside	599	814	643
D	Double Circuit			
	East Campus to Blount	638	880	695
	East Campus to Lakeside	638	880	695
E	Single Circuit			
	East Campus to Walnut #1	655	875	697

Table 5-11
Continuous Ratings for Existing Cables
(12 foot depth)

Case	Circuit	Normal Ampacity Rating (amps)	24 hrs Emerg. Ampacity Rating (amps)	300 hrs Emerg. Ampacity Rating (amps)
A	Double Circuit			
	Blount to Commercial Riser	638	1063	736
	Blount to Gateway	699	1141	799
B	Double Circuit			
	Blount to East Campus	521	799	624
	Blount to East Campus	521	799	624
C	Single Circuit			
	Blount to Lakeside	569	821	645
D	Double Circuit			
	East Campus to Blount	569	871	683
	East Campus to Lakeside	569	871	683
E	Single Circuit			
	East Campus to Walnut #1	605	866	686

6.0 RECOMMENDATIONS

As a result of this study, POWER recommends that ATC modify the ampacity ratings for their existing HPFF cable circuits and future circuit as follows.

				RECOMMENDED			
Case	Circuit	Circuit #	Cond Size	Normal Ampacity Rating (amps)	2 hrs Emerg. Ampacity Rating (amps)	24 hrs Emerg. Ampacity Rating (amps)	300 hrs Emerg. Ampacity Rating (amps
A	Double Circuit						
	Blount to Commercial Riser	13802	1500 AL	638	997	769	662
	Blount to Gateway	6902	1500 AL	699	1067	825	712
B	Double Circuit						
	Blount to East Campus	6906	650 CU	521	724	604	535
	Blount to East Campus	6907	650 CU	521	724	604	535
C	Single Circuit						
	Blount to Lakeside		650 CU	569	743	636	573
D	Double Circuit						
	East Campus to Blount	6908	800 CU	569	806	662	584
	East Campus to Lakeside	6977	800 CU	569	806	662	584
E	Single Circuit						
	East Campus to Walnut #1	6976	1250 AL	605	838	680	607
F	Single Circuit						
	East Campus to Walnut #2	6975	2500 CU	741	1337	904	764