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1.0 Scope

1.1 This document establishes American Transmission Company's (ATC) substation equipment 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 transmission line conductors – all of which could otherwise limit or affect the ampacity of a transmission line.

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

2.0 Introduction

2.1 The electrical ampacity rating of most substation equipment is dependent upon the physical and metallurgical characteristics of associated components. This document considers maximum total temperatures for these components in determining ratings appropriately applied to general types of equipment. For each type of substation equipment, this document includes:

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

2.1.2 Detailed explanation or documentation of methods, formulas, standards, sources, and assumptions used in determining current ratings.

2.1.3 Qualification of any difference in ratings calculation methodology based upon:

2.1.3.1 Equipment age or vintage

2.1.3.2 Maintenance history, condition, etc.

2.1.3.3 Pre-loading levels

2.1.4 Explanations of any specific manufacturer exceptions to the standard criteria in this document.

2.2 This document is consistent with ATC material specifications for substation equipment items specifically addressed, including power transformers, circuit breakers, disconnect switches, circuit switchers, current transformers, conductors, series inductors and relays. The manufacturer's nominal continuous current rating shall serve as the limiting rating under all conditions for any equipment not specifically covered in this document.

2.3 This document does not provide for ratings of shunt connected capacitors, reactors and potential devices, in that they are not in the normal current carrying path and are not part of the operational load flow consideration.

2.4 The ratings provided in this document are static ratings based upon several assumptions and are generally applicable for broad equipment categories and under ambient conditions determined to best represent ATC's service territory. Should specific equipment details or ambient conditions be available, Asset Planning & Engineering can perform specific-case ratings analysis when required.

2.4.1 Additionally, users of this document's ratings must be cognizant of ATC's standard ambient conditions criteria (Table 1 – Legacy Substation Ambient Conditions Criteria). Users shall recognize that known extreme weather circumstances, especially ambient temperatures above 104°F (40°C) requires the user to exercise caution in application of this document's ratings. Contact Asset Planning & Engineering for analysis under such extreme circumstances. For the user's reference in this context, the tables in this document do provide ratings associated with most equipment's design temperatures of 104°F (40°C).

2.4.2 ATC uses numerous rating software and programs to rate the various substation components as described in the subsequent sections of this document. These applications may not provide identical results, however the comparable results that are within meting accuracy are acceptable for rating purposes. Metering accuracy is considered to be 1 to 3 percent.

3.0 References

The latest revisions of the following documents shall be applied when a version is not specifically addressed. If there is any apparent contradiction or ambiguity among these documents and this criteria document, the legislative code shall take first precedence followed by Procedure PR-0285 and this document. Bring the issue to the attention of Asset Planning & Engineering for resolution before application.

3.1 The Aluminum Association, Aluminum Electrical Conductor Handbook, Third Edition, 1989

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

3.3 ANSI/NEMA C93.3 Requirements for Power-Line Carrier Line Traps

3.4 ASTM B241 Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extrude Tube

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

3.6 ATC Criteria CR-0062; Underground Transmission Line Ampacity Ratings

3.7 ATC Design Criteria DS-0000; Substation

3.8 ATC Design Guide ECS-GD-0130, Equipment Connection Diagram Requirements

3.9 ATC Design Guide GD-3100; Bus

3.10 ATC Guide GD-0480; Document Control

3.11 ATC Procedure PR-0285; Facility Ratings

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

3.13 ATC White Paper, Analysis of Substation Jumper Conductor Operating Temperatures

3.14 CIGRE Technical Bulletin 299, Guide for Selection of Weather Parameters for Overhead Bare Conductors Ratings

3.15 IEC 60287-1-1, Electric Cables, Calculation of the Current Rating, Current Rating Equations (100% Load Factor) and Losses

3.16 IEEE 605, Substation Rigid-Bus Structures

3.17 IEEE 738, Standard for Calculating the Current-Temperature of Bare Overhead Conductors

3.18 IEEE C37.010, Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis

3.19 IEEE C37.04, Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis

3.20 IEEE C37.30, Standard Requirements for High-Voltage Switches

3.21 IEEE C37.37, Loading Guide for AC High-Voltage Air Switches (in Excess of 1000 V)

3.22 IEEE C37.100, Standard Definitions for Power Switchgear

3.23 IEEE C37.110, Guide for the Application of Current Transformers Used for Protective Relaying Purposes

3.24 IEEE C57.12.00, Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers

3.25 IEEE C57.13, Standard Requirements for Instrument Transformers

3.26 IEEE C57.19.00, Standard General Requirements and Test Procedures for Outdoor Power Apparatus Bushings

3.27 IEEE C57.19.100, Guide for Application of Power Apparatus Bushings

3.28 IEEE C57.91, Guide for Loading of Mineral-Oil-Immersed Transformers

3.29 IEEE C93.3, Requirements for Power-Line Carrier Line Traps

3.30 NEMA CC1, Electrical Power Connection for Substations

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

3.32 PTLoad v 6.1; Electric Power Research Institute, Inc

3.33 RateKit v.5.0; The Valley Group, Inc.

3.34 Report of the Ad Hoc Line Trap Rating Procedure Working Group of the System Design Task Force, SDTF-22, June 1990

3.35 Southwire Overhead Conductor Manual, Second Edition, 2007

4.0 Definitions

The bolded definitions are from the NERC Glossary of Terms

4.1 Ambient Air Temperature: The temperature of surrounding air that comes into contact with the subject equipment[1].

4.2 Ampacity: The current-carrying capacity of a circuit or one of its components. This value is measured in amperes and is a rating for each phase 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 **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.

4.4 **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.

4.5 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.

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

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

4.8 Transient Loading: The electrical load is continuously increasing or decreasing due to changing electrical demand. The changing loading causes an associated increase or decrease in the conductor and equipment temperature that lags the change in loading due to thermal inertia equipment and conductors.

4.9 Electrical Load Duration: All ATC ratings assume a steady-state load. The load duration is assumed valid for the following durations

- Continuous (24 hours) for Normal Ratings
- 2 Hours for Emergency Ratings

5.0 Ambient Conditions

5.1 ATC is transitioning from legacy weather parameters to study-based weather parameters.

5.1.1 Substation equipment and transformers shall be rated utilizing legacy weather parameters.

5.1.2 Substation conductors may be rated utilizing either the legacy weather parameters or study-based weather parameters. Refer to the Section 12.1.1 for specifics on related to substation conductor study-based weather parameters.

5.2 Legacy Weather Parameters

[1] IEEE C37.100 Standard Definitions for Power Switchgear, 1992, page 3.

5.2.1 The ambient weather conditions as shown in Table 1 - Legacy Substation Ambient Conditions Criteria, 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.

5.2.2 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.

5.2.3

5.2.4 The ratings of outdoor substation equipment, especially conductors, are based upon a standard set of ambient conditions (those determined to be most probable during peak load conditions) as shown in Table 1. Ratings calculations for substation equipment and conductors are consistently based upon these common conditions. This criteria is also consistent with that in ATC Criteria CR-0061; Overhead Transmission Line Ampacity Ratings.

Table 1 – Legacy Substation Ambient Conditions Criteria

Criteria	Summer	Fall	Winter	Spring
Ambient temperature	90°F (32.2°C)	60°F (15.6°C)	30°F (-1.1°C)	60°F (15.6°C)
Wind velocity	4.4 fps	4.4 fps	4.4 fps	4.4 fps
Wind direction relative to conductor direction	Perpendicular	Perpendicular	Perpendicular	Perpendicular
Latitude	44°N	44°N	44°N	44°N
Conductor orientation	E-W	E-W	E-W	E-W
Elevation above sea level	800 ft.	800 ft.	800 ft.	800 ft.
Atmosphere Clear vs. Industrial (cloudy)	Clear	Clear	Industrial*	Clear
Date (for solar conditions)	June 30	October 21	December 31	October 21
Time of Day (for solar conditions) Flux	12:00Noon 100%	12:00 Noon 100%	12:00 Noon 100%	12:00 Noon 100%
Coefficient of radiant emission	0.8	0.8	0.8	0.8
Coefficient of solar absorption	0.8	0.8	0.8	0.8

6.0 Power Transformer Ratings

6.1 Power transformer ratings are a function of numerous variables, many of which are not directly measured. This section discusses how these variables are addressed and sets criteria for operational and planning limits for ATC power transformers.

6.2 Power transformer capability will be determined based upon the following criteria:

6.2.1 Straight-line preloading of 70 and 90 percent

6.2.2 Maximum top oil temperature = 95°C (203°F) for a 55°C rise insulation
110°C (230°F) for a 65°C rise insulation

6.2.3 Maximum hot-spot temperature = 125°C (257°F) for a 55°C rise insulation
140°C (284°F) for a 65°C rise insulation

6.2.4 A maximum loss of life (LOL) = 1% per event

6.2.5 Tertiary loading capability = 25% of base rating

6.2.6 Manufacturer warranty limitations (variable per unit)

6.2.7 Oil expansion

6.2.8 Bushing limitations

6.2.9 Tap changer limitations

6.2.10 Stray flux heating issues

6.2.11 Current transformer (CT) limitations

6.2.12 Present condition of the transformer

6.3 PTLoad, a power transformer analysis software program based on IEEE C57.91, Guide for Loading of Mineral-Oil-Immersed Transformers, is used to evaluate transformer thermal performance under various loading conditions. PTLoad evaluation shall be performed using a top oil model and shall assume non-directed flow for forced oil cooling. Figure 1 is a typical transformer overload report for the previously stated conditions.

6.3.1 The PTLoad analysis of transformers shall be performed based on the full ratio of all current transformers (CTs) included as part of the transformer equipment. The limits for the actual in-service CT connections shall be listed as a separate individual entry within the SELD Transformer Section.

6.4 SELD and Energy Management System (EMS) limits may reflect power transformer network capability limitations imposed by high and/or low side devices. However, individual power transformer loading curves will not reflect these limiters. The power transformer rating established shall apply bushing-to-bushing, taking into account all ancillary devices including tap changers, bushings, current transformers, etc. Consideration is given to the existing condition of the transformer. Therefore, a power transformer may require de-rating when operations or maintenance history dictates.

6.5 ATC Specification for New Power Transformer Purchases

6.5.1 Power transformers purchased according to ATC's standard specifications shall only be designed with 65°C rise insulation and to operate at 125% of the maximum nameplate rating for 24 hours, following a 70% pre-load, and under an ambient temperature of 40°C. Overload ratings will be established by adhering to the following parameters:

6.5.1.1 The top oil temperature of the power transformer shall not exceed 110°C.

6.5.1.2 Hot spot temperature shall not exceed 140°C.

6.5.1.3 The power transformer's calculated loss of life shall not exceed 1% per overload. Calculations to determine operating limits shall be performed according to established IEEE or ANSI guidelines as adopted by Asset Planning and Engineering. Guidelines differ based upon the type or size of the power transformer being evaluated.

Figure 1 – Transformer Overload Table Template

Substation: **Any sub**
Serial Number: 9999999

Operators number: T21 Sk # : ________
HV 345 kV Co. # : ________
LV 138 kV Date created: 12/21/2005

H-X MVA @ 65°C Rise 120 / 160 / 200 [7]
Y MVA @ 65°C Rise 28.74 / 38.32 / 47.9

Nameplate Rating	120 MVA ONAN				200 MVA ONAN/ONAF/ONAF					
		Pre-Load 70%		Pre-Load 90%		Pre-Load 70%		Pre-Load 90%	Ambient Temperature	
Time	%	MVA [4]	%	MVA [4]	%	MVA [4]	%	MVA [4]	°F	°C
30 minutes	130%	156	130%	156	130%	260	130%	260	0	-18
	130%	156	130%	156	130%	260	130%	260	30	-1
	130%	156	130%	156	130%	260	130%	260	60	16
	130%	156	130%	156	130%	260	130%	260	90	32
2 hours [6]	130%	156	130%	156	130%	260	130%	260	0	-18
	130%	156	130%	156	130%	260	130%	260	30	-1
	130%	156	130%	156	130%	260	130%	260	60	16
	130%	156	130%	156	130%	260	130%	260	90	32
8 hours	130%	156	130%	156	130%	260	130%	260	0	-18
	130%	156	130%	156	130%	260	130%	260	30	-1
	130%	156	130%	156	130%	260	130%	260	60	16
	130%	156	130%	156	130%	260	130%	260	90	32
24 hours	125%	150	125%	150	125%	250	125%	250	0	-18
	125%	150	125%	150	125%	250	125%	250	30	-1
	125%	150	125%	150	125%	250	125%	250	60	16
	125%	150	125%	150	125%	250	125%	250	90	32

Comments:
Provisions:

[1] The arithmetic sum of the loads on the X wdg and the Y wdg shall not exceed the rating of the H wdg nor shall their individual ratings be exceeded.

[2] All fans need to be checked for operation. Calculations based on the fact that all fans will be working.

[3] The final output of PTLoad is a thru calculation from High side to Low side. If there is any tertiary loading it will reduce the PTLoad thru calculation by the tertiary load.

[4] Overload is limited by ATC standard 125% for 24hours, CT, bushing, LTC, DETC, thermal capability of the transformer or letter in the transformer file.

[5] With the bushing manufacturer's approval, the bushing may be loaded up to twice the nameplate rating for 2 hours. Without such approval, it may be loaded to 1.5 times the rating for 2- and 8–hour periods. For periods longer than 8 hours, the nameplate rating may not be exceeded. These ratings apply to both bottom-connected and draw-lead connected bushings.

[6] The 2 hour rating is the same as the emergency rating in SELD.

[7] The nameplate rating is the same as the normal rating in SELD.

Calculations made by: ____________________
Approved by: ____________________

6.6 Operating Conditions

6.6.1 Operations

6.6.1.1 The Operations Department requires detailed loading information that is not available in conventional EMS systems. Generally EMS systems allow only for display of data associated with a normal and emergency rating.

6.6.1.2 The ATC EMS will display normal and emergency limits for the operating period using the 70% preload assumption.

6.6.2 Loading Periods

6.6.2.1 Asset Planning & Engineering will develop, maintain, and distribute a loading table for each ATC-owned power transformer. The loading table will reflect the most limiting element for the high-voltage to low-voltage winding. Together with manufacturer test reports, these loading tables will be available through SELD.

6.6.2.2 While SELD models include ratings for the more traditional 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.

6.6.3 Normal Rating

6.6.3.1 The normal rating of a transformer is the maximum nameplate MVA rating of the transformer. It is indicative of an indefinite or continuous loading period.

6.6.4 30 Minutes

6.6.4.1 An operator may use a 30 minute limit under circumstances where contingency overloads can be mitigated within 30 minutes. An operating guide will outline the process for managing this 30-minute mitigation scenario.

6.6.4.2 Mitigation schemes of this sort usually require the starting of fast start gas turbines, opening of network elements and in more extreme circumstances the shedding of load, or a combination of schemes that can be demonstrated to occur in 30 minutes or less to reduce the power transformer to the normal continuous load limit.

6.6.5 2 Hours, Standard Emergency Rating

6.6.5.1 The standard emergency limitation period for power transformer operation is based on the 2-hour rating with maximum forced cooling with a 70% preload condition. It is generally accepted practice that, through a combination of system topology changes, Transmission Load Relief (TLR), or other actions, a power transformer overload will be mitigated to the normal rating within 2 hours.

6.6.5.2 If a contingency would cause a power transformer to reach the 2-hour limit, the operator develops a mitigation strategy to reduce the power transformer load 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 power transformer, the system will not be operated such that the power transformer would exceed this limit upon first contingency. Action needs to be taken, including TLR or development of such a mitigation plan.

6.6.6 8 Hours

6.6.6.1 An 8-hour limit allows Operators to utilize a longer term loading limit of a transformer.

6.6.7 24 Hours

6.6.7.1 For durations longer than 8 hours the maximum percent overload for the top end rating of a power transformer is 125 percent. Generally, the 24-hour limits are for information during operation following the loss of system facilities for which replacement is expected to take several days or for operation of radial and/or limited source networks where load within a geographical area has the highest influence on power transformer loading.

6.6.8 Tertiary Loading

6.6.8.1 The majority of ATC power transformers are rated for arithmetic loading. Therefore, the nameplate rating includes any tertiary loading capability. For example, if the tertiary load is 10 MVA on a 100 MVA power transformer, the maximum load for the high-voltage (HV) to low-voltage (LV) winding is 90 MVA.

6.6.8.2 For all ATC power transformers, the tertiary load shall not exceed 25% of the nameplate rating of the power transformer unless documented in the individual loading criteria for the power transformer.

6.6.9 Stray Flux Heating

6.6.9.1 Stray flux heating may drive some power transformer limits. In no case can the transformer maximum rating exceed the stray flux loading limit. This will be determined within Asset Planning & Engineering and in conjunction with the manufacturers. Flux leakage occurs especially in joints and corners in a magnetic circuit.

6.6.9.2 The stray flux can link one or two of the windings. The stray flux is not measured as a voltage drop at the terminals. It can be measured within a coil in the neighborhood of the power transformer. A portion of the leakage flux can also be stray flux when it escapes the power transformer boundaries. Stray fields emitted from a power transformer (or any other electrical device) can cause serious operating problems to the surrounding electronic components.

6.6.10 Ancillary Equipment

6.6.10.1 ATC's transformer specifications require that all ancillary devices be sized to allow emergency loading application in accordance with IEEE C57.91, Guide for Loading Transformer. However, ancillary equipment may drive existing power transformer limits.

6.6.11 Load Tap Changer

6.6.11.1 Load tap changer normal and emergency capabilities are obtained from ATC records inherited from the local distribution companies as former asset owners or from the manufacturer.

6.6.12 Bushings

6.6.12.1 IEEE C57.19.100, Guide for Application of Power Apparatus Bushings, Section 5.4, limits the bushing temperature to 105°C for normal loss of life. So transformer operation at the 110°C top oil temperature, where the bottom of the bushing resides provides that the bushing should be sized larger than the nameplate rating of the transformer for new and old units.

6.6.12.2 With the bushing manufacturer's approval, the bushing may be loaded up to twice the nameplate rating for 2 hours. Without such approval, it may be loaded to 1.5 times the rating for 2- and 8-hour periods. For periods longer than 8 hours, the nameplate rating may not be exceeded. These ratings apply to both bottom-connected and draw-lead connected bushings.

6.6.13 Extreme Emergency Operation

6.6.13.1 At times circumstances will call for a variance to the power transformer limits outlined in this operating instruction. If such a situation arises, the Operations Department will consult Asset Management for a Special Exception rating.

6.6.14 Reporting

6.6.14.1 Any time a power transformer is operated above its normal rating, Operations should notify Asset Maintenance for follow-up inspection.

7.0 Circuit Breaker Ratings

7.1 The circuit breaker ratings contained herein are applicable to breakers that are in good condition and have been well maintained. Consult Asset Maintenance if a loading concern is driven by condition assessment.

7.2 A circuit breaker's design features dictate appropriate values for maximum total temperature and temperature rise. The rated continuous current is based upon the limitations of a breaker's individual components when the breaker is carrying rated current at 40°C ambient temperature. Therefore, operating the breaker under loads higher than nameplate is acceptable but is dependent on the combination of ambient temperature and load duration. The breaker ratings provided will not compromise the mechanical strength of current-carrying components due to annealing at excessively high component temperatures. Such effects are cumulative and could otherwise prove detrimental to a breaker's intended successful operation.

7.3 This criterion provides ratings separated into two groups of breaker types; 1) gas breakers and 2) oil circuit breakers. Section 7.7 details the calculations used for the ratings provided in Sections 7.5 and 7.6.

7.4 The ratings provided in Table 2 and Table 3 are also based upon the following factors:

7.4.1 The allowable load current limits provided are associated with nominal continuous current ratings that are consistent with ATC material specifications. The values assume ANSI standard for transformer bushings (per IEEE C57.19.00, clause 5.4 and IEEE C57.19.100, clause 6.0) also apply for oil circuit breakers and do not consider any limitations due to internal bushing current transformers tapped at less than full ratio. Refer to section 11.0 for current transformer ratings.

Breaker allowable load currents are based on IEEE C37.010 Application Guide for AC High-Voltage Circuit Breakers, clause 5.4. Breakers normal and emergency allowable load current limits are obtained by multiplying the nominal continuous current rating by the appropriate listed loadability factor (LF_n or LF_s):

$I_a = I_r \times LF_n$ and $I_s = I_r \times LF_s$

Where:

I_r = breaker nominal rated continuous current @ 40°C ambient.

I_a = allowable continuous (normal) current at ambient temperature.

I_s = allowable short-time emergency load current.

LF_n = normal loadability factor.

LF_s = emergency (short-time) loadability factor.

7.4.2 The permissible temperature rise above ambient temperature (θ_r) of a breaker is based on the highest permissible temperature rise breaker component. Without analyzing each circuit breaker for particular component details, the maximum temperature rise values used for calculating ratings presented in this section provide the most conservative loadability factors. Under most circumstances, identifying specific component characteristics is difficult, therefore the limits used herein are the most conservative.

7.4.3 Circuit breakers operated at temperatures that exceed their limits of total temperature may experience a reduction in operating life. After every four instances of 2-hour emergency loadings, the circuit breaker must be inspected and maintained in accordance with the manufacturer's recommendations before the circuit breaker is subjected to additional emergency loadings.

7.4.4 Following any single emergency period, the load current shall be limited to no more than 95% of the nominal rating (I_a) at the specific ambient temperature, for a minimum of 2 hours (IEEE C37.010 clause 5.4.4.4d).

7.4.5 Higher operating temperatures will have little effect on the interrupting capability of a breaker because the influence is minimal when compared to those temperatures attained during interruption.

7.5 Gas Circuit Breakers

7.5.1 The ratings provided in Table are generally applicable to any ATC-owned gas circuit breaker >1000V (and presumed designed per IEEE standards in effect at the time of manufacture), including live- or dead-tank breakers or those utilized in gas-insulated switchgear (GIS). More aggressive ratings may be possible on a case-specific basis through analysis, which is aided by the manufacturers' heat run test limits (if available). Consult Asset Planning & Engineering for such analysis as required.

7.5.2 For any other size breakers, multiply the nominal continuous current rating by the appropriate listed loadability factor (LF_n or LF_s) to obtain load current limits.

7.5.3 For example:

Given: 600A nominally rated gas circuit breaker in winter.

Find: The emergency load current rating.

Solution: = I_r x LF_s = 600 x 1.365 = 819A.

Table 2 - Gas Circuit Breakers Allowable Load Current[2]

Nomimal Gas Breaker Rating (I_r)	Maximum Allowable Load Current Ratings (Amps)						Reference Breaker Design Basis [4]	
	Summer		Spring & Fall		Winter			
	Ambient Temperature (θ_A)							
	32.2°C (90°F)		15.6°C (60°F)		-1.1°C (30°F)		40°C (104°F)	
	Normal	Emerg.	Normal	Emerg.	Normal	Emerg.	Normal	Emerg.
600	634	696	702	760	765	819	600	665
1200	1268	1393	1404	1520	1530	1639	1200	1330
1600	1690	1857	1871	2026	2040	2185	1600	1774
2000	2113	2321	2339	2533	2550	2731	2000	2217
3000	3169	3482	3509	3799	3824	4096	3000	3326
	Loadability Factor, Normal (LF_n) & Emergency (LF_s)							
	1.056	1.161	1.170	1.266	1.275	1.365	1.000	1.109

7.6 Oil Circuit Breakers

7.6.1 The ratings provided in Table are generally applicable to any ATC-owned oil circuit breaker >1000V (designed per IEEE standards in effect at the time of manufacture). Ratings that are more aggressive may be possible on a case-specific basis through analysis, which is aided by the manufacturers' heat run test limits (if available). Consult Asset Planning & Engineering for such analysis as required.

7.6.2 For any other size breakers, multiply the nominal continuous current rating by the appropriate listed loadability factor (LF_n or LF_s) to obtain load current limits.

7.6.3 For example:

Given: 600A nominally rated oil circuit breaker in winter.

Find: The emergency load current rating.

Solution: = I_r x LF_s = 600 x 1.415 = 849A.

[2] 40°C (104°F) ratings are provided as this ambient temperature is the standard design basis for new breakers per IEEE C37.04.

Table 3 - Oil Circuit Breakers Allowable Load Current[3]

Nominal Oil Breaker Rating (I_r)	Maximum Allowable Load Current Ratings (Amps)						Reference Breaker Design Basis [4]	
	Summer		Spring & Fall		Winter			
	Ambient Temperature (θ_A)							
	32.2°C (90°F)		15.6°C (60°F)		-1.1°C (30°F)		40°C (104°F)	
	Normal	Emerg.	Normal	Emerg.	Normal	Emerg.	Normal	Emerg.
600	639	710	716	782	788	849	600	675
1200	1278	1420	1433	1564	1576	1698	1200	1349
1600	1704	1894	1910	2085	2101	2264	1600	1799
2000	2130	2367	2388	2607	2626	2830	2000	2249
3000	3194	3551	3582	3910	3939	4245	3000	3373
	Loadability Factor, Normal (LF_n) & Emergency (LF_s)							
	1.065	1.184	1.194	1.303	1.313	1.415	1.000	1.124

7.7 Circuit Breaker Ratings Calculation

7.7.1 While the allowable component temperatures vary among breaker types (especially gas vs. oil), the method for determining breaker ratings is the same for all types.

I_r = manufacturer's rated continuous current @ 40°C ambient.

θ_a = ambient temperature (in °C).

$LF_n = \left[\frac{\theta_{max_r} - \theta_a}{\theta_r}\right]^{\left(\frac{1}{1.8}\right)} = \frac{I_a}{I_r}$ = normal loadability factor (all temperature variables in °C).[4]

I_a = I_r x LF_n = allowable continuous current at ambient temperature (θ_a).

θ_r = 65°C (OCBs) or 75°C (GCBs); allowable hottest-spot temperature rise (in °C) at rated current, per IEEE C37.010 clause 5.4.3 and C37.04 Table 1. The value for θ_r is based on the highest temperature rise breaker components listed in C37.04 Table 1; circuit breaker; connections, bolted or equivalent and class A insulation. A 65°C or 75°C maximum temperature rise above ambient and 105°C or 115°C maximum total temperature provide the most conservative loadability factors for oil and gas circuit breakers, respectively. The use of these values in the calculation will result in an allowable continuous current that will not cause the temperature of any part of the circuit breaker to exceed permissible standard limits when operating in ambient temperatures <40°C; the IEEE standard design basis.

θ_{max_r} = (θ_r +40°C) = 105°C (OCBs) or 115°C (GCBs) = allowable hottest-spot total temperature (in °C), per IEEE C37.010 clause 5.4.3 and C37.04 Table 1.

θ_{max_s} = 120°C (OCBs) or 130°C (GCBs); maximum allowable short-time emergency total temperature (in °C) = (θ_{max_r} + 15°C), per IEEE C37.010 clause 5.4.4.2. The maximum allowable short time emergency total temperature (120°C or 130°C for oil or gas breakers, respectively) used here is based upon an IEEE-provided allowable additional short-time (≤ 4 hours) temperature rise of 15°C.

[3] The temperature rise of a current-carrying part is proportional to an exponential value of the current flowing through it. Industry experience has shown that although the exponent may have different values, depending on breaker design and components within the breaker, it generally is in the range of 1/1.6 to 1/2.0. IEEE provides that a factor of 1.8 is appropriate for these calculations.

τ = 0.5 hours; circuit breaker thermal time constant (per IEEE C37.010 Table 4). The length of time required for the temperature to change from the initial value to the ultimate value if the initial rate of change was continued until the ultimate temperature was reached. While this time constant varies by specific breaker design, the value used here is generally applicable and consistent with IEEE suggestion.

θ_i = θ_{max_r} ; total temperature due to the current carried prior to emergency loading. Ratings here are based upon this pre-loading equaling the circuit breaker's rated continuous current.

t_s = permissible time for carrying I_s at θ_a after initial current I_a.

$\theta_s = \left[\frac{\theta_{max_s} - \theta_i}{1 - 1/e^{t_s/\tau}}\right] + \theta_i$ = total temperature that would be reached if I_s were applied continuously at ambient temperature (θ_a).

$LF_s = \left[\frac{\theta_s - \theta_a}{\theta_r}\right]^{\left(\frac{1}{1.8}\right)} = \frac{I_s}{I_r}$ = short-time emergency loadability factor (all temperatures in °C).[5]

I_s = I_r x LF_s = allowable short-time emergency load current.

8.0 Switch Ratings

8.1 The ratings provided in this section are applicable to ATC-owned switches installed in substations or on transmission line structures. The switch ratings contained herein are applicable to switches that are in good condition and have been well maintained.

8.2 An air disconnect switch is composed of many different parts made from various materials. Since the determining characteristics of different materials vary widely, IEEE C37.30 groups these parts according to their material and function and gives them a switch part class designation. The loadability factors of each switch part class, as a function of ambient temperature, are represented by a curve (e.g., AO1 from IEEE Std C37.37). The allowable continuous current class (ACCC) designation of an air switch is a code that identifies the composite curve derived from the limiting switch part classes.

8.3 Air switches designed to meet IEEE C37.30 – 1962 and earlier standards have a 30°C limit of observable temperature rise in a maximum ambient temperature of 40°C. These switches have an ACCC designation of AO1.

8.4 In the 1960s, aluminum and alloys with good conductivity, such as 6063 aluminum tubing, became available. The reduced cost, reduced weight, and superior annealing compared to copper brought on IEEE C37.30 – 1971. This updated standard allowed a variety of temperature rises depending on individual piece parts.

Switches built to IEEE C37.30 – 1971 and later standards have a variety of ACCC designations with the vast majority follows the DO4 and DO6 curves. Earlier switch designs generally have an ACCC designation of AO1 and were phased out. Table 4 represents ratings for switches manufactured after 1975 and assumes adherence to the DO6 curve, which is more conservative than DO4[4]. The present ATC Material Specification for Group-Operated Disconnect Switches, MS-4510, calls for silver-to-silver contacts, placing these new switches into a DO6 curve.

The ATC rating methodology for switches of unknown manufacturer changed from a A01 rating to a A06 rating in the 2007 version of this criteria. This change in methodology was made because an A06 rating is more conservative than the combined A01 and D06 ratings that were in effect prior to 2007. Retroactive application of changes to the switch rating will be evaluated and applied at ATCs discretion.

[4] 1975 was used as an arbitrary cut-off date to allow for the fact that some manufacturers may not have immediately converted to the newer version of the standard.

Table 4 - Air Disconnect Switches (Manufactured >1975) Allowable Load Current[5]

DO6 Nominal Switch Rating (I_r)	Maximum Allowable Load Current Ratings (Amps)						Reference Switch Design Basis [7]	
	Summer		Spring/Fall		Winter			
	Ambient Temperature (θ_A)							
	32.2°C (90°F)		15.6°C (60°F)		-1.1°C (30°F)		40°C (104°F)	
	Normal	Emerg.	Normal	Emerg.	Normal	Emerg.	Normal	Emerg.
600	695	797	779	866	849	931	647	763
1200	1391	1595	1559	1733	1698	1861	1294	1525
1600	1854	2126	2078	2310	2264	2482	1725	2034
2000	2318	2658	2598	2888	2830	3102	2156	2542
3000	3477	3987	3897	4332	4245	4653	3234	3813
	Loadability Factor, Normal (LF) & Emergency (LE1)							
	1.159	1.329	1.299	1.444	1.415	1.551	1.078	1.271

Table 5 - Air Disconnect Switches (Manufactured ≤1975) Allowable Load Current

AO1 Nominal Switch Rating (I_r)	Maximum Allowable Load Current Ratings (Amps)						Reference Switch Design Basis [7]	
	Summer		Spring/Fall		Winter			
	Ambient Temperature (θ_A)							
	32.2°C (90°F)		15.6°C (60°F)		-1.1°C (30°F)		40°C (104°F)	
	Normal	Emerg.	Normal	Emerg.	Normal	Emerg.	Normal	Emerg.
600	673	836	808	950	923	1052	600	778
900	1010	1255	1212	1426	1385	1578	900	1166
1200	1346	1673	1616	1901	1847	2104	1200	1555
1600	1795	2230	2155	2534	2462	2805	1600	2074
2000	2244	2788	2694	3168	3078	3506	2000	2592
3000	3366	4182	4041	4752	4617	5259	3000	3888
	Loadability Factor, Normal (LF) & Emergency (LE1)							
	1.122	1.394	1.347	1.584	1.539	1.753	1.000	1.296

Table 6 - Air Disconnect Switches (Unknown Manufacture Date) Allowable Load Current

AO6 Nominal Switch Rating (I_r)	Maximum Allowable Load Current Ratings (Amps)						Reference Switch Design Basis [7]	
	Summer		Spring/Fall		Winter			
	Ambient Temperature (θ_A)							
	32.2°C (90°F)		15.6°C (60°F)		-1.1°C (30°F)		40°C (104°F)	
	Normal	Emerg.	Normal	Emerg.	Normal	Emerg.	Normal	Emerg.
600	673	797	779	866	849	931	600	763
900	1010	1196	1169	1300	1274	1396	900	1144
1200	1346	1595	1559	1733	1698	1861	1200	1525
1600	1795	2126	2078	2310	2264	2482	1600	2034
2000	2244	2658	2598	2888	2830	3102	2000	2542
3000	3366	3987	3897	4332	4245	4653	3000	3813
	Loadability Factor, Normal (LF) & Emergency (LE1)							
	1.122	1.329	1.299	1.444	1.415	1.551	1.000	1.271

[5] 40°C (104°F) ratings are provided since this ambient temperature is the standard design basis for new switches per IEEE C37.30 Standard Requirements for High-Voltage Switches.

8.5 While IEEE C37.30 – 1971 introduced a new requirement for the nameplate to include the switch's ACCC designation, this was not always the case. When the ACCC designation can not be determined, check the nameplate for switch manufacturer date and apply the following:

8.5.1 Switches manufactured after 1975, assume an ACCC designation of DO6 and use Table 4.

8.5.2 Switches manufactured before or during 1975, assume an ACCC designation of AO1 and use Table 5.

8.6 If the age of the switch is absolutely unavailable, assume an ACCC designation of AO6 and use Table 6. The ACCC designation of AO6 is the more conservative composite curve of a combined AO1 and DO6 loadability classes.

8.7 If a switch has been upgraded since 1975 (e.g. new live parts to increase from 1200 to 1600 ampere rating) assume that the upgrade parts have the same ACCC designation as the original switch, unless a new ACCC designation was provided on the nameplate as part of the upgrade.

The ratings and loadability factors in Table 4, Table 5 and Table 6 are only appropriate for use if such loading is not encountered in a 2-hour period preceding the emergency-loading event.

8.7.1 The loadability factor of a specific switch at a specific temperature not shown in the tables or with a known ACCC designation other than provided above may be calculated from the formulas below or may be taken directly from the appropriate curve in IEEE C37.37 based on the switch's ACCC designation.

8.7.1.1 Continuous Load Current Formula (from IEEE Std C37.30)[6]:

I_a = allowable continuous current at ambient temperature (θ_A) = I_r x LF

Where:

I_r = manufacturer's rated continuous current

θ_A = ambient temperature (in °C)

LF = Loadability Factor = $\sqrt{\frac{(\theta_{max} - \theta_A)}{\theta_r}}$

θ_r = limit of observable temperature rise (in °C) at rated continuous current

θ_{max} = allowable maximum total temperature (in °C)

8.7.1.2 Emergency Load Current Formula (from IEEE Std C37.37)[9]:

I_s = allowable emergency current at ambient temperature (θ_A) = I_r x L_{E1}

Where:

I_r = manufacturer's rated continuous current

L_{E1} = Emergency Loadability Factor (<24 hours) = $\sqrt{\frac{\left(\theta_{max} + \Delta\theta_{E1} - \theta_r e^{-d/T} - \theta_A\right)}{\theta_r\left(1 - e^{-d/T}\right)}}$

θ_{max} = allowable maximum total temperature (in °C)

$\Delta\theta_{E1}$= the additional temperature, 20°C, allowed during emergency conditions for durations less than 24 hours.

θ_r = limit of observable temperature rise (in °C) at rated continuous current

θ_A = ambient temperature (in °C)

T = the switch thermal time constant in minutes (generally 30 minutes for switches)

d = the duration of the emergency in minutes

[6]Table 5 and Table 6 provide values for allowable load currents for common non-load break air disconnect switches. Note that if a disconnect switch is equipped with a load-break device or interrupter, it may not successfully interrupt currents above the nameplate rating of the interrupter.

8.8 Switches carrying loads and being subjected to outdoor environmental conditions for several years rely upon adequate maintenance for satisfactory performance. A switch not properly aligned, with poor or dirty contact condition, or without proper contact pressure[7] will not carry rated current without excessive temperatures or resistance.

9.0 Gas Insulated Switchgear (GIS) Ratings

9.1 The GIS component ratings, both Normal and Emergency, are rated at the nameplate value. ATC assumes GIS components have no overload capability unless the GIS manufacturer provides emergency ratings based on ATC defined ambient temperatures and load durations.

10.0 Circuit Switcher Ratings

10.1 S&C Electric was specifically consulted for the circuit switcher ratings represented in Table 7. For any circuit switchers that cannot be referenced in this table, defer to the nameplate continuous current rating for all seasons' normal and emergency ratings or consult Asset Planning & Engineering for specific analysis. Additionally, consult Asset Planning & Engineering for special ampacity analysis for circuit switchers used for capacitor bank switching.

Table 7 – Circuit Switchers Allowable Load Current[8]

S&C Model Info			Nominal Ratings		Maximum Allowable Load Current Rating (Amps)					
					Summer 90°F (32.2°C)		Spring/Fall 60°F (15.6°C)		Winter 30°F (-1.1°C)	
Device	Style	Type	kV	Amps	Normal	Emerg[10]	Normal	Emerg[10]	Normal	Emerg[10]
C-S	VB	G, MK II-V	69-161	1200	1270	1590	1400	1650	1500	1750
C-S	CB	G, MK II-V	115-161, 345	1600	1690	2000	1870	2100	2000	2200
C-S	CB	G, MK II-V	115-345	2000	2100	2100	2300	2300	2500	2500
C-S	VB	MK-VI	69-161	1200	1270	1590	1400	1650	1500	1750
C-S	VB	MK-VI	230	1200	1270	1790	1400	1800	1500	1960
C-S	VB	MK-VI	69-230	1600	1690	2000	1870	2100	2000	2200
C-S	All	Series 2000	All	1200	1270	1450	1400	1550	1500	1750
T-R	VB		69-161	1200	1270	1590	1400	1650	1500	1750
T-R	VB		230	1200	1270	1790	1400	1800	1500	1960
L-R	VB		69-161	1200	1270	1590	1400	1650	1500	1750
L-R	VB		230	1200	1270	1790	1400	1800	1500	1960
L-R	VB		69-230	1600	1690	2000	1870	2100	2000	2200

C-S = circuit switcher, T-R = trans-rupter, and L-R = line-rupter.
VB = veritical-break disconnect, CB = center-break disconnect, SB = side-break disconnect.

11.0 Current Transformer Rating

11.1 The operation of current transformers is covered in general by IEEE C57.13, Standard Requirements for Instrument Transformers. In general the current rating associated with a current transformer (CT) is determined by the following formula:

I_{CT} = TRF x I_{Tap}

Where:

TRF = CT's nominal or calculated thermal rating factor

I_{Tap} = CT's connected primary tap rating (amps)

[7] Proper contact pressure is largely dependent on the condition of springs. Most spring materials (Phosphor-bronze, berillium copper) are subject to degradation from the cumulative effect of elevated temperatures. Stainless steel springs are not similarly effected except at extremely high temperatures.

[8] Email to ATC's Greg Thornson, July 14, 2003, from S&C Electric's Leslie McGahey, Mike McHugh, & Peter Meyer.

11.2 The thermal rating factor (TRF) is the number by which the rated primary current of a CT is multiplied to obtain the maximum primary current that can be carried continuously without exceeding the limiting temperature rise from a 30°C average ambient air temperature (and 40°C maximum ambient air temperature).

11.3 Current transformers form any manufacturer with identical style/part numbers are assumed to have the same thermal rating factor (TRF). The source of TRFs can be from any of the following:

11.3.1 As stated on equipment records for the respective CT or device

11.3.2 As stated on an equipment nameplate for the respective CT

11.3.3 By consultation with the equipment /CT manufacturer (e.g. from factory records or calculations)

11.3.4 Certified field test for the thermal rating

11.4 The TRF may be adjusted based upon the following factors:

11.4.1 Free-standing CTs, insulated by air, will be affected by changes in the ambient air temperature different from the CT design standard of 30°C average. Ambient temperatures lower than 30°C will yield higher TRFs.

11.4.2 CTs installed within another device (i.e. power circuit breaker or power transformer) will be limited by the thermal limits of this parent device.

11.4.3 TRFs adjusted according to any of the preceding factors should not ultimately result in excessive current on the circuit connected to the CT secondary. Unless specifically known, the continuous thermal limits of CT secondary circuits (and associated connected equipment) should be considered to be 10 amperes.

11.5 The consequences of overloading a current transformer include, but are not limited to, the following:

11.5.1 While accuracy will often increase at higher current loadings, should a CT actually reach saturation, accuracy will be significantly compromised, and relay or meter misoperation or misrepresentation may be the result.

11.5.2 Core or winding insulation may be degraded and effectively result in some loss of life. While each overload instance in itself may have little discernable effect on the CT, the cumulative insulation shrinkage and breakdown effects of the resulting excessive temperatures can ultimately result in a short circuit between windings or between a winding and the core.

11.6 Free-Standing Current Transformers

11.6.1 The following ratings methods apply to all free-standing wire wound CTs. Free-standing CTs (mounted separate from an associated transformer or breaker) differ from bushing-mounted CTs in that they are designed to meet permissible overloading by independent control of such parameters as primary and secondary winding current density, geometry, area of radiating surfaces, and heat transfer characteristics.

11.6.2 Free standing optical sensing type current transformers have no secondary wire windings and are limited only by the CT primary limitations.

11.7 Current Rating for Free-Standing CT

11.7.1 Single Nominal Thermal Rating Factor (TRF) for Free-Standing CTs

11.7.1.1 If only a single <u>nominal</u> TRF is assigned, this same TRF value applies to all taps of a free-standing CT. A single TRF is typically representative of CT secondary thermal limits (which are more restrictive than any CT primary thermal limits for any tap). If a nominal TRF is unavailable or unknown, the nominal TRF shall be assumed equal to 1.0.

11.7.2 Multiple Nominal Thermal Rating Factors (TRF) for Free-Standing CTs

11.7.2.1 Free-standing CTs may have multiple nominal thermal rating factors, since both the primary and secondary components are integral parts of these CTs. Any taps assigned a TRF derived from the CT primary limits, shall have CT ratings according to the following:

$$TRF = TRF_P \times \frac{I_{FR}}{I_{Tap}}$$

Where:

TRF = thermal rating factor assigned to the CT, based on the actual connected tap

TRF_P = CT nominal thermal rating factor associated with CT primary thermal limits

I_{FR} = CT full ratio nominal primary rating (amps)

I_{Tap} = CT connected tap nominal primary rating (amps)

11.7.2.2 Any taps assigned a TRF derived from CT secondary limits, shall have CT ratings according to the following:

$TRF = TRF_S$

Where:

TRF = thermal rating factor assigned to the CT, based on the actual connected tap

TRF_S = CT nominal thermal rating factor associated with secondary thermal limits

11.7.2.3 For example:

Given a 2000:5 multi-ratio (taps at 2000, 1600, 1200, 800, & 600) free-standing CT with TRF = 1.0 @ 2000A and TRF =2.0 at 800A. The TRF at each tap would be as follows (nominal TRFs in bold):

Tap	TRF
2000:5	**1.0**
1600:5	1.25 (= 2000/1600)
1200:5	1.67 (= 2000/1200)
800:5	**2.0**
600:5	2.0

Note that the 600:5 tap TRF is equal to that nominally assigned to the 800:5 tap. The second nominal TRF (2.0) specified by the manufacturer for the lower 800:5 tap is indicative of CT secondary thermal limits (that would not permit current ratings higher than 10A on a 5A-rated secondary winding).

11.7.3 Ambient Temperature Adjustment for Free-Standing CT

11.7.3.1 A CT's winding temperature rise under load conditions is the result of heat dissipated by the winding I^2R (copper or load) losses. In open air, ambient temperatures different than the 30°C IEEE standard design ambient temperature will affect these losses. Ambient air temperature adjustment factors can be calculated using the following formula:

$$AF_{FS} = \sqrt{\frac{\theta_{max} - \theta_a}{\theta_r}}$$

Where:

AF_{FS} = the adjustment factor for ambient temperatures other than 30°C

θ_{max} = the total average temperature limit at a 30°C ambient temperature

θ_r = the allowable maximum temperature rise above 30°C

θ_a = the actual ambient temperature

11.7.3.2 Table 8 provides adjustment factors, based upon ATC standard ambient air temperatures, which can be applied to the nominal TRF. If the insulation class of CT (maximum winding temperature rise) is unknown, the conservative application is to use those adjustment factors for 65°C rise CTs.

Table 8 – Free-Standing CTs (in Air) Ambient Temperature Adjustment Factors[9]

Maximum Winding Temp Rise, θ_r (°C)	Ambient Temperature, θ_a			Maximum Total Temperature, θ_{max} (°C)	TRF Adjustment Factor (AF_{FS})
	Season	(°F)	(°C)		
55	Summer	90.0	32.2	85	0.98
	Spring & Fall	60.0	15.6	85	1.12
	Winter	30.0	-1.1	85	1.25
	Design Ref.	86.0	30.0	85	1.00
65	Summer	90.0	32.2	95	0.98
	Spring & Fall	60.0	15.6	95	1.11
	Winter	30.0	-1.1	95	1.22
	Design Ref.	86.0	30.0	95	1.00

11.7.3.3 Steps for calculating a Free-Standing CT rating

1. Identify or determine the nominal TRF and the connected tap.
2. Identify the maximum winding temperature rise (or insulation class); if not available, assume a 65°C rise, as the AF_{FS} values provide for a more conservative result.
3. Determine the appropriate ambient temperature adjustment factor in Table 8 – Free-Standing CTs (in Air) Ambient Temperature Adjustment Factors.
4. The CT rating is:

   $I_{CT} = I_{Tap} \times TRF \times AF_{FS}$

Example 1:

Given a 55°C rise class 2000:5 full-ratio free-standing CT with nominal TRF = 3.0 and connected at 1200:5, calculate the CT rating for summer, spring/fall, and winter conditions.

1. For a 55°C rise CT, the ambient temperature adjustment factor for summer (90°F) is 0.98, for spring/fall (60°F) is 1.12, and for winter (30°F) is 1.25.
2. summer: $I_{CT} = I_{Tap} \times TRF \times AF_{FS} = 1200 \times 3.0 \times 0.98 = 3528A$.

   spring/fall: $I_{CT} = I_{Tap} \times TRF \times AF_{FS} = 1200 \times 3.0 \times 1.12 = 4032A$.

   winter: $I_{CT} = I_{Tap} \times TRF \times AF_{FS} = 1200 \times 3.0 \times 1.25 = 4500A$.

Example 2:

Given a 2000:5 full-ratio free-standing CT of unknown insulation class and with unknown TRF and connected at 1600:5, calculate the CT rating for winter conditions.

1. Assume the TRF = 1.00.
2. Assuming a 65°C rise, the ambient temperature adjustment factor for winter (30°F) is 1.22.
3. $I_{CT} = I_{Tap} \times TRF \times AF_{FS} = 1600 \times 1.0 \times 1.22 = 1952A$.

11.7.4 Emergency current ratings for free-standing CTs are not supported by IEEE C57.13 or by many CT manufacturers. Therefore, the ATC CT emergency ratings will equal normal ratings.

11.8 Breaker Bushings Current Transformers (CTs)

11.8.1 When CTs are installed in or on power circuit breakers, the parameters as described for free-standing CTs are not independently controllable. Bushing CTs in these cases are restricted by the characteristics of the breaker on which they are mounted. Note that the ambient adjustment factors in Table 8 do not apply to bushing CTs.

[9] IEEE C57.13 provides for standard current transformer (CT) ratings, including rating factor, are based upon designs at 55°C temperature rise above 30°C ambient air temperature. Rating factors in this table are derived from IEEE C57.13 Figure 1.

11.8.2 Bushing CTs, when mounted as accessories of power circuit breakers, are subjected to wide variations in their environmental ambient temperature ($\theta_{a\text{-}CT}$). This variation is dependent upon the thermal characteristics of the breaker and the relative current loading with respect to the rated current of the breaker and its bushing CT. Once a CT manufacturer knows the CT's ambient temperature as specified by the breaker manufacturer or IEEE standard, the CT manufacturer designs the CT to limit the total temperature (θ_{max}) to 105°C, thereby driving the CT's temperature rise limit (θ_r). Any desired increase or decrease in the CT temperature rise will be proportional to the increase or decrease in load current squared.

11.8.3 No adjustment due to ambient air temperatures shall normally be determined for bushing CTs mounted on breakers.

11.8.4 Manufacturers design a bushing CT with a particular nominal thermal rating factor (TRF) on the basis of both 1) the short-time thermal rating (i.e. fault-current) and 2) longer-term continuous loading (including ATC's normal and emergency loadings).

11.8.5 Current Rating for Circuit Breaker Bushing CTs:

11.8.5.1 Known Nominal Thermal Rating Factors (TRF) for All Circuit Breakers:

If the bushing CT's nominal TRF is available, the CT rating (I_{CT}) would be:

$I_{CT} = I_{Tap}$ x TRF

Where:

I_{Tap} = primary current rating of bushing CT ratio (connected tap) used.

<u>Example:</u>

Given a 1200:5 full-ratio bushing CT with nominal TRF = 2.00, connected at 600:5, installed on a 2000A gas breaker, calculate the CT rating.

$I_{CT} = I_{Tap}$ x TRF = 600 x 2.00 = 1200A

11.8.5.2 Unknown Nominal Thermal Rating Factors (TRF) for Oil Circuit Breakers

If an oil breaker-mounted bushing CT's nominal full-ratio TRF is unavailable or is unknown, but a CT part number is available, consult the breaker manufacturer for specific CT design TRF capability. Otherwise, the nominal TRF shall be determined by considering the nominal current rating of the breaker on which it is installed as follows:

- Assume a conservative thermal rating factor (TRF) of 1.0 for the circuit breaker CT. With the assumed TRF of 1.0, the CT current rating (I_{CT}) is equal to the CT ratio (connected tap, I_{Tap}) that the CT is being used at.

  Assumed TRF = 1.00

  and $I_{CT} = I_{Tap}$ x 1.0

- When the primary current rating of the CT ratio (connected tap, I_{Tap}) being used <u>is less than</u> the circuit breaker continuous current rating (I_B) <u>and</u> the current rating of the CT when using the assumed TRF of 1.0 is the <u>most limiting element</u> in the section, a calculated TRF can be applied to the emergency ratings only. Under these conditions, the circuit breaker and CT temperature rises would be lower and therefore, the CT can be operated at a continuous thermal rating factor greater than 1.0. It is impractical to provide the maximum permissible thermal rating factor for every condition, but it is possible to calculate rating factors based on constant maximum power dissipation. For this occasion, the following equation shall be used to determine a calculated emergency TRF for bushing CTs used on oil breakers.[10]

[10] From "Memorandum on Thermal Current Characteristics of Current Transformers Used with Power Circuit Breakers and Power Transformers"; C.F. Burke, G.J. Easley, C.A. Woods, and E.E. Conner; Westinghouse; August 18, 1969.

If $I_{Tap} < I_B$ & I_{CT} (with an assumed TRF=1.0) is most limiting element, then

$$TRF = \sqrt{\frac{I_B}{I_{Tap}}}$$

and $I_{CT} = I_{Tap} \times TRF$

Where:

TRF = calculated thermal current rating factor, when a nominal TRF is unavailable.

I_B = breaker continuous current rating (amps).

I_{Tap} = primary current rating of bushing CT ratio (connected tap) used.

This equation is valid only for:

- calculated TRF ≤ 2.00 and
- the continuous current rating of the associated breaker is not exceeded.

Example 1:

Given a 1200:5 full-ratio bushing CT with unknown nominal TRF, connected at 600:5, installed on a 2000A oil breaker, calculate the CT rating.

$$TRF = \sqrt{\frac{I_B}{I_{Tap}}} = \sqrt{\frac{2000}{600}} = 1.83$$

Since the calculated TRF < 2.00;

$I_{CT} = I_{Tap} \times TRF = 600 \times 1.83 = 1095A.$

Example 2:

Given a 1200:5 full-ratio bushing CT with unknown nominal TRF, connected at 300:5, installed on a 2000A oil breaker, calculate the CT rating.

$$TRF = \sqrt{\frac{I_B}{I_{Tap}}} = \sqrt{\frac{2000}{300}} = 2.58$$

Since the calculated TRF > 2.00, the TRF will be set equal to 2.00;

$I_{CT} = I_{Tap} \times TRF = 300 \times 2.00 = 600A.$

11.8.5.3 Unknown Nominal Thermal Rating Factors (TRF) for Gas Breakers

If a gas breaker bushing CT's nominal TRF is unavailable or unknown, but the breaker serial number is available, consult the breaker manufacturer. Otherwise the nominal TRF shall be assumed equal to 1.00.

11.8.5.4 Emergency Current Rating for Circuit Breaker Bushing CTs

Emergency ratings for CTs are not supported by IEEE C57.13 or by many CT manufacturers. Therefore, ATC CT emergency ratings will equal normal ratings, with the exception of applying a calculated emergency TRF, as outlined in section 12.7.5.2.

11.9 Power Transformer Bushing Current Transformer

11.9.1 Bushing CTs are integral to the power transformers and are similar to oil circuit breakers in that they are subjected to high ambient temperatures due to the temperature rise of the internal transformer environment. Note that the ambient adjustment factors in Table 8 do not apply to bushing CTs.

11.9.2 No adjustment due to ambient air temperatures shall normally be determined for bushing CTs mounted on power transformers.

11.9.3 Current Rating for Power Transformer CTs

11.9.3.1 Known Nominal Thermal Rating Factors (TRF)

If the bushing CT's nominal TRF is available, the CT rating (I_{CT}) would be:

$I_{CT} = I_{Tap}$ x TRF

Example:

Given a 1200:5 full-ratio bushing CT with nominal TRF = 2.00, connected at 600:5, installed on a 100 MVA 345 kV-138kV power transformer 345 kV bushing, calculate the CT rating.

$I_{CT} = I_{Tap}$ x TRF = 600 x 2.00 = 1200A.

11.9.3.2 Unknown Nominal Thermal Rating Factors (TRF) for Power Transformers

If the power transformer CT's nominal full-ratio TRF is unavailable or is unknown, however a CT part number is available, consult the power transformer manufacturer for specific CT design TRF capability. Otherwise the nominal TRF shall be determined by considering the maximum nominal current rating (nameplate, I_T) of the power transformer on which it is installed as follows:

- Assume a conservative thermal rating factor (TRF) of 1.0 for the power transformer CT. With the assumed TRF of 1.0, the CT current rating (I_{CT}) is equal to the CT ratio (connected tap, I_{Tap}) that the CT is being used at.

  Assumed TRF = 1.00

  and $I_{CT} = I_{Tap}$ x 1.0

- When the primary current rating of the CT ratio (connected tap, I_{Tap}) being used <u>is less than</u> the power transformer continuous current rating (I_T) <u>and</u> the current rating of the CT when using the assumed TRF of 1.0 is the <u>most limiting element</u> in the section, a calculated TRF can be applied to the emergency ratings only. Under these conditions, the power transformer and CT temperature rises would be lower and therefore, the CT can be operated at a continuous thermal rating factor greater than 1.0. It is impractical to provide the maximum permissible thermal rating factor for every condition, but it is possible to calculate rating factors based on constant maximum power dissipation. For this occasion, the following equation shall be used to determine a calculated emergency TRF for bushing CTs used on power transformers.[11]

  If $I_{Tap} < I_T$ & I_{CT} (with an assumed TRF=1.0) is most limiting element,

  then $\mathrm{TRF} = \sqrt{\dfrac{I_T}{I_{Tap}}}$

  and $I_{CT} = I_{Tap}$ x TRF

  Where:

  TRF = calculated thermal current rating factor, when a nominal TRF is unavailable.

  I_{Tap} = primary current rating of bushing CT ratio (connected tap) used.

  $I_T = \dfrac{P}{\sqrt{3} \times \dfrac{V}{1000}}$

  Where:

  I_T = transformer full load current (in amps) on bushing that CT is located.

  P = power transformer nominal base (nameplate) power rating (in MVA) at the highest installed cooling stage.

[11] From "Memorandum on Thermal Current Characteristics of Current Transformers Used with Power Circuit Breakers and Power Transformers"; C.F. Burke, G.J. Easley, C.A. Woods, and E.E. Conner; Westinghouse; August 18, 1969.

V = the nominal voltage rating (in kV) associated with the bushing on which the CT is installed.

This equation is valid only for:

- calculated TRF ≤ 2.00 and
- the power transformer nominal full load is not exceeded.

General Electric states that the above formula does not apply to CTs used in their power transformers because these CTs should not be operated beyond their nameplate rating.Example 1:

Given a 1200:5 full-ratio bushing CT with unknown nominal TRF, connected at 600:5, installed on a 500 MVA 345 kV-138kV power transformer 345 kV bushing, calculate the CT rating.

$$I_T = \frac{P}{\sqrt{3} \times V} = \frac{500}{\sqrt{3} \times \frac{345}{1000}} = 837A$$

Since I_{Tap} (600A) < I_T (837A), then

$$TRF = \sqrt{\frac{I_T}{I_{Tap}}} = \sqrt{\frac{837}{600}} = 1.18$$

$I_{CT} = I_{Tap}$ x TRF = 600 x 1.18 = 709A.

Example 2:

Given a 1200:5 full-ratio bushing CT with unknown nominal TRF, connected at 600:5, installed on a 100 MVA 345 kV-138kV power transformer 345 kV bushing, calculate the CT rating.

$$I_T = \frac{P}{\sqrt{3} \times V} = \frac{100}{\sqrt{3} \times \frac{345}{1000}} = 167A$$

Since I_{Tap} (600A) > I_T (167A), then,

TRF = 1.00 (since otherwise unknown) and

$I_{CT} = I_T$ x TRF = 600 x 1.00 = 600A.

11.9.3.3 Emergency Current Rating for Power Transformer CTs

Emergency ratings for CTs are not supported by IEEE C57.13 or by many CT manufacturers. Therefore, ATC CT emergency ratings will equal normal ratings, with the exception of applying a calculated emergency TRF, as outlined in section 13.8.3.2.

12.0 Substation Conductor Ratings

12.1 Substation Conductor Ambient Conditions

12.1.1 ATC is transitioning from legacy weather parameters, as indicate in Table 1, to study-based weather parameters as indicated in Table 9.

12.1.2 Substation conductors may be rated utilizing either legacy weather parameters or study-based weather parameters.

12.1.3 Note “Special Exception Ratings” for a conductor, which is a temporary rating defined in PR-0285, may be applied using either sets of ambient conditions.

12.1.4 Study-Based Substation Conductor Weather Parameters

12.1.4.1 Study-based ratings are based on the ambient conditions as shown in Table 9 according to the prescribed seasons defined in ATC Transmission Operating Procedure TOP-20-GN-000034, EMS Facility Seasonal Limit Transition.

12.1.4.2 Study-based conductor weather parameters were developed through a study following industry guidelines in CIGRE TB 299.

12.1.4.3 These study-based weather parameters are consistent with that in ATC Criteria CR-0061; Overhead Transmission Line Ampacity Ratings

Table 9- Study-Based Weather Parameters for Rating Substation Conductors

Criteria	Summer	Fall	Winter	Spring
Ambient temperature	90°F (32.2°C)	59°F (15°C)	38°F (3.3°C)	77°F (25°C)
Wind velocity	1.2 fps	1.1 fps	1.15 fps	1.3 fps
Wind direction relative to conductor direction	Perpendicular	Perpendicular	Perpendicular	Perpendicular
Latitude	44°N	44°N	44°N	44°N
Conductor orientation	E-W	E-W	E-W	E-W
Elevation above sea level	800 ft.	800 ft.	800 ft.	800 ft.
Atmosphere	Clear	Clear	Clear	Clear
Date (for solar conditions)	Aug 15	Oct 15	Nov 15	May 15
Time of Day Flux (percent of noon radiation)	12:00 Noon 18%	12:00 Noon 14%	12:00 Noon 24%	12:00 Noon 12%
Coefficient of radiant emission	0.8	0.8	0.8	0.8
Coefficient of solar absorption	0.8	0.8	0.8	0.8

12.2 Rigid Bus Temperature Limits

12.2.1 The maximum ATC operating temperature limits for rigid substation conductors are listed in Table 10. The normal temperature is limited to the temperature at which no annealing or loss of strength will occur. The emergency temperature is limited to the temperature at which minimal annealing or loss of strength occurs. Copper conductors operated above 80°C can experience increased oxidation; therefore rigid copper bus is being limited to a lower emergency temperature limit than aluminum.

Table 10 – Temperature Limits for Rigid Bus Conductors

Conductor Material	Temperature Limits	
	Normal Rating	Emergency Rating
Aluminum (6061-T6 & 6063-T6)	200°F (93°C)	221°F (105°C)
Copper	176°F (80°C)	200°F (93°C)

12.2.2 The finding in the ATC White Paper, titled "Analysis of Substation Jumper Conductor Operating Temperatures" that conductor connectors run cooler then the adjacent conductor due to the heat dissipating mass of the connector, will also apply to a reduced extent to rigid bus conductors.

12.3 Stranded Strain Bus Temperature Limits

12.3.1 The maximum operating temperature limits for stranded substation conductors are listed in Table11. Since strain bus, with stranded conductors in tension, is comparable in construction to transmission lines, the operating temperature limits are consistent with those for ATC's overhead transmission line conductors. The normal operating temperature for strain bus is limited to the temperature at which no significant annealing or loss of strength will occur. The emergency bus temperature is limited to a temperature at which up to 10% loss of ultimate strength may occur over 30 years of conductor life or a temperature that does not result in conductor sag to a point where required clearances are compromised. Strain bus designs with spans under 50 feet generally do not require consideration of conductor sag effects on clearances but may have a design clearance concern under fault conditions. With the additional concern of the increase in oxidation of copper conductors operated above 80°C and the reliability of the associated connectors, the emergency temperature for copper strain bus spans of less than 50 feet is limited to 110°C.

Table 11 – Temperature Limits for Strain Bus and Jumper Conductors

Conductor Material	Stranded Conductor Temperature Limits		
	Normal Rating	Emergency Rating	
		Bus	Jumpers
ACSR & ACSS ≥ 7.5% steel	200°F (93°C)	300°F (149°C)	300°F (149°C)
ACSR & ACSS < 7.5% steel	200°F (93°C)	275°F (135°C)	275°F (135°C)
AAAC, AAC & ACAR	200°F (93°C)	230°F (110°C)	275°F (135°C)
Copper (spans > 50’)	167°F (75°C)	185°F (85°C)	n/a
Copper (spans ≤ 50’)	167°F (75°C)	230°F (110°C)	230°F (110°C)

12.3.2 The normal temperature rating for stranded copper conductor is limited to 167°F (75°C), versus 176°F (80°C) for rigid copper bus, because of conductor elongation in tension applications.

12.3.3 For the purpose of substation application and limiting the temperature to connecting equipment, ACSS conductor will have the same maximum temperature operating limit as for ACSR.

12.3.4 When bus design spans exceed 50 feet, consult a transmission line design engineer for special clearance analysis and determination if operating temperatures lower than those listed in Table 11 Table are required.

12.4 Stranded Jumper Conductors Temperature Limits

12.4.1 The allowable operating temperature limits for stranded aluminum and copper jumper conductors are as shown in Table 11. For jumpers the normal temperature limit or the emergency temperature limit may be used in determination of the normal rating.

12.4.2 Since conductor sag is not a critical concern for jumpers, emergency operating temperatures of jumper conductors are permitted to be higher and therefore tolerant of annealing. Copper substation jumper conductors are permitted to operate to the higher 230°F (110°C) limit and aluminum substation jumper conductors (AAC, AAAC & ACAR) are permitted to operate to a 275°F (135°C) limit.

12.4.3 The operation of jumper conductors at their maximum emergency operating temperature assumes that the connectors on the jumper are in good mechanical and electrical operating condition.

12.4.4 Substation conductors are infrared scanned on a routine basis to assure that connector deterioration has not occurred.

12.4.5 Jumpers connected to substation equipment are not limited by the operating temperature limits of that equipment. A review of industry tests by ATC has concluded that jumper connectors run significantly cooler than the jumper conductors themselves. As a result, jumper conductors have no significant effect on the temperature of the equipment to which they are connected. An ATC White Paper, titled Analysis of Substation Jumper Conductor Operating Temperatures, documents that jumpers can operate at least at the same temperatures as bus conductors without adverse effect on adjacent connected equipment.

12.4.6 Previous revisions of this rating criteria limited jumper allowable operating temperatures based on the equipment to which they were connected. As a result, some jumper ratings may reflect the more conservative temperature limits.

12.5 Rigid Conductor Ampacity

12.5.1 The rigid conductor temperature limits as summarized in Section 12.2 and Table 10 have been applied to ratings summarized by conductor type in this section.

12.5.2 Rigid conductor ratings were calculated using an ATC spreadsheet application based on IEEE 605, Substation Rigid-Bus Structures and IEEE 738, Standard for Calculating the Current-Temperature of Bare Overhead Conductors, for use in SELD. The ATC standard for rigid bus is schedule 40, 6063-T6 alloy/temper aluminum tube.[12] If the alloy/temper composition and/or schedule of a rigid aluminum tube is unknown, use ratings associated with schedule 40, 6063-T6.

12.5.3 Legacy rigid conductor ratings - Table 13 and Table 14 list allowable load currents for rigid copper and aluminum conductors used in substations, based in legacy weather parameters as summarized in section 5.2.

Table 12 – Legacy Rigid Copper Conductor Allowable Load Current

Conductor Description	Maximum Allowable Load Current Ratings (Amps)					
	Summer; 90°F		Spring & Fall; 60°F		Winter; 30°F	
	Normal	Emerg.	Normal	Emerg.	Normal	Emerg.
	80°C	93°C	80°C	93°C	80°C	93°C
	176°F	200°F	176°F	200°F	176°F	200°F
Copper Tubular Conductors						
0.75" Cu Tube	1032	1179	1242	1358	1438	1533
1.0" Cu Tube	1315	1503	1584	1734	1840	1962
1.25" Cu Tube	1588	1820	1918	2104	2234	2384
1.5" Cu Tube	1804	2072	2183	2396	2546	2719
2.0" Cu Tube	2257	2601	2740	3013	3205	3426
2.5" Cu Tube	3140	3629	3824	4212	4486	4798
3.0" Cu Tube	3651	4235	4461	4924	5248	5619
3.5" Cu Tube	4008	4661	4908	5425	5786	6200
4.0" Cu Tube	4621	5387	5671	6277	6697	7183
Copper Tubular A-Frames						
1.5" Cu A-Frame	3608	4144	4366	4792	5096	5438
Flat Bar Conductors						
1/4x3" Cu Bar, IACS 99	1915	2174	2151	2377	2525	2708
1/2x3" Cu Bar, IACS 99	2665	3034	3024	3343	3546	3806
1/4x4" Cu Bar, IACS 99	2333	2657	2599	2886	3072	3303
1/2x4" Cu Bar, IACS 99	3210	3666	3611	4010	4262	4586

[12] Characteristic physical data used in ratings calculations is per ASTM B241 Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extrude Tube.

Table 14 – Legacy Rigid Aluminum Conductor Allowable Load Current

Conductor Description	Maximum Allowable Load Current Ratings (Amps)					
	Summer; 90°F		Spring & Fall; 60°F		Winter; 30°F	
	Normal	Emerg.	Normal	Emerg.	Normal	Emerg.
	93°C	105°C	93°C	105°C	93°C	105°C
	200°F	221°F	200°F	221°F	200°F	221°F
Aluminum 6063 Tubular Conductors						
0.5" Al Tube, Sch 40, 6063-T6	679	743	780	835	878	924
0.75" Al Tube, Sch 40, 6063-T6	833	916	960	1028	1084	1141
1.0" Al Tube, Sch 40, 6063-T6	1091	1200	1259	1350	1424	1500
1.25" Al Tube, Sch 40, 6063-T6	1369	1508	1581	1698	1793	1890
1.5" Al Tube, Sch 40, 6063-T6	1563	1725	1808	1943	2052	2164
2.0" Al Tube, Sch 40, 6063-T6	1949	2154	2258	2429	2569	2710
2.5" Al Tube, Sch 40, 6063-T6	2610	2892	3029	3263	3451	3645
3.0" Al Tube, Sch 40, 6063-T6	3183	3533	3701	3991	4224	4465
3.5" Al Tube, Sch 40, 6063-T6	3647	4054	4245	4582	4851	5131
4.0" Al Tube, Sch 40, 6063-T6	4125	4592	4807	5194	5501	5821
4.5" Al Tube, Sch 40, 6063-T6	4604	5131	5371	5807	6152	6514
5.0" Al Tube, Sch 40, 6063-T6	5148	5745	6011	6506	6895	7304
6.0" Al Tube, Sch 40, 6063-T6	6211	6946	7266	7874	8350	8853
0.5" Al Tube, Sch 80, 6063-T6	768	842	882	944	992	1045
0.75" Al Tube, Sch 80, 6063-T6	951	1045	1096	1173	1238	1303
1.0" Al Tube, Sch 80, 6063-T6	1241	1365	1432	1535	1620	1706
1.25" Al Tube, Sch 80, 6063-T6	1571	1731	1815	1949	2057	2169
1.5" Al Tube, Sch 80, 6063-T6	1806	1993	2089	2244	2370	2500
2.0" Al Tube, Sch 80, 6063-T6	2283	2524	2645	2845	3007	3173
2.5" Al Tube, Sch 80, 6063-T6	2995	3317	3475	3744	3959	4182
3.0" Al Tube, Sch 80, 6063-T6	3690	4097	4290	4628	4896	5177
3.5" Al Tube, Sch 80, 6063-T6	4252	4727	4950	5344	5657	5984
4.0" Al Tube, Sch 80, 6063-T6	4832	5380	5631	6085	6444	6820
4.5" Al Tube, Sch 80, 6063-T6	5417	6038	6319	6834	7239	7666
5.0" Al Tube, Sch 80, 6063-T6	6082	6789	7102	7688	8146	8631
6.0" Al Tube, Sch 80, 6063-T6	7494	8384	8763	9504	10075	10686
Aluminum 6063 Tubular A-Frames						
1.0" Al A-Frame, Sch 40, 6063-T6	2183	2401	2518	2700	2849	3001
1.5" Al A-Frame, Sch 40, 6063-T6	3127	3450	3617	3885	4104	4329
2.0" Al A-Frame, Sch 40, 6063-T6	3897	4309	4516	4858	5135	5420
2.5" Al A-Frame, Sch 40, 6063-T6	5221	5783	6059	6526	6902	7291
3.0" Al A-Frame, Sch 40, 6063-T6	6366	7067	7401	7983	8447	8930
3.5" Al A-Frame, Sch 40, 6063-T6	7293	8107	8489	9164	9702	10263
4.0" Al A-Frame, Sch 40, 6063-T6	8250	9184	9614	10388	11001	11643

Conductor Description	Maximum Allowable Load Current Ratings (Amps)					
	Summer; 90°F		Spring & Fall; 60°F		Winter; 30°F	
	Normal	Emerg.	Normal	Emerg.	Normal	Emerg.
	93°C	105°C	93°C	105°C	93°C	105°C
	200°F	221°F	200°F	221°F	200°F	221°F
Aluminum 6061 Tubular Conductors						
0.5" Al Tube, Sch 40, 6061-T6	689	757	791	849	890	939
0.75" Al Tube, Sch 40, 6061-T6	853	940	983	1055	1110	1171
1.0" Al Tube, Sch 40, 6061-T6	1088	1200	1256	1350	1421	1500
1.25" Al Tube, Sch 40, 6061-T6	1422	1572	1644	1769	1863	1969
1.5" Al Tube, Sch 40, 6061-T6	1619	1791	1873	2017	2126	2247
2.0" Al Tube, Sch 40, 6061-T6	2002	2219	2320	2502	2638	2792
2.5" Al Tube, Sch 40, 6061-T6	2566	2850	2979	3216	3393	3593
3.0" Al Tube, Sch 40, 6061-T6	3269	3638	3800	4109	4337	4597
3.5" Al Tube, Sch 40, 6061-T6	3902	4348	4511	4915	5190	5504
4.0" Al Tube, Sch 40, 6061-T6	4318	4819	5032	5450	5758	6109
4.5" Al Tube, Sch 40, 6061-T6	4727	5282	5514	5978	6317	6706
5.0" Al Tube, Sch 40, 6061-T6	5178	5793	6047	6560	6935	7365
6.0" Al Tube, Sch 40, 6061-T6	6011	6739	7032	7639	8081	8589
Flat Bar 6061 Conductors						
1/4x3" Al Bar, 6061-T61	1691	1853	1846	1994	2100	2227
3/8x3" Al Bar, 6061-T61	2077	2278	2280	2459	2596	2746
1/2x3" Al Bar, 6061-T61	2441	2647	2657	2865	3056	3189
1/4x4" Al Bar, 6061-T61	2082	2287	2261	2446	2588	2742
3/8x4" Al Bar, 6061-T61	2539	2791	2768	2995	3167	3355
1/2x4" Al Bar, 6061-T61	2924	3217	3199	3461	3658	3877
3/4x4" Al Bar, 6061-T61	3550	3911	3907	4228	4466	4735
Angle 6061 Conductors						
1/4x1½x1½" Al Angular, 6101-T6	1472	1619	1686	1810	1910	2014
1/4x3¼x3¼" Al Angle, 6101-T6	2745	3047	3162	3415	3620	3830
1/4x4x4" Al Angle, 6101-T6	3206	3509	3700	4005	4250	4502
3/8x4x4" Al Angle, 6101-T6	3777	4208	4359	4721	5006	5307
Integral Web Conductors						
1/4x4x4" Al Integral Web, 6101-T61	5795	6324	6447	6907	7209	7601

12.5.4 Study-based rigid conductor ratings - Table 15 and Table 16 list allowable load currents for rigid copper and aluminum conductors used in substations, based in legacy conductor weather parameters as summarized in section 12.1.4.

Table 15 – Study-Based Rigid Copper Conductor Allowable Load Current

Conductor Description	Maximum Allowable Load Current Ratings (Amps)							
	Spring; 77°F		Summer; 90°F		Fall; 59°F		Winter; 38°F	
	Normal	Emerg.	Normal	Emerg.	Normal	Emerg.	Normal	Emerg.
	80°C	93°C	80°C	93°C	80°C	93°C	80°C	93°C
	176°F	200°F	176°F	200°F	176°F	200°F	176°F	200°F
Copper Tubular Conductors								
0.5" Cu Tube	732	808	669	752	769	837	833	894
0.75" Cu Tube	961	1062	878	988	1010	1099	1092	1174
1.0" Cu Tube	1229	1360	1123	1265	1292	1408	1396	1503
1.25" Cu Tube	1495	1656	1366	1541	1573	1716	1697	1828
1.5" Cu Tube	1706	1891	1559	1760	1795	1960	1936	2087
2.0" Cu Tube	2154	2390	1968	2225	2268	2479	2443	2637
2.5" Cu Tube	3025	3359	2764	3128	3187	3486	3429	3703
3.0" Cu Tube	3557	3951	3247	3679	3745	4111	4025	4388
3.5" Cu Tube	3946	4386	3598	4078	4149	4589	4489	4895
4.0" Cu Tube	4593	5109	4188	4751	4853	5370	5248	5725
5.0" Cu Tube	5835	6493	5321	6039	6217	6876	6717	7327
6.0" Cu Tube	6868	7654	6264	7121	7365	8154	7953	8683
Copper Tubular A-Frames								
1.5" Cu A-Frame	2584	2864	2361	2666	2719	2969	2933	3161
Flat Bar Conductors								
1/4x3" Cu Bar, IACS 99	1753	1941	1604	1808	1829	1998	1966	2122
1/2x3" Cu Bar, IACS 99	2455	2721	2244	2533	2563	2804	2758	2980
1/4x4" Cu Bar, IACS 99	2171	2409	1986	2244	2264	2479	2428	2626
1/2x4" Cu Bar, IACS 99	3002	3334	2745	3105	3133	3434	3363	3641

Table 16 – Study-Based Rigid Aluminum Conductor Allowable Load Current

Conductor Description	Maximum Allowable Load Current Ratings (Amps)							
	Spring; 77°F		Summer; 90°F		Fall; 59°F		Winter; 38°F	
	Normal	Emerg.	Normal	Emerg.	Normal	Emerg.	Normal	Emerg.
	93°C	105°C	93°C	105°C	93°C	105°C	93°C	105°C
	200°F	221°F	200°F	221°F	200°F	221°F	200°F	221°F
Aluminum 6063 Tubular Conductors								
0.5" Al Tube, Sch 40, 6063-T6	605	653	563	614	626	669	669	709
0.75" Al Tube, Sch 40, 6063-T6	751	811	698	762	777	831	830	880
1.0" Al Tube, Sch 40, 6063-T6	987	1067	918	1004	1022	1095	1091	1158
1.25" Al Tube, Sch 40, 6063-T6	1245	1347	1158	1267	1290	1382	1374	1460
1.5" Al Tube, Sch 40, 6063-T6	1427	1545	1328	1454	1479	1586	1575	1674
2.0" Al Tube, Sch 40, 6063-T6	1791	1941	1667	1828	1858	1994	1976	2102
2.5" Al Tube, Sch 40, 6063-T6	2415	2620	2249	2468	2507	2693	2663	2841
3.0" Al Tube, Sch 40, 6063-T6	2970	3222	2765	3037	3090	3345	3298	3536
3.5" Al Tube, Sch 40, 6063-T6	3432	3724	3190	3504	3590	3887	3830	4107
4.0" Al Tube, Sch 40, 6063-T6	3913	4248	3638	3997	4112	4453	4384	4703
4.5" Al Tube, Sch 40, 6063-T6	4398	4777	4090	4496	4640	5026	4946	5306
5.0" Al Tube, Sch 40, 6063-T6	4954	5383	4608	5075	5246	5683	5590	5998
6.0" Al Tube, Sch 40, 6063-T6	6050	6596	5629	6241	6446	6985	6864	7368
0.5" Al Tube, Sch 80, 6063-T6	684	738	636	694	708	756	757	802
0.75" Al Tube, Sch 80, 6063-T6	857	925	797	870	887	949	947	1005
1.0" Al Tube, Sch 80, 6063-T6	1122	1213	1044	1141	1163	1245	1240	1316
1.25" Al Tube, Sch 80, 6063-T6	1429	1546	1329	1455	1480	1587	1577	1676
1.5" Al Tube, Sch 80, 6063-T6	1648	1784	1534	1680	1709	1832	1819	1934
2.0" Al Tube, Sch 80, 6063-T6	2098	2273	1953	2141	2176	2336	2314	2463
2.5" Al Tube, Sch 80, 6063-T6	2771	3005	2581	2832	2876	3090	3055	3259
3.0" Al Tube, Sch 80, 6063-T6	3443	3736	3206	3521	3582	3878	3823	4100
3.5" Al Tube, Sch 80, 6063-T6	4002	4343	3720	4086	4186	4533	4466	4790
4.0" Al Tube, Sch 80, 6063-T6	4583	4977	4262	4683	4817	5217	5136	5510
4.5" Al Tube, Sch 80, 6063-T6	5175	5621	4812	5291	5460	5914	5819	6244
5.0" Al Tube, Sch 80, 6063-T6	5853	6361	5444	5998	6199	6716	6604	7088
6.0" Al Tube, Sch 80, 6063-T6	7300	7962	6792	7533	7778	8431	8282	8893
Aluminum 6063 Tubular A-Frames								
1.0" Al A-Frame, Sch 40, 6063-T6	1974	2134	1837	2008	2045	2190	2182	2315
1.5" Al A-Frame, Sch 40, 6063-T6	2854	3089	2656	2908	2959	3173	3150	3349
2.0" Al A-Frame, Sch 40, 6063-T6	3582	3881	3335	3655	3716	3988	3951	4205
2.5" Al A-Frame, Sch 40, 6063-T6	4831	5239	4499	4936	5014	5386	5326	5682
3.0" Al A-Frame, Sch 40, 6063-T6	5939	6445	5531	6074	6180	6690	6595	7072
3.5" Al A-Frame, Sch 40, 6063-T6	6863	7448	6380	7007	7180	7774	7659	8214
4.0" Al A-Frame, Sch 40, 6063-T6	7825	8496	7276	7995	8224	8906	8769	9406

Conductor Description	Maximum Allowable Load Current Ratings (Amps)							
	Spring; 77°F		Summer; 90°F		Fall; 59°F		Winter; 38°F	
	Normal	Emerg.	Normal	Emerg.	Normal	Emerg.	Normal	Emerg.
	93°C	105°C	93°C	105°C	93°C	105°C	93°C	105°C
	200°F	221°F	200°F	221°F	200°F	221°F	200°F	221°F
Aluminum 6061 Tubular Conductors								
0.5" Al Tube, Sch 40, 6061-T6	613	663	570	624	635	680	678	721
0.75" Al Tube, Sch 40, 6061-T6	769	832	715	783	796	853	850	903
1.0" Al Tube, Sch 40, 6061-T6	985	1067	916	1004	1020	1095	1088	1158
1.25" Al Tube, Sch 40, 6061-T6	1294	1403	1204	1321	1341	1440	1428	1522
1.5" Al Tube, Sch 40, 6061-T6	1478	1604	1376	1510	1532	1647	1631	1739
2.0" Al Tube, Sch 40, 6061-T6	1840	1999	1713	1883	1909	2054	2030	2166
2.5" Al Tube, Sch 40, 6061-T6	2375	2582	2212	2433	2465	2655	2618	2800
3.0" Al Tube, Sch 40, 6061-T6	3050	3317	2840	3127	3173	3444	3387	3640
3.5" Al Tube, Sch 40, 6061-T6	3672	3995	3413	3758	3841	4169	4097	4405
4.0" Al Tube, Sch 40, 6061-T6	4095	4458	3808	4195	4304	4673	4589	4935
4.5" Al Tube, Sch 40, 6061-T6	4516	4917	4200	4628	4764	5173	5078	5462
5.0" Al Tube, Sch 40, 6061-T6	4983	5428	4635	5118	5277	5731	5623	6049
6.0" Al Tube, Sch 40, 6061-T6	5855	6399	5448	6055	6238	6776	6642	7148
Flat Bar 6061 Conductors								
1/4x3" Al Bar, 6061-T61	1520	1643	1415	1546	1564	1677	1661	1766
3/8x3" Al Bar, 6061-T61	1869	2021	1740	1902	1925	2064	2045	2175
1/2x3" Al Bar, 6061-T61	2175	2352	2024	2214	2240	2403	2381	2533
1/4x4" Al Bar, 6061-T61	1899	2056	1769	1937	1954	2098	2071	2205
3/8x4" Al Bar, 6061-T61	2317	2510	2158	2364	2386	2563	2529	2695
1/2x4" Al Bar, 6061-T61	2672	2895	2489	2727	2752	2957	2919	3111
3/4x4" Al Bar, 6061-T61	3256	3530	3032	3324	3356	3608	3561	3797
Angle 6061 Conductors								
1/4x1½x1½" Al Angular, 6101-T6	1339	1446	1244	1359	1385	1482	1480	1569
1/4x3¼x3¼" Al Angle, 6101-T6	2627	2847	2444	2680	2724	2925	2898	3085
1/4x4x4" Al Angle, 6101-T6	3115	3380	2899	3183	3232	3475	3435	3661
3/8x4x4" Al Angle, 6101-T6	3670	3985	3415	3752	3808	4096	4047	4315
Integral Web Conductors								
1/4x4x4" Al Integral Web, 6101-T61	5095	5501	4758	5191	5260	5630	5609	5952
5/16x4x4 Al Integral Web, 6101-T61	5491	5930	5128	5595	5670	6070	6047	6417
1/4x6x6" Al Integral Web, 6101-T61	8540	9242	7984	8731	8823	9465	9388	9986

12.6 Stranded Conductor Ampacity

12.6.1 The stranded conductor temperature limits summarized in Section 12.3 and Table 11 have been applied to ratings summarized by conductor type in this section.

12.6.2 Stranded conductor ratings are calculated using the methods and equations in IEEE 738, Standard for Calculating the Current-Temperature of Bare Overhead Conductors. There are commercial software programs that have been accepted for use by ATC and ATC has developed an application, which is based on IEEE 738, for use in SELD. Although these programs may not provide identical results, the comparable results are acceptable for rating purposes.

12.6.3 Conductor ratings are based upon characteristic data from the Aluminum Electrical Conductor Handbook[13]. Conductors shown in the tables are those known to presently exist in service or commonly used at ATC. Consult ATC Asset Planning & Engineering for ratings of any conductors not included in this document.

12.6.4 Legacy stranded conductor ratings - Table 17, Table 18 and Table 19 list allowable load currents for stranded copper and various types of aluminum conductors used in substations, based in legacy weather parameters as summarized in section 5.2

Table 17 – Legacy Stranded Copper Conductor Allowable Load Current

Conductor Description	Maximum Allowable Load Current Ratings (Amps)											
	Summer; 90°F				Spring & Fall; 60°F				Winter; 30°F			
	Normal	Emergency			Normal	Emergency			Normal	Emergency		
		Strain Bus		Jumper		Strain Bus		Jumper		Strain Bus		Jumper
		> 50 Ft.	≤ 50 Ft.			> 50 Ft.	≤ 50 Ft.			> 50 Ft.	≤ 50 Ft.	
	75°C	85°C	110°C	110°C	75°C	85°C	110°C	110°C	75°C	85°C	110°C	110°C
	167°F	185°F	230°F	230°F	167°F	185°F	230°F	230°F	167°F	185°F	230°F	230°F
1500 kcmil Cu 61	1765	2001	2477	2477	2182	2369	2766	2766	2566	2718	3053	3053
1000 kcmil Cu 37	1393	1573	1933	1933	1716	1856	2155	2155	2013	2128	2379	2379
750 kcmil Cu 61	1170	1319	1619	1619	1438	1553	1801	1801	1684	1779	1984	1984
500 kcmil Cu 37	915	1028	1255	1255	1118	1207	1396	1396	1304	1377	1535	1535
500 kcmil Cu 19	914	1027	1254	1254	1117	1206	1394	1394	1303	1375	1534	1534
350 kcmil Cu 19	733	822	1000	1000	893	963	1111	1111	1040	1097	1220	1220
300 kcmil Cu 19	666	746	906	906	811	874	1007	1007	943	994	1106	1106
250 kcmil Cu 19	594	664	803	803	722	777	907	907	839	883	996	996
250 kcmil Cu 12	601	673	817	817	732	788	892	892	850	896	979	979
4/0 AWG Cu 19	536	599	725	725	651	701	806	806	755	796	884	884
4/0 AWG Cu 7	534	597	723	723	649	698	803	803	753	793	881	881
4/0 AWG Cu 1	525	586	707	707	636	684	785	785	736	776	861	861
2/0 AWG Cu 7	400	446	538	538	484	520	597	597	560	590	654	654
1/0 AWG Cu 7	346	385	464	464	418	449	514	514	483	508	563	563
1 AWG Cu 7	299	333	400	400	360	387	443	443	416	438	486	486
1 AWG Cu 1	292	325	390	390	352	378	433	433	406	428	473	473
2 AWG Cu 7	259	287	345	345	311	334	382	382	359	378	419	419
3 AWG Cu 3	230	256	307	307	277	297	340	340	320	336	372	372

[13] For those conductors not included in the Aluminum Electrical Conductor Handbook, characteristic data was obtained from Southwire Overhead Conductor manual, 2nd Edition or from consultation directly with Southwire.

Table 18 – Legacy Stranded ACSR and ACSS Conductors Allowable Load Current

Conductor Description	Maximum Allowable Load Current Ratings (Amps)								
	Summer; 90°F			Spring & Fall; 60°F			Winter; 30°F		
	Normal	Emergency		Normal	Emergency		Normal	Emergency	
	93°C	135°C	149°C	93°C	135°C	149°C	93°C	135°C	149°C
	200°F	275°F	300°F	200°F	275°F	300°F	200°F	275°F	300°F
ASCR Conductors									
2156.0 kcmil ACSR 84/19 Bluebird	2257	2973	n/a	2611	3223	n/a	2957	3481	n/a
1033.5 kcmil ACSR 54/7 Curlew	1442	—	1990	1664	—	2133	1880	—	2281
1033.5 kcmil ACSR 45/7 Ortolan	1416	1837	n/a	1634	1990	n/a	1845	2147	n/a
954 kcmil ACSR 54/7 Cardinal	1367	—	1883	1578	—	2018	1782	—	2158
954 kcmil ACSR 45/7 Rail	1351	1753	n/a	1557	1899	n/a	1759	2049	n/a
900 kcmil ACSR 45/7 Ruddy	1301	1692	n/a	1500	1832	n/a	1694	1972	n/a
795 kcmil ACSR 45/7 Tern	1200	1560	n/a	1383	1688	n/a	1561	1818	n/a
795 kcmil ACSR 26/7 Drake	1225	—	1688	1412	—	1807	1594	—	1930
795 kcmil ACSR 24/7 Cuckoo	1215	—	1676	1401	—	1794	1581	—	1915
605 kcmil ACSR 26/7 Squab	1027	—	1413	1181	—	1513	1330	—	1614
556.5 kcmil ACSR 26/7 Dove	973	—	1336	1119	—	1430	1259	—	1526
477 kcmil ACSR 26/7 Hawk	881	—	1206	1013	—	1291	1139	—	1377
477 kcmil ACSR 24/7 Flicker	876	—	1199	1007	—	1283	1132	—	1369
397.5 kcmil ACSR 26/7 Ibis	785	—	1070	901	—	1145	1012	—	1222
336.4 kcmil ACSR 30/7 Oriole	715	—	974	820	—	1043	921	—	1112
336.4 kcmil ACSR 26/7 Linnet	706	—	961	810	—	1028	909	—	1096
336.4 kcmil ACSR 18/1 Merlin	693	890	n/a	795	962		892	1035	n/a
266.8 kcmil ACSR 26/7 Partridge	610	—	829	700	—	887	785	—	946
4/0 AWG ACSR 6/1 Penguin	473	—	609	542	—	652	607	—	695
3/0 AWG ACSR 6/1 Pigeon	410	—	529	470	—	566	526	—	603
2/0 AWG ACSR 6/1 Quail	362	—	469	414	—	502	463	—	534
1/0 AWG ACSR 6/1 Raven	317	—	412	363	—	441	405	—	470
2.0 AWG ACSR 7/1 Sparate	244	—	319	279	—	341	311	—	363
2.0 AWG ACSR 6/1 Sparrow	240	—	312	274	—	334	306	—	356
4.0 AWG ACSR 6/1 Swan	181	—	237	207	—	253	231	—	270
ACSS Conductors									
1233.6 kcmil ACSS/TW 38/19 Yukon	1585	—	2184	1829	—	2341	2066	—	2503
959.6 kcmil ACSS/TW 22/7 Suwannee	1358	—	1868	1567	—	1999	1768	—	2134
556.5 kcmil ACSS/TW 20/7 Dove	962	—	1315	1106	—	1408	1243	—	1502
1033.5 kcmil ACSS 54/7 Curlew	1431	—	1952	1650	—	2092	1865	—	2237
954 kcmil ACSS 54/7 Cardinal	1358	—	1849	1566	—	1981	1769	—	2119
795 kcmil ACSS 26/7 Drake	1237	—	1701	1426	—	1820	1610	—	1944
477 kcmil ACSS 26/7 Hawk	892	—	1219	1024	—	1304	1153	—	1392

Table 19 – Legacy Stranded ACAR and AAC Conductor Allowable Load Current

Conductor Description	Maximum Allowable Load Current Ratings (Amps)								
	Summer; 90°F			Spring & Fall; 60°F			Winter; 30°F		
	Normal	Emergency		Normal	Emergency		Normal	Emergency	
		Bus	Jumper		Bus	Jumper		Bus	Jumper
	93°C	110°C	135°C	93°C	110°C	135°C	93°C	110°C	135°C
	200°F	230°F	275°F	200°F	230°F	275°F	200°F	230°F	275°F
ACAR Conductors									
1700 kcmil ACAR 54/7 Lapwing1	1896	2162	2419	2189	2412	2622	2478	2666	2830
1172 kcmil ACAR 24/13 Curlew3	1484	1687	1894	1712	1882	2052	1934	2077	2214
1109 kcmil ACAR 24/13 Ortolan2	1433	1629	1829	1654	1817	1982	1868	2005	2138
927.2 kcmil ACAR 18/19 Drake3	1266	1437	1610	1460	1603	1742	1647	1768	1878
853.7 kcmil ACAR 30/7 Tern1	1223	1387	1571	1410	1546	1699	1590	1705	1830
543.9 kcmil ACAR 12/7 Flicker1	913	1031	1178	1047	1140	1274	1177	1261	1371
AAC Conductors									
2500 kcmil AAC 91 Lupine	2380	2726	3151	2755	3045	3417	3121	3367	3690
1590 kcmil AAC 61 Coreopsis	1831	2086	2397	2116	2329	2598	2393	2572	2804
1272 kcmil All Alum 259 Rope Lay	1640	1867	2142	1859	2084	2321	2144	2302	2505
1272 kcmil AAC 61 Narcissus	1594	1812	2077	1840	2022	2251	2079	2231	2429
954 kcmil AAC 37 Magnolia	1324	1502	1719	1527	1675	1860	1724	1847	2006
795 kcmil AAC 61 Lilac	1184	1345	1540	1364	1497	1666	1539	1649	1794
795 kcmil AAC 37 Arbutus	1183	1344	1539	1363	1496	1665	1538	1648	1793
750 kcmil AAC 37 Petunia	1138	1291	1477	1309	1436	1598	1477	1581	1720
556.5 kcmil AAC 19 Dahlia	942	1066	1216	1082	1185	1315	1217	1304	1415
336.4 kcmil AAC 19 Tulip	686	774	881	787	860	953	883	945	1024
4/0 AWG AAC 19 Oxlip-19	510	574	652	584	638	704	655	700	758
4/0 AWG AAC 7 Oxlip	509	572	650	582	636	702	652	697	755

12.6.5 Study-based stranded conductor ratings - Table 20, Table 21 and Table 22 list allowable load currents for rigid copper and various types of aluminum conductors used in substations, based in study-based conductor weather parameters as summarized in section 12.1.4.

Table 20 – Study-based Stranded Copper Conductor Allowable Load Current

Conductor Description	Maximum Allowable Load Current Ratings (Amps)															
	Summer; 90°F (32.2°C), 1.2 fps, 18%				Fall; 60°F (15.5°C), 1.1 fps, 14%				Winter; 38°F (3.3°C), 1.15 fps, 24%				Spring; 77°F (25.0°C), 1.3 fps, 12%			
	Normal	Emergency			Normal	Emergency			Normal	Emergency			Normal	Emergency		
		Strain Bus		Jumper		Strain Bus		Jumper		Strain Bus		Jumper		Strain Bus		Jumper
		≥ 50 Ft.	< 50 Ft.			≥ 50 Ft.	< 50 Ft.			≥ 50 Ft.	< 50 Ft.			≥ 50 Ft.	< 50 Ft.	
	75°C	85°C	110°C	110°C	75°C	85°C	110°C	110°C	75°C	85°C	110°C	110°C	75°C	85°C	110°C	110°C
	167°F	185°F	230°F	230°F	167°F	Cond	230°F	230°F	167°F	185°F	230°F	230°F	167°F	185°F	230°F	230°F
1500.0 kcmil Cu 61	1524	1699	2071	2071	1785	1928	2243	2243	1938	2068	2362	2362	1684	1845	2193	2193
1000.0 kcmil Cu 37	1195	1329	1610	1610	1399	1507	1744	1744	1520	1619	1839	1839	1321	1443	1706	1706
750.0 kcmil Cu 61	1000	1111	1342	1342	1170	1259	1454	1454	1272	1353	1530	1530	1105	1206	1422	1422
500.0 kcmil Cu 37	771	856	1030	1030	902	969	1116	1116	982	1043	1178	1178	852	929	1092	1092
500.0 kcmil Cu 19	771	855	1029	1029	901	968	1115	1115	981	1042	1177	1177	851	928	1091	1091
350.0 kcmil Cu 19	611	677	814	814	715	767	882	882	779	826	932	932	675	726	863	863
300.0 kcmil Cu 19	553	613	736	736	646	694	797	797	705	748	842	842	611	665	780	780
250.0 kcmil Cu 19	491	544	652	652	574	616	706	706	626	664	747	747	542	590	692	692
250.0 kcmil Cu 12	498	551	662	662	582	624	717	717	634	673	758	758	550	599	702	702
4/0 AWG Cu 7	439	486	582	582	513	550	631	631	560	593	667	667	485	528	618	618
4/0 AWG Cu SD 7	448	496	594	594	523	561	643	643	571	605	681	681	495	538	630	630
4/0 AWG Cu 1	428	474	567	567	500	536	614	614	546	578	650	650	473	514	602	602
2/0 AWG Cu 7	325	359	429	429	379	406	465	465	414	439	492	492	359	390	456	456
1/0 AWG Cu 7	279	309	369	369	326	349	399	399	356	377	423	423	308	335	391	391
2 AWG Cu 7	207	228	272	272	241	258	295	295	264	279	313	313	228	248	289	289

Table 21 – Study-based Stranded ACSR Conductors Allowable Load Current

Conductor Description	Maximum Allowable Load Current Ratings (Amps)											
	Summer; 90°F(32.2°C), 1.2 fps, 18%			Fall; 60°F (15.5°C), 1.1 fps, 14%			Winter; 38°F (3.3°C), 1.15 fps, 24%			Spring; 77°F (25.0°C), 1.3 fps, 12%		
	Normal	Emergency		Normal	Emergency		Normal	Emergency		Normal	Emergency	
	93°C	135°C	149°C	93°C	135°C	149°C	93°C	135°C	149°C	93°C	135°C	149°C
	200°F	275°F	300°F	200°F	275°F	300°F	200°F	275°F	300°F	200°F	275°F	300°F
ASCR Conductors												
2156.0 kcmil ACSR 84/19 Bluebird	1918	2490	N/A	2134	2633	N/A	2270	2738	N/A	2060	2601	N/A
1590.0 kcmil ACSR 54/19 Falcon	1604	—	2202	1784	—	2307	1899	—	2390	1723	—	2290
1590.0 kcmil ACSR 45/7 Lapwing	1575	2031	N/A	1753	2147	N/A	1866	2235	N/A	1692	2122	N/A
1033.5 kcmil ACSR 54/7 Curlew	1215	—	1659	1352	—	1738	1441	—	1802	1306	—	1726
1033.5 kcmil ACSR 45/7 Ortolan	1192	1529	N/A	1326	1616	N/A	1413	1684	N/A	1281	1598	N/A
954.0 kcmil ACSR 54/7 Cardinal	1151	—	1569	1281	—	1643	1365	—	1705	1237	—	1632
954.0 kcmil ACSR 45/7 Rail	1137	1458	N/A	1264	1542	N/A	1348	1607	N/A	1221	1525	N/A
900.0 kcmil ACSR 45/7 Ruddy	1093	1401	N/A	1216	1481	N/A	1296	1543	N/A	1174	1465	N/A
795.0 kcmil ACSR 45/7 Tern	1008	1293	N/A	1122	1367	N/A	1196	1425	N/A	1084	1352	N/A
795.0 kcmil ACSR 26/7 Drake	1030	—	1402	1145	—	1469	1221	—	1524	1106	—	1459
795.0 kcmil ACSR 24/7 Cuckoo	1021	—	1390	1136	—	1457	1211	—	1512	1097	—	1447
605.0 kcmil ACSR 26/7 Squab	859	—	1166	955	—	1222	1019	—	1268	923	—	1214
556.5 kcmil ACSR 26/7 Dove	812	—	1100	903	—	1153	964	—	1197	873	—	1146
477.0 kcmil ACSR 26/7 Hawk	733	—	990	815	—	1037	870	—	1077	787	—	1031
477.0 kcmil ACSR 24/7 Flicker	728	—	983	809	—	1030	864	—	1070	782	—	1024
397.5 kcmil ACSR 26/7 Ibis	649	—	875	722	—	917	771	—	953	698	—	911
336.4 kcmil ACSR 26/7 Linnet	581	—	783	646	—	820	691	—	853	625	—	816
336.4 kcmil ACSR 18/1 Merlin	569	723	N/A	633	765	N/A	676	799	N/A	612	758	N/A
266.8 kcmil ACSR 26/7 Partridge	500	—	672	556	—	705	594	—	733	537	—	701
4/0 AWG ACSR 6/1 Penguin	385	—	492	428	—	515	457	—	536	414	—	513
3/0 AWG ACSR 6/1 Pigeon	332	—	425	369	—	445	395	—	463	357	—	443
1/0 AWG ACSR 6/1 Raven	254	—	329	283	—	345	303	—	359	274	—	343
T2 ACSR Conductor												
1113.0 kcmil ACSR T-2 45/7 T2-Bluejay	2011	2554	N/A	2238	2700	N/A	2378	2806	N/A	2159	2666	N/A
556.5 kcmil ACSR T-2 26/7 T2-Dove	1353	—	1845	1505	—	1933	1602	—	2003	1453	—	1919
477.0 kcmil ACSR T-2 26/7 T2-Hawk	1229	—	1682	1367	—	1762	1456	—	1826	1320	—	1749
336.4 kcmil ACSR T-2 26/7 T2-Linnet	975	—	1329	1085	—	1392	1157	—	1444	1048	—	1382
4/0 AWG ACSR T2 6/1 T2-Penguin	661	—	905	735	—	948	785	—	985	711	—	942

Note: N/A indicates that 300°F emergency operating temperature is not applicable for this conductor with less tha 7.5 % steel core.

Table 22 – Study-based Stranded ACAR and AAC Conductor Allowable Load Current

Conductor Description	Maximum Allowable Load Current Ratings (Amps)											
	Summer; 90°F(32.2°C), 1.2 fps, 18%			Fall; 60°F (15.5°C), 1.1 fps, 14%			Winter; 38°F (3.3°C), 1.15 fps, 24%			Spring; 77°F (25.0°C), 1.3 fps, 12%		
	Normal	Emergency		Normal	Emergency		Normal	Emergency		Normal	Emergency	
		Bus	Jumper		Bus	Jumper		Bus	Jumper		Bus	Jumper
	93°C	110°C	135°C	93°C	110°C	135°C	93°C	110°C	135°C	93°C	110°C	135°C
	200°F	230°F	275°F	200°F	230°F	275°F	200°F	230°F	275°F	200°F	230°F	275°F
ACAR Conductors												
1700.0 kcmil ACAR 54/7 Lapwing1	1604	1809	2077	1785	1960	2195	1900	2063	2285	1723	1915	2170
1172.0 kcmil ACAR 24/13 Curlew3	1250	1407	1611	1391	1524	1703	1482	1606	1774	1344	1490	1684
927.2 kcmil ACAR 18/19 Drake3	1065	1199	1372	1185	1298	1451	1263	1369	1512	1145	1270	1435
543.9 kcmil ACAR 12/7 Flicker1	755	847	965	840	917	1020	896	968	1065	812	898	1010
396.3 kcmil ACAR 12/7 Linnet2	607	679	771	675	736	815	722	777	852	653	720	807
AAC Conductors												
2500.0 kcmil AAC 91 Lupine	2050	2291	2641	2254	2482	2792	2399	2609	2903	2175	2424	2758
1590.0 kcmil AAC 61 Coreopsis	1548	1745	2000	1723	1890	2115	1834	1990	2202	1663	1847	2091
1272.0 kcmil Alum 259 Rope-Lay	1388	1562	1790	1544	1693	1892	1644	1782	1970	1461	1654	1870
1272.0 kcmil AAC 61 Narcissus	1344	1512	1730	1495	1638	1829	1593	1725	1905	1444	1602	1809
1000.0 kcmil AAC 37 Hawkweed	1151	1293	1476	1280	1400	1561	1364	1476	1627	1236	1369	1544
954.0 kcmil AAC 37 Magnolia	1113	1250	1428	1238	1354	1509	1320	1428	1573	1197	1325	1493
795.0 kcmil AAC 61 Lilac	994	1116	1274	1105	1209	1347	1179	1275	1405	1068	1183	1333
795.0 kcmil AAC 37 Arbutus	993	1115	1273	1105	1208	1346	1178	1274	1404	1067	1182	1332
636.0 kcmil AAC 37 Orchid	856	960	1093	952	1039	1156	1016	1097	1206	920	1017	1144
4/0 AWG AAC 7 Oxlip	413	461	523	459	499	552	491	528	578	444	489	547

12.7 Paralleled conductors and Jumpers

12.7.1 Current flow in closely-spaced conductors creates mutual inductance effects on nearby conductors. This phenomenon, known as the proximity effect, causes a non-symmetric current distribution across the conductor, increasing the effective AC resistance and reducing the current-carrying capacity. This is proportional to the current magnitude and, thus, has a more significant effect on larger conductor sizes. The proximity effect (y_p) can be calculated for two concentric round conductors operated at 60 hertz, with the following formula from IEC-60287-1-1- 2006, Section 2.1.3:

$$y_p = \frac{2.9 \times x_p^4}{192 + 0.8 x_p^4}\left(\frac{d_c}{s}\right)^2$$

where:

$$x_p^2 = \frac{8\pi f}{R_{dc@t}} \times 10^{-7}(k_p) = \frac{1.508 \times 10^{-4}}{R_{dc@t}}$$, for concentric round conductor at 60 hertz

d_c = diameter of conductor (inches)

s = distance between conductor axes (inches)

$R_{dc@t}$ = conductor DC resistance adjusted to temperature "t" (Ω/m)

12.7.2 Manufactured pre-assembled multiple conductor welded flexible rope-lay, flat-pad to flat-pad connectors shall be de-rated 10 percent from that of a single conductor to account for proximity effect and mutual heating from the adjacent conductor(s).

12.7.3 Paralleled bus and jumper conductors having adequate center-to-center spacing (measured at the spacer) shall have an allowable load current that is equal to the number of paralleled conductors times the rating of a single conductor.

12.7.4 For fully-rated parallel conductors (i.e. not de-rated), the minimum center-line spacing of paralleled conductors shall be at least as follows:

Table 23 – Paralleled Conductor Spacing

Conductor Size (kcmil)	Minimum C-L Spacing (in.)
Less than 800	No Minimum
800 to 1199	2
1200 to 1999	4
Greater than 2000	6

12.7.5 For aluminum conductors smaller than 1000 kcmil and all other conductor sizes smaller than 800 kcmil, the impact of the proximity effect is less than 5 percent and is considered negligible.

12.7.6 For paralleled conductors that are not manufactured pre-assembled multiple connectors and have a center-line spacing less than the minimum spacing indicated in Table 23, the per conductor allowable load current may have to be de-rated from that for a single conductor rating. The de-rating is dependent on the conductor's current-carrying capability and spacing**.** Table Table 24 indicates the de-rating factor, to the nearest 5 percent, for common conductor sizes at various reduced conductor spacing. For other conductor types, sizes and spacing, the de-rating factor will need to be calculated using the above formula.

Table 24 – De-rating Factors for Two Paralleled Conductor

Conductor Description (kcmil)	De-Rating Factor, for Spacing				
	1.5”	2”	2.5”	3”	4”
2500 AAC, 91, Lupine	n/a	0.75	0.8	0.85	0.95
1590 AAC, 61, Coreopsis	0.90	0.95	0.95	1	1
1272 AAC, 61, Narcissus	0.95	0.95	1	1	1
1272 Alum, 259, Rope-lay	0.95	0.95	1	1	1
1700 ACAR, 54/7, Lapwing1	0.90	0.95	0.95	1	1
2156 ACSR, 84/19, Bluebird	n/a	0.8	0.85	0.9	0.95
1113 ACSR, 45/7, Bluejay	0.95	1	1	1	1
1033.5 ACSR, 54/7, Curlew	0.95	1	1	1	1
1033.5 ACSR, 45/7, Ortolan	0.95	1	1	1	1
1500 Cu, 61	0.75	0.85	0.9	0.95	1
1000 Cu, 37	0.9	0.95	1	1	1

12.8 Flexible Braid Conductors

12.8.1 Flexible braid conductors are occasionally used as jumper connection to compensate for expansion/misalignment and/or to isolate vibration. The connectors are composed of one or more extra flexible braided strands with solid rectangular ferrules on either end of the braided section(s). The braided sections can vary in widths and total cross sectional area, with the ferrule cross sectional area being proportional to the total braid area.

12.8.2 Analysis of various readily available manufacturers braided connectors, identified that the manufactures published ratings were approximately equal a flat bar conductor of the same cross-section size of the ferrule at a conductor temperature 120 degrees F during summer conditions. ATC ratings of flexible braid are based on the ferrule cross section size.

12.8.3 The ferrules are flat pads used as a bolted connector to transfer the current flow into the braided conductor and therefore skin affect is negligible. Also the loose thin individual strands of the braid(s) are assumed to also have negligible skin affect. Therefore a skin affect factor of 1.0 is used in calculating the flexible braid conductor ratings.

13.0 Series Inductors Ratings

13.1 Series inductors include series reactors and wave traps. ATC does not rate shunt reactors in that they are not in the normal current carrying path.

13.2 Series reactors are rated according to the manufactures ratings recommendations or nameplate ratings.

13.3 Wave traps:

13.3.1 Wave traps for new installation at ATC shall be designed per ANSI C93.3; Requirements for Power-Line Carrier Line Traps and applicable ATC material specifications. Wave traps are designed within temperature-rise limitations to ensure normal life expectancy. These temperature-rise limitations are categorized into three classes or insulation temperature indices as shown in Table 25. The industry traditionally used class to indicate temperature-rise limitations but, more recently, has referenced the insulation temperature index. The insulation temperature index is indicative of the total permissible cumulative lifetime operating time at this temperature without loss of life and is specified by the trap winding insulation film manufacturer. This index is not applicable to older traps that utilized air gaps between windings.

Table 25 – Trap Temperature Rise Classifications[14]

Insulation Class	B	F	H
Insulation Temperature Index (°C)	130	155	180
Average Rise Above 40°C Ambient (°C)	90	115	140
Hotspot Rise Above 40°C Ambient (°C)	150	175	200
Total Trap Limiting Temperature (°C)	285	315	350
Total Terminal Limiting Temperature (°C)	150	150	150

13.3.2 Any values of current in excess of rated current in this standard may result in the designed temperature rise being exceeded and may shorten the life expectancy of the wave trap. Ultimate consequence may be a trap failure when insulation between windings deteriorates extensively due to excessive temperatures. Since it is difficult to field-test a trap for indication of this deterioration, visual inspection for fiberglass delamination, resins evaporating from the trap surface, or paint peeling would be the only indications of excessive overload wear before premature failure. In order to minimize trap loss of life risk, a return to nominal continuous current for a minimum of 5 hours is required after any trap emergency overload condition.

13.3.3 Table 26 provides loadability factors and load current ratings for standard size wave traps. The factors provided minimize the reduction in operating life and should be applied with great care. For any size not listed, multiply the nominal continuous current rating (I_r) by the appropriate listed loadability factor (LF_n or LF_s) to obtain load current limits.

$I_a = I_r \times LF_n$ and $I_s = I_r \times LF_s$

Where:

I_r = switch nominal rated continuous current @ 40°C ambient.

I_a = allowable continuous (normal) current at ambient temperature.

I_s = allowable short-time emergency load current.

LF_n = normal loadability factor.

LF_s = emergency (short-time) loadability factor.

For example:

Given: 1600A nominally rated wave trap.

Find: The winter emergency load current rating.

Solution: = $I_r \times LF_s$ = 1600 x 1.20 = 1920A.

[14] Per ANSI C93.3-1995, Tables 6 & 7. Correlation to insulation class, provided by Ross Presta, Engineering Manager, Line Traps and RCC, Trench Ltd. (2/5/04)

Table 26 – Wave traps Allowable Load Current[15]

Nominal Line Trap Rating (I_r)	Maximum Allowable Load Current Ratings (Amps)						Reference Trap Design Basis [18]	
	Summer		Spring & Fall		Winter			
	Ambient Temperature (θ_A)							
	32.2°C (90°F)		15.6°C (60°F)		-1.1°C (30°F)		40°C (104°F)	
	Normal	Emerg.	Normal	Emerg.	Normal	Emerg.	Normal	Emerg.
400	408	448	416	464	420	480	400	440
800	816	896	832	928	840	960	800	880
1200	1224	1344	1248	1392	1260	1440	1200	1320
1600	1632	1792	1664	1856	1680	1920	1600	1760
2000	2040	2240	2080	2320	2100	2400	2000	2200
3000	3060	3360	3120	3480	3150	3600	3000	3300
	Loadability Factor, Normal (LF_n) & Emergency (LF_s)							
	1.020	1.120	1.040	1.160	1.050	1.200	1.000	1.100

14.0 Relay and Meter Readings

14.1 Relays

14.1.1 Relays settings and thermal capability can limit facility ratings, based upon any of the following characteristics – dependent on the specific type of relaying employed:

14.1.1.1 A thermal limit of the relay itself reflects the relays capability to carry current without causing deterioration of its insulation and/or other internal components.

14.1.1.2 An impedance setting translated into an ampacity rating on the basis of an assumed maximum torque angle and 1.0 per unit voltage. As applicable, such ratings are calculated for both forward and reverse directions. System Protection and Commissioning is responsible for maintaining all applicable impedance relays within NERC recommendations for relay load limiting criteria. However, relay setting ampacity limits in SELD will be determined via the following historically conservative formulas:

$$I_{Trip} = \frac{V_{L-L}}{\sqrt{3} * Z_{Setting} * \left(\frac{PTR}{CTR}\right)} = \frac{1000}{\sqrt{3}} * \frac{kV_{L-L}}{Z_{Setting}} * \frac{CTR}{PTR}$$

and

$$MVA_{Trip} = \frac{{V_{L-L}}^2}{Z_{Setting} * \left(\frac{PTR}{CTR}\right) * 1\varepsilon 6} = \frac{(kV_{L-L})^2}{Z_{Setting}} * \frac{CTR}{PTR}$$

Where:

V_{L-L} = line-to-line voltage (volts)
$Z_{Setting}$ = Distance relay secondary impedance setting (ohms)
PTR = Potential transformer ratio
CTR = Current transformer ratio (wye connected)

14.1.1.3 A phase overcurrent setting is at 100% pickup current. Such rating may be specific to direction, as in impedance relays above.

14.1.1.4 Ground relay and differential relay settings do not limit normal system load flows.

[15] This table applies to all traps, designed per ANSI C93.3, without any distinction between horizontal vs. vertical mounting or vintage. (While some may argue that open-type designs may provide more efficient heat transfer than comparable fiberglass-encapsulated traps, the ratings effects are minimal and therefore, the ratings in this table are not type-dependent.)

14.1.2 Relay setting limits are typically absolute; normal and emergency ratings are equal and have no seasonal variation. Aside from a thermal limit, typically no short-time or emergency overload capability exists. Any difference between relay normal and emergency thermal limits must be qualified in the SELD Comments field and indicate manufacturer approval.

14.1.3 Any real time delay settings are very short (20 cycles to a few seconds) and thus are ignored when considering operating limits. In general, no alarm or warning is given prior to exceeding a relay setting limit. When the limit is exceeded, the relay is expected to trip, removing the associated transmission element from service.

14.1.4 Relay thermal limits are determined by the most restrictive of all of the relays associated with any substation segment. The relay continuous thermal rating shall be used for all seasonal normal ratings and also for emergency ratings if a 2-hour short duration thermal ratings is not available. If the relay manufacturer has identified that a higher relay thermal limit for a specific two hour time duration, it shall be used to determine the emergency rating limit.

14.1.4.1 If the original relay design allowed for a higher short duration thermal limit (e.g. 2-hour), it will be considered to have that capability for it life, without regard for its age.

14.1.4.2 All relays that normally carry phase currents must be taken into consideration for the limiting relay thermal limiter. These relays include, but are not limited to, phase distance, impedance and overcurrent relays, power relays and differential relays. Ground relays of all types are not a thermal limiting component.

14.1.4.3 ATC will consider the thermal limit that the equipment was originally designed and manufactured to exist throughout its life, regardless of age.

14.1.5 Relay ratings are not of themselves representative of any limits that are characteristic of the current transformers to which they are connected. See section 11.0 for current transformer ratings criteria.

14.2 Meters

14.2.1 The thermal ampacity limits of meter current coils and internal electronics may also serve as possible limiting elements and will be as defined by the specific manufacturer and as translated to a nominal high voltage basis. The EMS group is responsible for the RTU.

14.2.2 The ampacity limits in SELD will be determined by the actual ampacity measured or via the following formula when no ampacity is measured:

$$I = \frac{MW}{\left(kV * \sqrt{3}\right)}$$

14.3 Remote Terminal Unit and Transducers

14.3.1 The thermal ampacity limits of power transducers (data as communicated through a remote terminal unit – RTU), the RTU internal electronics and/or electronic devices may also serve as possible limiting elements and will be as defined by the specific manufacturer and as translated to a nominal high voltage basis. The EMS group is responsible for the RTU, with the limits established by one of the following:

14.3.1.1 Analog rating, via transducer/scaling resistors

14.3.1.2 Digital rating, via Intelligent Electronic Device (IED), generally microprocessor-based protective relays or meters,

14.3.2 The ampacity limits in SELD will be determined by the actual ampacity measured or via the following formula when no ampacity is measured:

$$I = \frac{MW}{\left(kV * \sqrt{3}\right)}$$

15.0 Revision Information

15.1 Document Review

This Criteria will be reviewed annually 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 listed in Section 3.

Version	Author	Date	Section	Description
01	S. Newton	03-27-2007	All	Reformatted and replaces former Operating Procedure 02-03.
02	R. Knapwurst	12-05-2007	12 and Various	Major revision to Conductors, various other changes/clarifications.
03	R. Knapwurst	08-04-2008	6, 10, 12 & Various	Revised seasons and switch section, various minor corrections/changes
04	R. Knapwurst	10-06-2009	3, 7-10 &12-15	Title change, remove standard conductor designation, added switcher and trap data, and various minor clarifications and updates. Annual review as required by NERC Standards.
05	R. Knapwurst	05-24-2010	5, 6, 11 & 13	Removed season definition, add season comment to Ambient Conditions Section, add stray flux rating limit, added flex braid section, changed Wave trap section to Series Inductors and other minor corrections / changes. Annual review as required by NERC Standards.
06	R. Knapwurst	04-30-2012	2, 7, 10, 11 & 13	Added shunt device non-inclusion, removed reference to air-blast breakers, added CT rating factor sources, added stranded conductor rating per 738 and study-based conductor ratings, revised RTU section, and various minor clarifications, updates and formatting changes.