

V.I.C
CIRCUIT BREAKERS

GUIDE FOR DETERMINATION OF CIRCUIT BREAKER LOAD CURRENT CAPABILITY RATINGS

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SCOPE AND PURPOSE

This guide presents principles and procedures to be used in establishing normal and emergency load current carrying capabilities for circuit breakers affecting the PJM Interconnection. It does not consider close and latch, three-second and interrupting capabilities. The resulting ratings can be used for selecting the most economical nameplate ratings for new circuit breakers. Circuit breakers built under standards listed in the References of this report are included. This guide includes methods for determination of ratings of all circuit breaker current transformers except oil-filled wound-type current transformers. Recognition is made that exceptions such as those listed in the subheading entitled "Current Transformer and Connected Equipment Limitations" may be necessary for special conditions. "Circuit breaker" and "circuit breaker parts" terms used in this report include current transformers unless they are specifically excepted.

BACKGROUND

The recognition that various design of breakers can carry different normal and emergency currents led to the establishment of ratings based on breaker capabilities, operating procedures, physical environment, and special conditions. These variables resulted in widely different methods of rating and produced different ratings for identical circuit breakers. Accordingly, the goal of a common circuit breaker rating period for all PJM Companies has been pursued for some time and is now required for proper PJM rating administration.

DISCUSSION OF RATING METHOD

The rating methods established by this report represent compromises in the various factors and consider provisions of ANSI Standard C37.010-1979, C37.010b-1985, and C37.010-199X-D1.2 (02/98). The method developed is based primarily on the following:

- a. Ambient temperature (θ_a).
- b. Temperature rise as function of the 1.8 power of the current.
- c. Maximum temperature determined to be acceptable for various circuit breaker components under normal and emergency conditions.
- d. Acceptable accelerated deterioration of some circuit breaker parts under emergency conditions.

DEFINITIONS

Following are definitions of terms used in this report for use in determining PJM circuit breaker ratings.

Rated Continuous Current (Nameplate Rating) (I_r)

Maximum current in ampere at rated frequency a device can carry continuously without any part exceeding its limit of observable temperature rise.

Rated Continuous Current (Nameplate Rating) of a Current Transformer Tap (I_{tap_r})

Maximum current in amperes at rated frequency a specific tap of a current transformer can carry continuously without the current transformer exceeding its limit of observable temperature rise.

Adjusted Rated Continuous Current of a Circuit Breaker (I)

Rated continuous current of a circuit breaker corrected to limit of observable temperature rise using specific temperature rise by test. Note: $I = I_r$ when specific temperature rise test data is not available.

Adjusted Rated Continuous Current of a Current Transformer Tap (I_{tap})

Rated continuous current of a specific tap of a current transformer corrected for connection on a reduced tap and to limit of observable temperature rise.

Normal Current Rating (I_a)

Current which can be carried continuously without any circuit breaker part exceeding its normal allowable maximum temperature.

Emergency Current Rating (I_{ea})

Current which can be carried for a specified period of time, at selected ambient temperature, without any circuit breaker part exceeding its emergency allowable maximum temperature, e.g. $i_{ea8} = 4$ to 8 hour emergency current, and $i_{ea4} = 0$ to 4 hour emergency current.

Short Time Emergency Current Rating (I_s)

Short time emergency currents which can be carried for less than 4 hours, e.g. $I_{s,25}$ is the current which can be carried for a $\frac{1}{4}$ of an hour (15 minutes).

Limit of Observable Temperature Rise (θ_r), i.e., the allowable hottest spot temperature rise at rated current.

Maximum value of observable temperature rise of any part of a circuit breaker as limited by C37.010-1979 and C37.4 1953. Values are listed in Table I of this report.

Actual Ambient Temperature (θ_a)

Actual ambient temperature expected.

Test Observable Temperature Rise (θ)

Actual steady-state temperature rise above ambient temperature of any part of a circuit breaker when tested at rated continuous current.

Limit of Total Temperature (θ_{max}), i.e. the allowable hottest spot total temperature

Maximum temperature which any circuit breaker part can withstand continuously. Values from C37.010-1979 and C37.4 1953 are listed in Table I of this report.

Emergency Allowable Maximum Temperature (θ_{max_e})

Maximum temperature which any circuit breaker part can withstand for various emergency rating durations, e.g., $\theta_{max_{e8}}$ = 8 hour maximum temperature, $\theta_{max_{e4}}$ = 4 hour maximum temperature, etc..

Temperature Due to Initial Continuous Current (θ_i)

Total temperature due to initial continuous current at ambient θ_a . Utilized in calculation of short term ratings less than four hours.

Temperature Reached if I_s were applied continuously (θ_s)

Total temperature reached if the short term current I_s were to be applied continuously at ambient θ_a . Utilized in calculation of short term ratings less than four hours.

Thermal Time Constant (τ)

Time required, in hours, for the temperature of a circuit breaker part to change from the initial value to the ultimate value if the initial rate of change were continued until the ultimate temperature was reached.

(Assumed to be 1/2 hour minimum for all circuit breakers and current transformers in this report).

Continuous Thermal Current Rating Factor (RF) [Pertaining to Current Transformers Only]

The specified factor by which the rated continuous current of any current transformer tap can be multiplied to obtain the primary current that can be carried continuously without exceeding the limit of observable temperature rise.

AMBIENT TEMPERATURE

Since maximum circuit breaker temperature is a function of prevailing ambient temperature, θ_a , the value of ambient temperature is important for determination of ratings. For short-time intervals the maximum expected ambient temperature is of prime importance. Temperature records surveyed by the PJM Companies resulted in agreement on use of the following temperatures which are consistent with those used for all PJM equipment ratings.

<u>Rating Duration</u>	<u>Summer</u> (April thru October)	<u>Winter</u> November thru March
Normal continuous	30° C Daily	10° C Daily
Emergency 8 Hours or Less	35° C Daily	10° C Daily

NORMAL RATINGS

The normal current rating of a circuit breaker is that current which can be carried continuously without any circuit breaker part exceeding its normal allowable maximum temperature. The prime considerations in defining the normal current rating of a circuit breaker are ambient temperature and limit of observable temperature rise. The normal current rating is calculated by compensating the adjusted rated continuous current (rated continuous current if temperature rise from heat run test is not available) for specific ambient temperature.

EMERGENCY RATINGS

Emergency ratings for durations of four hours to eight hours are based on operation up to the emergency allowable maximum temperature for the limiting circuit breaker part. Emergency allowable maximum temperature limits of 10° C and 15° C above the normal allowable maximum temperature are utilized for ratings of eight hours in duration, and for ratings of four hours and less duration, respectively. These temperature limits may result in slightly accelerated deterioration of some circuit breaker parts but will not affect circuit breaker interrupting capability. Emergency ratings for durations of less than four hours are determined based on the circuit breaker thermal time constant which is a function of the heat storage capacity of the circuit breaker. Loading prior to applying emergency ratings assumed to be 100% of the normal rating for the prevailing ambient temperature. Although ratings can be increased by assuming pre-load current less than 100% of normal rating, this type of rating is difficult to supervise.

CURRENT TRANSFORMER AND CONNECTED EQUIPMENT LIMITATIONS

When current transformers have Class A insulation, a continuous thermal current factor of 1.0, and are connected on a tap equivalent to or greater than the circuit breaker rated continuous current, they will not limit the circuit breaker normal or emergency rating. Appendix II contains a method for determining the rating of a current transformer when connected on a tap which has a rating lower than that corresponding to the rated continuous current of the circuit breaker. When determining a current transformer thermal rating all accessory equipment connected to the secondary must be checked for thermal capability.

BUSHINGS & CONNECTIONS

Prior to 1964, θ_{max} for bushings was limited to 70°C, and this should be utilized for breakers manufactured prior to this time. Since 1964, circuit breaker emergency ratings have been described as requirements of ANSI standard C37.010 (Application Guide for AC High-Voltage Circuit Breakers). Breakers purchased to meet this standard should contain bushings, that would operate to the emergency conditions described. The circuit breaker manufacturer should be contacted to determine bushing capabilities.

Until recently the overload capability of bushings has not clearly been defined. Bushing standards have indicated that a bushing applied in a circuit breaker must be designed to operate satisfactorily at rated conditions without exceeding the temperature rise limitations of the insulation utilized. In recent years (1989-1999) work has been ongoing to determine the thermal performance of apparatus bushings, however, a final standard has not been issued. When issued, the standard is expected to apply only to recently manufactured bushings. Some guidance can be obtained from a paper published in 1978 (see bibliography) which describes the mathematical modeling that can be used as the basis for a loading guide.

Connections must also be considered when determining circuit breaker loading capabilities. Since 1964, ANSI bushing standards have indicated that external bus or cable connections under normal conditions should not operate with more than a 30°C rise (e.g. a total temperature of 70°C at a 40°C ambient) at normal rated currents. Design exceeding these levels would both deteriorate the bushing under normal conditions and could further elevate temperature rises under emergency conditions.

DETERMINATION OF RATINGS

Circuit breaker ratings can be determined as follows:

- a) If no information is available on circuit breaker materials or the year of manufacture, the following minimum ratings from Table II can be applied.

Minimum Rating of All Circuit Breaker Material Classes
(Percent of Circuit Breaker Adjusted Rated Continuous Current)

<u>Rating Duration</u>	<u>Winter</u> (%)	<u>Summer</u> (%)
Normal	121	107
Emergency, 4 to 8 hours	128	111

Emergency, 0 to 4 hours	131	115
Emergency, 15 minutes, (.25 hours)	171	135

These minimum ratings do not consider limitations of current transformers:

1. With 80° C rise insulation because only a small number are in service.
2. When connected to a reduced tap.
3. When connected equipment is thermally limiting.

These minimum ratings do not consider limitations of bushings and their external connections.

- b) If circuit breaker materials and/or the year of manufacture is known, refer to Table I and then determine ratings from Table II.
- c) If circuit breaker materials and year of manufacture are known and temperature rise data from heat run tests is available, refer to Table I and then determine ratings from Appendix I or II.

MAINTENANCE REQUIREMENTS

Satisfactory performance of circuit breakers carrying loads based on ratings established by this report are dependent upon adequate maintenance. The required frequency and extend of maintenance will be determined by severity of short circuit current, frequency of circuit breaker operation and application of emergency loadings. The ability of a circuit breaker to carry normal, emergency or short circuit currents may be impaired if the circuit breaker is not properly maintained.

TABLE I
TEMPERATURE LIMITATIONS FOR CIRCUIT BREAKERS¹

Circuit Breaker Component Description	Limit of Observable Temperature Rise at Rated Current θ_r (°C)	Limit of Total Allowable Maximum Temperature θ_{max} (°C)	Emergency Allowable Maximum Temperature Rating θ_{max_e} (°C)	
			8 Hours or Less $\theta_{max_{e8}}$	4 Hours or Less $\theta_{max_{e4}}$
Breakers manufactured prior to 1964				
1 Contacts in oil, oil and bushings	30	70	80	85
2 Contacts in air or gas	35	75	85	90
3 Average Winding Temperature Rise of Current Transformer with 55°C Rise (Class A) Insulation	55	95	105	110
4 Average Winding Temperature Rise of Dry-Type Current Transformer with 80°C Rise (Class B) Insulation	80	120	130	135
Breakers manufactured 1964 and later ²				
1 Copper Contacts, Copper-to-Copper Conducting Joints, External Terminal Connected to Bushing	30	70	80	85
2 Top Oil	40	80	90	95
3 Hot Spot Oil at Points in Contact with Hot Parts, Silver (or Equal) Contacts or Conducting Joints in Oil	50	90	100	105
4 Average Winding Temperature Rise of Current Transformer with 55°C Rise (Class A) Insulation	65	105	115	120
5 Silver (or Equal) Contacts or Conducting Joints in Air or Gas, Hottest Spot of Bushing Metal Parts in Contact with Class A Insulation or with Oil	65	105	115	120
6 Average Winding Temperature Rise of Dry-Type Current Transformer with 80°C Rise (Class B) Insulation	110	150	160	165

¹ Adapted from ANSI C37.010-1979, C37.010b-1985, and C37.4-1953

² Unless indicated otherwise by manufacturer contacts and conducting joints in other than oil or air are assumed to be at 65°C hottest spot rise and 105°C hottest spot total temperature per ANSI C37.01b-1985

TABLE II
CIRCUIT BREAKER RATINGS¹
 (% OF ADJUSTED RATED CONTINUOUS CURRENT)

Allowable Max. Temp.	70°C		75°C		80°C		85°C		90°C		95°C		105°C		110°C		120°C		150°C		Minimum Rating of all temperatures ⁵	
	<u>W</u> ²	<u>S</u> ³	<u>W</u> ²	<u>S</u> ³	<u>W</u> ²	<u>S</u> ³	<u>W</u> ²	<u>S</u> ³	<u>W</u> ²	<u>S</u> ³	<u>W</u> ²	<u>S</u> ³	<u>W</u> ²	<u>S</u> ³	<u>W</u> ²	<u>S</u> ³	<u>W</u> ²	<u>S</u> ³	<u>W</u> ²	<u>S</u> ³	<u>W</u> ²	<u>S</u> ³
Normal Ambient Adjusted	147	117	141	115	136	113	132	111	129	110	127	109	123	108	121	107	119	106	114	105	121	107
8 Hrs.	160	125	152	121	147	119	142	117	138	115	135	114	130	112	128	111	125	110	118	107	128	111
4 Hrs.	166	132	158	128	152	125	147	122	142	120	139	118	133	116	131	115	128	113	121	109	131	115
15 minute	200 ⁶	173	200 ⁶	164	200 ⁶	157	200 ⁶	152	193	147	186	143	175	137	171	135	163	131	131	148	171	135

Notes:

1. CAUTION: The ratings in this table do not include limitations of bushings, and/or current transformers connected on reduced taps or limitations of equipment connected to current transformers. ANSI limits loading beyond nameplate to 200%.
2. Winter ambient temperature is 10°C for all rating durations.
3. Summer ambient temperatures are 30°C for continuous normal ratings and 35°C for rating durations of 8 hours or less.
4. These emergency rating factors are based on breaker half-hour thermal time constants, per ANSI C37.010-1979. For time constants other than one-half hour, special calculations can be made as outlined in Appendix II.
5. Minimum ratings listed do not include 120°C and 150°C because of the limited number of bushing current transformers that use 80°C rise insulation.

ANNEX I - FORMULAE AND SAMPLE CALCULATIONS

PART A - CIRCUIT BREAKER RATING FORMULAE

1.0 Correction of Rated Continuous Current (Based on factory temperature rise test only)

When a circuit breaker test temperature rise is less than guaranteed, ratings may be adjusted as follows for each material class.

$$I = I_r \left(\frac{q_r}{q} \right)^{\frac{1}{n}}$$

I = Adjusted rated continuous current

I_r = Rated continuous current (circuit breaker nameplate rating)

θ = Test observable temperature rise at rated continuous current

θ_r = Limit of observable temperature rise at rated continuous current

n = 1.8 for circuit breakers

For subsequent calculations the adjusted rated continuous current (I) should be used when test data is available. When test data is not available, use rated continuous current (I_r). Note: ANSI nomenclature utilizes (I_r), moreover $I = I_r$ when temperature rise tests are unavailable.

2.0 Calculation of Normal (Continuous) Current Ratings (Based on actual ambient temperature)

Winter and summer normal ratings may not be equal to rated continuous current but can be determined as follows:

$$I_a = I \left(\frac{q_{\max} - q_a}{q_r} \right)^{\frac{1}{n}}$$

I_a = Normal current rating

θ_a = Ambient temperature

θ_{\max} = Allowable maximum temperature ($\theta_{\max} = \theta_r + 40^\circ\text{C}$)

3.0 Calculation of Emergency Ratings of 8 Hour Duration

Winter and summer emergency ratings of 8 hour duration can be determined as follows:

$$I_{ea8} = I \left(\frac{q_{\max_{e8}} - q_a}{q_r} \right)^{\frac{1}{n}}$$

I_{ea8} = Emergency rating for 8 hour duration

$\theta_{\max_{e8}}$ = Emergency (8 hour) allowable maximum temperature

4.0 Calculation of Emergency Ratings of 4 Hour Duration

Winter and summer emergency ratings of 4 hour duration can be determined as follows:

$$I_{ea4} = I \left(\frac{q_{\max_{e4}} - q_a}{q_r} \right)^{\frac{1}{n}}$$

I_{ea4} = Emergency rating of 4 hour duration.

$\theta_{\max_{e4}}$ = Emergency (4 Hour) allowable maximum temperature

5.0 Calculation of Emergency Ratings of Less Than 4 Hour Duration

Winter and summer emergency ratings of less than 4 hour duration can be determined as follows:

$$q_i = (q_{\max} - 40^\circ C) \left(\frac{I_i}{I_r} \right)^n + q_a$$

For PJM ratings in this guide it is assumed that the initial load I_i is equal to I_r the rated load. Therefore the equation above reduces to:

$$q_i = (q_{\max} - 40^\circ C) + q_a$$

$$q_s = \left(\frac{q_{\max} e^{4 - \frac{t}{\tau}} - q_i}{1 - e^{-\frac{t}{\tau}}} \right) + q_a$$

$$I_s = I_r \left(\frac{q_s - q_a}{q_{\max} - 40^\circ C} \right)^{\frac{1}{n}}$$

θ_i = total temperature due to initial continuous current at ambient θ_a .

θ_s = total temperature reached if I_s were applied continuously at ambient θ_a .

I_s = Emergency rating of less than 4 hour duration

t = Rating duration (hours)

τ = Thermal time constant of the circuit breaker (hours)

τ , The thermal time constant of a circuit breaker, preferably should be obtained by test or it can be conservatively used as .5 hours (30 minutes).

PART B - CURRENT TRANSFORMER RATING FORMULAE

The current transformer is designed to allow operation in the higher temperature environment of a circuit breaker. For simplification of calculation of current transformer ratings, the assumption is made that the temperature rise of the current transformer with the continuous thermal current rating factor applied is equal to its allowable maximum temperature less the ambient temperature of the air surrounding the circuit breaker.

1.0 Correction of Rated Continuous Current for Operation on Any Tap

Using the current transformer tap setting, the adjusted rated continuous current of the tap may be determined as follows:

$$I_{tap} = I_{tap_r} \left(\frac{I_r}{I_{tap_r}} \right)^{\frac{1}{n}} \times RF$$

I_{tap} = Adjusted rated continuous current of specific current transformer tap under consideration

I_r = Rated continuous current (current transformer nameplate rating)

I_{tap_r} = Rated continuous current of specific current transformer tap under consideration

RF = Continuous thermal current rating factor (Manufacturer should be consulted for value of the continuous thermal current rating factor. Assume 1.0 if not available.)

n = 1.8 for current transformers

Note: If temperature rise data from a heat run test is available for a current transformer, the adjusted rated continuous current of the tap may be determined using the formulae in Annex I, Part C, 2.0, "Determination of Current Transformer Ratings".

2.0 Calculation of Normal (Continuous) Current Ratings

Winter and summer normal ratings for current transformers can be determined as follows:

$$I_a = I_{tap} \left(\frac{q_{max} - q_a}{q_r} \right)^{\frac{1}{n}}$$

3.0 Calculation of Emergency Ratings

Winter and summer emergency ratings for current transformers can be determined as follows:

8 Hour Duration

$$I_{ea8} = Itap \left(\frac{\mathbf{q} \max_{e8} - \mathbf{q}_a}{\mathbf{q}_r} \right)^{\frac{1}{n}}$$

$$I_{ea4} = Itap \left(\frac{\mathbf{q} \max_{e4} - \mathbf{q}_a}{\mathbf{q}_r} \right)^{\frac{1}{n}}$$

Less Than 4 Hour Duration

$$\mathbf{q}_i = (\mathbf{q} \max - 40^{\circ}\text{C}) + \mathbf{q}_a$$

$$\mathbf{q}_s = \left(\frac{\mathbf{q} \max_{e4} - \mathbf{q}_i}{1 - e^{-\frac{t}{\tau}}} \right) + \mathbf{q}_i$$

$$I_s = I_{tap} \left(\frac{\mathbf{q}_s - \mathbf{q}_a}{\mathbf{q} \max - 40^{\circ}\text{C}} \right)^{\frac{1}{n}}$$

PART C - SAMPLE CALCULATIONS

1.0 Determination of Circuit Breaker Ratings (Includes current transformer limitations)

Since all circuit breakers may contain more than one material class, it will be necessary to determine ratings for each material class and select the limiting rating for the appropriate conditions.

Assume a 1200 ampere nameplate oil circuit breaker with silver contacts, 1200/5 ampere multi-ratio bushing current transformers with Class A insulation, a continuous thermal current rating factor RF of 1.33 and connected on the 1200 ampere tap. Temperature rises from heat run test data are as follows:

<u>Component</u>	Observable Temperature Rise, θ °C
Bushing Terminal (Silver Plated)	50.4
Contacts (Silver-to-Silver)	43.5
Top Oil	28.0

Adjusted Rated Continuous Current (Based on factory temperature rise test only)

For the 1200 ampere (I_r) oil circuit breaker, the adjusted rated continuous current should be determined for each component.

$$I = I_r \left(\frac{q_r}{q} \right)^{\frac{1}{1.8}}$$

	θ (°C)	θ_r (°C)	I (amp.)
Bushing Top Terminal	50.4	65	1382
Contacts	43.5	50	1296
Top Oil	28.0	40	1463

For the 1200/5 ampere multi-ratio bushing current transformer on the 1200 ampere tap, the adjusted rated continuous current should be determined.

$$I_{tap} = I_{tap_r} \left(\frac{I_r}{I_{tap_r}} \right)^{1.8} \times RF$$

$$= 1200 \left(\frac{1200}{1200} \right)^{1.8} \times 1.33$$

$$I_{tap} = 1596$$

Ambient Adjusted Normal Continuous Current Ratings (Based on adjusted current ratings evaluated from factory temperature rise test)

For all parts except CT:

$$I_a = I \left(\frac{q_{max} - q_a}{q_r} \right)^{1.8}$$

For CT:

$$I_a = I_{tap} \left(\frac{q_{max} - q_a}{q_r} \right)^{1.8}$$

	I or Itap (amp.)	θ_r (°C)	θ_{max} (°C)	I _a (amp.)	
				Summer $\theta_a=30^\circ\text{C}$	Winter $\theta_a=10^\circ\text{C}$
Bushing Top Terminal	1382	65	105	1496	1706
Contacts	1296	50	90	1434	1682
Top Oil	1463	40	80	1656	1996
CT	1596	55	95	1751	2032

Contacts are limiting for summer and winter ratings.

Emergency Ratings of 8 Hour Duration

(I = nameplate current rating, Itap = Nameplate current of CT with a RF of 1.33)

For all parts except CT:
$$I_{ea8} = I \left(\frac{q_{\max_{e8}} - q_a}{q_r} \right)^{\frac{1}{1.8}}$$

For CT:
$$I_{ea8} = Itap \left(\frac{q_{\max_{e8}} - q_a}{q_r} \right)^{\frac{1}{1.8}}$$

	I or Itap (amp.)	θ_r (°C)	$\theta_{\max_{e8}}$ (°C)	I_{ea8} (amp.)	
				Summer $\theta_a = 35^\circ\text{C}$	Winter $\theta_a = 10^\circ\text{C}$
Bushing Top Terminal	1200	65	115	1346	1566
Contacts	1200	50	100	1388	1663
Top Oil	1200	40	90	1432	1763
CT	1596	55	105	1824	2162

Bushing top terminal is limiting for summer and winter ratings.

Emergency Ratings of 4 Hour Duration

(I = nameplate current rating, Itap = Nameplate current of CT with a RF of 1.33)

For all parts except CT:
$$I_{ea4} = I \left(\frac{q_{\max_{e4}} - q_a}{q_r} \right)^{\frac{1}{1.8}}$$

For CT:
$$I_{ea4} = Itap \left(\frac{q_{\max_{e4}} - q_a}{q_r} \right)^{\frac{1}{1.8}}$$

	I or Itap (amp.)	θ_r (°C)	$\theta_{\max_{e4}}$ (°C)	I_{ea4} (amp.)	
				Summer $\theta_a = 35^\circ\text{C}$	Winter $\theta_a = 10^\circ\text{C}$
Bushing Top Terminal	1200	65	120	1392	1607
Contacts	1200	50	105	1446	1714
Top Oil	1200	40	95	1150	1824
CT	1596	55	110	1896	2224

Bushing top terminal is limiting for summer and winter ratings.

Emergency Ratings of 15 Minute Duration

(I = nameplate current rating, Itap = Nameplate current of CT with a RF of 1.33)

Assumes .5 hour (30 minute) circuit breaker time constant with $t = .25$ and $\tau = .5$.

For all parts except CT: $q_i = (q_{\max} - 40^\circ\text{C}) + q_a$

$$q_s = \left(\frac{q_{\max} e^{4t} - q_i}{1 - e^{-\frac{t}{\tau}}} \right) + q_i$$

$$I_s = I_r \left(\frac{q_s - q_a}{q_{\max} - 40^\circ\text{C}} \right)^{\frac{1}{1.8}}$$

For CT:
$$I_s = I_{tap} \left(\frac{q_s - q_a}{q_{\max} - 40^\circ\text{C}} \right)^{\frac{1}{1.8}}$$

				I _{s,25} (A)					
				Summer			Winter		
I or Itap		θ _{max}	θ _{max,e4}	θ _a = 35°C			θ _a = 10°C		
(A)	(°C)	(°C)	θ _i (°C)	θ _s (°C)	I _s	θ _i (°C)	θ _s (°C)	I _s	
Bushing Top									
Terminal	1200	105	120	100	150.8	1654	75	189.3	2112
Contacts	1200	90	105	85	135.8	1771	60	174.3	2316
Top Oil	1200	80	95	75	125.83	1892	50	164.3	2400
CT	1596	95	110	90	140.8	2295	65	179.3	2968

Note: θ_s is the final temperature reached if the .25 hour (15 minute) rating was applied continuously.

Bushing top terminal is limiting for summer and winter ratings.

2.0 Determination of Current Transformer Ratings

The following example illustrates the impact on emergency ratings that results from utilizing a reduced tap on a CT. Compare these ratings to the previous example (Annex I, Part C, 1.0) and note the CT will become the component limiting circuit breaker emergency ratings.

Assume the circuit breaker in the above example has 1200/5 ampere multi-ratio current transformers with Class A insulation, a continuous thermal current rating factor (RF) of 1.33 and is connected on the 800 ampere tap.

Adjusted Rated Continuous Current

$$I_{tap} = I_{tap_r} \left(\frac{I_r}{I_{tap_r}} \right)^{\frac{1}{1.8}} \times RF$$
$$I_{tap} = 800 \left(\frac{1200}{800} \right)^{\frac{1}{1.8}} \times 1.33 = 1332 \text{ amp.}$$

Ambient Adjusted Normal Continuous Current Ratings (Based on adjusted current ratings evaluated from factory temperature rise test)

$$I_a = I_{tap} \left(\frac{q_{max} - q_a}{q_r} \right)^{\frac{1}{1.8}}$$
$$I_a = 1332 \left(\frac{95 - q_a}{55} \right)^{\frac{1}{1.8}}$$

$q_a = 30^\circ C$ summer; $10^\circ C$ winter.

$$I_a (\text{winter}) = 1332 \times 1.27 = 1696 \text{ amp.}$$

$$I_a (\text{summer}) = 1332 \times 1.09 = 1461 \text{ amp.}$$

Emergency Ratings of 8 Hour Duration

(I = nameplate current rating, I_{tap} = Nameplate current of CT with a RF of 1.33)

$$I_{ea8} = I_{tap} \left(\frac{q_{max_{e8}} - q_a}{q_r} \right)^{\frac{1}{1.8}}$$
$$I_{ea8} = 1332 \left(\frac{105 - q_a}{55} \right)^{\frac{1}{1.8}}$$

$q_a = 35^\circ C$ summer; $10^\circ C$ winter.

$$I_{ea8} (\text{winter}) = 1332 \times 1.35 = 1804 \text{ amp.}$$

$$I_{ca8}(\text{summer}) = 1332 \times 1.14 = 1523 \text{ amp.}$$

Emergency Ratings of 4 Hour Duration

(I = nameplate current rating, Itap = Nameplate current of CT with a RF of 1.33)

$$I_{ea4} = Itap \left(\frac{q \max_{e4} - q_a}{q_r} \right)^{\frac{1}{1.8}}$$

$$I_{ea4} = 1332 \left(\frac{110 - q_a}{55} \right)^{\frac{1}{1.8}}$$

$q_a = 35^\circ C$ summer; $10^\circ C$ winter.

$$I_{ca4}(\text{winter}) = 1332 \times 1.39 = 1856 \text{ amp.}$$

$$I_{ca4}(\text{summer}) = 1332 \times 1.18 = 1582 \text{ amp.}$$

Emergency Ratings of 15 Minute (.25 hour) Duration

$$q_i = (q \max - 40^\circ C) + q_a$$

$$q_s = \left(\frac{q \max_{e4} - q_i}{1 - e^{-\frac{t}{\tau}}} \right) + q_i$$

$$I_{s.25} = I_{tap} \left(\frac{q_s - q_a}{q \max - 40^\circ C} \right)^{\frac{1}{1.8}}$$

Summer $\theta_a = 35^\circ\text{C}$

$$q_i = (110^\circ\text{C} - 40^\circ\text{C}) + 35^\circ\text{C} = 105^\circ\text{C}$$

$$q_s = \left(\frac{110^\circ\text{C} - 105^\circ\text{C}}{1 - e^{-\frac{.25}{.5}}} \right) + 105^\circ\text{C}$$

$$I_{s.25} = I_{tap} \left(\frac{117.7 - 35}{110 - 40^\circ\text{C}} \right)^{\frac{1}{1.8}} = 1.097 I_{tap}$$

$$I_{s.25}(\text{summer}) = 1332 \times 1.09 = 1461 \text{ amp.}$$

Winter $\theta_a = 10^\circ\text{C}$

$$q_i = (110^\circ\text{C} - 40^\circ\text{C}) + 10^\circ\text{C} = 80^\circ\text{C}$$

$$q_s = \left(\frac{110^\circ\text{C} - 80^\circ\text{C}}{1 - e^{-\frac{.25}{.5}}} \right) + 80^\circ\text{C}$$

$$I_{s.25} = I_{tap} \left(\frac{156.24 - 10}{110 - 40^\circ\text{C}} \right)^{\frac{1}{1.8}} = 1.505 I_{tap}$$

$$I_{s.25}(\text{winter}) = 1332 \times 1.50 = 2005 \text{ amp.}$$

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