# VI.C

# CIRCUIT BREAKERS

*GUIDE FOR DETERMINATION OF*

*CIRCUIT BREAKER LOAD CURRENT CAPABILITY RATINGS*

*PJM INTERCONNECTION*

*Transmission and Substation Subcommittee*

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## REVISION HISTORY

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|---|---|
| May 1971: | Rev. 0 - Original Document. |
| June 1999: | Rev. 1 - Format changes and general revision. |
| October 2009: | Rev. 2 - General revision and document standardization and clarification of emergency and load dump ratings, and revision of associated equations. |
| June 2024: | Rev. 3 – Revision to support FERC Order 881 Line Rating Methodology changes. |

## SCOPE AND PURPOSE

This guide presents principles and procedures to be used in establishing normal, emergency four hour and load dump current carrying capabilities for circuit breakers designed, built and tested under IEEE/ANSI standards. It does not consider close and latch, short circuit and interrupting capabilities. The resulting thermal ratings can be used for selecting the most economical nameplate ratings for new circuit breakers. Circuit breakers built under standards listed in the Bibliography of this report are included. This guide includes methods for determination of thermal ratings of all circuit breaker current transformers except free standing, external 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 bushing current transformers unless they are specifically excluded. A spreadsheet, available from PJM upon request, was developed to perform breaker ratings calculations. A sample calculation is provided in Annex II.

## DISCUSSION OF RATING METHOD

The rating methods established by this report comprise the various factors and consider provisions of IEEE/ANSI Standard C37.010-2000. The method developed is based primarily on the following:

a. Ambient temperature ($\theta_a$).
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.

It is assumed that power levels will be maintained and managed within the requirements of PJM Manual 3, Section 2, "Thermal Operating Guidelines". PJM operating philosophy strives to restore loads to below the Normal Rating in four hours or less. The intent of this guide is that equipment loading will not be above the Normal Rating for greater than four hours. It is understood that under a single event restoration, cumulative time of loading, in excess of the Normal Rating, beyond four hours may occur. Operating in excess of four hours above the Normal Rating for a single event restoration should be evaluated by the equipment owner.

## DEFINITIONS

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

**Adjusted Rated Continuous Current of a Circuit Breaker** $(I)$
Continuous current capability of a circuit breaker corrected to Limit of Observable Temperature Rise using specific Test Observable Temperature Rise data. Note: $I = I_r$ when specific temperature rise test data is not available.

**Adjusted Rated Continuous Current of a Current Transformer Tap** $(\mathbf{I_{tap}})$
Continuous current capability of a specific tap of a current transformer corrected for connection on a reduced tap and to Limit of Observable Temperature Rise using specific Test Observable Temperature Rise data.

**Ambient Temperature** $(\theta_a)$
Expected air temperature surrounding the rated circuit breaker.

**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.

**Emergency Allowable Maximum Temperature** $(\boldsymbol{\theta_{max_e}})$
Maximum temperature which any circuit breaker part can withstand for various emergency rating durations, e.g., $\theta_{max_{e4}}$= 4 hour maximum temperature, etc.

**Emergency Current Rating** $(\mathbf{I_{ea}})$
Current that can be carried for a specified period of time, at selected ambient temperature, without any circuit breaker part exceeding its emergency allowable maximum temperature. In PJM the Emergency Current Rating is for a four hour duration, e.g., $I_{ea_4}$ = 0 to 4 hour emergency current.

**Limit of Observable Temperature Rise** $(\boldsymbol{\theta_r})$
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 IEEE C37.010-1999 and C37.4 1953. Values are listed in Table I of this report.

**Load Dump Current Rating** $(\boldsymbol{I_{s_{0.25}}})$
In PJM a Load Dump Current Rating is a Short Time Emergency Current Capability for 15 minute duration, e.g. $\boldsymbol{I_{s_{0.25}}}$ is the current which can be carried 15 minutes, or a ¼ of an hour.

**Normal Allowable Maximum Temperature** $(\boldsymbol{\theta_{max}})$
The allowable hottest spot temperature. Maximum temperature that any circuit breaker part can withstand continuously. Values from IEEE C37.010-2000 and IEEE C37.4 1953 are listed in Table I of this report.

**Normal Current Rating** $(\mathbf{I_a})$
Current that can be carried continuously without any circuit breaker part exceeding its normal allowable maximum temperature.

**Rated Continuous Current (Nameplate Rating)** $(\mathbf{I_r})$
Maximum current in Amperes 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**$(\mathbf{I_{tap_r}})$
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.

**Short Time Emergency Current Capability** $(\mathbf{I_s})$
Short time emergency currents which can be carried for less than 4 hours, e.g. $I_{s_{0.25}}$ is the current which can be carried for a ¼ of an hour.

**Temperature Due to Initial Continuous Current** $(\boldsymbol{\theta_i})$
Maximum temperature due to initial continuous current at ambient $(\theta_a)$. Utilized in calculation of short time capabilities for less than four hours.

**Temperature Reached if** $(\mathbf{I_s})$ **were applied continuously**$(\boldsymbol{\theta_s})$
Maximum temperature reached if the short term current $I_s$ were to be applied continuously at ambient $(\theta_a)$. Utilized in calculation of short time capabilities for less than four hours.

**Test Observable Temperature Rise** $(\boldsymbol{\theta})$
Measured steady-state temperature rise above measured ambient temperature of any part of a circuit breaker when tested at rated continuous current.

**Thermal Time Constant** $(\boldsymbol{\tau})$
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).

## AMBIENT TEMPERATURE

Since maximum circuit breaker temperature is a function of ambient temperature, $\theta_a$ 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 for planning purposes, which are consistent with those used for all PJM equipment ratings (Normal, Emergency and Load Dump):

| Description | Summer | Winter | Light Load |
|---|---|---|---|
| PJM Planning Basis Temperatures | 35 ˚C | 10 ˚C | 15 ˚C |

PJM Operations utilizes ambient adjusted ratings in 5 °C increments. The method described in this document allows the calculation of these capabilities.

## 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 & LOAD DUMP CURRENT RATINGS

Emergency ratings for durations of four hours are based on operation up to the emergency allowable maximum temperature for the limiting circuit breaker part. Emergency allowable maximum temperature limits of 15 °C above the normal allowable maximum temperature are utilized for ratings of four hours and less duration. This temperature limit 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, for example load dump current ratings, 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, including load dump current rating, shall be 100% or less of the normal rating for the ambient temperature. Ratings can be increased by assuming pre-load current less than 100% of normal rating.

After the emergency duration, it is assumed that temperatures shall be reduced to the normal rating limit prior to the emergency rating being used again. For a time constant of 30 minutes, a three hour cool down period is recommended.

## 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 generally will not limit the circuit breaker normal, emergency or load dump rating. Annex I 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, $\theta_{max}$ 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 IEEE/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.

Connections must also be considered when determining circuit breaker loading capabilities. 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. Designs exceeding these levels would both deteriorate the bushing under normal conditions and could further elevate temperature rises under emergency and load dump conditions.

## DETERMINATION OF RATINGS

Circuit breaker ratings can be determined as follows:

a. If circuit breaker materials and/or the year of manufacture is known, refer to Table I and then determine ratings from Table II.

b. 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)

| Rating Duration | Winter (%) | Summer (%) |
|---|---|---|
| Normal | 123 | 104 |
| Emergency, 0 to 4 hours | 134 | 116 |
| Load Dump, 0.25 hours, (15 minutes) | 176 | 138 |

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.

See Annex II for sample 230 kV, 3000 A, post 1964, Class A insulation circuit breaker ratings at 5˚C increments of ambient temperature. Note that a functional rating spreadsheet is available upon request from PJM.

## MAINTENANCE REQUIREMENTS

Satisfactory performance of circuit breakers carrying loads based on ratings established by this report are dependent upon adequate maintenance.

## TABLE I - TEMPERATURE LIMITATIONS FOR CIRCUIT BREAKERS

| TEMPERATURE LIMITATIONS FOR CIRCUIT BREAKERS[1] | | | | | |
|---|---|---|---|---|---|
| Circuit Breaker Component Description | | Limit of Observable Temperature Rise at Rated Current $\theta_r$ (°C) | Limit of Total Allowable Maximum Temperature $\theta max$ (°C) | Emergency Allowable Maximum Temperature Rating $\theta_{max_e}$ (°C) | |
| | | | | 4 Hours or Less $\theta_{max_{e4}}$ | 15 Minutes or Less $\theta_{max_{e.25}}$ |
| Breakers manufactured prior to 1964 | | | | | |
| 1 | Contacts in oil, oil and bushings | 30 | 70 | 85 | 85 |
| 2 | Contact in air or gas | 35 | 75 | 90 | 90 |
| 3 | Average Winding Temperature Rise of Current Transformer with 55˚C Rise (Class A) Insulation | 55 | 95 | 110 | 110 |
| 4 | Average Winding Temperature Rise of Dry-Type Current Transformer with 80˚C Rise (Class B) Insulation | 80 | 120 | 135 | 135 |
| Breakers manufactured 1964 and later[2] | | | | | |
| 1 | Copper Contacts, Copper-to-Copper Conducting Joints, External Terminal Connected to Bushing | 30 | 70 | 85 | 85 |
| 2 | Top Oil | 40 | 80 | 95 | 95 |
| 3 | Hot Spot Oil at Points in Contact with Hot Parts, Silver (or Equal) Contacts or Conducting Joints in Oil | 50 | 90 | 105 | 105 |
| 4 | Average Winding Temperature Rise of Current Transformer with 55˚C Rise (Class A) Insulation | 65 | 105 | 120 | 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 | 120 | 120 |
| 6 | Average Winding Temperature Rise of Dry-Type Current Transformer with 80˚C Rise (Class B) Insulation | 110 | 150 | 165 | 165 |

1 Adapted from IEEE/ANSI C37.010-2000

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 temperature per IEEE/ANSI C37.010-2000

## TABLE II - CIRCUIT BREAKER RATINGS

(% OF ADJUSTED RATED CONTINUOUS CURRENT)[1]

| Allowable Max. Temp. $\theta_{max}$ (°C) | 70°C | | 75°C | | 80°C | | 90°C | | 95°C | | 105°C | | 120°C | | 150°C | | Minimum Rating of all temperatures[5] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Winter/ Summer | W[2] | S[3] | W[2] | S[3] | W[2] | S[3] | W[2] | S[3] | W[2] | S[3] | W[2] | S[3] | W[2] | S[3] | W[2] | S[3] | W[2] | S[3] |
| Normal Ambient Adjusted | 147 | 109 | 141 | 108 | 136 | 107 | 130 | 105 | 127 | 105 | 123 | 104 | 119 | 103 | 114 | 103 | 123 | 104 |
| 4 Hrs. | 166 | 133 | 158 | 129 | 152 | 125 | 143 | 121 | 139 | 119 | 134 | 116 | 128 | 113 | 121 | 110 | 134 | 116 |
| 15 minute[4] | 200[6] | 173 | 200[6] | 165 | 200[6] | 158 | 194 | 148 | 187 | 144 | 176 | 138 | 164 | 131 | 149 | 123 | 176 | 138 |

**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.
2. Winter ambient temperature is 10˚C for all rating durations.
3. Summer ambient temperatures are 35˚C for all rating durations.
4. These emergency rating factors are based on breaker half-hour thermal time constants, per IEEE/ANSI C37.010-2000.
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.
6. IEEE/ANSI limits loading beyond nameplate to 200%.

## 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.

$$I = I_r \left(\frac{\theta_r}{\theta}\right)^{\frac{1}{n}}$$

I = Adjusted rated continuous current

$I_r$= Rated continuous current (circuit breaker nameplate rating)

$\theta$ = Test observable temperature rise at rated continuous current

$\theta_r$ = 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 ($I_r$).**

**<u>Note:</u> ANSI nomenclature utilizes ($I_r$), moreover I = $I_r$ when temperature rise tests are unavailable.**

2.0 <u>Calculation of Normal (Continuous) Current Ratings</u> (Based on ambient temperature)

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

$$I_a = I \left(\frac{\theta_{max} - \theta_a}{\theta_r}\right)^{\frac{1}{n}}$$

$I_a$= Normal current rating

$\theta_a$ = Ambient temperature

$\theta_{max}$ = Allowable maximum temperature ($\theta_{max}$ = $\theta_r$ + 40 °C)

3.0 <u>Calculation of Emergency Ratings of 4 Hour Duration</u>

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

$$I_{ea4} = I \left(\frac{\theta_{max_{e4}} - \theta_a}{\theta_r}\right)^{\frac{1}{n}}$$

$I_{ea4}$ = Emergency rating for 4 hour duration

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

## 4.0 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:

$$\theta_i = (\theta_{max} - 40°C)\left(\frac{I_i}{I_r}\right)^n + \theta_a$$

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

$$\theta_i = (\theta_{max} - 40°C) + \theta_a$$

$$\theta_s = \left(\frac{\theta_{max_{e4}} - \theta_i}{1 - e^{-\frac{t}{\tau}}}\right) + \theta_i$$

$$I_s = I_r \left(\frac{\theta_s - \theta_a}{\theta_{max} - 40°C}\right)^{\frac{1}{n}}$$

$\theta_i$ = Total temperature due to initial continuous current at ambient $\theta_a$

$\theta_s$ = Total temperature reached if $I_s$ were applied continuously at ambient $\theta_a$.

$I_s$ = Emergency rating of less than 4 hour duration

t = Rating duration (hours)

$\tau$ = Thermal time constant of the circuit breaker (hours)

$\tau$ , the thermal time constant of a circuit breaker, preferably should be obtained by test or it can be conservatively used as 0.5 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 <u>Correction of Rated Continuous Current for Operation on Any Tap</u>

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 <u>Calculation of Normal (Continuous) Current Ratings</u>

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

$$I_a = I_{tap}\left(\frac{(\theta_{max} - \theta_a)}{\theta_r}\right)^{\frac{1}{n}}$$

## 3.0 Calculation of Emergency Ratings

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

**4 Hour Duration**

$$I_{ea4} = I_{tap} \left( \frac{\theta_{max_{e4}} - \theta_a}{\theta_r} \right)^{\frac{1}{n}}$$

**Less Than 4 Hour Duration**

$$\theta_i = (\theta_{max} - 40\ °C) + \theta_a$$

$$\theta_s = \left( \frac{\theta_{max_{e4}} - \theta_i}{1 - e^{-\frac{t}{\tau}}} \right) + \theta_i$$

$$I_s = I_r \left( \frac{\theta_s - \theta_a}{\theta_{max} - 40°C} \right)^{\frac{1}{n}}$$

## 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:

| Component | 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.

$$I = I_r \left(\frac{\theta_r}{\theta}\right)^{\frac{1}{1.8}}$$

| | $\theta$°C | $\theta_r$ °C | I (A) |
|---|---|---|---|
| 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.

$$I_{tap} = I_{tap_r} \left(\frac{I_r}{I_{tap_r}}\right)^{\frac{1}{1.8}} \times RF$$

$$I_{tap} = 1200 \left(\frac{1200}{1200}\right)^{\frac{1}{1.8}} \times 1.33$$

$$I_{tap} = 1596$$

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

For all parts except CT:

$$I_a = I\left(\frac{\theta_{max} - \theta_a}{\theta_r}\right)^{\frac{1}{1.8}}$$

For CT:

$$I_a = I_{tap}\left(\frac{\theta_{max} - \theta_a}{\theta_r}\right)^{\frac{1}{1.8}}$$

| | I or $I_{tap}$ (A) | $\theta_r$ ($°C$) | $\theta_{max}$ ($°C$) | $I_a$(A) Summer $\theta_a = 35°$ C | $I_a$ (A) Winter $\theta_a = 10°$ C |
|---|---|---|---|---|---|
| **Bushing Top Terminal** | 1382 | 65 | 105 | 1440 | 1706 |
| **Contacts** | 1296 | 50 | 90 | 1366 | 1682 |
| **Top Oil** | 1463 | 40 | 80 | 1562 | 1996 |
| **CT** | 1596 | 55 | 95 | 1675 | 2032 |

Contacts are limiting for summer and winter ratings.

## Emergency Ratings of 4 Hour Duration

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

For all parts except CT:

$$I_{ea4} = I\left(\frac{\theta_{max_{e4}} - \theta_a}{\theta_r}\right)^{\frac{1}{1.8}}$$

For CT:

$$I_{ea4} = I_{tap}\left(\frac{\theta_{max_{e4}} - \theta_a}{\theta_r}\right)^{\frac{1}{1.8}}$$

| | I or $I_{tap}$ (A) | $\theta_r$ ($°C$) | $\theta_{maxe4}$ ($°C$) | $I_{ea4}$(A) Summer $\theta_a = 35° C$ | $I_{ea4}$ (A) Winter $\theta_a = 10° C$ |
|---|---|---|---|---|---|
| **Bushing Top Terminal** | 1200 | 65 | 120 | 1392 | 1607 |
| **Contacts** | 1200 | 50 | 105 | 1446 | 1714 |
| **Top Oil** | 1200 | 40 | 95 | 1503 | 1824 |
| **CT** | 1596 | 55 | 110 | 1896 | 2224 |

Bushing top terminal is limiting for summer and winter ratings.

<u>Emergency Ratings of 15 Minute Duration</u>

(I = nameplate current rating, $I_{tap}$ = Nameplate current of CT with a RF of 1.33)
Assumes 0.5 hour (30 minute) circuit breaker time constant with t = 0.25 and $\tau = 0.5$.

For all parts except CT:

$$\theta_i = (\theta_{max} - 40\ °C) + \theta_a$$

$$\theta_s = \frac{\theta_{max_{e4}} - \theta_i}{1 - e^{-\frac{t}{\tau}}} + \theta_i$$

$$I_s = I_r \left(\frac{\theta_s - \theta_a}{\theta_{max} - 40°C}\right)^{\frac{1}{1.8}}$$

For CT:

$$I_s = I_{tap} \left(\frac{\theta_s - \theta_a}{\theta_{max} - 40°C}\right)^{\frac{1}{1.8}}$$

| | | | | Summer $\theta_a = 35\ °C$ | | | Winter $\theta_a = 10\ °C$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | I or $I_{tap}$ (A) | $\theta_{max}$ ($°c$) | $\theta_{max_{e4}}$ ($°c$) | $\theta_i$ ($°c$) | $\theta_s$ ($°c$) | $I_{s0.25}$ (A) | $\theta_i$ ($°c$) | $\theta_s$ ($°c$) | $I_{s0.25}$ (A) |
| **Bushing Top Terminal** | 1200 | 105 | 120 | 100 | 150.8 | 1654 | 75 | 189.3 | 2109 |
| **Contacts** | 1200 | 90 | 105 | 85 | 135.8 | 1771 | 60 | 174.3 | 2324 |
| **Top Oil** | 1200 | 80 | 95 | 75 | 125.83 | 1892 | 50 | 164.3 | 2541 |
| **CT** | 1596 | 95 | 110 | 90 | 140.8 | 2298 | 65 | 179.3 | 2984 |

Bushing top terminal is limiting for summer and winter ratings.

## 2.0 <u>Determination of Current Transformer Ratings</u>

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

$$I_{tap} = I_{tap_r}\left(\frac{I_r}{I_{tap_r}}\right)^{\frac{1}{1.8}} \times RF$$

$$I_{tap} = 1200\left(\frac{1200}{800}\right)^{\frac{1}{1.8}} \times 1.33 = 1333\ A$$

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

$$I_a = I\left(\frac{\theta_{max} - \theta_a}{\theta_r}\right)^{\frac{1}{1.8}}$$

$$I_a = 1333\left(\frac{95 - \theta_a}{55}\right)^{\frac{1}{1.8}}$$

$\theta_a$ = 35°$C$ summer; 10 °$C$ winter
$I_a$ (winter) = 1333 ×1.27 = 1698 A
$I_a$ (summer) = 1333 × 1.05 = 1399 A

Emergency Ratings of 4 Hour Duration

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

$$I_{ea4} = I\left(\frac{\theta_{max_{e4}} - \theta_a}{\theta_r}\right)^{\frac{1}{1.8}}$$

$$I_{ea4} = 1333\left(\frac{110 - \theta_a}{55}\right)^{\frac{1}{1.8}}$$

$I_{ea4}$(winter) = 1333 × 1.05 = 1858 A

$I_{ea4}$(summer) = 1333 × 1.18 = 1584 A

Emergency Ratings of 0.25 hour (15 Minute) Duration

$$\theta_i = (\theta_{max} - 40\ °C) + \theta_a$$

$$\theta_s = \frac{\theta_{max_{e4}} - \theta_i}{1 - e^{-\frac{t}{\tau}}} + \theta_i$$

$$I_{s_{0.25}} = I_{tap}\left(\frac{\theta_s - \theta_a}{\theta_{max} - 40°C}\right)^{\frac{1}{1.8}}$$

**Summer $\boldsymbol{\theta_a = 35\,°\,C}$**

$$\theta_i = (95°C - 40\,°C) + 35°C = 90°C$$

$$\theta_s = \left(\frac{110°C - 90°C}{1 - e^{\frac{-0.25}{0.5}}}\right) + 90°C = 140.8\,°C$$

$$I_{s0.25} = I_{tap}\left(\frac{140.8°C - 35°C}{95°C - 40°C}\right)^{\frac{1}{1.8}} = 1.436\,I_{tap}$$

$$I_{s0.25}(summer) = 1333\ \times 1.438 = 1917\ amp$$

**Winter $\boldsymbol{\theta_a = 10\,°\,C}$**

$$\theta_i = (95°C - 40\,°C) + 10°C = 65°C$$

$$\theta_s = \left(\frac{110°C - 65°C}{1 - e^{\frac{-0.25}{0.5}}}\right) + 65°C = 179.4\,°C$$

$$I_{s0.25} = I_{tap}\left(\frac{179.4°C - 10°C}{95°C - 40°C}\right)^{\frac{1}{1.8}} = 1.868\,I_{tap}$$

$$I_{s0.25}(winter) = 1333\ \times 1.868 = 2490\ amp$$ [1]

[1] IEEE/ANSI limits loading beyond nameplate to 200% (2128 A).

## ANNEX II - SAMPLE 230 KV, 4000A, POST-1964, CLASS A INSULATION

**Breaker Rating**

### SUBSTATION EQUIPMENT RATING WORKSHEET

**CIRCUIT BREAKER**

1) Populate the nameplate information table as fully as possible

| | NAMEPLATE |
|---|---|
| STATION | |
| EQUIPMENT | Circuit Breaker |
| TYPE | |
| MANUFACTURER | |
| YEAR MANUFACT. | 1976 |
| POSITION | |
| DESIGNATION | |
| RATED VOLTAGE (KV) | 230 |
| RATED CURRENT (A) | 4000 |

NOTE: Correct system voltage must be entered for corresponding MVA values in the tables below.

2) Identify a material class and complete the input table

| | Breakers manuf. Prior to 1964 | | | | Breakers manuf. 1964 and later | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 5 | 6 |
| θmax e4 | 85 | 90 | 110 | 135 | 85 | 95 | 105 | 120 | 120 | 165 |
| θmax | 70 | 75 | 95 | 120 | 70 | 80 | 90 | 105 | 105 | 150 |
| θr | 30 | 35 | 55 | 80 | 30 | 40 | 50 | 65 | 65 | 110 |

| | INPUT |
|---|---|
| θmax e4 | **120** |
| θmax | **105** |
| θr | **65** |
| I Rated | **4000** |
| Rated KV | **230** |

| Ratings | Summer 35°C | | Winter 10°C | |
|---|---|---|---|---|
| | MVA | Amps | MVA | Amps |
| Normal | 1660 | 4168 | 1967 | 4939 |
| Emergency (4 Hr) | 1850 | 4643 | 2134 | 5358 |

**CALCULATED RATINGS**

| AMBIENT TEMP. | | RATING ( P.U. ) | | | RATING ( MVA ) | | | RATINGS (AMPS) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| θa Deg. C | θa Deg. F | NORMAL | 4 HOUR | LOAD DUMP | NORMAL | 4 HOUR | LOAD DUMP | NORMAL | 4 HOUR | LOAD DUMP |
| 0 | 32 | 1.31 | 1.41 | 1.89 | 2080 | 2240 | 3015 | 5221 | 5623 | 7567 |
| 5 | 41 | 1.27 | 1.37 | 1.83 | 2024 | 2188 | 2909 | 5082 | 5492 | 7303 |
| **10** | **50** | **1.23** | **1.34** | **1.76** | **1967** | **2134** | **2801** | **4939** | **5358** | **7030** |
| 15 | 59 | 1.20 | 1.31 | 1.69 | 1909 | 2080 | 2689 | 4793 | 5221 | 6749 |
| 20 | 68 | 1.16 | 1.27 | 1.61 | 1850 | 2024 | 2573 | 4643 | 5082 | 6458 |
| 25 | 77 | 1.12 | 1.23 | 1.54 | 1788 | 1967 | 2452 | 4489 | 4939 | 6156 |
| 30 | 86 | 1.08 | 1.20 | 1.46 | 1725 | 1909 | 2327 | 4331 | 4793 | 5842 |
| **35** | **95** | **1.04** | **1.16** | **1.38** | **1660** | **1850** | **2197** | **4168** | **4643** | **5514** |
| 40 | 104 | 1.00 | 1.12 | 1.29 | 1593 | 1788 | 2059 | 4000 | 4489 | 5169 |

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