VI.F

CURRENT TRANSFORMERS

GUIDE FOR DETERMINATION
OF
CURRENT TRANSFORMER RATINGS

PENNSYLVANIA-NEW JERSEY-MARYLAND INTERCONNECTION
TRANSMISSION AND SUBSTATION DESIGN SUBCOMMITTEE
STATION EQUIPMENT RATING TASK FORCE

R. W. Alexander	PP&L, Inc
P. M. Balma	Public Service Electric and Gas Company
J. M. Burdis	PJM Interconnection, L.L.C.
B. A. Chernisky	GPU Energy
J. R. Daisey, Jr.	Conectiv, Inc
V. C. Jhonsa	Conectiv, Inc
G. Nabet	Baltimore Gas and Electric Company
J. C. Shaffer	PECO Energy Company
M. V. Thaden, Chairman	Potomac Electric Power Company
C. M. Leas	GPU Energy

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SCOPE AND PURPOSE

This report represents principles and procedures to be used in establishing normal and emergency ratings for all current transformers affecting the PJM Interconnection. The rating method applies to bushing-type, doughnut, and separately mounted wound-type current transformers. Although this rating method is intended to be all inclusive, it is recognized that exceptions such as those listed in the subheading entitled "Connected Equipment Limitations" may be necessary for special conditions.

BACKGROUND

The recognition that various designs of current transformers can carry different normal and emergency currents led to the establishment of ratings based on current transformer capabilities, operating procedures, physical environment, and special conditions. These variables resulted in different methods of rating and produced different ratings for identical current transformers. Accordingly, it was recognized that a common current transformer rating method is now required for proper PJM rating administration.

DISCUSSION OF RATING METHODS

The rating methods established by this report represent compromises of the various factors and consider provisions of ANSI C57.13-1993. The method developed is based primarily on the following:

(a) Ambient temperature (θa).

(b) Temperature rise as a function of the 2 power of the current.

(c) Maximum temperature determined to be acceptable for various current transformer components under normal conditions.

DEFINITIONS

Following are definitions of terms used in this report intended for use in determining PJM current transformer ratings.

Rated Continuous Current (Nameplate Rating) (I_r)

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

DEFINITIONS (Continued)

Rated Continuous Current of a Current Transformer Tap ($Itap_r$)

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

Adjusted Rated Continuous Current of a Current Transformer Tap (Itap)

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 current transformer part exceeding its normal and allowable maximum temperature.

Emergency Current Rating (Ie)
Current which can be carried for a specified period of time without any current transformer part exceeding its emergency allowable maximum temperature.

Continuous Thermal Current Rating Factor (RF)
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.

Limit of Observable Temperature Rise (θ_r)
Maximum value of observable temperature rise of any part of a current transformer. Values are listed in Table I of this report.

Test Observable Temperature Rise (θ)
Actual steady-state temperature rise above ambient temperature of any part of a current transformer when tested at rated continuous current.

Normal Allowable Maximum Temperature (Allowable Maximum Temperature) (θmax)
Maximum temperature which any current transformer part can withstand continuously.

Emergency Allowable Maximum Temperature (θmax_e)
Maximum temperature which any current transformer part can withstand for emergency rating duration.

Thermal Time Constant (τ)
The length of time required for the temperature to change from the initial value to the ultimate value if the initial rate of change were continued until the ultimate temperature was reached.

AMBIENT TEMPERATURE

Since maximum current transformer temperature is a function of prevailing ambient temperature, θa, 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.

Rating Duration	Summer (April thru October)	Winter (November thru March)
Normal and Emergency Greater Than 24 Hours	30°C Daily	10°C Daily
Emergency 24 Hours or Less	35°C Daily	10°C Daily

Bushing-type current transformers are designed to allow operation in the higher temperature environment of a circuit breaker or transformer. For simplification of calculation of current transformer ratings, the assumption is made that the temperature rise of the current transformer is equal to its allowable maximum temperature less the ambient temperature of the air surrounding the circuit breaker.

NORMAL RATINGS

The normal current rating of a current transformer is that current which can be carried continuously without any part exceeding its normal allowable maximum temperature. The prime considerations in defining the normal current rating of a current transformer are ambient temperature and continuous thermal current rating factor. The normal current rating of a current transformer tap is calculated by compensating the adjusted rated continuous current of the tap for a specific ambient temperature, or if a rating factor is given for the tap; use this rating factor to calculate the continuous current limit. The adjusted rated continuous current of any current transformer tap is calculated by compensating the rated continuous current (nameplate rating) of the tap as follows:

(a) If temperature rise data from a heat run test is not available, compensate the rated continuous current of the tap for the tap setting and continuous thermal current rating factor.

(b) If temperature rise data from a heat run test is available and was made at the rated continuous current, compensate the rated continuous current of the tap for the tap setting and temperature rise data.

(c) If temperature rise data from a heat run test is available and was made at the rated continuous current times the continuous thermal current rating factor; compensate the rated continuous current for the tap setting, temperature rise data, and continuous thermal current rating factor.

EMERGENCY RATINGS

Emergency ratings for current transformers is not supported by IEEE standard C57.13, or by current transformer suppliers. The recommended procedure for new current transformers is to specify a transformer with a continuous thermal current rating factor that is sufficient to handle foreseeable emergencies. The calculations for emergency ratings from the 1971 PJM report of the same name are provided as a reference. These calculations may be used if the appropriate temperature rise information is provided for the current transformer. It is not recommend that emergency ratings be followed.

Emergency ratings are determined based on operation up to the emergency allowable maximum temperature for the limiting current transformer part. These emergency allowable maximum temperature limits are listed in Table I. The temperature limits may result in slightly accelerated deterioration of some current transformer performance.

Emergency ratings for duration of less than twenty-four hours are determined based on the current transformer thermal time constant, which is a function of the heat storage capacity of the current transformer.

The thermal time constant (τ) for the current transformer should be obtained by test or calculated according to the physical characteristics of the current transformer. Thirty minutes is a conservative approximation for other than oil-filled wound-type current transformers. The PJM report on Determination of Power Transformer Rating should be consulted for the method of calculating the time constant of an oil-filled transformer, based on its physical characteristics. The weight of the porcelain should not be used in calculating the thermal time constant.

Loading prior to applying emergency ratings is 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.

DETERMINATION OF RATINGS

Current transformer ratings can be determined as follows:

(a) If no information is available on current transformer materials and rating factor: Assume RF = 1 and rating is Itap calculated in Appendix.

(b) If current transformer materials are known, refer to Table I and calculate rating from Appendix.

(c) If current transformer materials are known and temperature rise data from heat run tests is available, determine ratings from Appendix.

(d) When current transformers are incorporated internally as parts of larger transformers or power circuit breakers, they shall meet allowable average winding temperature limits under the specific conditions and requirements of the larger apparatus. To calculate the rating of a current transformer that is mounted on a circuit breaker bushing, follow method prescribed in the PJM report "Determination of Circuit Breaker Load Current Capability Ratings."

CONNECTED EQUIPMENT LIMITATIONS

When determining a current transformer thermal rating, all equipment connected to the secondary must be checked for thermal capability. Current transformer accuracy limitations will not be encountered within the emergency allowable maximum temperatures. However, accuracy curves should be consulted when operating current transformers at temperatures above the limit of observable temperature rise.

TEMPERATURE LIMITATIONS FOR CURRENT TRANSFORMERS IN CIRCUIT BREAKERS

TABLE I

No.	Current Transformer Part	Current Transformer Material Class and Nomograph Number	Limit of Observable Temperature Rise at Rated Current θr (°C)	Normal Allowable Maximum Temperature θmax_n (°C)	Emergency Allowable Maximum Temperature (θmax) Rating Duration: Greater Than 24 Hours θmax_{e24} (°C)	Emergency Allowable Maximum Temperature (θmax) Rating Duration: 24 Hours or Less θmax_{e2} (°C)
1	Top Oil	A 1	45	85	100	110
2	Average Winding Temp. Rise with 55°C Rise (Class A) Insulation - 55°C	B 2	55	95	105	115
3	Average Winding Temp. Rise with 65°C Rise Insulation, with 55°C Rise Insulation - 65°C	C 3	65	105	115	125
4	Average Winding Temp. Rise with 80°C Rise (Class B) Insulation, or Winding Hottest Spot with 65°C Rise Insulation	D 4	80	120	130	140

CURRENT TRANSFORMER RATING
(Percent of Adjusted Rated Continuous Current)

TABLE II

CT Material Class	A		B		C		D		Minimum Rating of A, B, C	
Normal Allowable Maximum **Temperature**	85°C		95°C		105°C		120°C			
Rating Duration	W	S	W	S	W	S	W	S	W	S
Normal	120	100	116	100	114	100	111	100	114	100
Emergency - Greater Than 24 Hours	141	125	131	116	127	114	122	111	127	114
Emergency - 2 to 24 Hours	149	129	138	120	133	117	127	114	133	117
Emergency - 15 Minutes	175	159	157	142	150	136	142	130	150	136

Notes:

1. These ratings do not include limitations of current transformers connected on reduced taps or limitations of equipment connected to current transformers.

2. Winter ambient temperature is 10°C for all rating duration.

3. Summer ambient temperatures are 30°C for rating duration greater than 24 hours and 35°C for rating duration of 24 hours and less.

4. Refer to Table I for current transformer material class.

5. These emergency rating factors are based on current transformer half-hour terminal time constants. The two-hour emergency and fifteen-minute emergency rating factors for current transformers with thermal time constants greater than thirty minutes will be greater than the value given here.

6. The minimum ratings listed do not include Material Class D because only a limited number of current transformers use 80°C rise insulation.

REFERENCES

1. ANSI Standard	C57.13-1993 Requirements for Instrument Transformers
2. ANSI Standard	C37.010-1979 Application Guide for AC High Voltage Breakers
3. IEC Recommendation	Publication 185 1966 Current Transformers
4. PJM Report	Determination of Power Transformer Ratings, September, 1969, by Transformer Rating Task Force
5. PJM Report	Determination of Circuit Breaker Load Current Capability Ratings, December, 1997, by Station Equipment Rating Task Force

APPENDIX - FORMULAE AND SAMPLE CALCULATIONS

PART A - RATING FORMULAE

Correction of Rated Continuous Current for Operation on Any Tap

The adjusted rated continuous current of a tap may be determined by one of three methods, depending upon the data available.

If temperature rise data from a heat run test is not available, the adjusted rated continuous current may be determined from the formula:

$$\mathrm{Itap} = \mathrm{Itap_r} \times \left(\frac{\mathrm{I_r}}{\mathrm{Itap_r}}\right)^{\frac{1}{n}} \times \mathrm{RF}$$

If temperature rise data from a heat test run is available and was made at the rated continuous current, the adjusted rated continuous current may be determined from the formula:

$$\mathrm{Itap} = \mathrm{Itap_r} \times \left(\frac{\mathrm{I_r}}{\mathrm{Itap_r}}\right)^{\frac{1}{n}} \left(\frac{\theta_r}{\theta}\right)^{\frac{1}{n}}$$

If temperature rise data from a heat run test is available and was made at the rated continuous current times the continuous thermal current rating factor, the adjusted rated continuous current may be determined from the formula:

$$\mathrm{Itap} = \mathrm{Itap_r} \times \left(\frac{\mathrm{I_r}}{\mathrm{Itap_r}}\right)^{\frac{1}{n}} \left(\frac{\theta_r}{\theta}\right)^{\frac{1}{n}} \times \mathrm{RF}$$

Itap = Adjusted rated continuous current of specific current transformer tap under consideration

I_r = Rated continuous current (Full ratio rating)

$Itap_r$ = Rated continuous current of specific current transformer tap under consideration

θ = Test observable temperature rise

θ_r = Limit of observable temperature rise at rated continuous current

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 = 2

For subsequent calculations the adjusted rated continuous current of the specific current transformer tap under consideration should be used.

Calculation of Normal (Continuous) Current Rating

For operation at temperatures other than 30°C ambient, use the following equation:

$$I_a = I_{tap} \times \left(\frac{30 + \theta_r - \theta_a}{\theta_r} \right)^{\frac{1}{n}}$$

I_a = Normal current rating

θ_a = Ambient temperature

Calculation of Emergency Ratings

Winter and summer emergency ratings can be determined as follows:

$$I_{e24} = I_{tap} \times \left(\frac{\theta \max_{e24} - \theta_a}{\theta_r} \right)^{\frac{1}{n}}$$

$$I_{e2} = I_{tap} \times \left(\frac{\theta \max_{e2} - \theta_a}{\theta_r} \right)^{\frac{1}{n}}$$

$$I_{et} = I_{tap} \times \left[\frac{1}{\theta_r} \left(\frac{\theta \max_{e2} - \theta \max_n}{1 - e^{\frac{-t}{\tau}}} + \theta \max_n - \theta_a \right) \right]^{\frac{1}{n}}$$

I_{e24} = Emergency rating of greater than 24 hour duration.

θmax_{e24} = Emergency (greater than 24 hours) allowable maximum temperature.

I_{e2} = Emergency rating of 2 time constants through 24 hour duration.

θmax_{e2} = Emergency (24 hours and less) allowable maximum temperature.

I_{et} = Emergency rating of less than two time constants (2τ) duration.

t = Rating duration (minutes).

τ = Thermal time constant of current transformer (minutes).

PART B - SAMPLE CALCULATIONS

Since current transformers 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 1000x2000/5 ampere multi-ratio oil-filled wound-type current transformer with Class A insulation, a continuous thermal current rating factor (RF) 1.5 and connected on the 1500/5 tap.

Adjusted Rated Continuous Current

$$\mathrm{Itap} = \mathrm{Itap}_r \times \left(\frac{I_r}{\mathrm{Itap}_r}\right)^{\frac{1}{2}} \times \mathrm{RF}$$

RF = 1.5

I_r (amp)	Itap_r (amp)	Itap (amp)
2000	1500	2598

$$I_a = I_{tap} \times \left(\frac{30 + \theta_r - \theta_a}{\theta_r}\right)^{\frac{1}{2}}$$

$\theta_r = 55°C$

Itap (amp)	I_a (amp) Summer $\theta a = 30°C$	I_a (amp) Winter $\theta a = 10°C$
2598	2598	3033

If temperature rise data were provided, the example would proceed as follows.

Component	Rise, θ	Observable Temperature (°C)
CT Windings, Average		44
Hottest Spot	49	
Top Oil		35

Adjusted Rated Continuous Current

$$\text{Itap} = \text{Itap}_r \times \left(\frac{I_r}{\text{Itap}_r}\right)^{\frac{1}{2}} \left(\frac{\theta_r}{\theta}\right)^{\frac{1}{2}} \times \text{RF}$$

RF = 1.5

	I_r (amp)	Itap_r (amp)	θ (°C)	θr (°C)	Itap (amp)
CT Winding	2000	1500	44	55	2904
Hottest Spot	2000	1500	49	65	2992
Top Oil	2000	1500	35	45	2945

These adjusted current ratings (Itap) are used in all subsequent calculations.

Normal Ratings

$$I_a = I_{tap} \times \left(\frac{30 + \theta_r - \theta_a}{\theta_r}\right)^{\frac{1}{2}}$$

	Itap (amp)	θ_r (°C)	I_a (amp) Summer θa = 30°C	I_a (amp) Winter θa = 10°C
CT Winding	2904	55	2904	3391
Hottest Spot	2992	65	2992	3421
Top Oil	2945	45	2945	3539

If maximum emergency temperature limits were provided by the manufacture, the emergency ratings would be calculated as follows:

<u>Emergency Ratings of Greater Than 24 Hours Duration</u>

$$I_{e24} = I_{tap} \times \left(\frac{\theta \max_{e24} - \theta_a}{\theta_r} \right)^{\frac{1}{2}}$$

	Itap	θ_r	θmax_{e24}	Ie24 (amp) Summer	Winter
	(amp)	(°C)	(°C)	θa = 30°C	θa = 10°C
CT Winding	2904	55	105	3391	3816
Hottest Spot	2992	65	115	3421	3802
Top Oil	2945	45	100	3673	4165

The winding is limiting for summer ratings. The hottest spot is limiting for winter ratings.

<u>Emergency Ratings of 2 Time Constants to 24 Hours Duration</u>

$$I_{e2} = I_{tap} \times \left(\frac{\theta \max_{e2} - \theta_a}{\theta_r} \right)^{\frac{1}{2}}$$

	Itap	θ_r	θmax_{e2}	Ie2 (amp) Summer	Winter
	(amp)	(°C)	(°C)	θa = 35°C	θa = 10°C
CT Winding	2904	55	115	3502	4012
Hottest Spot	2992	65	125	3520	3979
Top Oil	2945	45	110	3801	4390

The winding is limiting for summer ratings. The hottest spot is limiting for winter ratings.

Emergency Rating of Less than 2 Time Constants Duration

$$I_{et} = I_{tap} \times \left[\frac{1}{\theta_r} \left(\frac{\theta \max_{e2} - \theta \max_n}{1 - e^{\frac{-t}{\tau}}} + \theta \max_n - \theta_a \right) \right]^{\frac{1}{2}}$$

t = 30   τ = 120

	Itap (amp)	θmax$_n$ (°C)	θmax$_e$2 (°C)	θr (°C)	Iet (amp) Summer θa = 35°C	Iet (amp) Winter θa = 10°C
CT Winding	2904	95	115	55	4123	4559
Hottest Spot	2992	105	125	65	4069	4488
Top Oil	2945	85	110	45	4682	5153

The hottest spot is limiting for summer ratings. The hottest spot is limiting for winter ratings.