VI.G

LINE TRAPS

GUIDE FOR DETERMINATION OF

LINE TRAP RATINGS

PJM INTERCONNECTION

Heritage MAAC Group

a task force of the Transmission and Substation Subcommittee

R. W. Munley	Baltimore Gas and Electric Company
D. J. Lemmerman	Exelon
V. C. Jhonsa	Pepco Holdings Incorporated
D. M. Egan	PJM Interconnection, L.L.C.
R. W. Alexander	PPL Electric Utilities
A. Mannarino	Public Service Electric and Gas Company

THIS PAGE WAS LEFT BLANK

INTENTIONALLY

Contents

List of Tables

REVISION HISTORY

November 1972:	Rev. 0 – Original Document
August 1999:	Rev. 1 – Format changes, general revisions, and manufacturers' correspondence added.
September 2009:	Rev. 2 – General revision and document standardization, clarification of Emergency and Load Dump ratings, update of short duration equations and addition of more recent line trap types.

SCOPE AND PURPOSE

This guide presents principles and procedures to be used in establishing normal, emergency 4 hour, and load dump current carrying capabilities for line traps. The resulting thermal ratings can be used for selecting the most economical nameplate ratings for new line traps. All line traps built under standards listed in the references of this report are included. Although this rating method is intended to be all-inclusive, it is recognized that exceptions may be necessary for special conditions. A spreadsheet, available from PJM upon request, was developed to perform line trap rating calculations. A sample calculation is provided in Annex II.

DISCUSSION OF RATING METHOD

The rating methods established by this report represent compromises in the various factors included in the latest thinking of the utility industry. The method developed is based primarily on the following:

a. Ambient temperature (θ_a).
b. Temperature rise as a function of the 2.0 power of the current.
c. Maximum temperature determined to be acceptable for various line traps under normal and emergency conditions.

Note: Maximum temperatures are established to manage loss of line trap life for 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 line trap ratings.

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

Ambient Temperature (θ_a)
Expected air temperature surrounding the rated line trap.

Emergency Allowable Maximum Temperature (θ_{maxe})

Maximum temperature which a line trap can withstand for various emergency rating durations, e.g., θmax_{e4} = 4 hour maximum temperature.

Emergency Current Rating (I_{ea})
Short time currents that can be carried for a specified period of time, at selected ambient temperature, without a line trap exceeding its emergency allowable maximum temperature. In PJM, the Emergency Current Rating is for a four hour duration, e.g., $i_{ea4} = 0$ to 4 hour emergency current.

Limit of Observable Temperature Rise (θ_r)
Maximum value of observable winding temperature rise of a line trap. Values are listed in Table 2 of this report.

Load Dump Current Rating ($I_{s0.25}$)
In PJM, a Load Dump Current Rating is a Short Time Emergency Current Capability for 15 minutes duration e.g., $I_{s0.25}$ is the current which can be carried 15 minutes, or a ¼ of an hour.

Normal Allowable Maximum Temperature (θ_{max})
The maximum allowable temperature which a line trap can withstand continuously. In this report it is defined as $\theta_{max} = \theta_r + 40°C$.

Normal Current Rating (I_a)
Current which can be carried continuously without a line trap exceeding its normal allowable maximum temperature

Rated Continuous Current (Nameplate Rating) (I_r)
Maximum current in amperes at rated frequency a line trap can carry continuously without exceeding its Limit of Observable Temperature Rise.

Short Time Emergency Current Capability (I_s)
Short time emergency currents which can be carried for less than 4 hours, e.g., $I_{s0.25}$ is the current which can be carried for a ¼ of an hour.

Short Time Rating Duration (t)
Duration of the short term rating (< 4 hours) in minutes.

Test Observable Temperature Rise (θ)
Measured steady-state temperature rise above ambient temperature of a line trap when tested at rated continuous current.

Thermal Time Constant (τ)
The length of time required, in minutes, for the initial temperature to reach 63.2% of final value after a change in current in the line trap. In practice, it is generally agreed that after 4 time constants that the ultimate temperature is reached (actually 98.2% of its final value). Assumed to be 30 minutes (1/2 hour) minimum for all line traps in this report.

AMBIENT TEMPERATURE

Since maximum line trap 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 (Normal, Emergency and Load Dump).

Description	Summer	Winter
PJM Planning Basis Temperatures	35 °C	10 °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 line trap is that current which can be carried continuously without a line trap exceeding its normal allowable maximum temperature. The prime considerations in defining the normal current rating of a line trap 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 less than four hours, for example load dump current ratings, are determined based on the line trap thermal time constant which is a function of the heat storage capacity of the line trap. Loading prior to applying emergency ratings, including load dump current ratings, shall be 100% or less of the normal rating for the ambient temperature. Ratings can be increased by assuming the pre-load current is less than 100% of the normal rating; however, safely operating to this type of rating is difficult and is not recommended.

Because of the basic differences in line trap design over time, it is not possible to establish a single uniform emergency allowable maximum temperature for line traps. Maximum temperature limits can be due to the cumulative reduction in tensile strength of the aluminum conductors at higher temperatures (critical to short circuit strength), or from insulation systems that can lose mechanical and/or dielectric strength when operated at the elevated temperatures. For example in the 1960's and 1970's, the maximum temperature limits for certain General Electric traps were limited by conductor tensile strength concerns; and for other similar vintage Westinghouse and Trench line traps the temperatures were limited by the reduction in mechanical strength of polyester insulation when operated at the elevated temperatures. Line trap materials have changed, and starting with ANSI standards in 1981 operating temperatures and rises are better defined, nonetheless higher limiting emergency temperatures can accelerate deterioration of the wave trap.

Operation at the specified emergency allowable maximum temperatures will not significantly affect the accuracy of the tuning pack in the line trap. ANSI Standards [2], [3], specify that the resonant frequency shall not vary more than two percent for ambient temperatures within the range of minus 40°C to plus 45°C, and up to rated continuous current.

DETERMINATION OF RATINGS

Line trap ratings can be determined as follow:

a. If no information is available on the line trap, the following minimum ratings from Table 3 can be applied:

Table 1 Minimum Rating of All Line Trap Classes

(Percent of Line Trap Adjusted Rated Continuous Current)

Rating Duration	Winter (%)	Summer (%)
Normal	110	102
Emergency, 0 to 4 hours	116	109
Load Dump, 0.25 hours, (15 minutes)	138	121

b. If the line trap manufacturer or Insulation Class is known refer to Table 2, and then determine ratings from Table 3.

c. If the line trap manufacturer is known and temperature rise data from heat run tests is available, refer to Table 2, determine adjusted rated continuous current from Annex I, and then determine ratings from Table 3, adjusted according to the Annex I.

See Annex II for a sample calculation for a 230 kV, 3000 Amp, post 1981, Class 155 Insulation line trap, with ratings at 5°C increments of ambient temperature (Note: this is line trap Identification Number 7, Table 2). A functional rating spreadsheet is available upon request from PJM.

MAINTENANCE REQUIREMENTS

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

Table 2 Temperature Limitations for Line Traps

Year	Line Trap Identification Manufacturer or Insulation Class	Line Trap Identification Number	Limit of Observable Temperature Rise at Rated Current θ_r (°C)	Normal Allowable Maximum Temperature $\theta_{max} = \theta_r + 40°C$ (°C)	Emergency Allowable Maximum Temperature Rating 4 Hours or Less θ_{maxe} (°C)
<1981	General Electric Type CF (1954-1965)	1	90	130	160
	Westinghouse Type M	2	110	150	180
	Trench Type L <1981	3	110	150	190
	General Electric Type CF (after 1965)	4	115	155	190
1981 to present	105	5	65	105	125
	130	6	90	130	160
	155 (Areva)	7	115	155	185
	180 (Trench)	8	140	180	200

Table 3 Line Trap Ratings

(% of adjusted rated continuous current[1])

Line Trap Identifying Number[3]	1		2		3		4		5		6		7		8		Minimum Rating	
Rating Duration[2]	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S
Normal	115	103	113	102	113	102	112	102	121	104	115	103	112	102	110	102	110	102
Emergency 4 Hours	129	118	124	115	128	119	125	116	133	118	129	118	123	114	116	109	116	109
Emergency 15 Minutes	164	141	154	134	162	143	156	137	172	141	164	141	153	133	138	121	138	121

Notes:

1. Percent of rated continuous current if heat-run test data is not available.

2. For all rating durations, winter ambient temperature is 10°C and summer ambient temperature is 35°C.

3. Refer to Table 2 for Line Trap Identifying Numbers.

ANNEX I - FORMULAE AND SAMPLE CALCULATIONS

PART A. - LINE TRAP RATING FORMULAE

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

When a line trap test temperature rise is less than guaranteed, ratings may be adjusted as follows,

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

I = Adjusted rated continuous current

I_r = Rated continuous current (nameplate rating)

θ = Test observable temperature rise at rated continuous current

θ_r = Limit of observable temperature rise at rated continuous current

n = 2.0

For subsequent calculations, the adjusted rated continuous current (I) should be used when test data are available. When test data is not available, use rated continuous current (I_r).

<u>Note:</u> $I = I_r$ when temperature rise tests are unavailable.

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

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

$$I_a = I \left(\frac{\theta \max - \theta_a}{\theta_r} \right)^{1/n} \qquad (2)$$

I_a = Normal current rating

θ_a = Ambient temperature

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

3.0 Calculation of Emergency Ratings of 4 Hour Duration

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

$$I_{ea_4} = I\left(\frac{\theta max_{e_4} - \theta_a}{\theta_r}\right)^{\frac{1}{n}} \quad (3)$$

I_{ea4} = Emergency rating of 4 hour duration

θ_{maxe4} = Emergency (4 hour) allowable maximum temperature

4.0 Calculation of Emergency Ratings of Less Than 4 Hours Duration

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

$$I_{eat} = I\left[\left(\frac{\theta max_{e_4} - \theta_a - \theta_r\left(\frac{I_a}{I}\right)^n e^{-\frac{t}{\tau}}}{\theta_r\left(1 - e^{-\frac{t}{\tau}}\right)}\right)\right]^{\frac{1}{n}} \quad (4)$$

For determination of the PJM Load Dump rating, I_a is set equal I_n as determined in (2), I_r is adjusted to I as determined in (1), and by definition I_{ea_t} becomes $I_{s_{0.25}}$. With these preconditions, (4) simplifies to the following:

$$I_{s_{0.25}} = I\left[\frac{1}{\theta_r}\left(\frac{\theta max_{e_4} - \theta max}{1 - e^{\frac{-t}{\tau}}} + \theta_{max} - \theta_a\right)\right]^{\frac{1}{n}} \quad (5)$$

I_{ea_t} = Emergency rating of less than 4 hours

t = Rating duration (minutes)

τ = Thermal time constant of the switch (minutes). The thermal time constant of a switch preferably should be obtained by test, or can conservatively use 30 minutes for switches rated 1200 amperes and above.

e = Euler’s constant

PART B - SAMPLE CALCULATIONS

Assume a 2000 ampere General Electric Co. Type CF line trap built after 1965 has a test observable temperature rise at rated continuous current (θ) of 100°C.

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

$$I = I_r \left(\frac{\theta_r}{\theta} \right)^{1/2}$$

$$I = 2000 \left(\frac{115}{100} \right)^{1/2}$$

$$I = 2144 \text{ amp}$$

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

$$I_a = I \left(\frac{\theta \max - \theta_a}{\theta_r} \right)^{1/2}$$

$$I_a = 2144 \left(\frac{155 - \theta_a}{115} \right)^{1/2}$$

$$\theta_a = 35°C \text{ summer; } 10°C \text{ winter}$$

$$I_n \text{ (winter)} = 2144 \times 1.123 = 2407 \text{ amp}$$

$$I_n \text{ (summer)} = 2144 \times 1.023 = 2193 \text{ amp}$$

Emergency Ratings of 4 Hour Duration

$$I_{ea_4} = I \left(\frac{\theta_{max_{e_4}} - \theta_a}{\theta_r} \right)^{\frac{1}{n}}$$

$$I_{ea_4} = 2144 \left(\frac{190 - \theta_a}{115} \right)^{\frac{1}{2}}$$

$\theta_a = 35°C$ summer; $10°C$ winter

$\mathrm{I}_{\varepsilon a_4}$(winter) = 2144 x 1.251 = 2682 amp

$\mathrm{I}_{\varepsilon a_4}$(summer) = 2144 x 1.161 = 2489 amp

Emergency Ratings of 0.25 hour (15 Minute) Duration

$$I_{s_{0.25}} = I\left[\frac{1}{\theta_r}\left(\frac{\theta_{max_{\varepsilon_4}} - \theta_{max}}{1 - e^{\frac{-t}{\tau}}} + \theta_{max} - \theta_a\right)\right]^{\frac{1}{n}}$$

$$I_{s_{0.25}} = 2144\left[\frac{1}{115}\left(\frac{190 - 155}{1 - e^{\frac{-15}{30}}} + 155 - \theta_a\right)\right]^{\frac{1}{2}}$$

$\theta_a = 35°C$ summer; $10°C$ winter

$\mathrm{I}_{s_{0.25}}$(winter) = 2144 x 1.426 = 3058 amp

$\mathrm{I}_{s_{0.25}}$(summer) = 2144 x 1.348 = 2890 amp

ANNEX II – Sample 230 kV, 3000A, Post 1981, Class 155 Insulation

Line Trap Rating

SUBSTATION EQUIPMENT RATING WORKSHEET

LINE TRAPS

1) Populate the nameplate information table as fully as possible

	NAMEPLATE
STATION	
EQUIPMENT	Line Trap
TYPE	Class 155 Insulation
MANUFACTURER	
YEAR MANUFACT.	1985
POSITION	
DESIGNATION	
RATED VOLT. (kV)	230
RATED CURRENT	3000

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

	Line Trap Identifying Number							
	< 1981				1981 to present			
	1	2	3	4	5	6	7	8
$\theta max e4$	160	180	190	190	125	160	185	200
θmax	130	150	150	155	105	130	155	180
θr	90	110	110	115	65	90	115	140

	INPUT
$\theta max e4$	185
θmax	155
θr	115
I Rated A	3000
Rated KV	230

Ratings	Summer 35°C		Winter 10°C	
	MVA	Amps	MVA	Amps
Normal	1221	3065	1342	3369
Emergency (4 Hr)	1365	3426	1474	3701

CALCULATED RATINGS

AMBIENT TEMP.		RATING (P.U.)				RATING (MVA)			RATINGS (AMPS)		
θ_a Deg. C	θa Deg. F	NORMAL	4 HOUR	LOAD DUMP		NORMAL	4 HOUR	LOAD DUMP	NORMAL	4 HOUR	LOAD DUMP
0	32	1.16	1.27	1.60		1387	1516	1907	3483	3805	4788
5	41	1.14	1.25	1.56		1365	1495	1865	3426	3753	4683
10	**50**	**1.12**	**1.23**	**1.53**		**1342**	**1474**	**1823**	**3369**	**3701**	**4575**
15	59	1.10	1.22	1.49		1319	1453	1779	3310	3648	4465
20	68	1.08	1.20	1.45		1295	1432	1734	3250	3593	4353
25	77	1.06	1.18	1.41		1271	1410	1688	3190	3539	4237
30	86	1.04	1.16	1.37		1246	1387	1640	3128	3483	4118
35	**95**	**1.02**	**1.14**	**1.33**		**1221**	**1365**	**1592**	**3065**	**3426**	**3995**
40	104	1.00	1.12	1.29		1195	1342	1541	3000	3369	3869

BIBLIOGRAPHY

1. NEMA Standards SG 11-1955 Coupling Capacitor Potential Devices and Line Traps

2. ANSI Standard C93.3-1981 Requirements for Power-Line Carrier Line Traps

3. ANSI Standard C93.3-1995 Requirements for Power-Line Carrier Line Traps

4. PJM "*Guide for Determination of Line Trap Normal and Emergency Ratings*," Pennsylvania-New Jersey-Maryland Interconnection Planning and Engineering Committee, Transmission and Substation Design Sub-Committee, August, 1999.

5. Hall, David E., Black, W. Z., Parker, T. J. "*Transient Thermal Performance of Line Traps*," IEEE Transactions on Power Delivery, vol. 11, No. 1, January 1996.

6. PJM Manual 03: "Transmission Operations", Revision: 37, June 18, 2010.