

**VI.G**  
**LINE TRAPS**

**GUIDE FOR DETERMINATION  
OF  
LINE TRAP NORMAL AND EMERGENCY RATINGS**

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## SCOPE AND PURPOSE

This report presents principles and procedures to be used in establishing normal and emergency ratings for all line traps affecting the PJM Interconnection. The resulting 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.

## BACKGROUND

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

## DISCUSSION OF RATING METHODS

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

- a. Ambient temperature ( $\theta_a$ ).
- 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.
- d. Acceptable loss of favorable line trap life or short circuit withstand capability for emergency conditions.

## DEFINITIONS

Following are definitions of terms used in this report.

### 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.

### Adjusted Rated Continuous Current ( $I$ )

Rated continuous current of a line trap corrected to limit of observable temperature rise using specific temperature rise by test.

### Normal Current Rating ( $I_n$ )

Current which can be carried continuously without a line trap exceeding its normal allowable maximum temperature.

### Emergency Current Rating ( $I_e$ )

Current which can be carried for a specified period of time without a line trap exceeding its emergency allowable maximum temperature.

### Limit of Observable Temperature Rise ( $\theta_r$ )

Maximum value of observable temperature rise of a line trap. Values are listed in Table I of this report.

Test Observable Temperature Rise ( $\theta$ )

Actual steady-state temperature rise above ambient temperature of a line trap when tested at rated continuous current.

Normal Allowable Maximum Temperature (Allowable Maximum Temperature) ( $\theta_{max,n}$ )

Maximum temperature which a line trap can withstand continuously.

Emergency Allowable Maximum Temperature ( $\theta_{max,e}$ )

Maximum temperature which a line trap can withstand for emergency rating durations.

Thermal Time Constant ( $\tau$ )

The length of time required for the temperature to change from the initial value to the ultimate value if the initial rate of change was continued until the ultimate temperature was reached.

AMBIENT TEMPERATURE

Since maximum line trap temperature is a function of prevailing 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 which are consistent with those used for all PJM equipment ratings.

<u>Rating Duration</u>	<u>Summer</u> (April Through October)	<u>Winter</u> (November Through 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

NORMAL RATINGS

The normal current ratings 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 RATINGS

Emergency ratings for durations of two hours to six months are based on operation up to the emergency allowable maximum temperature for the line trap. Emergency allowable maximum temperature limits of at least 15°C and 30°C above the normal allowable maximum temperature are utilized for ratings greater than twenty-four hours duration, and for ratings of twenty-four hours and less duration, respectively. The strength reduction resulting from such operation will not affect the capability of a line trap to withstand its rated short circuit current for a duration of 2 seconds when operating at its normal current rating or for a duration of 30 cycles when operating at its emergency current rating. In order to realize the additional line trap emergency current capability, the 30 cycles duration was chosen as being more than adequate to meet the longest back-up clearing times.

Because of the basic differences in line trap design, it is not possible to establish uniform emergency allowable maximum temperatures for all traps. The maximum temperature of the General Electric line trap is limited by the cumulative reduction in tensile strength of the aluminum conductors when operated at the elevated temperatures (their polyester insulation can be operated up to 220°C). The maximum temperature of the Westinghouse and Trench line traps is limited by the reduction in mechanical strength of their polyester insulation when operated at the elevated temperatures.

Operation at the specified emergency allowable maximum temperatures will not affect the accuracy of the tuning pack in the line trap. NEMA Standards specify that the resonant frequency shall not vary more than two percent for ambient temperatures within the range of minus 40°C to plus 40°C, and all manufacturers have indicated that the variation at the emergency allowable maximum temperatures will not exceed this 2 percent limit.

Emergency ratings for durations of less than two hours 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 less than two hour emergency ratings is assumed to be 100 percent of the normal rating for the prevailing ambient temperature. Although ratings can be increased by assuming pre-load current less than 100 percent of normal rating, this type of range is difficult to supervise.

ANSI C93.3 - 1981 Table A1 lists short time overload capabilities for line traps. While the 15 minute capabilities are more generous than those calculated by the method in this guide, the longer time capabilities are more conservative. This guide provides a technically consistent approach.

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 II can be applied:

Minimum Rating of All Line Traps  
(Percent of Line Trap Rated Continuous Current)

<u>Rating Duration</u>	<u>Winter</u> (%)	<u>Summer</u> (%)
Normal	112	104
Emergency, Greater Than 24 Hours	118	110
Emergency, From 2 to 24 Hours	125	116
Emergency, 15 Minutes	142	135

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

TEMPERATURE LIMITATIONS FOR LINE TRAPS

TABLE I

Line Trap Identification	Line Trap Identifying Number and Nomograph Number	Limit of Observable Temperature Rise at Rated Current $\theta_r$	Normal Allowable Maximum Temperature $\theta_{max_n}$	Emergency Allowable Maximum Temperature ( $\theta_{max_e}$ )	
				Rating Durations: Greater Than 24 Hours $\theta_{max_e2}$	24 Hours or Less $\theta_{max_e2}$
		(°C)	(°C)	(°C)	(°C)
General Electric Type CF (1954-1965)	1	90	130	145	160
Westinghouse Type M	2	110	150	165	180
Trench Type L	3	110	150	170	190
General Electric Type CF (after 1965)	4	115	155	170	190

LINE TRAP RATINGS  
(PERCENT OF ADJUSTED RATED CONTINUOUS CURRENT<sup>[1]</sup>)

TABLE II

<u>Line Trap Identifying Number</u> <sup>[4]</sup>	1		2		3		4		<u>Minimum Rating</u>	
	<u>W</u> <sup>[2]</sup>	<u>S</u> <sup>[3]</sup>	<u>W</u>	<u>S</u>	<u>W</u>	<u>S</u>	<u>W</u>	<u>S</u>	<u>W</u>	<u>S</u>
Normal	115	105	112	104	112	104	112	104	112	104
Emergency Greater than 24 Hrs.	123	113	119	110	120	110	118	110	118	110
Emergency 2 to 24 Hours	130	118	125	116	129	119	126	117	125	116
Emergency 15 Minutes	149	141	142	135	150	144	144	138	142	135

Notes:

1. Percent of rated continuous current if heat run test data is not available.
2. Winter ambient temperature is 10°C for all rating durations.
3. Summer ambient temperatures are 30°C for rating durations greater than 24 hours and 35°C for rating durations 24 hours and less.
4. Refer to Table I for line trap identifying number.

## REFERENCES

1. NEMA Standard SG-11-1955. Coupling Capacitor Potential Devices and Line Traps
2. ANSI C 93.3 Requirements for Power-Line Carrier Line Traps

## APPENDICES

### FORMULAS AND SAMPLE CALCULATIONS

#### A. LINE TRAP RATING FORMULA

##### Correction of Rated Continuous Current

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

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

I = Adjusted rated continuous current

$I_r$  = Rated continuous current (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 subsequent calculations, the adjusted rated continuous current should be used when test data are available.

##### Calculation of Normal (Continuous) Current Ratings

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

$$I_n = I \left( \frac{\theta \max_n - \theta_a}{\theta_r} \right)^{1/n}$$

$I_n$  = Normal current rating

$\theta_a$  = Ambient temperature

$\theta \max_n$  = Normal allowable maximum temperature =  $\theta$ , + 40°C

##### Calculation of Emergency Ratings of Greater Than 24 Hour Duration

Winter and summer emergency ratings of durations greater than 24 hours can be determined as follows:

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

$I_{e24}$  = Emergency rating of greater than 24 hours duration

$\theta \max_{e24}$  = Emergency (greater than 24 hours) allowable maximum temperature

##### Calculation of Emergency Ratings of 2 to 24 Hour Duration

Winter and summer emergency ratings of 2 to 24 hour duration can be determined as follows:

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

$I_{e2}$  = Emergency rating of 2 to 24 hours duration

$\theta \max_{e2}$  = Emergency (2 to 24 Hour) allowable maximum temperature

Calculation of Emergency Ratings of Less Than 2 Hours Duration

Winter and summer emergency ratings of less than 2 hours duration can be determined as follows:

$$I_{tr} = I \left[ \frac{I}{\theta_r} \left( \frac{\theta \max_{e2} - \theta \max_n}{1 - e^{-t/\tau}} + \theta \max_n - \theta_o \right) \right]^{1/n}$$

$I_{tr}$  = Emergency rating of less than 2 hours

t = Rating duration (minutes)

$\tau$  = Thermal time constant of a line trap (minutes)

$\tau$ , the thermal time constant of a line trap preferably should be obtained by test or it can be conservatively used as 30 minutes.

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 ( $\theta$ ) of 100°C.

Adjusted Rated Continuous Current

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

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

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

The adjusted rated continuous current (I) is used in all subsequent calculations.

Normal Ratings

$$I_n = I \left( \frac{\theta_{\max_n} - \theta_a}{\theta_r} \right)^{1/2}$$

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

$$\theta_a = 30^\circ \text{C summer}; 10^\circ \text{C winter}$$

$$I_n (\text{winter}) = 2144 \times 1.12 = 2407 \text{ amp}$$

$$I_n (\text{summer}) = 2144 \times 1.04 = 2190 \text{ amp}$$

Emergency Ratings of Greater Than 24 Hours Duration

$$I_{e24} = I \left( \frac{\theta_{\max_{e24}} - \theta_a}{\theta_r} \right)^{1/2}$$

$$I_{e24} = 2144 \left( \frac{170 - \theta_a}{115} \right)^{1/2}$$

$$q_a = 30^\circ \text{C summer}; 10^\circ \text{C winter}$$

$$I_{e24} (\text{winter}) = 2144 \times 1.18 = 2529 \text{ amp}$$

$$I_{e24} (\text{summer}) = 2144 \times 1.10 = 2358 \text{ amp}$$

Emergency Ratings of 2 to 24 Hours Duration

$$I_{e2} = I \left( \frac{\theta_{\max_{e2}} - \theta_a}{\theta_r} \right)^{1/2}$$

$$I_{e2} = 2144 \left( \frac{190 - \theta_a}{115} \right)^{1/2}$$

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

$$I_{e2} (\text{winter}) = 2144 \times 1.26 = 2701 \text{ amp}$$

$$I_{e2} (\text{summer}) = 2144 \times 1.17 = 2508 \text{ amp}$$

Emergency Ratings of 15 Minutes Duration

$$I_{e15} = I \left[ \frac{1}{\theta_r} \left( \frac{\theta_{\max_{e2}} - \theta_{\max_n}}{1 - e^{-t/\tau}} + \theta_{\max_n} - \theta_a \right) \right]^{1/2}$$

$$I_{e15} = 2144 \left[ \frac{1}{115} \left( \frac{190 - 155}{1 - e^{-15/30}} + 155 - \theta_a \right) \right]^{1/2}$$

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

$$I_{e15} (\text{winter}) = 2144 \times 1.44 = 3087 \text{ amp}$$

$$I_{e15} (\text{summer}) = 2144 \times 1.37 = 2937 \text{ amp}$$

## C) Background to the April 1998 revision

### "Determination of Line Trap Ratings" Summary of Changes

#### Substantive

1. Temperature rise as 2.0 power of current instead of 1.8 power (change "n" from 1.8 to 2.0). This will reduce capabilities some. The largest reduction comes in the short time "emergency" capabilities where the calculated capability drops about 3%.

#### Editorial

2. Eliminate Appendix I and all nomographs (this brings the guides into the pocket calculator age. (This is consistent with what has been done on other PJM TSDS guides.)
3. Title: insert "Normal, and Emergency" before "Ratings." This will bring the terminology in line with standard IEEE terminology. Also add "Guide for" at the beginning.
4. Add reference to ANSI C93.3 "Requirements for power-line carrier Line Traps."

#### Discussion

I've checked with some IEEE colleagues about the origin of the 1.8 temperature rise versus current exponent. It seems the 1.8 exponent applies to enclosed conductors, in particular oil circuit breakers. Air switch people also have used it. I have some switch temperature rise data which supports 1.8 for copper and 1.9 to 2.0 for aluminum. I think a trap may be a little different, but most traps are wound with aluminum. I have a hard time reconciling using an "n" < 2. The heat energy generated by an electrical device carrying current is  $I^2 R$ . The heat flow from convective cooling of a surface is modeled as a linear thermal resistance, in accord with Newton's law of cooling. In an air atmosphere radiational cooling depends on the surface area not subject to back scatter, i.e., the outside surfaces and ends of the line trap. If part of the 1.8 is due to radiational cooling being proportional to the 4th power of the absolute temperature, I don't think it would be a large player for a trap, due to the small exposed surface of the trap (density of the windings). For a switch radiational cooling is attributed to about 35% of the total cooling.

I'm a little concerned that perhaps the newer traps have a higher design temperature and thus less room for overload. This will affect the 2-24 hour and >24 hour emergencies. Standards don't require much! I've forwarded a copy of the guide to Haefely Trench for review and applicability to 1980 and current designs.

#### Sample Comparison of Results for a "Generic" Trap (percent of "adjusted" nameplate rating)

Rating Class	Proposed Rating n=2	11/72 Version n=1.8	C93.3 Table A1
Summer normal	104	105	NA
Winter normal	112	114	NA
Emerg >24 hr W	118	120	NA
Emerg >24 hr S	110	112	NA
Emerg 2-24 W	125	127	117 (4 hr)
Emerg 2-24 S	116	117	111 (2 hr)
Emerg 15 min W	142	146	147.5
Emerg 15 min S	135	136	141

The response from Haefely Trench's review is attached. My summary of their response: "don't change the guide, but be aware that older traps may fail as a result of overload."

Roy W. Alexander

Al Thornton  
Haefely Trench  
71 Maybrook Drive  
Scarboro, Ontario  
Canada M1V 4B6

12/12/97

Al, per our conversation of 12/4/97 enclosed is a draft copy of a PJM guide for line trap normal and emergency ratings. Please comment on the applicability:

- to designs before 1972
- to designs after 1972.

If there is a date past which the design base changed, please let us know.

For PJM Transmission Substation Design Subcommittee

Roy Alexander  
Sr. Engineer, PP&L, Inc.

Haefely Trench



4 PAGES

January 27th, 1988

PP &L, Inc.  
Two North Ninth Street  
Allentown, PA 18101-1179  
USA

Attention: Ray Alexander 610 - 774 - 6300

Dear Sir:

Subject: Overload Ratings of Haefely Trench Line Traps

We must point out that any overload condition will result in some loss of life, and therefore we do not recommend overloading any line trap. If an overload situation may occur then we recommend having the line trap designed for this situation.

We have attached a set of curves which will provide a guide to allowable overload conditions with a minimum loss of life and the ANSI Table "A1". You can see that the Haefely Trench curves are slightly less than the ANSI table. This is not to say that the information in your package is incorrect, what this means is that the ratings in your package would result in a higher loss of life. In the case of older traps where the insulation has already aged naturally the overload condition may result in a failure.

Therefore, no change in the information in your package and a recommendation to over-rate any new traps for the overload condition so that no loss of life will occur.

Yours truly  
HAEFELY TRENCH

Al Thornton  
Sales Contracts Section Leader  
for North America

AT:jb

**Appendix** (This Appendix is not a part of American National Standard Requirements for Power-Line Carrier Line Traps, ANSI C93.3-1981, but is included for information purposes only.)

**Guide for Emergency Overload Current Capability of Line Traps**

Line traps are designed within temperature-rise limitations to ensure normal life expectancy. Any value of currents in excess of the rated current in this standard may cause the designed temperature rise to be exceeded and may shorten the life expectancy of the line trap.

Table A1 shows percentages of rated continuous current that have been selected to minimize the reduction in operating life and should be applied with great care.

The guidelines in Table A1 may be applied to all line traps covered in this standard.

**Table A1  
Emergency Overload Current as a Percentage  
of Rated Continuous Current**

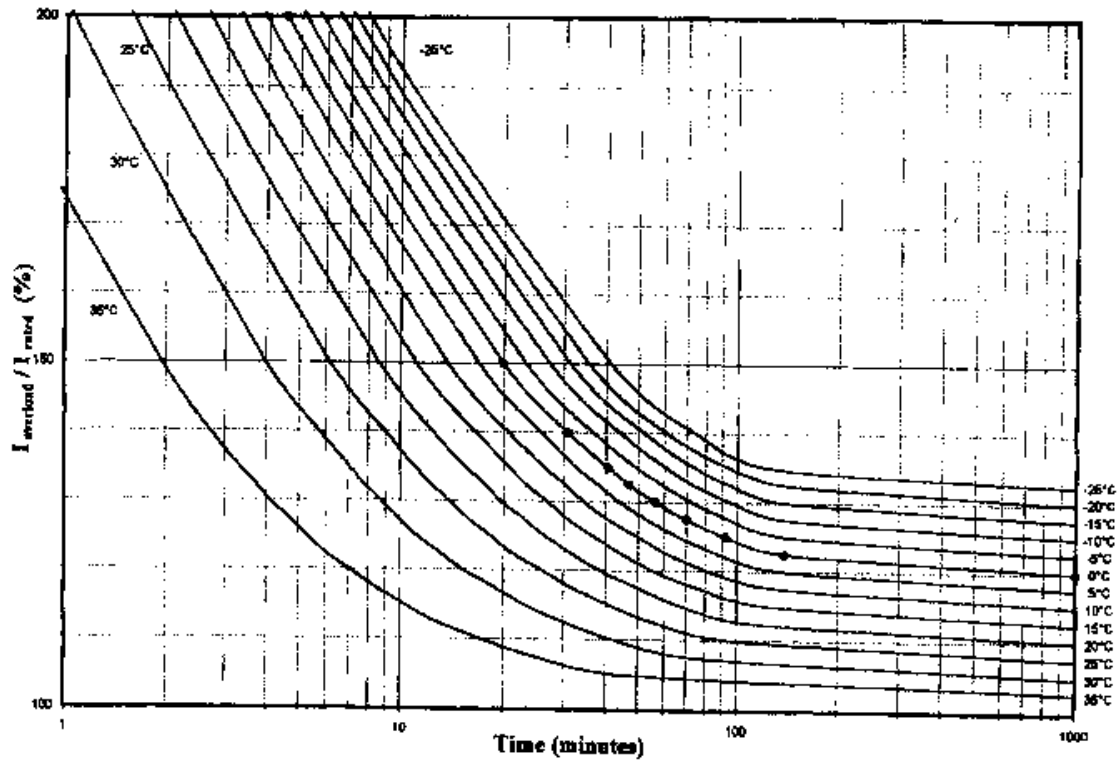
Ambient Temperature, °C	Emergency Period			
	15 Minutes	30 Minutes	1 Hour	4 Hours
45	138	128	118	-
40	140	130	120	110
20	145	135	125	115
0	150	140	130	120
-20	155	145	135	125
-40	160	150	140	130

## **COMMENTS ON TRENCH ELECTRIC STANDARD OVERLOAD CURVES**

These curves are meant to provide a guide to allowable overload conditions with a minimum of reactor loss of life. If overloads of longer duration than 1000 minutes or less than 5 minutes occur often, please supply appropriate requirements and Trench Electric can provide more customized overload curves.

All overloads shown are assumed to be rare occurrences with at least 4 hours between consecutive events. The ambient temperatures shown are maximum values. As these reactors have been designed for a maximum ambient temperature of 40°C., only rare overloads of very short duration are acceptable without some loss of rated reactor life.

### Current Overload Curves Starting at 100% Rated Current



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**ANNEXES**

**SYSTEM PHASING DIAGRAMS**

# PJM SYSTEM VOLTAGE PHASE RELATIONS

## VOLTAGE PHASE RELATIONS – ROTATION COUNTERCLOCKWISE

\* TYPICAL AT MOST INSTALLATIONS: ANY SPECIFIC AREA SHOULD BE CHECKED.

	500 KV	345 KV	230	138 KV	115 KV	69 KV	46 KV	34.5 KV	25 KV	22 KV	13.2 KV
PUBLIC SERVICE ELECTRIC & GAS CO.											
BALTIMORE GAS & ELECTRIC CO.											
POTOMAC ELECTRIC POWER CO.											
PECO ENERGY											
P P & L INC.											
		SAFE HARBOR & HOLTWOOD									
GPU ENERGY JCP & L											
GPU ENERGY METROPOLITAN EDISON CO.											
GPU ENERGY PENNSYLVANIA ELECTRIC CO.											
CONNECTIV											