VI.B

POWER TRANSFORMERS

DETERMINATION

OF

POWER

TRANSFORMER

RATINGS

PENNSYLVANIA - NEW JERSEY - MARYLAND INTERCONNECTION

PLANNING AND ENGINEERING COMMITTEE

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SCOPE

This guide documents procedures to be used in establishing normal and emergency thermal ratings for power transformers. This information may also be used for selecting the nameplate ratings of new transformers. This report is based on the latest revision of IEEE Guide for Loading Mineral Oil Immersed Transformers (ANSI/IEEE C57.91-1995). It is intended for use on all transformers affecting the PJM Interconnection, except generator step-up transformers. The principles used in establishing the various parameters and limits are discussed in the body of the report. Although this rating method is intended to be all inclusive, it is recognized that exceptions may be necessary for special conditions.

REFERENCES

1. ANSI/IEEE C57.91-1995, IEEE Guide for Loading Mineral-Oil-Immersed Transformers

2. PJM Power Transformer Rating Procedures-1969, Determination of Power Transformer Ratings

3. PJM Power Transformer Rating Program developed by Dr, Edwin Cohen

BACKGROUND

The original PJM Power Transformer Rating Procedures were developed by a Task Force of the Transmission and Substation Design Subcommittee in 1969. Those Procedures were developed to form a common transformer rating method to coordinate planning, engineering, and operating practices within the PJM Interconnection. The Procedures were based on then current industry guidelines which were USAS C57.92-1962 and NEMA TR98-1964.

TSDS formed a task force in 1987 to review transformer rating practices within PJM due to significant changes taking place in the industry guidelines. At that time, the Procedures were not revised, but many variations in rating procedures were noted among the member companies.

Further changes in industry loading guidelines led to formation of another task force in 1995 to revise the Procedures to incorporate up-to-date industry guidelines and to provide appropriate default parameters for operation of transformers on the PJM Interconnection System.

ANNEX A has been provided which compares the present guidelines with those used in the past.

PJM LOADING GUIDE

This report provides guidance for the calculation of transformer loading capability, under prescribed conditions. The calculations are to be performed following the method identified in Clause 7 of Reference 1. The task force believes that this guide represents the most up to date reference on loading. Employees of five of the PJM companies served on the IEEE Transformers Committee Working Group which produced the 1996 revision.

The equations produce values for temperatures of the hottest spot and top oil, and a value for the loss of insulation life which result from a given loading cycle. The results can then be compared to our limiting criteria, to determine if that load level produces acceptable internal temperatures. By iteration, the load can be increased to identify the maximum peak load acceptable for that load cycle, emergency condition, and ambient temperature combination.

This report addresses the loading capability of transformers built in the past 30 years, which have 65°C (or 55/65°C) average winding rise insulation systems. Reference 1 contains an Annex titled "Philosophy of Guide Applicable to Transformers with 55°C Average Winding Rise Insulation Systems". If a transformer built with only a 55°C rise insulation system must be evaluated, refer to that Annex for the modifications to the calculations required.

The emergency ratings determined using this guide are only for emergency conditions. These conditions are considered to be rare events. For planned loading beyond "Normal" ratings, the Task Force recommends reference to Clause 9 of Reference 1.

Other Factors to be Considered:

The overload capability calculation has traditionally been accepted as highly accurate and definitive, even though, the temperature calculations were the only factor considered. There are other factors that must be reviewed for loading transformers beyond nameplate, particularly for large units. Ancillary devices such as bushings, CT's, and tap changers, or even internal components such as the core and flux shields, may not be designed to tolerate overloading at these levels. Unless the purchase specifications have required that the unit be designed to ensure that all components can handle the stresses of overloading at the levels calculated by the program, further review is required.
Reference 1 provides tutorial information on this topic in section 4.1.

Suggested Limiting Conditions:

The task force has adopted the following limiting conditions, and updated the loss of life criteria to be used.

Top Oil Temperature	110°C
Hottest Spot Conductor Temperature	180°C
Maximum Loading	200%
Loss of Insulation Life * See note.	

* The calculation of insulation life has been updated. Now when using this procedure, one must choose the most appropriate basis of determining Normal Insulation Life for his transformer. The task force has selected the point of 200 retained Degree of Polymerization in insulation, as being most representative of the lifetime of the transformers on the PJM system. This corresponds to the expected condition of the insulation after continuous operation with a hottest spot temperature of 110°C for 17.12 years. In the previous loading guides, the criteria had been the point where insulation retained 50% of it's tensile strength. That would correspond to a lifetime of 7.42 years under the same temperature and operating condition. Additional information is available in Annex I Reference 1.

Default Values:

The Task force has reviewed the data inputs, and the default values that were set up for the computer program written in 1969 by a previous PJM loading study group. We concluded that the best option today is to establish default values, to be used if the individual company does not have better actual (or historical) data to use. However, we would encourage the use of more appropriate, actual, data for the case being studied. The defaults are listed in the Default Parameters section of the guide.

Computer Program:

At this time, PJM TSDS committee does not have a common computer program for member companies to use as they implement the procedures documented in this report.

Input Data Required:

The inputs required to perform the calculations are contained in Clause 4.4 of Reference 1. They are:
Top oil temperature rise over ambient temperature at rated load.
Average conductor temperature rise over ambient temperature at rated load.
Winding/lead hottest spot conductor temperature rise over ambient temperature at rated load.
Load loss at rated load.

No-load (core) loss.
Total loss at rated load
Confirmation of oil flow design (directed or non-directed)
Weight of core and coil assembly
Weight of tank and fittings
Volume of oil in the tank and cooling equipment.

Ambient temperatures are a critical factor in determining the loading capability, since insulation temperature determines the degree of insulation aging, and it is dependent on the ambient. The ambient temperature value required for use in these equations is the 24 hour average ambient, during the load cycle being studied. Each company should determine the appropriate value of average ambient to use for the particular study required. There can be significant difference in the average ambient during a summer emergency loading condition across the geographical area covered by this report. While a 30°C summer average may be appropriate for transformers in the northern areas, a similar emergency in southern areas may require analysis in an average summer ambient of 30-38°C. Similarly, winter emergencies may require analysis using ambient of -10°C, to 5°C across the systems.

DEFAULT PARAMETERS

Long Time Ratings:
The method of calculating transformer ratings for durations greater than or equal to 24 hours i.e. (normal, 6 month., ... 24 hr.) requires the use of a daily load cycle for the specific transformer. In the event that a daily load cycle for a specific transformer is known or can be predicted, it's ratings can be calculated using the known values. Otherwise, the default daily load cycle is shown in figure 1.

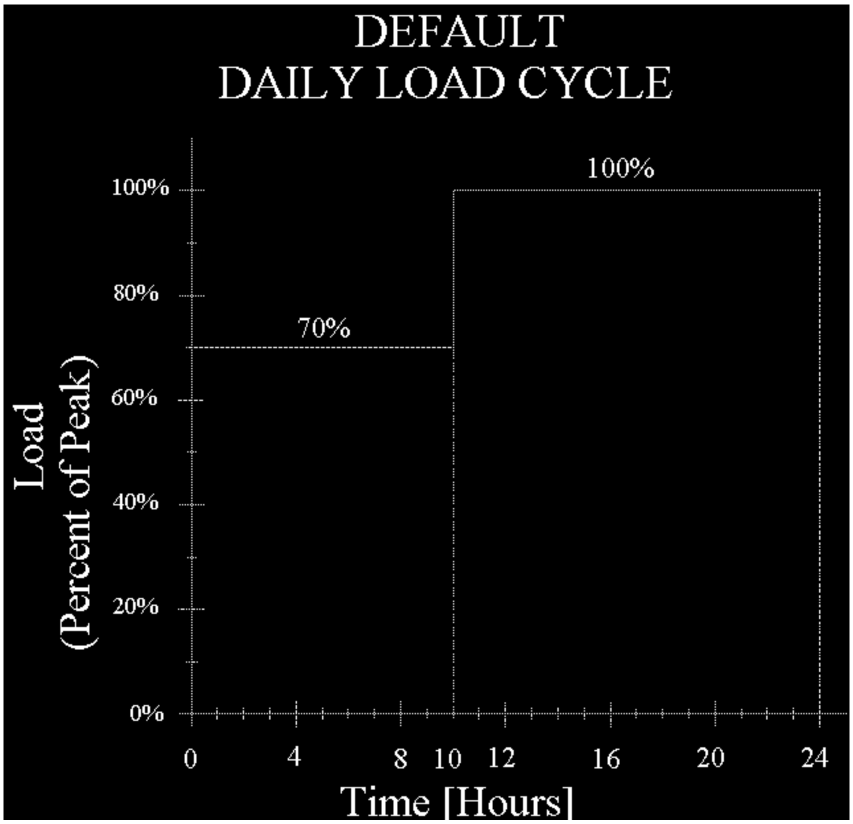

FIGURE 1,
Default Load Curve For Long Time Ratings

Short Time Ratings:

Short time overload events are assumed to occur at the end of a normal[1] load day. Therefore, short time rating calculations use a normal daily load cycle which has been modified to include the overload event. The default load curve for short[2] time ratings is shown in Figure 2. If the load curve for the specific transformer is known for the period prior to the overload i.e.(T_p, see Fig. 2), it may be substituted in place of the default values shown in Fig. 2.

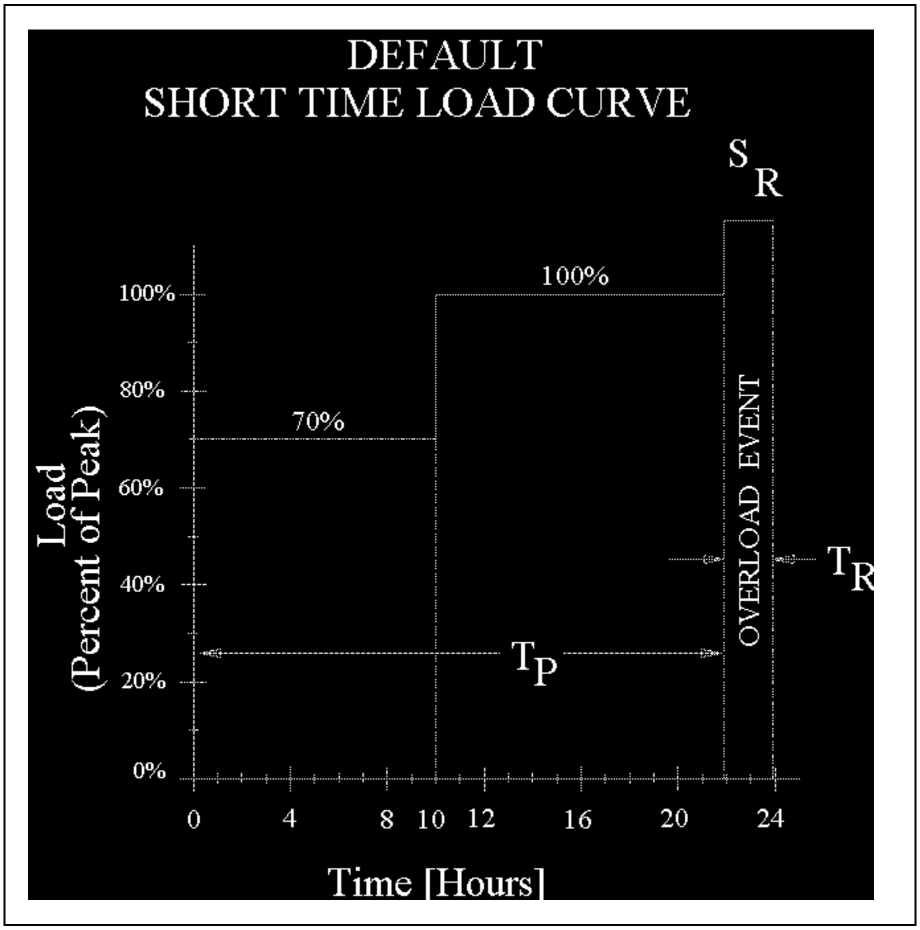

FIGURE 2,
Default Load Curve For Short Time Ratings

Notes: 1) "Normal Load Day" indicates a transformer which is loaded at it's normal rating and load cycle.

2) Load curve shown for 2 hr. rating, adjust T_R & T_P accordingly for other overload durations.

3) T_R is the duration of the overload.

4) S_R is the loading/rating during the overload.

5) T_P designates the portion of the day (prior to the overload) when the transformer is loaded at normal" loading.

Ambient Temperature:
Table I lists the ambient temperatures which shall be used for summer and winter ratings calculations. Seasonal weather conditions vary across PJM's service territory, therefore, each member company shall define time frames for winter and summer in accordance with their practices.

Table I, Ambient Temperatures

	Ambient Temperature (Deg. C)	
Rating	Winter	Summer
Normal	10	30
Emergency (>24hrs.)	10	30
Emergency (<=24hrs.)	5	35

Temperature & Load Limitations:
Absolute temperatures limits of 180 Deg. C for the hot spot and 110 Deg. C for top oil have been selected. However, when hot spot temperature exceeds 140 Degree C, it is possible for free gas bubble to form in an operating transformer. In addition, a limit of 200% of maximum nameplate rating has been imposed. These values are upper limits, lower values may be selected based on engineering judgment.

Loss of Life:
Loss of life shall be based upon the 200 Retained Degree of Polymerization
(DP 200) criteria as defined in the Reference 1. Normal loss of life is defined as 0.016% as derived from the DP 200 curve at 110°C. Acceptable loss of life percentages for emergencies are as follows -

Duration	Typical Emergency	Loss of Life (% total)
1 day or less	First or second contingency loss	5
1 month	Replacement of ancillary components	10
3 months	Replacement with spare	10
6 months	Major field repair	10

Any emergencies greater than 6 months shall default to the normal loss of life rating.

Oil and Hotspot Exponents:
Exponents shall be per Reference 1.

ANNEX A
PAST AND PRESENT LOADING GUIDE DIFFERENCES

The following is a summary of the significant differences between the methods used in References 1 and 2.

1. The PJM program developers decided to include a resistance correction factor in the calculation of the top oil rise. Winding resistance losses increase with increasing temperature. However, oil viscosity increases with temperature which improves heat transfer and removal. In general, the two effects cancel each other and applying a correction factor leads to overly conservative ratings. Loading guides at that time stated that the empirically derived exponent in the top oil rise equation must be revised if the resistance correction factor was used. Reference 1 and some PJM member company guidelines do not use the resistance correction factor because it is less accurate.

2. The PJM program asks for input of a two step load cycle (in percent) for the location to be studied. It then assumes that the peak of that cycle is equal to the transformer's calculated "normal" rating. Then any short time emergency is preceded by loading at that level. The actual load cycle should be used to determine the temperatures at the start of an emergency.

3. Reference 1 includes an exponent "m" in the formula for calculation of the hot spot rise over top oil, and the exponent "n" in the formula for calculation of the top oil rise over ambient. The PJM program uses a single exponent for both which is only accurate for directed flow, forced-oil cooled units. The exponents "m" and "n" are not the same value as indicated in the PJM program for other modes of cooling. This change will improve the accuracy of the calculations today, particularly if the manufacturer is requested to provide specific exponents for the transformer being evaluated.

4. The program calculates the insulation loss of life based on the peak value of hot spot temperature during each step of the load. It assumes that this temperature is constant throughout the time period. This restricts the capability, particularly for longer overloads.

5. Reference 1 includes different limiting conditions for determining the loss of life of the insulation. The PJM program, and old loading guides, based aging on the historical time vs. temperature Arrhenius curves for the loss of 50% of the tensile strength. Tests of insulation on service aged transformers indicate loss of 50% tensile strength as overly conservative. Now Reference 1 asks the user to pick from several choices of end of life criteria. The task force has chosen the degree of polymerization as a more appropriate criteria.