

American National Standard

**guide for loading
mineral-oil-immersed overhead and pad-mounted
distribution transformers**

**rated 500 kVA and less with
65 °C or 55 °C average winding rise**

ANSI/IEEE C57.91-1981



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IEEE Guide for Loading Mineral-Oil-Immersed Overhead and Pad-Mounted Distribution Transformers Rated 500 kVA and Less with 65 °C or 55 °C Average Winding Rise

1. Scope

1.1 This guide covers general recommendations for loading 65 °C rise mineral-oil-immersed overhead and pad-mounted distribution transformers described in American National Standards and rated 500 kVA and less. (For transformers rated 501 kVA and larger, see ANSI/IEEE C57.92-1981, [3]¹) Recommendations for 55 °C rise transformers are included in this guide because a substantial percentage of these transformers are still in service.

1.2 Loading recommendations in tabular form are contained in Section 5 of this guide. A method to establish winding temperature and loss of life by nomographs is also given in Section 5.

1.3 The method used for the calculation of the loading guide tables in Section 5 is given in Section 6 of this guide.

1.4 The recommendations of this guide are based on winding hottest-spot calculations only. Other factors such as listed in 3.6.1 may limit the permissible load to lower values.

2. References

When the following ANSI standards and guides referred to in this guide are superseded by a revision approved by the American National Standards Institute, the latest revision shall apply.

[1] ANSI/IEEE C57.12.00-1980, General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

[2] ANSI/IEEE C57.12.90-1980, Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers and Guide for Short-Circuit Testing of Distribution and Power Transformers.

[3] ANSI/IEEE C57.92-1981, Guide for Loading Mineral-Oil-Immersed Power Transformers up to and Including 100 MVA with 55 °C or 65 °C Winding Rise.

[4] ANSI/IEEE C57.100-1972, American National Standard Test Procedure for Thermal Evaluation of Oil-Immersed Distribution Transformers

3. General

3.1 Transformer Rated Output

3.1.1 The terms *rated output* or *rated load* used in this guide refer to nameplate rating as defined in ANSI/IEEE C57.12.00-1980 [1].

3.1.2 The temperature rise on which the rating of a transformer is based takes into consideration the experience of the industry regarding:

(1) Insulation life as affected by operating temperature

(2) The ambient temperature assumed to exist throughout the life of the transformer

¹The numbers in brackets correspond to the references listed in Section 2 of this guide.

3.1.3 The actual output which a transformer can deliver at any time in service without undue deterioration of the insulation may be more or less than the nameplate kVA rating, depending upon the ambient temperature and other attendant operating conditions.

3.2 Transformer Temperature Rises

3.2.1 65 °C Rise Transformers. Transformers with an average winding rise of not more than 65 °C and hottest-spot winding rise of not more than 80 °C will be referred to as 65 °C rise transformers.

3.2.2 55 °C Rise Transformers. Transformers with an average winding rise of not more than 55 °C and hottest-spot winding rise of not more than 65 °C will be referred to as 55 °C rise transformers.

3.2.3 In the text of this guide values for 65 °C rise transformers will appear first followed by values for 55 °C rise transformers in parentheses, that is, 65 (55) °C.

3.3 Factors Affecting Transformer Cooling.

In daily operation the ambient temperature, the altitude, and the transformer's exterior finish may be different than is assumed for the basis of rating. These departures may influence the thermal performance of a transformer as follows:

3.3.1 Influence of Ambient Temperature on Loading. The ambient temperature is an important factor in determining the load capability of a transformer since the temperature rise for any load must be added to the ambient to determine operating temperature. Whenever the actual ambient temperature can be measured, such ambient should be used in determination of winding hottest-spot temperature and the load capability of the transformer.

Average ambient temperatures should cover periods of time not exceeding 24 h with maximum temperatures not more than 10 °C greater than average temperatures for air. Table 1 gives the increase or decrease in rated loads for other than average daily ambients of 30 °C for air. It is recommended that the 5 °C margin described in 3.3.2 be used when applying the factors from Table 1. It should be pointed out that the increase or decrease obtained from Table 1 is more conservative than the corresponding calculated values. Table 1 is used for quick approximations.

Table 1
Loading on Basis of Ambient Temperature
Other Than 30 °C
(for Quick Approximation, 0 °C–50 °C)

	% of Rated kVA
Decrease load for each °C the ambient temperature exceeds 30 °C	1.5
Increase load for each °C the ambient temperature is below 30 °C	1.0

Loading on the basis of ambient temperature with loads permitted by Table 1 will give approximately the same life expectancy as if transformers were operated at nameplate rating and standard ambient temperatures over the same period.

Table 1 covers a range in ambients of 0 °C to 50 °C for cooling air. A check should be made with the manufacturer before loading on the basis of cooling air ambient less than 0 °C or greater than 50 °C.

Since ambient temperature is an important factor in determining the load capability of a transformer, it should be controlled for indoor installations by adequate ventilation and should always be considered in outdoor installations.

3.3.2 Approximating Ambient Temperature. It is often necessary to predict the load which a transformer can safely carry at some future time when the ambient temperature is unknown. The probable ambient temperature for any month may be approximated as follows from reports prepared by the Weather Bureau of the US Department of Commerce which are available for various sections of the country:

(1) *Average Temperature.* Use average daily temperature for the month involved, averaged over a number of years

(2) *Average of Maximum Daily Temperatures.* Use average of the maximum daily temperature for month involved, averaged over several years

These ambients should be used as follows: for loads with normal life expectancy, use item (1) as the ambient for the month involved; for

short-time loads with moderate sacrifice of life expectancy, use item (2) for the month involved.

During any one day the average or maximum temperatures may exceed the values derived from (1) or (2) above. To be conservative, it is recommended that these temperatures be increased by 5 °C since aging at higher than average temperature is not fully offset by decreased aging at lower than average temperature. With this margin the approximated temperature will not be exceeded on more than a few days per month and, where it is exceeded, the additional loss of life will not be serious.

3.3.3 Influence of Altitude on Loading. The decreased air density due to high altitude increases the temperature rise of transformers since they are dependent upon air for the dissipation of heat losses.

3.3.3.1 Operation at Rated kVA. Transformers may be operated at rated kVA at altitudes greater than 1000 m (3300 ft) without exceeding temperature limits provided the average temperature of the cooling air does not exceed the values of Table 2 for the respective altitudes.

3.3.3.2 Operation at Less than Rated kVA. Transformers may be operated at altitudes greater than 1000 m (3300 ft) without exceeding the normal temperature limits provided the load to be carried is reduced below nameplate rating by 0.4% for each 100 m (330 ft) that the altitude is above 1000 m (3300 ft). The manufacturer should be consulted to ascertain what influence the application of fan cooling will have on the rating at various altitudes.

3.3.3.3 Recommended Calculation of Average Temperature. It is recommended that the average temperature of the cooling air be calculated by averaging 24 consecutive hourly readings. When the outdoor air is the

cooling medium, the average of the maximum and minimum daily temperature may be used. The value obtained in this manner is usually slightly higher than the true daily average by not more than 0.3 °C.

3.3.4 Influence of Exterior Finish on Loading. The thermal radiation characteristic of a transformer is affected by its external finish. Temperature limits and tests are based upon the use of a pigment paint finish, which is a standard finish for transformer tanks and radiators.

Metallic flake paints, such as aluminum, zinc, etc have radiation properties which increase the temperature rise of transformers except in direct sunlight. Particular note should be made of a coating's radiation properties when a transformer is refinished in the field.

3.4 Aging of Insulation

3.4.1 Aging or deterioration of insulation is a function of temperature and the time it is at this temperature. Since, in most apparatus, the temperature distribution is not uniform, that part which is operating at the highest temperature will ordinarily undergo the greatest deterioration. Therefore, in aging studies it is usual to consider the aging effects produced by the highest (hottest-spot) temperature.

3.4.2 Much of the fundamental insulation aging data at different temperatures has been based on laboratory and model tests in which the decrease in mechanical and electrical strength has been measured. This has been supplemented by a series of functional life expectancy tests made under controlled conditions on commercially produced distribution transformers, under the auspices of the IEEE Transformers Committee. For test procedures see ANSI/IEEE C57.100-1972 [4].

Data from these tests, and judgment, has resulted in the life expectancy curves shown in Fig 1. This guide adopts these curves as the *normal* life expectancy for distribution transformers with average winding temperature rises of 65 °C and 55 °C. The loss of life data given in this guide are derived from these normal life expectancy curves. It is the best distribution transformer life information currently available.

3.4.3 This guide assumes the insulation deterioration relationship with respect to tem-

Table 2
Maximum Allowable Average
Temperature of Cooling Air to
Permit Carrying Rated kVA

1000 m (3300 ft)	2000 m (6600 ft)	3000 m (9900 ft)	4000 m (13 200 ft)
30 °C	28 °C	25 °C	23 °C

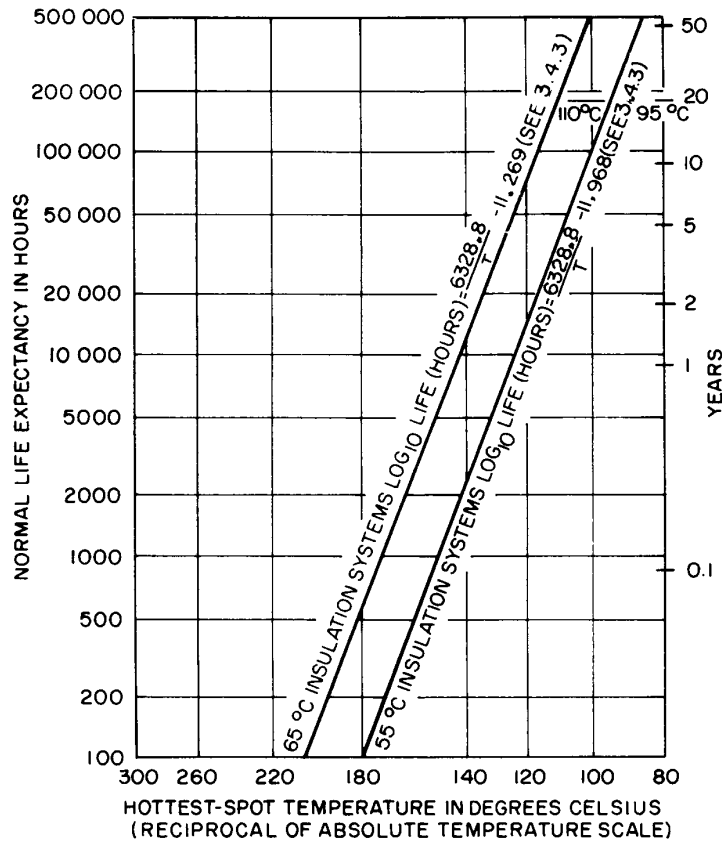


Fig 1
Life Expectancy Curve

perature and time follows an adaptation of the Arrhenius reaction rate theory which states that the logarithm of insulation life is a function of the reciprocal of absolute temperature:

$$\text{Log}_{10} \text{ life(h)} = A + \frac{B}{T} \quad (\text{Eq 1})$$

where

T = absolute temperature in degrees kelvin, $= \theta_{hs} + 273$ (as shown in Eq 14) where θ_{hs} equals the temperature at the hottest-spot

A and B = constants for appropriate life expectancy curve

For the 65 °C insulation systems

$$A = -11.269 \quad B = 6328.8$$

For the 55 °C insulation systems

$$A = -11.968 \quad B = 6328.8$$

3.5 Transformer Life Expectancy

3.5.1 Transformer life expectancy at any operating temperature is not accurately known, but the information given regarding loss of insulation life at elevated temperatures is considered to be conservative and the best that can be produced from present knowledge of the subject. The effects of temperature on insulation life are being investigated continuously, and new data may affect future revisions of this guide. The word *conservative* as used above is used in the sense that the

expected loss of insulation life for a single overload cycle will not be greater than the amount stated.

3.5.2 Because the cumulative effects of temperature and time in causing deterioration of transformer insulation are not thoroughly established, it is not possible to predict with any great degree of accuracy the length of life of a transformer even under constant or closely controlled conditions, much less under widely varying service conditions.

Deterioration of insulation is generally characterized by a reduction in mechanical strength and in dielectric strength, but these characteristics may not necessarily be directly related. In some cases, insulation in a charred condition will have sufficient insulating qualities to withstand normal operating electrical and mechanical stresses. A transformer having insulation in this condition may continue in service for many months or even years, if undisturbed. On the other hand, any unusual movement of the conductors, such as may be caused by expansion of the conductors due to heating resulting from a heavy overload or to large electromagnetic forces resulting from short circuit, may disturb the mechanically weak insulation such that turn-to-turn or layer-to-layer failure will result.

3.5.3 The recommendations of this guide are based upon the life expectancy curves of Fig 1 which relate to the insulation system, but do not account for such factors as deterioration of gaskets, rusting of tanks, etc. which are induced by exposure to the elements of the weather in normal operations.

3.5.4 Normal Life Expectancy.

(1) The basic loading of a transformer for normal life expectancy is continuous loading at rated output when operated under normal service conditions as indicated in 4.1.6(1) and 4.1.6(2) of ANSI/IEEE C57.12.00-1980 [1]. It is assumed that operation under these conditions is equivalent to operation in a constant 30 °C ambient. Normal life expectancy will result from operating continuously with hottest-spot conductor temperature of 110(95) °C or an equivalent cycle.

(2) The hottest-spot conductor temperature is the principal factor in determining life due to loading. This temperature cannot be directly measured on commercial designs because of the hazard in placing any temperature detector at the proper location because of

voltage. The indicated allowances have therefore been obtained from tests made in the laboratory.

(3) The hottest-spot temperature at rated load is the sum of the average winding temperature and a hottest-spot allowance, usually 15(10)°C. For mineral oil-immersed transformers operating continuously under the foregoing conditions this temperature has been limited to a maximum of 110(95)°C.

(4) The normal life expectancy at a continuous hottest-spot temperature of 110(95) °C is 20 years as shown in Fig 1.

3.5.5 The many variables and, particularly, the many varying conditions of load and ambient to which a transformer can be subjected in service make it impossible to give definite rules for the loading of transformers. It is possible to give only suggested loadings under specified conditions, and look to the user to make the best use of this information for his particular problem.

3.6 Limitations

3.6.1 It must be recognized that when loading transformers above nameplate rating, other limitations may be encountered. Among these limitations are: oil expansion, pressure in sealed units, and the thermal capability of bushings, leads, tap changers or associated equipment such as cables, reactors, circuit breakers, disconnecting switches, and current transformers. Any of these items may limit the loading and manufacturers should, therefore, be consulted before loading transformers above nameplate rating.

Operation at hottest-spot temperatures above 140 °C may cause gassing in the solid insulation and the oil. Gassing may produce a potential risk to the dielectric strength integrity of the transformer and this risk should be considered when the guide is applied.

3.6.2 Transformers are sometimes installed in subsurface manholes and vaults of minimum size with natural ventilation through roof gratings. This type of installation results in a higher ambient temperature than the outdoor air. The amount of increase depends on the design of the manholes and vaults, net opening area of the roof gratings, and the adjacent subsurface structures. Therefore, the increase in effective ambient temperature for expected

transformer losses must be determined before loading limitations can be estimated.

3.6.3 The heating effects of loading a transformer and of solar radiation, each may result in an enclosure surface temperature high enough to present a hazard to personnel who might come in contact with the enclosure surface where unlimited access to the transformer exists (such as certain pad-mounted units).

4. Loading of Transformers

4.1 Loading for Normal Life Expectancy Under Specific Conditions. When the ambient temperature is below the 30 °C ambient used to establish the transformers' rating, or when the transformers' temperature rises at nameplate rated load, as determined by test, are less than the normal limiting values, some additional load beyond nameplate rating is possible within normal life expectations.

4.1.1 Loading by Oil Temperature. Oil temperature alone should not be used as a guide for loading transformers. The hottest-spot winding rise over top-oil temperature at full load should be determined from the factory tests and Eq 7 and should then be corrected for the actual load carried, using Eq 5 or Fig 10. This hottest-spot rise over top-oil, subtracted from 110(95) °C, will give the maximum permissible top-oil temperature for normal life expectancy. It should be recognized that, due to the thermal lag in the oil temperature rise, time is required for a transformer to reach a stable temperature for any change in load. Therefore, higher peak loads may be carried for a short duration. This is reflected in the loading tables.

If the transformer characteristics are not accurately known, maximum top-oil temperatures derived from Fig 2 may be used as an approximate guide. Figure 2 is based on a difference between hottest-spot temperature and top-oil temperature of 25(20)°C at rated load.

4.1.2 Continuous Loading Based on Average Winding Test Temperature Rise. For each °C in excess of 5 °C that the average winding test temperature rise is below 65(55) °C, the transformer load may be

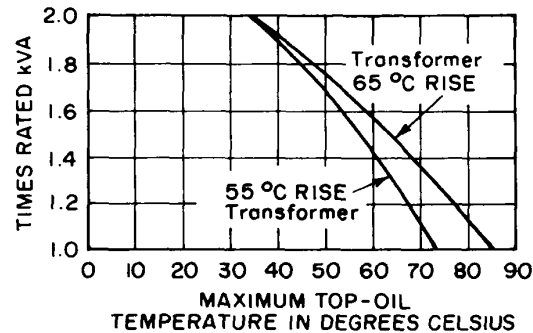


Fig 2
Approximate Continuous Loading for
Normal Life Expectancy Based on
Maximum Top-Oil Temperature

increased above rated kVA by 1.5%. The 5 °C margin is taken to provide a tolerance in the measurement of temperature rise. The load value thus obtained is the kVA load which the transformer can carry at 65(55) °C rise. Since this may indicate a load capability beyond that contemplated by the designer, the limitations given in 3.6.1 should be checked before taking full advantage of this increase.

The above is not applicable to all transformers; some transformers are designed to have the difference between the hottest-spot and average winding temperatures greater than the 15(10) °C allowance. This will result in an average winding temperature rise of less than 65(55) °C, while the hottest-spot winding rise may be at the 80(65) °C limiting value. This condition may exist in transformers with large differences between top and bottom oil temperatures.

The manufacturer should be consulted for information on the hottest-spot allowances used for these designs.

4.1.3 Loading on Basis of Short-Time Loads Above Rating. Transformers may be operated above 110(95) °C average continuous hottest-spot temperature for short periods provided they are operated for much longer periods at temperatures below 110(95) °C. This is due to the fact that thermal aging is a cumulative process. This permits loads above the rating to be safely carried under specified conditions without encroaching upon the normal life expectancy of the transformer.