TSEWG TP-5: INTERIOR TRANSFORMER RATINGS AND INSTALLATION

TRANSFORMER RATINGS.

Voltage and Current.

The transformer primary voltage rating must be determined by the voltage available to the transformer from the facility electrical distribution system. Select the transformer secondary voltage based on the required voltage on the secondary as determined by the most economical facility distribution voltage, the largest loads with previously fixed voltages, and energy usage density.

The rated secondary voltage is the voltage at which the transformer secondary is designed to deliver the rated kVA capacity. Transformer windings are connected in either series or parallel to obtain the desired output (secondary) voltage. Common nominal voltages are shown in Table 1.

Table 1 Common Primary and Secondary Transformer Voltages

Single-Phase Transformer		Three-Phase Transformer	
Primary	Secondary	Primary	Secondary
240 × 480	120	208	208Y/120
120/208/240/277	120/240	240	240/120
480		480	480Y/277
		4,160	4,160
		13,800	

Note: Table 1 does not include all possible combinations of transformer ratios. Overseas facilities will commonly be designed around a 400Y/230 volt, 50 Hertz system. Contact the transformer vendor for non-standard voltage and frequency ratings.

Temperature and kVA.

The kVA capacity of a transformer is the output that it can deliver for a specified period of time, at the rated secondary voltage and rated frequency, without exceeding a specified temperature rise based on insulation life and ambient temperature. Transformers can be loaded above their kVA ratings with no loss of life expectancy only when operated within the manufacturer’s stated limits. Select the transformer based on its kVA capacity and temperature rating.

The rated kVA capacity is based on the maximum current delivered at rated voltage. The real limit in the transformer’s capability is the amount of current that it can provide without exceeding a defined temperature rise. Dry type transformers are designed with various insulation types and the rating and loading of a transformer are based on the temperature limits of the particular system. Note that the transformer’s rated temperature will be reached when it is operated at full load under the manufacturer's specified conditions, meaning that some caution is warranted in the selection, application, installation, and loading of a transformer. The following insulation systems are available (refer to Figure 1):

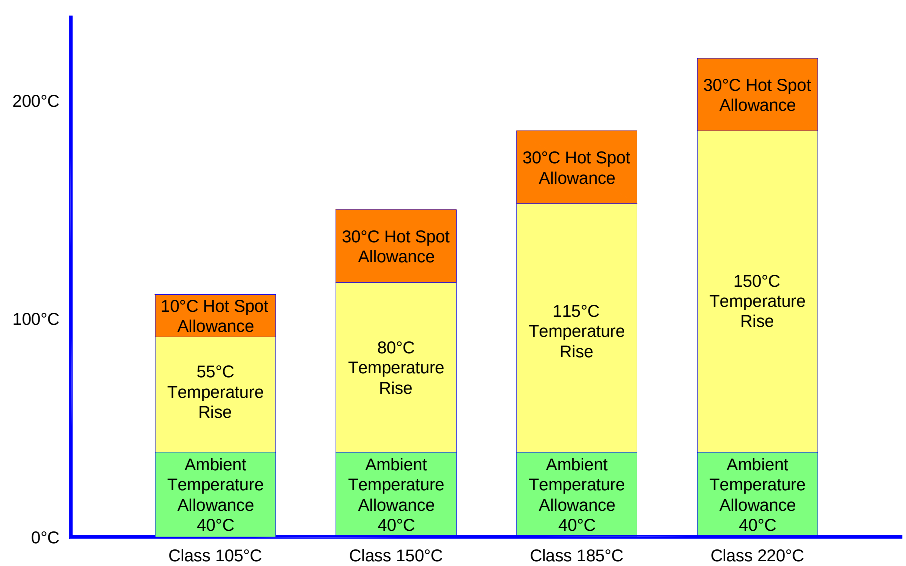
- Class 105—when loaded in an ambient temperature of not over 40 °C, will operate at no more than a 55 °C average temperature rise on the winding conductors, with an added 10 °C allowance for a hot spot. The sum of 40 °C + 55 °C + 10 °C provides the 105 °C designation. This insulation class is used only on very small transformers. Older designs refer to this as a Class A insulation or transformer rating.

- Class 150—allows an 80 °C rise in the winding plus a 30 °C hot spot allowance. Class 150 insulation is often used in transformers rated up to 2 kVA. Older designs refer to this as a Class B insulation or transformer rating.

- Class 185—allows a 115 °C rise in the winding plus a 30 °C hot spot allowance. Class 185 insulation is often used in transformers rated from 3 to 30 kVA. Older designs refer to this as a Class F insulation or transformer rating. Some documents refer to a Class 180 rating also.

- Class 220—allows a 150 °C rise in the winding plus a 30 °C hot spot allowance. Class 220 insulation is commonly used in transformers rated in all significant sizes. Older designs refer to this as a Class H insulation or transformer rating.

Figure 1 Insulation System Ratings



The kVA rating and the insulation system rating are related. Select the desired kVA rating or insulation system based on the following considerations:

- Relative loading—transformers loaded at or close to their kVA ratings will operate hotter than transformers that are lightly loaded. A higher kVA rating can be selected just to ensure that the transformer operates cooler to avoid long-term thermal damage.

- Duty cycle—the duty cycle might have the transformer fully loaded most of the time or lightly loaded most of the time. The transformer kVA rating has to be capable of supplying the system full-load current, but the capacity margin can be lower for lightly loaded duty cycles.

- Ambient temperature—the average and maximum ambient temperatures at the installation location must be determined (or estimated) as part of the selection process. If necessary, increase the kVA rating or insulation system class to reduce the degree of thermal damage at higher temperatures.

Unless there are special application or environmental requirements, transformers rated 15 kVA or greater should have a Class 220 insulation system. Transformers rated less than 15 kVA should have a Class 185 insulation system.

Impedance.

The transformer impedance is an important design characteristic; the impedance determines how the transformer will regulate voltage with variation in load. Additionally, the impedance limits the maximum fault current that can be supplied through the transformer. Transformer impedances commonly vary between 3 percent and 6 percent. A high impedance might limit short circuit current at the expense of regulation and a low impedance might provide acceptable regulation at the expense of higher short circuit currents.

Evaluate the selected transformer's impedance rating to ensure that it will not allow a greater short circuit current in its secondary than the downstream protective devices are capable of interrupting.

Impedance affects transformer regulation. As the impedance increases, the voltage regulation tends to increase. Unless the system requires a tighter tolerance, design for a voltage regulation range of 2 percent to 5 percent. For sensitive equipment, tighter regulation requirements might apply; review downstream equipment voltage requirements to verify that the regulation will be acceptable.

Transformers are readily available with an Energy Star rating, which are intended to reduce energy losses by a more efficient design. Wherever energy-efficient transformers are used, verify that the available short circuit current does not exceed the interrupting rating of downstream protective devices.

Number of Phases.

Use single-phase transformers on single-phase systems and on single-phase circuits derived from three-phase systems.

Use either three single-phase transformers or one three-phase transformer on three-phase circuits. A three-phase transformer weighs less; requires less space than three single-phase transformers of the same type, construction, and total kVA capacity; and is easier to install. The use of three single-phase transformers has the advantage that failure of one transformer requires only that the failed transformer be replaced and, if necessary, the remaining two transformers can still be connected to deliver about 57 percent of the nameplate rating. Failure of a three-phase transformer requires complete replacement.

Transformer Taps.

Depending on the system conditions, the nominal secondary voltage might not satisfy the voltage requirements of the loads. General purpose transformers should be provided with several taps on the primary to vary the secondary voltage. Taps are connection points along the transformer coil that effectively change the secondary voltage by changing the transformer turns ratio.

If available, two full capacity taps should be provided above nominal and two full capacity taps below nominal to allow increasing or decreasing the secondary voltage. Although designs vary among manufacturers, transformers smaller than 15 kVA usually only have two 5 percent taps below normal to provide a 10 percent voltage adjustment range. Larger transformers occasionally have four 2.5 percent taps below normal and two 2.5 percent taps above normal to provide a 15 percent voltage adjustment range.

Select the tap setting to optimize the range between the no-load voltage and full-load voltage as well as possible. Taps are commonly rated at 2.5 percent of nameplate rating and designated as FCAN (full capacity above normal) or FCBN (full capacity below normal), meaning that the kVA rating of the transformer is not affected when taps are adjusted. If taps are not rated as full capacity, then derating of the transformer should be performed per the manufacturer's requirements.

Noise.

All transformers transmit sound due to vibration generated within the magnetic steel core. Depending on other nearby ambient noise, the transformer sounds might not be noticeable. In low ambient noise areas, the transformer sound can be noticed. Determine if noise rating is a required design consideration for the intended installation location.

A transformer located in low ambient noise level areas should have a low decibel hum rating. The average sound level in decibels should not exceed the level specified in NEMA ST 20, *Dry Type Transformers for General Applications*, for the applicable kVA rating range. Manufacturers readily provide sound ratings lower than the limits listed in NEMA ST 20.

In addition to the transformer noise rating, consider the following actions to improve the generated sound level:

- Mount the transformer so that vibrations are not transmitted to the surrounding structure. Small transformers can usually be solidly mounted on a reinforced concrete floor or wall. Flexible mounting will be necessary if the transformer is mounted to the structure in a normally low-ambient noise area.

- Use flexible couplings and conduit to minimize vibration transmission through the connection points.

Locate the transformer in spaces where the sound level is not increased by sound reflection. For example, in terms of sound emission, the least desirable transformer location is in a corner near the ceiling because the walls and ceiling function as a megaphone.

Basic Impulse Insulation Levels (BIL).

The transformer winding BIL is the design and tested capability of its insulation to withstand transient overvoltages from lightning and other surges. The rated BIL usually increases with nominal voltage.

A 30 kV BIL is usually acceptable for system voltages up to 5 kV and 60 kV BIL is usually acceptable for system voltages up to 15 kV. Higher BIL levels can be applied in locations in which transient overvoltages are expected due to nearby lightning strikes; 60 kV BIL and 95 kV BIL are recommended in this case for 5 kV and 15 kV, respectively.

Do not specify lower BIL levels solely because surge protection has been installed.

TRANSFORMER INSTALLATION CRITERIA.

Introduction.

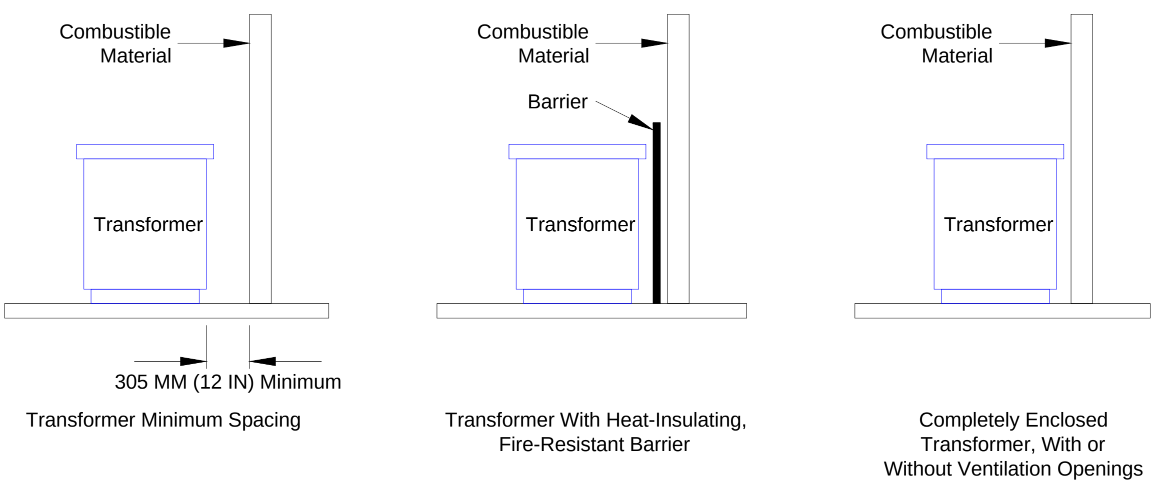
NEC Article 450 (2005 Edition) provides specific criteria applicable to transformers and transformer installations. For each of the specified criteria in the NEC, exceptions are often provided. As part of any installation design, review the NEC to ensure that applicable criteria, including allowed exceptions, are satisfied. Regardless of the location, ensure transformers have adequate ventilation to avoid overheating. Comply with clearances specified by NEC Articles 110.26 and 110.30 to 110.34 (2005 Edition) for installations below 600 volts or above 600 volts, respectively.

Dry-Type Transformers.

Dry-type transformers, available at voltage ratings of 15 kV and below, are cooled primarily by internal air flow. The three principal classes of dry-type transformers are: selcooled (AA), forced-air cooled (AFA) and selcooled/forced-air cooled (AA/FA). Selcooled transformers require adequate room ventilation to ensure proper transformer cooling. Forced-air cooled transformers can be integrated into the facility energy conservation design by a heat recovery system.

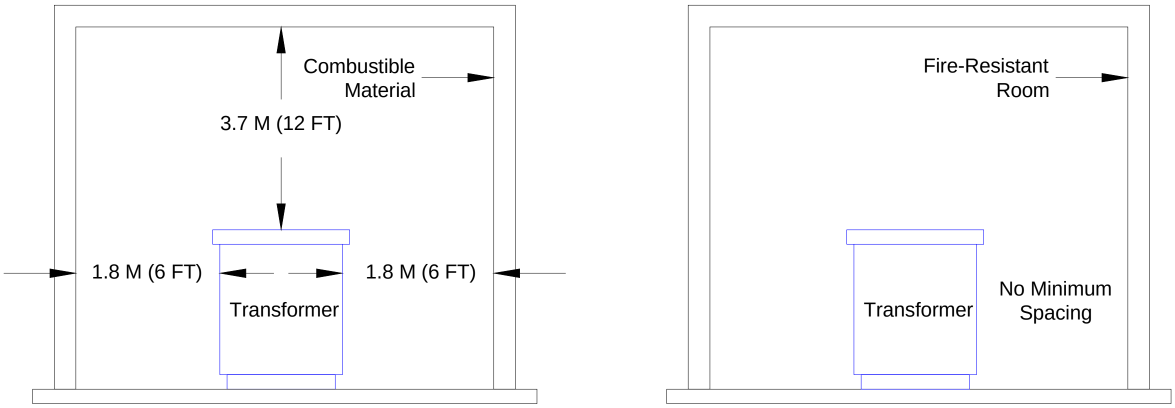
Figure 2 shows the NEC Article 450.21 (2005 Edition) installation spacing criteria for transformers rated 112.5 kVA or less. As shown, ensure these transformers have a minimum 0.3 meter (12-inch) spacing from combustible materials or have a fire-resistant, heat-insulating barrier. This requirement does not apply if the transformer is the nonventilating type.

Figure 2 Spacing Requirements for Transformers Rated 112.5 kVA or Less



Dry-type transformers rated for more than 112.5 kVA have different requirements, depending on the insulation rating as shown in Figure 3 and specified in NEC Article 450.21 (2005 Edition). Transformers with less than 80 °C (176 °F) temperature rise rated insulation require installation in a fire-resistant room. Transformers with greater than 80 °C (176 °F) temperature rise rated insulation require either the spacing shown in Figure 3 or a fire-resistant, heat-insulating barrier.

Figure 3 Spacing Requirements for Transformers Rated Over 112.5 kVA

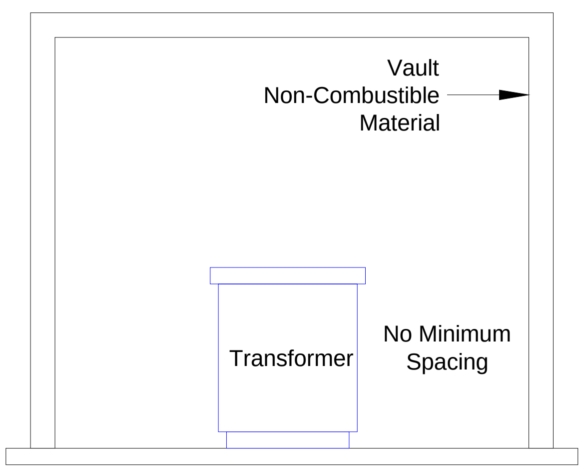


Not Totally Enclosed,
Ventilated Transformer

Transformer With Less
Than 80°C Rise Insulation

Install dry-type transformers rated for over 35,000 volts in a vault as shown in Figure 4 and specified in NEC Article 450.21 (2005 Edition).

Figure 4 Installation Requirements for Transformers Rated Over 35,000 Volts



Less-Flammable, Liquid-Insulated, and Oil-Insulated Transformers.

Use dry-type transformers wherever possible for interior applications.

The use of liquid-insulated and oil-insulated transformers must be justified for interior applications. If such use is justified for the particular application, refer to MIL-HDBK-1008C for guidance regarding installation criteria.

OTHER TRANSFORMER TYPES.

Isolation Transformers.

Isolation transformers can be used to establish a separately derived system. A separately derived system as defined in the NEC is a wiring system whose power has no direct electrical connection, including solidly connected grounds and neutrals to another wiring system. A separately derived system is usually made when it is desired to provide an isolated ground system for the wiring system.

When configured in a delta-wye configuration, the transformer provides a power ground reference close to the point of use. This reduces common-mode noise induced into the circuit from multiple ground loops upstream of the established reference point.

Isolation transformers provide a filtering function by separating the harmonic frequencies between the source and the load. The delta-wye winding configuration effectively cancels the third, ninth, fifteenth (and so on) harmonic currents in the delta primary winding, thereby isolating triplen harmonics from being fed back into the source.

Isolation transformers can be used for retrofit applications to address existing facility problems, but should not be arbitrarily used in new facilities because of the higher per-kVA cost.

Buck-Boost Transformers.

The buck-boost transformer has four separate windings, 2 windings in the primary and 2 windings in the secondary. It is intended to be field connected as an autotransformer to buck (lower) or boost (raise) the line voltage. Apply buck-boost transformers only when required to achieve voltages beyond the capability of the existing utilization equipment.

A buck-boost transformer cannot be used to develop a 3-phase, 4-wire, wye circuit from a 3-phase, 3-wire delta circuit. A delta to wye buck-boost configuration does not provide adequate carrying capability to allow for unbalanced currents flowing in the neutral of the 4-wire circuit. The neutral current is not stable and will not provide the desired line to neutral voltages under load. This connection also violates NEC Article 210.9 (2005 Edition).

Do not use buck-boost transformers to correct for voltage drop on a long circuit run in which the load fluctuates. Voltage drop varies with the load, but buck-boost transformers are connected for a specific voltage drop. If a buck-boost transformer is used to correct voltage drop under full load conditions, high voltages can occur under light load conditions.

Do not use buck-boost transformers to create a 120/240 volt single phase service from a 208Y/120 volt 3-phase supply. If done, two neutrals would exist on the same circuit. Also, unbalanced line to neutral voltages would be created; one line would be at 120 volts with the other line greater than 130 volts.

K-Factor Transformers.

Transformers are available for high harmonic-content power distribution systems without derating, often referred to as *k-factor transformers*, and usually have the following characteristics:

- Low induction core to reduce the flux density. Voltage harmonic distortion increases the core flux density, thereby creating higher core losses, higher magnetizing currents, higher audible noise, and overheating.

- Larger primary winding conductors to compensate for additional heating effects.

- Individual insulated secondary conductors to reduce stray losses.

- Larger neutral connections to compensate for harmonic currents causing larger neutral currents.

Evaluate the effect of nonlinear loads as part of the facility design. In some cases, nonlinear loads can require transformer derating or, in extreme cases, a transformer designed specifically for nonlinear loads might be required. Also, the transformer neutral conductors might require sizing for up to 200 percent of rated current. Excessive harmonic distortion causes higher eddy current losses inside a transformer, resulting in overheating. IEEE C57.110, *IEEE Recommended Practice for Establishing Transformer Capability When Supplying Nonsinusoidal Load Currents*, states that a transformer should be capable of carrying its rated current provided that the total harmonic distortion is less than 5 percent. Beyond this amount, derating of the transformer might be necessary. Newer transformers are often, but not always, already designed for some level of a higher harmonic distortion environment. Older transformers likely were not designed for harmonic distortion.

The k-factor relates transformer capability to serve varying degrees of nonlinear load without exceeding the rated temperature rise limits. The most common k-factor ratings are k-4 and k-13. Manufacturers recommend k-4 transformers if the connected load is 50 percent nonlinear electronic loads and k-13 transformers are recommended for 100 percent nonlinear electronic loads. This simplified approach allows the user to avoid calculating actual k-factor values for the facility. Transformer k-factor ratings greater than k-13 should never be necessary, and the use of such transformers actually can contribute to harmonic distortion problems because of their low impedance.

In practice, the system k-factor tends to decrease as the overall load increases. Thus, k-factor measurements taken in lightly loaded conditions can be quite high, but can be significantly lower on a fully loaded system. Transformer coil losses decrease with the square of the load and this reduction far exceeds the increased heating effect of higher harmonics at lighter loads. So, regardless of the load current harmonic distortion variation, the maximum loss point in transformer coils is always at full load. This is why transformer k-factor ratings must be based on full-load conditions. Nationwide surveys indicate average loading levels for dry-type transformers of between 35 percent for commercial facilities and 50 percent for industrial facilities. With such a light loading, a general purpose transformer will provide acceptable performance. A k-4 rating will provide acceptable performance in all but the most extreme harmonic distortion environments.

In almost all applications, the service entrance transformer will be acceptable if it is a general purpose dry-type transformer rather than a k-rated transformer. An individual lower-voltage transformer within the facility might need a k-factor rating (or derating if it is a general purpose transformer) under the following conditions:

- It supplies a large concentration of nonlinear electronic equipment, and
- It is operating near full load or there is a reasonable expectation that it will eventually be fully loaded.

Equipment suppliers can provide bundled power distribution systems that contain k-rated transformers or otherwise address power quality issues. Evaluate the applicability of this equipment before selecting a k-rated transformer.

Specialty Transformers.

Specialty transformers include control, industrial control, Class 2, signaling, ignition, and luminous tube transformers. Select these transformers using National Electrical Manufacturers Association (NEMA) ST 1, *Specialty Transformers (Except General Purpose)*, as a guide.