FAQ

# Understanding and Selecting Transformers & Power Factor Considerations

Among growing calls for electrification of heating and hot water plants and limitations of the existing power infrastructure, engineers are often forced to add large step-up or step-down transformers to their building designs. Equipment like heat pumps, resistance electric boilers and water heaters, and vehicle charging stations have high power draw requirements. Additionally, equipment utilizing large motors and pumps can substantially reduce a system's power factor, and thus increase power delivery requirements (in kVA/VA) needed by a system. By stepping up to a higher voltage, engineers can reduce the required current draw as well as the size of conductors and other power delivery equipment. Correcting for poor power factor in a system can yield additional savings by allowing the engineer to select smaller transformer sizes and smaller power delivery equipment as well. These power factor correction benefits are often accompanied by long term cost savings in commercial utility bills. Transformer selection has a significant impact on a building's electrical demand and should be carefully selected by a qualified electrical engineer to provide the best performance and efficiency and have the longest lifespan based on a building's electrical needs.

## Transformer Selection

Transformers are typically selected according to the following characteristics:

- Power rating in kVA
- Frequency, typically 60Hz only for North America
- Core type: material, lamination, and shape
- Number of phases
- Cooling type
- Current ratings at primary vs secondary windings
- Primary and secondary voltages

An example **Table 1** shows example current ratings for a transformer of a given number of phases and apparent power rating. These details will also be listed on the transformer nameplate.

**Table 1**

| Single Phase Transformer | | | | Three Phase Transformer | | | | |
|---|---|---|---|---|---|---|---|---|
| **KVA Rating** | **Amperes** | | | **KVA Rating** | **Amperes** | | | |
| | **120V** | **240V** | **600V** | | **120V** | **240V** | **480V** | **600V** |
| **0.75** | 6.25 | 3.13 | 1.25 | **3** | 8.33 | 7.22 | 3.61 | 2.89 |
| **1** | 8.33 | 4.17 | 1.67 | **9** | 25 | 21.7 | 10.8 | 8.66 |
| **1.5** | 12.5 | 6.25 | 2.5 | **15** | 41.6 | 36.1 | 18 | 14.4 |
| **2** | 16.7 | 8.33 | 3.33 | **20** | 55.5 | 48.1 | 24.1 | 19.2 |
| **3** | 25 | 12.5 | 5 | **25** | 69.4 | 60.1 | 30.1 | 24.1 |
| **5** | 41.6 | 20.8 | 8.33 | **30** | 83.3 | 72.2 | 36.1 | 28.9 |
| **7.5** | 62.5 | 31.3 | 12.5 | **37.5** | 104 | 90.2 | 45.1 | 36.1 |
| **10** | 83.3 | 41.7 | 16.7 | **45** | 125 | 108 | 54.1 | 43.3 |
| **15** | 125 | 62.5 | 25 | **75** | 208 | 180 | 90.2 | 72.2 |
| **25** | 208 | 104 | 41.7 | **100** | 278 | 241 | 120 | 96.2 |
| **37.5** | 313 | 156 | 62.5 | **112.5** | 312 | 271 | 135 | 108 |
| **50** | 417 | 208 | 83.3 | **150** | 416 | 361 | 180 | 144 |
| **75** | 625 | 313 | 125 | **225** | 625 | 541 | 271 | 217 |
| **100** | 833 | 417 | 167 | **300** | 833 | 722 | 361 | 289 |
| **167** | 1392 | 696 | 278 | **500** | 1388 | 1203 | 601 | 481 |
| **250** | 2083 | 1042 | 417 | **750** | 2082 | 1804 | 902 | 722 |

Electrical codes typically require a transformer be rated for higher than the maximum expected current draw. For example, if the electrical code requires no more than 70% usage of the capacity of a transformer, and the equipment full load amps is 50 A, the transformer should be rated to provide 50/70% = 71.4 A. For a step-up transformer from 208 V to 480 V, the power required is calculated as I*E=P, or 71.4 * 480 = 34.3 kVA.

This will allow you to select the correct size of the transformer, but we also need to address some relevant parasitics involved with power transformers, as well as how power factor plays into commercial buildings. An electrical power engineer should not only select a transformer based on ideal characteristics given the load and system, but they would need to perform load calculations on the entire system to ensure that the power delivery infrastructure requirements are met or exceeded, maximum transformer efficiency is achieved, and maximum lifetime of the downstream components and transformer is achieved. Below we describe only SOME of these considerations.

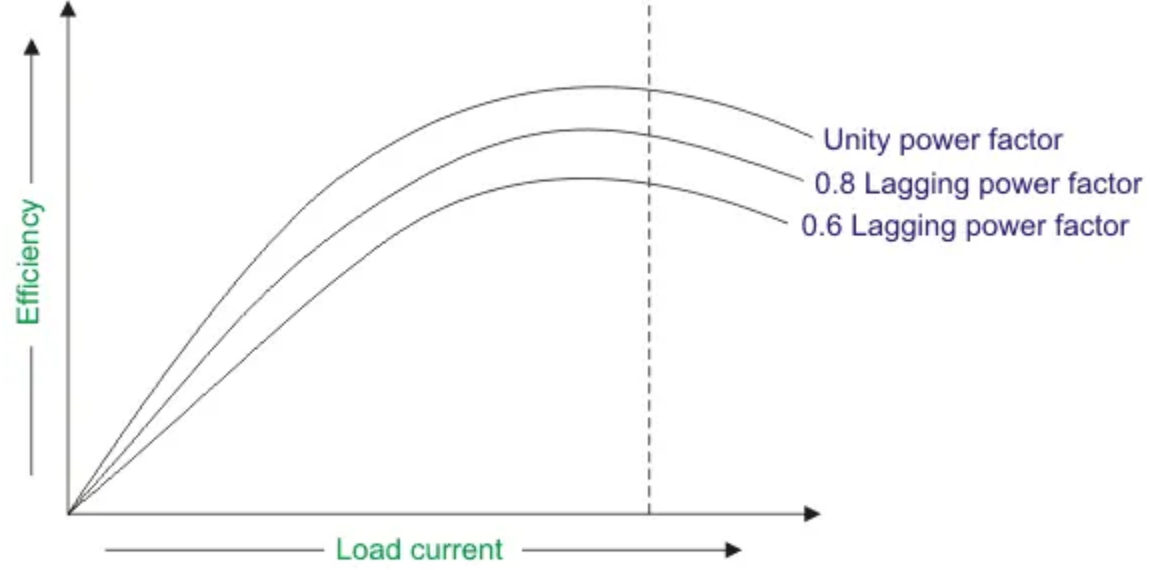
## Power Factor

The power factor of a building is a measure of how efficiently the delivered electricity is being used. It is a ratio of working power (kW) to apparent power (kVA). In an ideal circuit, the power factor will be 1.0 and there will be no losses. Inductive loads on mechanical equipment like pumps and compressors, which require a large reactive power, will have higher associated apparent and reactive power draw due to lower power factor. Utilities often charge commercial power customers a reactive demand charge based on the power factor of the building to encourage facilities to maximize their power factor. To combat this, engineers can install large capacitor banks to offset the inductive load with stored capacitive energy, thus increasing power factor and reducing apparent power usage. The amount of capacitance and scheduling of capacitance is determined on a case-by-case basis by a building's electrical engineer.

Managing power factor is also important for the transformer as well. Transformers are 'sized' according to apparent power ratings in units of KVA. Since power factor correction at your load may reduce apparent power usage for inductive loads, a smaller transformer could be selected.

Conversely, having loads with lower power factor on a transformer can reduce the overall efficiency of your transformer. This is important when sizing your transformer, as oversizing a transformer according to power factor may be necessary. See **Figure 1** below.

**Figure 1**



## Transformer Parasitic considerations: Eddy Currents

Eddy currents will cause the transformer to have a "load" of low power factor, also known as 'inductive load' or 'reactive load,' when the secondary taps are isolated from the load. Essentially the primary load is coupled to the transformer core. Transformers with laminated cores may be chosen to reduce eddy currents. Since power transformers will be used at relatively low frequencies of 60Hz, the effects of Eddy currents are limited. Alternatively, high flux cores made of nickel iron powder should be chosen when available.

### Leakage Inductance

Ideally, a transformer's primary windings couple only to the secondary windings. Unfortunately, some of this inductance is lost in the windings and can be modeled by series inductors on the primary or secondary windings. For low frequency power transformers (50/60 Hz), a low leakage inductance will yield less voltage sag as the load on the primary increases. Transformers with "interleaved" copper windings, can yield less leakage inductance at the expense of increased interwinding capacitance. Since most mechanical equipment operates at low frequencies, this is not often a major concern.

### Core Saturation

When excessive load is drawn by the transformer, the magnetic core of the transformer can saturate which distorts the AC waveform. This is VERY BAD for power factor and protecting downstream equipment. Transformers with large magnetic cores can mitigate this effect. Larger cores will not reach saturation as easily as smaller cores. Selecting core materials with high flux densities as described above in Eddy Currents will reduce the distortion due to core saturation.

### Efficiency

Transformer efficiency is a non-linear function of load. This analysis below will yield a value representing transformer efficiency, η, as a decimal between 0-1. An efficiency >.96 is highly encouraged/expected for power transformers in nominal conditions.

$$\eta = \frac{\text{output power}}{\text{input power}} = \frac{\text{output power}}{\text{output power} + \text{losses}}$$

$$\eta = \frac{\text{output power}}{\text{output power} + \text{iron losses} + \text{copper losses}}$$

$$\eta = \frac{V_2 I_2 \text{Cos}\varphi_2}{V_2 I_2 \text{Cos}\varphi_2 + P_i + P_c}$$

**Figure 2**

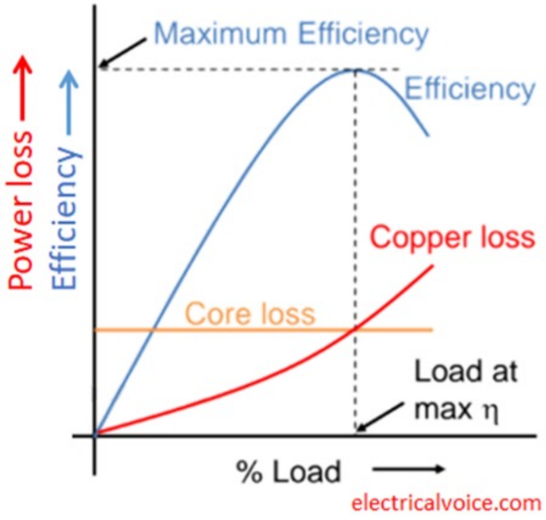


**Figure 3**

## Transformer Shape

Shell type transformer cores have lower leakage inductance than core type transformers and should be utilized for power transformer applications. Disadvantages for the shell type transformer involve greater cost, and a cost benefit analysis may be necessary to determine which transformer construction is correct for your application.

## Transformer and Load Circuit Considerations

During transformer startup at the zero-voltage crossing of AC cycle, a large inrush current will saturate the core. Circuit Breakers located on the downstream branch circuits from the transformer should be adequately sized based on the full load ampere and other connected loads. The circuit breaker tripping curve also needs to be carefully selected based on load characteristics.

Transformer conductors may need to be oversized to account for power factor losses. Transformers are inductive devices and will have a low associated power factor even with no load. In the case of equipment that drives lower power factors such as heat pumps, large conductors should be used to accommodate low power factors.

Transformers must be sized such that expected load will yield a maximum efficiency, designated as $\eta$.
See efficiency calculation section above. Keep in mind that efficiency will shift down with reducing power factor. Again, large core cross sections yield lower core saturation per given load, as well as better efficiencies.

## NEMA Insulation Ratings

Dry type transformers will self-heat due to internal losses. A NEMA insulation class is designated to transformers to specify maximum allowable temperature. Many engineers are familiar with the NEMA rating system for enclosures, which codifies a standard for the level of ingress for things like dust and water and provides a convenient way to specify enclosures. In the context of transformers, the NEMA insulation rating describes the allowable operating temperature for a transformer's insulation. The NEMA class number is simply the maximum temperature of the transformer insulation, measured in °C. A transformer with a high NEMA designation may operate at cooler temperatures while maintaining a high maximum temperature. (6)

## UL Listing

All transformers recommended should be listed to an appropriate third-party standard. The UL standard for most transformers is UL 1561 Standard for Dry-Type General Purpose and Power Transformers. Other standards, such as UL 506 Specialty Transformers, may also be applicable depending on the specific application requirements.

## Sizing for Overcurrent protection devices (OCPD)

Per CFR title 10 Chapter II Part 431, also known as the DOE 2016 efficiency levels for new transformers, transformer manufacturers were forced to re-design certain power distribution transformers to meet

U.S federal standards. Subsequent redesigns in transformers typically have higher inrush currents. (7) (8). Implications of higher inrush involves complications in sizing overcurrent protection devices based on the full load ampere (FLA) listed on the transformer nameplates. This also assumes that Minimum Current Ampacity or Minimum Circuit Ampacity (MCA), Maximum Over-Current Protection (MOCP), and other safety ratings on the nameplate have the adequate protective devices which meet all relevant safety regulations at the installation.

## Conclusion

The electrification of our built environment has significant impacts not just on the design of our plumbing and heating systems, but on our electrical systems as well. There are a variety of factors to consider when choosing transformers to support electrical equipment which can have significant impacts not only on the performance and service life of the equipment and the transformer but can have impacts on the overall building power factory and electrical utility charges. Whenever possible, a professional electrical engineer should be engaged to drive the specification of such electrical equipment.

## Sources

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