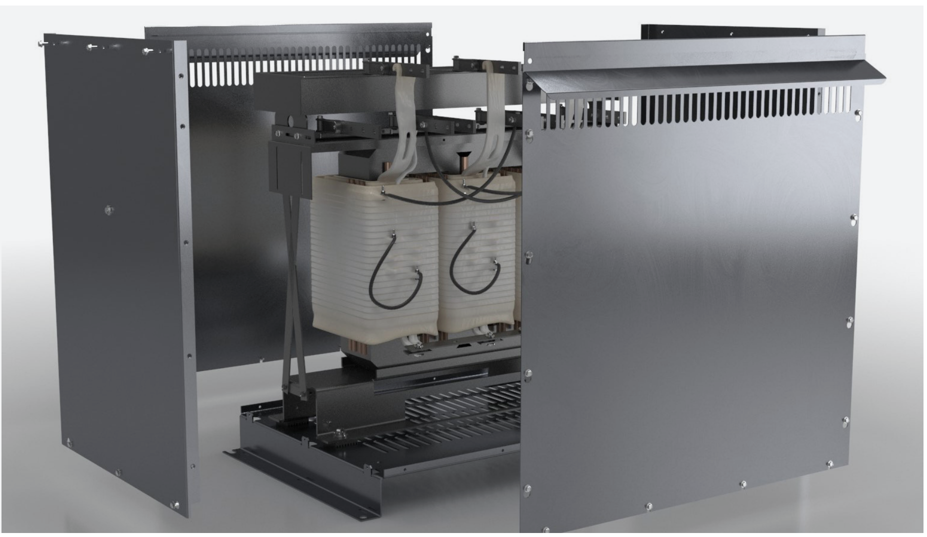
TECHNICAL PAPER

# What is a transformer K-factor rating?

## Non-linear transformer loads proliferate



K-factor transformers are required to supply electricity to harmonic-generating loads. Non-linear loads continue to proliferate in the market due to their desired benefit of reducing energy consumption. Harmonic-generating loads present a difficult electrical environment for general purpose transformers to supply electricity; therefore, K-factor transformers are installed.

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**Abstract**

Harmonics are integer multiples of the fundamental frequency (60 Hz for the purposes of this paper), so a third order harmonic would be 180 Hz, a fifth order harmonic would be 300 Hz and so forth (see figure 1). Harmonics exist for both voltage and current, but harmonic currents are the most challenging for transformer operation. Thus, special purpose K-factor transformers are a requirement in electrical systems where harmonic-generating non-linear loads proliferate.

**Troublesome triplen harmonics**

Non-linear loads cause unwanted side effects, known as harmonic currents, within electrical system wiring and, specifically, within the transformer supplying power to these non-linear loads. The harmonic currents cause extra heat and mechanical vibration within the transformer. Before we get into some of the transformer details that address these harmonic currents, let's understand the troublesome part of current harmonics — triplen harmonics.

Triplen harmonics are generated by single-phase, non-linear loads, such as personal computers and fluorescents lights. These currents are additive to the neutral wires, connectors and bus bars. For example, if a third-order harmonic (one of the triplens), is 1 amp and this harmonic current shows up on each phase of a three-phase system, then 3 amps of 180 Hz current flows on the neutral wire and neutral bus of the transformer. This is known as the neutral current. With linear loads (those operating at 60 Hz with no harmonic activity), the neutral current is near zero, presenting little to no heat buildup on the neutral wires or the transformer neutral bus bar and associated connectors.

UL 1561 addresses the additive harmonic current issue by requiring K-factor transformers to have a minimum neutral bar rating of approximately 200% of the transformer's full load amps. As an example, a 75 kVA transformer with a 208 V AC secondary will have full-load amps of approximately 360 amps. A 75 kVA K-factor rated transformer must have a neutral bar that will safely operate at 720 amps without reaching excessive temperatures.

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01 Sinusoidal graph showing a single cycle of 60 Hz current and a few harmonic orders at lower amplitudes

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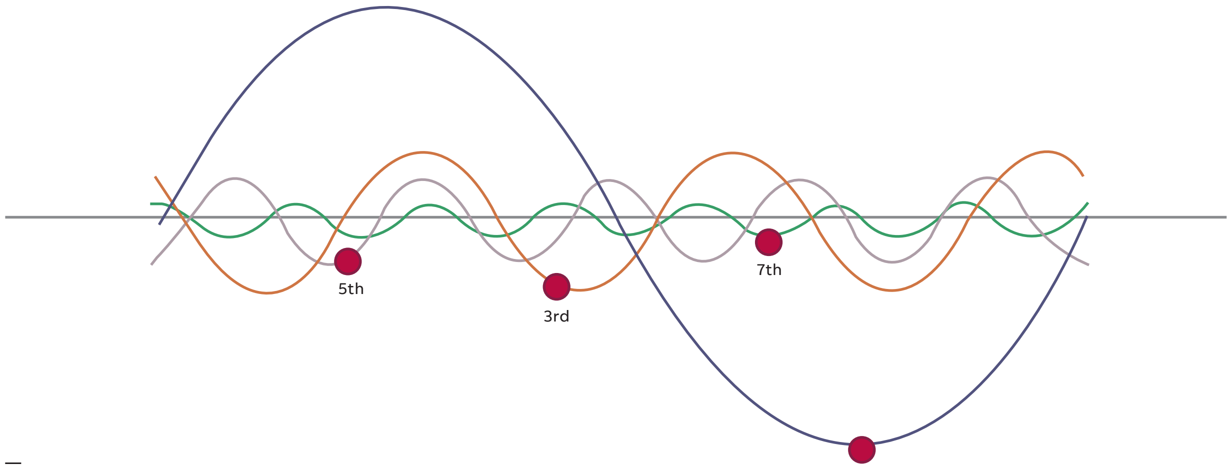
02 Typical 6-pulse SMPS sine wave signature

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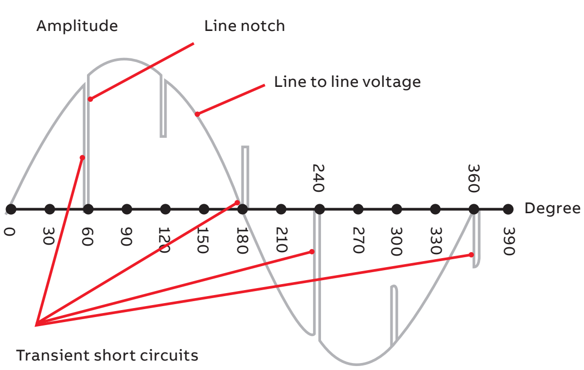
**Causes of harmonic currents**
The notching shown in figure 2 represents short bursts of current drawn from the power system, which is what allows energy-efficient operation of motors using drives. These notches provide the only power required to keep the motor running within system requirements after startup, and the motors run cooler, using less electrical energy to do the same work. However, these same power-draw notches generate harmonic activity.

A 6-pulse variable speed drive will have harmonic activity primarily at the 5th and 7th harmonic (one above and one below the pulse count, so 300 and 420 Hz, respectively). The 6-pulse drive non-linear load generates harmonic currents, which in turn generate heat in the distribution equipment, neutral conductors and distribution transformers. This is why K-factor transformers are specifically designed, tested and manufactured to operate with these harmonic currents without exceeding their temperature  rise rating.

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**Transformer design and test standards**
Most transformer manufacturers use Underwriter's Laboratories (UL) and/or Canadian Standards Association (CSA) to certify their products by evaluating the transformer designs and test results to UL 1561 and/or CSA C22.2 No. 47-13 or CSA C9-17. Several IEEE standards also apply to K-factor rated transformers, such as IEEE C57.96 and IEEE C57.110. These IEEE standards are also mentioned in the UL and CSA standards, so they are equally valid and important. All these rigorous standards apply to both general purpose and K-factor rated transformers. However, UL 1561 states a K-factor through a calculation (formula below) where h is the harmonic order, $I_h(pu)$ is the rms current at harmonic order, "h" (per unit of rated rms load current).

$$\sum_{h=1}^{\infty} I_n(pu)^2\, h^2$$

As mentioned previously, a unique and required design feature of a K-factor rated transformer is the incorporation of a double (200%) sized neutral conductor/bus bar.  Further, transformer construction changes may include a change in the geometry of their coil conductors or the use of multiple conductors for the coils. Quality transformers are manufactured with high-grade silicon (electrical, non-aging) steel, copper or aluminum coil windings and more/larger air spaces between the coil windings.

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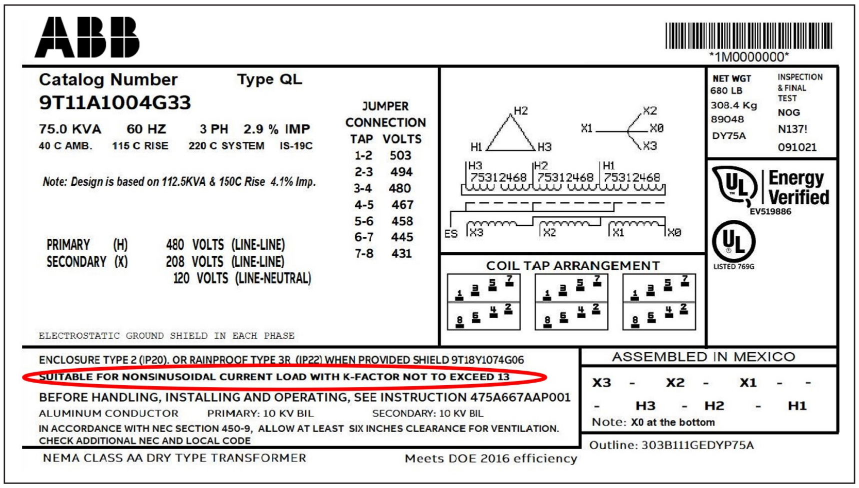
03 Transformer nameplate with K-factor rating circled in red

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**K values**

The K value is an index of a transformer's ability to withstand harmonic currents without exceeding its maximum temperature rise rating while supplying power containing harmonic content to its intended loads. K-factor values range from 1 to 50. A K-factor of 1 is mostly used for linear (60 Hz sinusoidal, see figure 1) loads. A transformer with a K-factor of 50 is installed for the harshest harmonic environment possible and is usually specified because of intimate knowledge of the harmonic signature of the loads. A K-factor of 4 or 13 is typical and is frequently specified and installed. When transformers use a K-factor value, they are said to be K-rated and this fact is stated on the transformer nameplate as shown in figure 3 circled in red.

UL has designated the K-factor as a means of rating a transformer's ability to handle loads that generate harmonic currents, and UL recognizes K-factor values of 4, 9, 13, 20, 30, 40 and 50. The K-factor ratings are based on information contained in ANSI/IEEE C57.110-2018, Recommended Practice for Establishing Liquid Immersed and Dry-Type Power and Distribution Transformer Capability When Supplying Non-sinusoidal Load Currents. The K-factor number tells us how much a transformer must be de-rated to handle a definite non-linear load or, conversely, how much it must be oversized to handle the same load.

The guidelines shown in table 1 generally result in an acceptable choice of K-factor value.

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**Table 1: General K-factor rating guidelines**

| K-factor | Description | Harmonic activity guide | Pricing |
|---|---|---|---|
| K1 | Standard transformer, general purpose, standard lighting, motors without drives | Little to no harmonic generating loads, typically <15% | Standard prices |
| K4 | Induction heating, SCR drives, AC drives | Up to 35% of loads generate harmonics | Standard price + $ |
| K13 | Institutional electronically controlled lighting, schools, hospitals, etc. | 35–75% of loads generate harmonics | Standard price + $$ |
| K20 | Data processing equipment, computer server loads, critical care facilities and hospital operating rooms | 60–100% of loads generate harmonics | Standard price + $$$ |
| K30–50 | Known loads that are consistently generating harmonics, extra K-factor strength | 100% of loads generate harmonics, known harmonic signature | Standard price + $$$$ |

**Conclusion**

It is important to note that K-factor rating is a heat-survival rating and not a treatment to lower the harmonic content from associated loads. Surviving the extra heat means using more core and coil material and, often, different construction techniques. Depending on the manufacturer's design, harmonic losses may be reduced to varying small degrees. Ironically, even though the designated use of the K-rated transformer is to feed non-linear loads, manufacturers publish their loss data under linear load conditions in order to evaluate transformer efficiency values required by governmental regulations.

Another type of transformer for non-linear loads are harmonic mitigating transformers (HMT). HMTs are designed to lower the harmonic activity from the harmonic-generating non-linear loads. The HMT, a more complex transformer, is out of scope for this paper and warrants its own technical paper.

**References**


- UL 1561 — Standard for Safety Dry-Type General Purpose and Power Transformers
- CSA C22.2 No. 47 — Air-Cooled Transformers (dry type)
- IEEE Std. C57.96 — IEEE Guide for Loading Dry-Type Distribution and Power Transformers
- ANSI/IEEE C57.110-2018 — Recommended Practice for Establishing Liquid Immersed and Dry-Type Power and Distribution Transformer Capability When Supplying Non-sinusoidal Load Currents


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