

In the last few years, there has been an increasing concern about harmonic distortion and the effects of harmonics on the power system. Nonlinear loads (such as electronic power supplies, lighting ballasts, battery chargers, motor drives, and UPS systems) are the primary source of harmonic currents. These currents, generated by the nonlinear loads, flow from the load toward the power source following the paths of least impedance.

Computer systems traditionally have been nonlinear loads. From a survey of computer power systems,⁽¹⁾ harmonic current distortions of 5.5% to 140% have been observed. Personal computers have typical harmonic current distortions of 100% to 140%.

The increased use of switched-mode power supplies along with a great proliferation of small electronic loads throughout the power system has precipitated a recent concern about high neutral currents. A number of published papers explain the high neutral currents associated with line-to-neutral power supplies.^(1,2,3,4,5)

High neutral currents in office areas have been known to overheat neutral conductors and distribution transformers without tripping the overcurrent protection. These conditions can be avoided by understanding the potential problem and designing systems to avoid or accommodate the high neutral currents. Typical steps include the elimination or oversizing of common (or shared) neutral conductors in multi-wire branch circuits; treating the neutral as a current-carrying conductor and the subsequent derating of all four-wire (three phase with neutral) circuit ampacities; and obtaining true-RMS and harmonic distortion measurements on transformer output currents so that the transformers can be derated to compensate for the additional heating effects of harmonic currents.

There is also concern about the effects of harmonics on the rest of the power system. Harmonic current flows cause additional heating in the power system components, cause voltage distortion, and may excite resonance or cause undesirable interactions in the power system. Harmonic current flows also reduce the system power factor. The harmonic distortion power factor cannot be compensated for by simply adding power factor correction capacitors. To deal with the problems associated with harmonics, some utilities are even considering a harmonic current surcharge. For these reasons, IEEE Standard 519 is being revised to specify limits to the amount of current distortion a user may inject into the utility power system.^(6,7) These limits vary from 5% to 20% total harmonic distortion (THD), depending on how large the user is relative to the capacity of the utility system.

Power system designs for data processing rooms tend to be much more conservative than designs for general office areas or typical building wiring systems where harmonic currents from electronic loads (like personal computers and terminals) have caused problems. Data processing room designs usually anticipate nonlinear loads and specify capacities accordingly. Allowances for growth and expansion may increase capacities further. A survey of computer power systems⁽¹⁾ showed that the majority are operated at less than half of their rated capacities. Operation at reduced loading improves performance, compensates for the effects of the nonlinear loads, and increases reliability and life expectancy.

Data processing rooms make frequent use of packaged power distribution units such as the Precision Power Center (PPC) made by Liebert Corporation. PPCs provide electrical isolation, voltage stepdown, controlled power distribution and grounding to the computer loads, and monitoring of the electrical parameters. Additionally, PPCs have a number of standard and optional features which specifically allow them to tolerate and control the harmonic currents of computer systems.

The characteristic harmonic current content of a computer power supply depends on whether it is connected line-to-line or line-to-neutral. In typical data processing rooms, there will be a mixture

of power supplies, along with other linear loads such as fan motors. The result is a lower harmonic current distortion for the full room because of additional 60 Hz current from linear loads and the cancelling of the out-of-phase components of the individual harmonic currents. Typical harmonic current distortions for data processing rooms are 30% to 60%. Table 1 describes the typical harmonic current components of individual line-to-neutral and line-to-line power supplies, as well as for a typical data processing room as a whole. Currents are normalized to one amp RMS for comparison purposes.

Table 1.
Harmonic Current Components in a Typical Data Processing Room

	Line-to-neutral power supplies (amps)	Line-to-line power supplies (amps)	Full room (amps)
Fundamental	0.65	0.82	0.92
3rd harmonic	0.52	0.0	0.26
5th harmonic	0.42	0.49	0.23
7th harmonic	0.29	0.29	0.13
9th harmonic	0.13	0.0	0.06
11th harmonic	0.12	0.074	0.06
13th harmonic	0.098	0.033	0.04
Total (RMS)	1.0	1.0	1.0
THD	116%	70%	42%
Ratio of neutral to phase current	1.61	0.0	0.80
Distortion power factor	0.65	0.82	0.92
Typical standard transformer derating	69-79%	71-81%	88-93%
K-Factor	16	12	5

The effects of nonlinear loads on transformers are described in ANSI/IEEE Standard C57.110-1986.⁽⁶⁾ Using this standard, the transformer derating is equal to:

$$\sqrt{\frac{1 + (P_{ec-r})}{1 + \frac{\sum I_h^2 h^2}{\sum I_h^2} \times (P_{ec-r})}}$$

where P_{ec-r} is the maximum transformer winding per unit eddy current loss (typical values for 15-225 kVA transformers are 0.05-0.10); I_h is the load current at harmonic h normalized by dividing by the fundamental (60 Hz) load current; and h is the harmonic frequency number, e.g., 1, 2, 3, The harmonic current content of the load must be known. As the formula shows, the increased loss (heating) of the transformer is proportional to the square of the harmonic current frequency.

Typical transformer deratings are given in Table 1 for the three different nonlinear loads -- line-to-neutral, line-to-line, and some combinations of the two as represented by the whole room. The

deratings are based on typical dry-type distribution transformer, convection cooled, and 40°C maximum ambient. For example, a 75 kVA building distribution transformer supplying power to all line-to-neutral power supplies should be loaded to only 69% to 79% of capacity (52-59 kVA). While line-to-neutral power supplies have received much attention because of their associated high crest factors (peak currents) and high neutral currents, line-to-line power supplies, which have normal crest factors and no neutral current, also require transformer derating.

PPCs are designed for use with nonlinear loads in data processing rooms. They are tested to UL standards based on 40°C ambient and convection cooling. In a typical data processing room, the ambient temperature is maintained at less than 25°C and a pressurized raised floor effectively provides forced-air cooling. In these applications, the standard PPCs can power nonlinear loads without derating. Additionally, all common neutral wiring in PPCs is rated for 1.73 times full load current to accommodate the high neutral currents associated with line-to-neutral power supplies.

Because of the increasing incidence of building distribution transformers being overheated by nonlinear loads, UL introduced a transformer nonlinear load rating system in UL1561, called K-Factor, which is based on C57.110. K-Factor is a weighting of the harmonic load currents based on their heating effects on dry-type transformers. A K-Factor of 1.0 indicates a linear load. The higher the K-Factor, the greater the harmonic heating effects. Transformers designed to accommodate the additional heating effects of particular levels of harmonic currents can be certified under UL1561 as having a particular K-Factor rating. Standard ratings are 1, 4, 9, 13, 20, 30, 40, and 50. Individual loads with K-Factors greater than 20 have not been widely observed. Computer rooms have been observed to have K-Factors of 4 to 9. Areas with high concentrations of single phase computers and terminals have observed K-Factors of 13 to 17.

For applications where high levels of nonlinear loads are anticipated, PPCs can be equipped with K-20 rated transformers. Again, the UL ratings are based on 40°C ambient and convection cooling. When used in a typical data processing room, significant improvements in operating margins are obtained.

PPCs are also available with an optional load distortion filter. The filter is connected on the transformer secondary to absorb harmonic currents generated by the computer system. This reduces the amount of harmonic current that flows through the transformer and to any upstream components. The results are less transformer heating, increased capacity for nonlinear load, lower input current distortion, and 60 Hz power factor compensation.

For applications in which harmonic current distortions must be minimized, PPCs can be furnished with specially designed transformers having multiple output windings which are phase shifted. With similar nonlinear loads connected to the multiple windings, non-triplen (5th, 7th, etc.) harmonic currents can be cancelled in the transformer. This is in addition to the normal cancelling of the triplen (3rd, 9th, etc.) harmonic currents in the delta winding.

PPCs are designed with individually enclosed and protected 42-pole 225 amp output panelboards for safety. Each panelboard has its own neutral and ground accessory. The total number of poles needed by a power distribution unit for data processing rooms has been observed to be between 0.6 and 1.25 poles per kVA.⁽⁹⁾ Using a one-pole-per-KVA average for line-to-neutral loads, the number of 225 amp panelboards required for full load is shown in Table 2.

Table 2.
Typical Power Center Panelboard Capacity

kVA size	Full load amps (FLA)	No. of panelboards	No. of poles	Total panelboard amps	Neutral capacity (% of FLA)
15	42	1	42	225	536

30	83	1	42	225	271
50	139	2	84	450	324
75	208	2	84	450	216
100	277	3	126	675	244
125	347	3	126	675	195
150	416	4	168	900	216
200	555	5	210	1125	203
225	625	6	252	1350	216

Overcurrent protection for transformers feeding nonlinear loads requires additional consideration. The National Electric Code allows primary-only overcurrent protection set at 125% of the transformer's rated primary current. However, since the balanced triplen harmonic currents (3rd, 9th, 15th, etc.) are cancelled in the delta winding of a delta-wye transformer, the transformer output current can exceed full load rating without exceeding rated input current. For example, with a load of one amp per phase of the line-to-neutral power supply current given in Table 1, assuming an ideal transformer with a 1-to-1 turns ratio and no losses, the transformer input current would be only 0.84 amps per phase. The output load current would reach 119% of full load before the input current could reach rated full load current. Additionally, the increased heating effects of the harmonic currents further overload the transformer. Therefore, supplemental overcurrent protection of transformers supplying nonlinear loads is necessary. Adding transformer secondary overcurrent protection still does not adequately protect the transformer from the additional heating effects of the harmonic currents.

PPCs are provided with supplemental overcurrent protection of the transformer in the form of temperature sensors in each of the three coils of the transformer. These temperature sensors trigger, first, an alarm and, second, system shutdown in the event of transformer overheating caused by overcurrent, excessive harmonic current, high ambient temperature, or inadequate cooling air flow.

Some of the premature failures of building distribution transformers that are blamed on the harmonic currents of line-to-neutral power supplies are actually the result of overloading due to inadequate monitoring and metering. True-RMS (root mean square) metering is required to give accurate measurements of nonlinear currents. Many of the analog clamp-on ammeters in widespread use are not true-RMS meters and can understate the RMS current of single phase power supplies by as much as 99%.⁽¹⁰⁾ For example, for a true-RMS load current of 199 amps, the ammeter indicates only 100 amps. Using non-RMS meters to measure the transformer's current results in an incorrect assessment of the transformer's loading. Additionally, monitoring of the transformer loading is usually sporadic at best, allowing overloaded transformers to go undetected until they fail.