Countering the Heating Effects From Troublesome Harmonics

This project proves you can overcome long horizontal runs and moderate levels of harmonics to provide reliable power

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When designing dense 120V power distribution systems, it's important to take into consideration harmonics and their resulting voltage drop and I²R heating effects, which can affect step-down transformers and feeder distribution wiring methods.

SASCO was the design/build electrical contractor on a fast-paced project to renovate an existing six-story, 750,000-square-foot manufacturing facility to provide for four towers of office structures. We reviewed the schematic level documents and took into account at the value engineering stage the possibility of harmonic-related problems and evaluated different wiring methods from the standpoint of good design and cost. The following is the result of this evaluation.

Step-down transformers. In our design evaluation process, we looked at traditional office distribution systems, where 480/277V power is distributed to locally mounted 480V delta-208 wye/120V, 3-phase, 4-wire transformers, with 277V fluorescent lighting used throughout. In this scenario, the triplen harmonic heating component typically isn't a problem on the distribution system ahead of the step-down transformers. However, it's a problem for the step-down transformers themselves. Any triplen harmonics (3rd, 9th, 15th, etc.) that flow in the neutral will reside in the delta winding of the step-down transformer. The harmonic currents will then circulate in the primary winding of these transformers and create heat.

While evaluating the proposed schematic design, we considered using K-factor transformers to combat this heating effect. These transformers differ in construction from standard dry-type

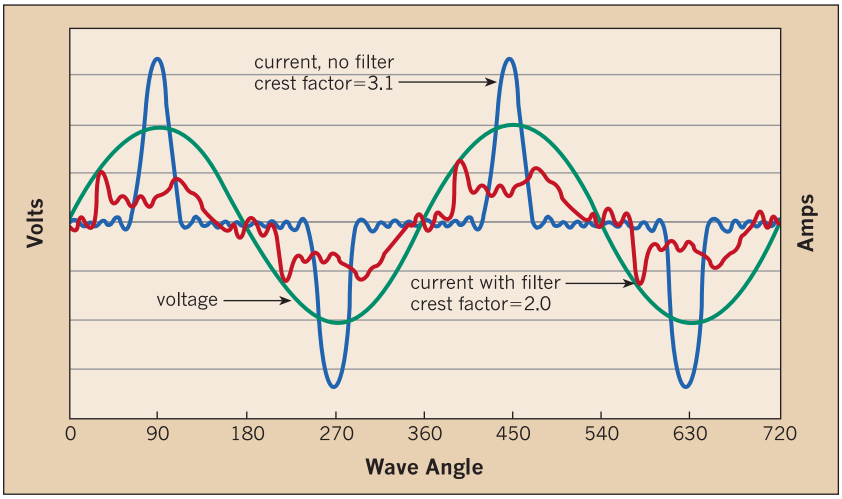

Diagram courtesy of Harmonics Limited

Fig. 1. These current plots show harmonic distortion with and without a filter.

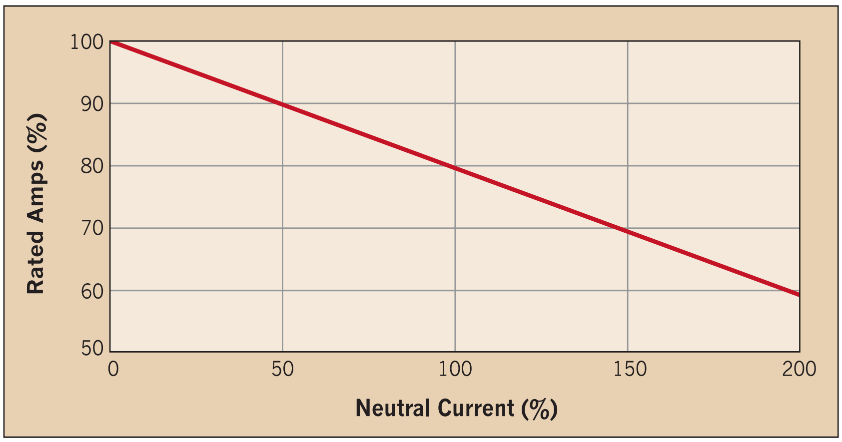

Diagram courtesy of GE Co.

Fig. 2. As neutral current loading increases, busway derating factor decreases.

transformers in that they're built to handle the extra heating. In other words, K-factor transformers can handle harmonic currents at or near capacity without the need for derating, which was the basis for this design option. Construction features include the following:

- Electrostatic shielding between the primary and secondary windings of each coil.
- Neutral conductor lug sizing that's twice that of the phase conductor lugs.
- Parallel smaller windings on the secondary to negate skin effect from high frequency currents.
- Transposition of primary delta winding conductors (in large size units) to reduce losses.

The proposed schematic design and second design option was to use harmonic mitigating transformers, which include both harmonic suppression technology and an electrostatically shielded transformer. Because they operate completely passively, they contain no electronic or switching elements, which means they use no power in operation and affect only those loads connected to them. They also limit the amount of current distortion (Fig. 1 on page 20). The benefit of this option was that the triplen harmonics would be eliminated from the secondary power distribution system.

The triplen harmonic heating component in a traditional office distribution system is a problem for step-down transformers.

Feeder wiring methods. Pipe-and-wire distribution was another value-engineering option we evaluated on this project. By increasing the size of feeder neutral conductors, you lower their impedance, thus reducing problems related to phase-to-neutral nonlinear loads. The 2005 NEC warns about problems with neutrals in the following sections:

- 210.4(A), Multiwire Branch Circuits, FPN
- 220.61(C)(2), Feeder Neutral Load, FPN 2
- 310.4, Conductors in Parallel, Ex. 4 FPN
- 310.10, Temperature Limitations of Conductors, FPN 1
- 310.15(4)(c), Ampacities for Conductors Rated 0-2000 Volts

This last section forces you to derate the ampacity of all conductors in a 4-wire circuit in a raceway by 20%. You may also

Photo 1. Using harmonics-mitigating 300kVA transformers with 1,200A busway proved to be the most cost effective solution.

Photo 2. Pipe and wire from the transformers led to a 1,200A disconnect, shown here from the side to reveal the transition to 1,200A busway.

need additional derating in cases where the addition of the neutral as a current carrying conductor pushes the assembly to the next level of required derating. This is dictated via adjustment factors listed in Table 310.15(B)(2)(a) of the 2005 NEC.

We also thought about offsetting the potential for de-rating by using 90°C rated conductors when derating based on the number of current carrying conductors. According to 110.14 (C), "Conductors with temperature ratings higher than specified for terminations shall be permitted to be used for ampacity adjustments, corrections or both." This would allow us to use the pre-derated ampacities of the 90°C column of the feeder and branch-circuit wiring sizes per Table 310.16.

A second option was to use oversized busway on the secondary side of the K-rated transformer, whose current carrying capacity is a function of heat rise, not cross-sectional area. With busway, the harmonics found in the neutral current heat up the entire busway assembly, so we would have to derate the phase and neutral conductors. With conventional pipe-and-wire distribution, the NEC only allows insulated conductors to occupy up to 40% of the area of the conduit. If

Photo 3. Plug-in style 1,200A busway and cable tray allowed for greater flexibility for future remodeling projects.

Photo 4. The plug-in style distribution also made it easier to manuever around obstacles like these drop clouds (suspended panels at right).

these fill ratios are met, the heat from the neutral conductors doesn't affect the current carrying capacity of the phase conductors. In the pipe-and-wire method, only the neutral needs to be oversized. As you can see from Fig. 2 on page 20, at 173% for the neutral current (theoretical maximum under worst case condition with rectifier conduction angles of 60°C), we would have to derate the entire busway assembly to 65%. This would essentially mean using 2,000A busway in lieu of the proposed 1,200A busway (2,000A × 0.65 = 1,300A).

On our project, each half tower required 300kVA for the 208Y/120V 3-phase, 4-wire distribution. Normally, this would result in a 1,200A busway on the secondary side of each 300kVA transformer. But to supply power to the harmonics-producing loads we would

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have to size the busway at 2,000A, based on derating requirements. This was a big deal because in a typical pipe-and-wire distribution we would have to oversize only the neutral. In a busway distribution system, we would have to oversize the entire assembly.

Final design solution. After running several price comparisons, it became apparent that harmonic-mitigating 300kVA transformers with 1,200A busway was more cost effective than providing K-13, 300kVA transformers with 2,000A busway (Photos 1 and 2 on page 22). As noted above, the harmonics-mitigating transformer removes the 3rd harmonic in the neutral, eliminating the need for oversized busway. We also decided to use "plug-in" style busway, which will provide greater flexibility for all future remodels (Photos 3 and 4 on page 22 and Photo 5 on page 24).

Life cycle cost savings was another consideration for the use of the harmonics-mitigating transformers. While suppressing the harmonic current at the source, these transformers also provide for life cycle efficiencies. In addition to reducing the total harmonic distortion and neutral current, this technology increased the number of computer loads that could be carried per circuit, reduced I^2R heat losses in the transformer and in building wiring, and decreased air conditioning expense resulting from the need to remove I^2R heat from the circulating 3rd harmonic in the delta windings of traditional transformers. The design also achieved real power-cost savings due to reduced I^2R heating that will apply for the life of the building.

This project required a unique electrical distribution system that would provide reliable and flexible power distribution over long horizontal runs in an environment with moderate levels of harmonics. Through an understanding of the effects of harmonics and the applications of appropriate technologies as well as providing in-depth cost analysis, SASCO was able to provide the client the most efficient solution. EC&M

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Photo 5. Circuit breaker bus plugs feature an easy-to-read position indicator, which allows maintenance personnel to quickly access system status.