

[Schneider Electric Case Study]

Neutral conductor and transformer overload issues

United States



Harmonic concerns at a battery charging plant

In Brief

Goal

To better understand the impact of harmonics on the 600 V bus duct and 2500 KVA transformer.

Solution

Use PowerLogic meters combined with StruxureWare Power Monitoring Expert software to calculate the true capacity of the facility's transformer. This information helps to solve problems with neutral overloads and transformer heating.

Results

- New bus duct purchased with a neutral ampacity of 100%.
- Temporarily shared harmonic loading between two transformers
- Avoided millions of dollars in damaged product and lost sales.

Background

The plant engineer at an automobile battery charging facility needed to replace the aging 600 V bus duct in the plant. He was struggling with conflicting claims that the replacement system needed a 200% neutral. He knew that battery chargers produce significant amounts of harmonic currents, but was it necessary to specify 200% neutrals and pay the price premium?

As if the neutral issue wasn't enough, the subject of harmonic currents led to a discussion of transformer loading: what are the effects of these harmonic currents on the 2500 kVA transformer serving the battery charging circuits?

With this dual concern about harmonic distortion, the plant engineer turned to Schneider Electric for help. Fortunately, his plant is equipped with Schneider Electric PowerLogic meters at the 2500 kVA transformer. Figure 1 shows a four-cycle captured waveform from these meters. As the plant engineer suspected, both voltage and current were badly distorted.

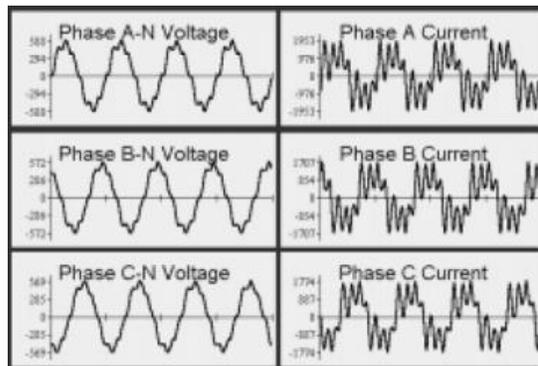


Figure 1: 4-cycle captured waveform illustrating voltage and current distortion.

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Key Concepts and Terms

Neutral currents

A widely-discussed concern with harmonic-producing loads is that they cause overloaded neutrals. These overloads occur because single-phase, 120 V power electronic devices produce harmonic current which does not cancel on a shared neutral conductor. Because they operated under the cancellation premise, outdated wiring systems allowed shared neutral conductors to be smaller than phase wires in 3-phase circuits. The problem was worsened by the fact that the neutral conductor, which was not protected by circuit breakers or fuses, could fail even when phase conductors were not overloaded.

Figure 2 shows the neutral current resulting from a circuit loaded with personal computers. The maximum amount of neutral current for a personal-computer load is 173% of the phase, although few systems reach this theoretical limit. For badly distorted phase currents (above 32%), the highest neutral currents occur with well-balanced phase currents. This is exactly the reverse of the harmonic-free state. Without harmonics, the current load on a shared neutral conductor is related to the amount of unbalance among the phase conductor currents.

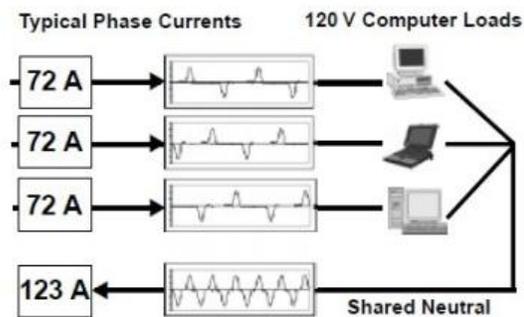


Figure 2: Normal current on a circuit loaded with personal computers.

So, why aren't commercial buildings burning to the ground all over the country? To answer this question, the National Electrical Code (NEC) formed an ad hoc committee to investigate the need for oversized neutrals. The committee found that neutrals sized to the same ampacity as phase conductors are overloaded in only about 5% of the cases. This is due, in part, to the fact that few 208/120 V systems operate at their fully rated capacity. Even if the neutral current exceeds the phase current, the conductor ampacity is not exceeded.

The second reason for the small number of actual failures is explained by another NEC requirement for phase wires. This rule says that phase conductors (and overcurrent protective devices) cannot be sized smaller than 125% of their continuous load. Since the neutral is sized the same as the phase conductor in most cases, the real current-carrying capacity of the neutral is 125% of the continuous current in the phase wire.

Transformer loading

Standard transformers are designed to supply their full rated capacity under limited harmonic conditions. The standard to which power transformers are designed says that they will transmit rated load at rated temperature rise when:

- Energized from voltages with less than 1% total harmonic distortion (THD)
- Serving loads with less than 5% THD current

In today's electronic world, these two conditions are often exceeded. The problem is assessing the effects of high harmonic distortion on standard transformers.

When transformer windings carry ac current, each conductor is surrounded by an ac magnetic field whose strength is directly proportional to the magnitude of the current. Each metallic conductor linked by the flux experiences an internal voltage that causes eddy currents to circulate in the conductor. The eddy currents are dissipated in the form of heat, producing an additional temperature rise in the conductor. This type of extra loss in the windings is referred to as *eddy-current loss*.

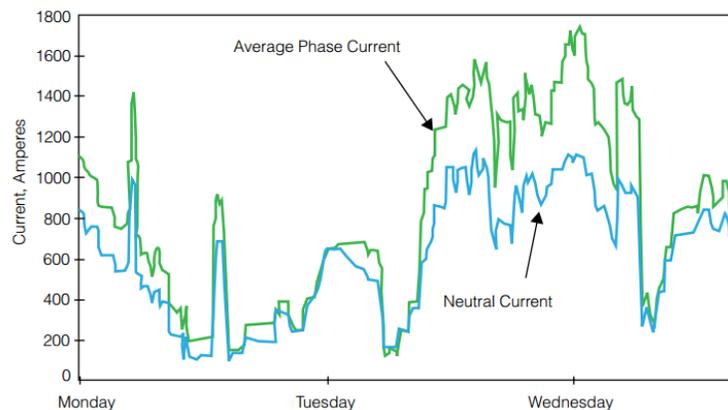


Figure 3: Average phase current and neutral current of a 2500 kVA transformer.

Eddy-current loss

Eddy-current loss in winding conductors is proportional to the square of the load current that produces the field, and to the square of the ac frequency of the current. Since harmonic currents contain high frequency components, the eddy-current losses associated with harmonics can cause a transformer's design temperature rise to be exceeded before its nameplate kVA rating is reached.

The solution

The plant engineer was correct to be concerned about the effects of harmonics on the proposed bus duct. However, the maximum neutral current at his plant does not exceed the phase current. In fact, there are no commercially available loads which contain enough triplen (multiples of three times the fundamental frequency) harmonic currents to require more than 100% neutrals at the 480 V level or above. The neutral overloading issue is limited to 208/120 V switch-mode power supply loads such as personal computers.

Schneider Electric verified its analytical predictions with actual data from the battery charging plant. Schneider Electric services engineers downloaded the meter data through a secured internet connection from LaVergne, Tennessee. Figure 3, on page 4, shows the average phase current and resulting neutral current as measured at the 2500 kVA transformer. Note that the neutral current does not exceed the average phase current.

Table 1 illustrates the neutral current makeup. These readings were obtained from StruxureWare Power Monitoring Expert software.

| Total Phase | Current | H1 | H3 | H5 |
|-------------|---------|-----|-----|-----|
| A | 1093 | 844 | 281 | 253 |
| B | 997 | 796 | 233 | 217 |
| C | 1036 | 862 | 278 | 250 |
| Neutral | 804 | 50 | 793 | 26 |

Table 1: Neutral Current Makeup (Amperes,)

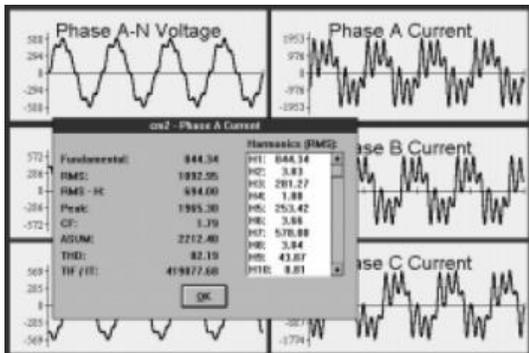


Figure 4: Four-cycle waveform capture from StruxureWare Power Monitoring software.

Note that the fundamental neutral current (H1) is small compared to the phase fundamental currents. The fundamental component of the phase current almost cancels on the shared neutral. The fundamental current on the neutral represents the unbalance of the fundamental component on the phase wires. The fifth harmonic component (H5) also represents the unbalance of H5.

The third harmonic component (H3), however, adds on a shared neutral. In fact, the predominant component on the neutral is third harmonic, or 180 Hertz. As figure 5 shows (on page 6), the neutral current frequency is three times that of the phase current.

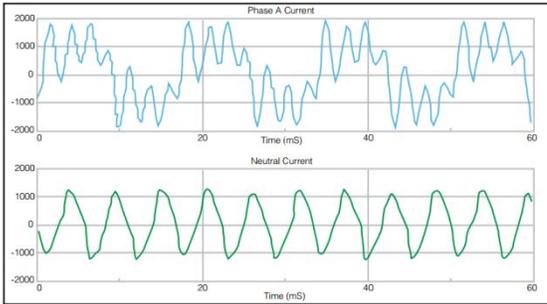


Figure 5: Badly distorted phase current (upper) at battery plant contains triplen components that show up on the shared neutral (lower).

IEEE/ANSI Standard C57.110-1986 offers a method to calculate transformer life of harmonic currents above 5%

If you are concerned about neutral overloading on a 208/120 V circuit, what should you do? One common solution is to increase the neutral current-carrying capacity. You can accomplish this by running a separate neutral wire for each phase wire, thus eliminating shared neutrals. Another way of increasing the neutral ampacity is to replace a shared neutral with one rated for 200% of the phase current. You may need to increase the neutral buses on panel boards and transformers, too, but keep in mind that only 4-wire, 208/120 V circuits are subject to neutral currents that exceed phase currents. While the neutral concern is easy to verify with power monitoring, the transformer loading issue is more complicated. IEEE/ANSI Standard C57.110-1986 offers a method to calculate the effect on transformer life of harmonic currents above 5%. The method has been used to de-rate a standard transformer based on the amount of harmonic current it must transmit; but de-rating a standard transformer is not recommended as a permanent solution.

Using an estimated eddy-current loss based on the battery plant transformer type and design, Schneider Electric calculated the true capacity of the transformer. Since the harmonic loading changes continuously, the estimated capacity of the transformer changes proportionately. Figure 6 (page 7) illustrates the results of the calculation.

The best method for dealing with harmonic currents in power transformers is to install power transformers designed to transmit more than the 5% current THD limit. K-factor transformers are manufactured for this purpose.

The k-factor rating is related to the harmonic content of the expected load. In fact, it is calculated from the harmonic current measured in the load. Certain PowerLogic meters perform this calculation for you.

K-rated transformers typically have additional coil capacity to reduce eddy-current losses. They are typically wound 480 V delta primary and 208/ 120 V secondary, with an electrostatic shield, and reduced core flux to compensate for harmonic voltage distortion. Since these transformers usually serve computer loads, they also contain double-size neutral terminals to accommodate extra neutral wires. The higher the k-rating, the more harmonic current the transformer can transmit; k-4 or k-13 ratings are adequate for most circuits.

Conclusion

After the Schneider Electric assessment, the plant engineer felt comfortable purchasing new bus duct with a neutral ampacity of 100%. At 600 V, the battery charging circuits do not inject enough triplen currents to cause excessive neutral loads. Shared neutrals serving 208/120 V circuits, however, can be subjected to currents which exceed the phase current. While it is good practice to maintain well-balanced 3-phase circuits, the neutral problem cannot be solved by improving the current balance among the phase conductors. Better balance only increases the neutral current for badly distorted phase currents.

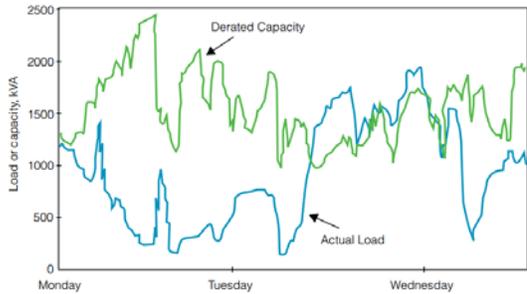


Figure 6: Schneider Electric calculation, illustrating the true capacity of the transformer.

Dealing with the transformer loading issue was more difficult. As a stopgap measure, the plant engineer closed a tie circuit breaker on this double-ended substation (to share the harmonic loading among two transformers). This temporarily reduced the overloading concern, but can lead to worse problems and is generally not recommended. The plant has not decided on a long-term solution. The only certainty is that catastrophic failure of transformers or bus duct would cost millions of dollars in damaged product and lost sales. Facing that economic risk, the plant will most certainly decide on a permanent solution.

Further reading

Visit the technical library at:

<http://www.schneider-electric.com/site/home/index.cfm/us/>

One document in particular gives more information about harmonics and neutral currents.

- *Neutral Currents in Three Phase Wye Systems*, order number 0104ED9501

Test your PQ (Power Quotient)

Test your understanding of the information. The answers are below.

1. K-factor is a measure of the harmonic current-carrying capacity of a transformer.
2. Neutral conductors should always be sized for 200% capacity.
3. Only triplen harmonic currents (common to computer loads) add on a shared neutral.
4. De-rating a standard transformer is the recommended solution for high harmonic loads.

Answers

1. True. Page 4.
2. False. Only 208/120 V circuits with shared neutrals serving computer loads are subject to neutral currents that exceed phase currents.
3. True. Other balanced harmonic currents cancel on a shared neutral.
4. False. The best solution to excessive transformer heating is to replace the standard transformer with a k-rated transformer properly sized for the harmonic load.