Energy Savings through the Application of Neutral Harmonic Filter: A Case Study

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Abstract: it is established that neutral and ground harmonic content will load transformers and systems. Prior work has been limited as to the direct relationship of this additional loading on power consumption for a facility. Over the past 24 months applied research has been performed on the measured impact of neutral and ground harmonics and energy consumption in commercial and industrial facilities. In this paper we will discuss the application of an Onics Neutral Harmonic Filter in a single panel at a facility and the change in energy consumption before and after installation, as well as changes over a two-month period in similar loading conditions. Data collection for comparing neutral harmonic content was performed with an EMPATH™ data collection system.

Key Words: harmonics, neutral, electrical reliability, Onics, EMPATH, ESA, Power Quality

INTRODUCTION

A traditional view of the loads on neutral relate to voltage and load unbalance and triplen, or zero sequence harmonics. Theoretically negative (5th) and positive (7th) sequency harmonics negate each other resulting in zero current from this harmonic content.[1] The losses associated with these conditions are significant as outlined by Neagu, Georgexcu, and Ivanov[2] from just the 3rd harmonic content. Additional concerns are identified as voltage differences between neutral and ground in which the noise will impact the operation of electrical and electronic systems.[3]

In power systems the losses that gather on ground can also generate problems for bearings in electric machines. Primarily an effect of noise in ground, the neutral point in a wye connected electric motor will generate shaft voltages that will result in damage to the bearings.[4] Aging insulation systems, overloaded transformers, and other conditions all relate to increased harmonic content and other referenced voltage and current noise in ground and neutral.

While reliability impact of systems is well known related to harmonic distortion and correction, the application of harmonic filters for energy reduction has received limited attention. An EPRI study published in November 2000, does identify the potential for energy savings in both power and neutral harmonic filters.[5] One of the solutions for managing neutral currents from harmonics identified in the

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[1] G. Chicco, P. Postolache and C. Toader, "Analysis of Three-Phase Systems with Neutral Under Distorted and Unbalanced Conditions in the Symmetrical Component-Based Framework," in IEEE Transactions on Power Delivery, vol. 22, no. 1, pp. 674-683, Jan. 2007, doi: 10.1109/TPWRD.2006.887095.
[2] B. C. Neagu, G. Georgescu and O. Ivanov, "The impact of harmonic current flow on additional power losses in low voltage distribution networks," 2016 International Conference and Exposition on Electrical and Power Engineering (EPE), 2016, pp. 719-722, doi: 10.1109/ICEPE.2016.7781433.
[3] J. C. Balda, A. R. Oliva, D. W. McNabb, and R. D. Richardson, "Measurements of neutral currents and voltages on a distribution feeder," in IEEE Transactions on Power Delivery, vol. 12, no. 4, pp. 1799-1804, Oct. 1997, doi: 10.1109/61.634208.
[4] T. Katayama, T. Ogitsu, H. Kokumai, H. Takemura, T. Nakayama and H. Mizoguchi, "Study on effect of neutral voltages on shaft voltages causing bearing currents," IECON 2013 - 39th Annual Conference of the IEEE Industrial Electronics Society, 2013, pp. 4690-4693, doi: 10.1109/IECON.2013.6699892.
[5] B. Banerjee, “Power Quality Mitigation Technology Demonstration at Industrial Customer Sites: Industrial and Utility Harmonic Mitigation Guidelines and Case Studies,” Report 1000566, EPRI, Palo Alto, CA, 2000.

study included increasing the size of neutral conductors, or placing neutral conductors in parallel. A solution for mitigation identified in the study included the application of a neutral harmonic filter.

The Onics filter solution as shown in Figure 1, is a passive parallel neutral harmonics filter. The system is tuned as a low-pass filter which may not always reduce the amount of current present on ground or neutral but will reduce noise and zero-crossings. The leads are connected in parallel to the neutral loads and one lead is connected to ground. The system can also be connected across ground to clean ground noise.[6]

Figure 1: Onics neutral harmonics devices installed at panels.

Monitoring can be set up on the incoming side of the revenue meter, or in a sub, to validate energy improvements using such devices as the ECMS-E1 (Figure 2), or periodically sampled using an EMPATH data collector. The EMPATH systems are Electrical Signature Analyzers that are normally calibrated to <0.1% (1% guaranteed) which provides a Revenue Grade Equivalent of 0.2. The basis for an ESA continuous analyzer or data collector is a power analyzer in which energy measurements, power quality, and even condition of associated transformers is maintained.[7]

[6] https://www.onicsenergy.com
[7] https://empathcms.com

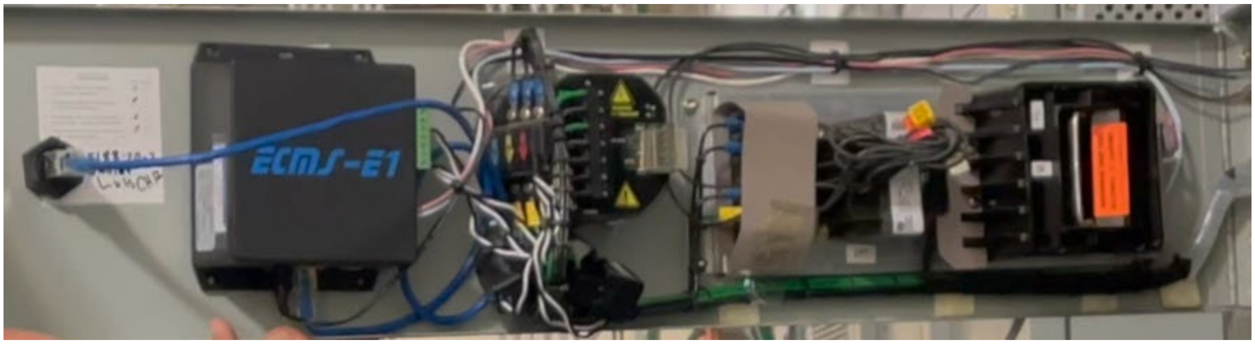

Figure 2: an ECMS-E1 with CTs and connected to control voltage at a sub relay meter.

In this paper we will discuss the application of a single Onics filter at a small facility with periodic data collection performed under same load conditions. The facility is located in Providence, RI, and had both variable frequency drives and energy efficient lighting installed. Reportedly there were no identifiable savings involved in the application of the efficient devices at which point measurements were taken with an EMPATH analyzer on the neutral.

INITIAL EVALUATION

Initial data was collected on the neutral of the distribution panel fed from the utility transformer. The data collected was found as Figure 3 and is found as a high harmonic condition at a fundamental of 60 Hz with a 3rd harmonic distortion in current of 94% as well as a 5th, 7th, 9th, 11^{th,} and 13th harmonic. The unbalance of the related 5th and 7th indicate that additional energy is lost due to the negative sequence harmonics. The neutral current was measured as ~23 Amps.

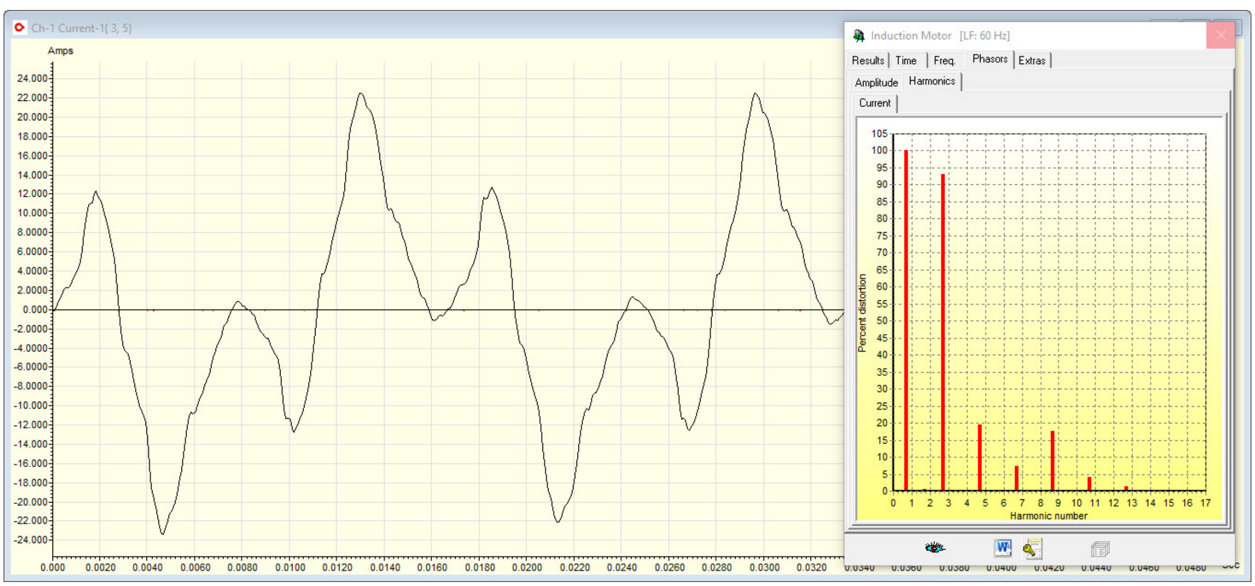

Figure 3: initial reading prior to the installation of the Onics neutral harmonic filter.

The Onics filter was installed on the primary lighting panel that fed the VFD, front office computers and lighting, and a store front.

POST INSTALLATION OF ONICS DEVICE

Immediately upon installation of the Onics device the value of the neutral harmonics was measured under identical load conditions. The neutral current appeared as shown in Figure 4. The waveshape changed significantly and harmonic content was reduced which directly impacts the losses.

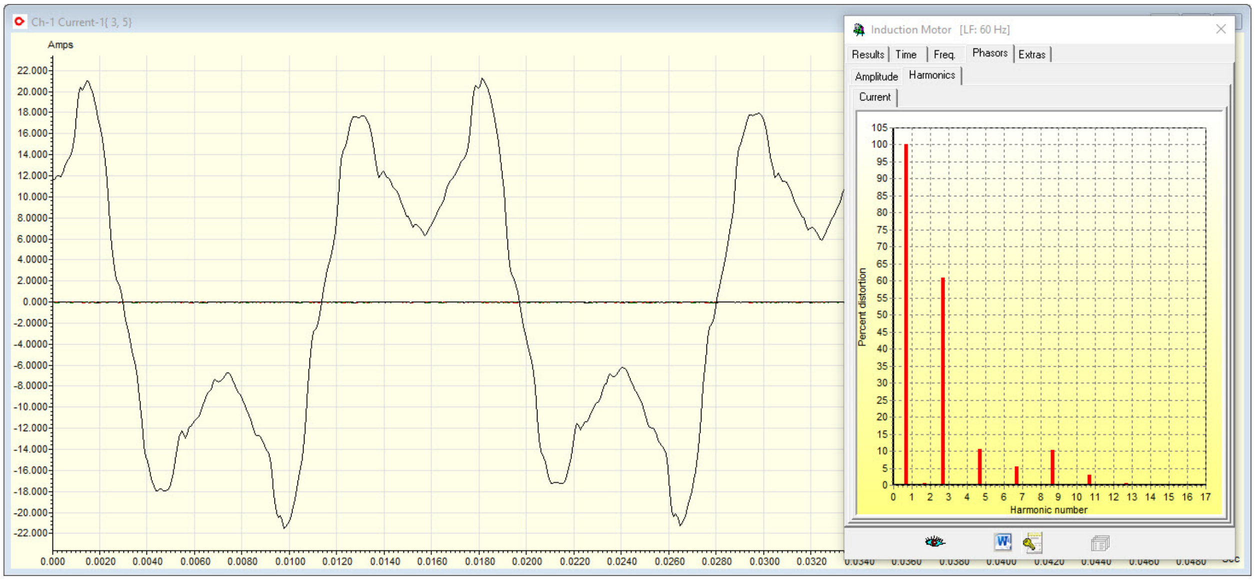

Figure 4: current peak drop to 21 amps peak and change in waveshape. Reduction of all harmonic values.

After 24 hours another data set was collected at the neutral during the same time of day and under the same conditions and loads. As shown in Figure 5, total current continued to decrease as did the harmonic content. In an unusual case, the remaining content is all 3rd harmonic and related.

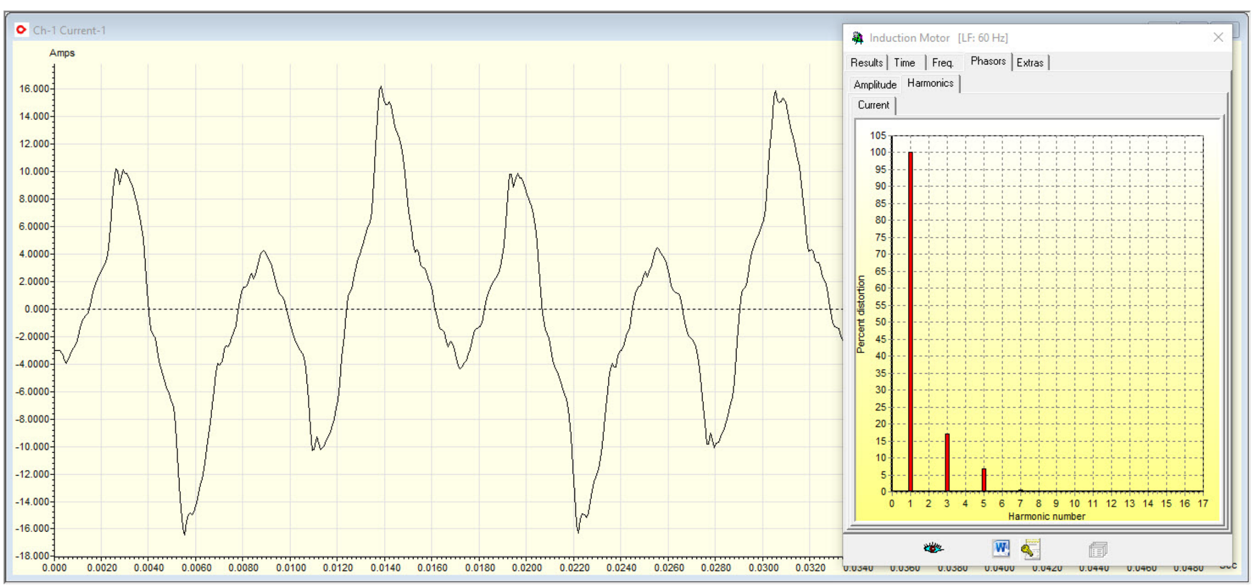

Figure 5: 24 hours after application. In an unusual case, the fundamental is the 3rd harmonic, and the remaining harmonics are all related to third harmonic. 5th and 7th are no longer present and the peak current is less than 16 Amps peak.

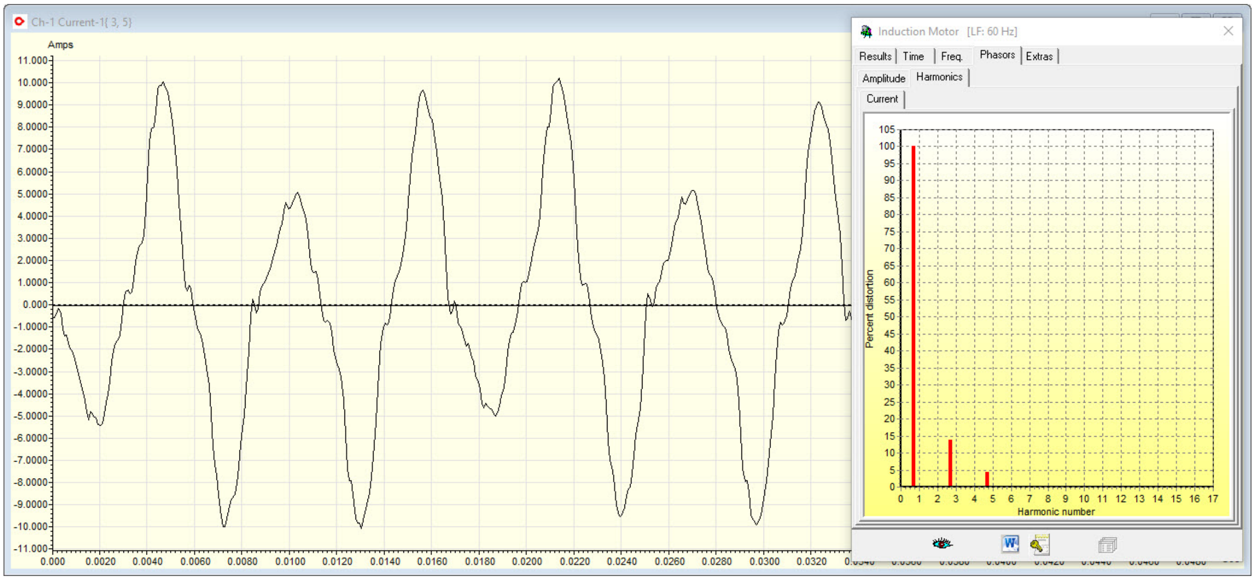

Figure 6: two months later. Current continues to drop and all remaining content is related to third harmonic but is consistent.

As noted in Figure 6, all remaining content is drawing less current, is all 3rd harmonic, and has a peak of 10 Amps or less in the same load conditions. It is suspected that the new energy efficient lighting system is causing a majority of the deep third harmonic.

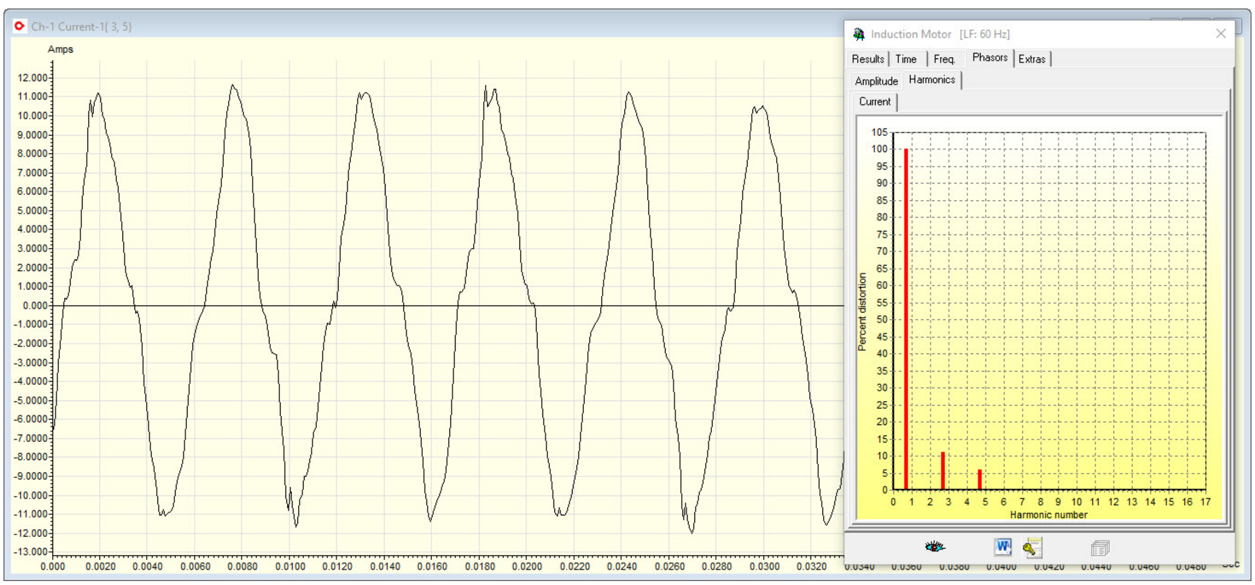

Figure 7: two weeks following Figure 6. Peaks are all the same height, but still all 3rd harmonics.

In Figure 7, in the same loading conditions, the current remains at multiples of third harmonic with consistent peak values of 11 Amps peak. This is a reduction by more than half the current in the neutral which also results in a reduction of loading in the transformer and overall kWh consumed during the period of operation.

ENERGY SAVINGS COMPARISON TO PRIOR YEAR

During the same period in 2021, the offices at this location were lightly occupied. During the installation of the technology and follow-up, the office was fully staffed. The average temperature in June 2021 was 71.4 F and in July 2021 was 72.1 F; in 2022 these temperatures were 67.8 F and 76.8 F respectively. The consumed kWh in 2021 across this period were 9,040 kWh and 11,360 kWh per the utility bill followed in 2022 by 8080 kWh and 9920 kWh. This represents a reduction of 960 kWh in the month of June, although with lower outside temperatures, but 1,440 kWh in July with much higher temperatures. Overall, a reduction of 10.6% in June and 12.7% in July considering lighter loads in 2021 and higher temperatures in July 2022, it can be expected that during an equivalent period the savings would be higher.

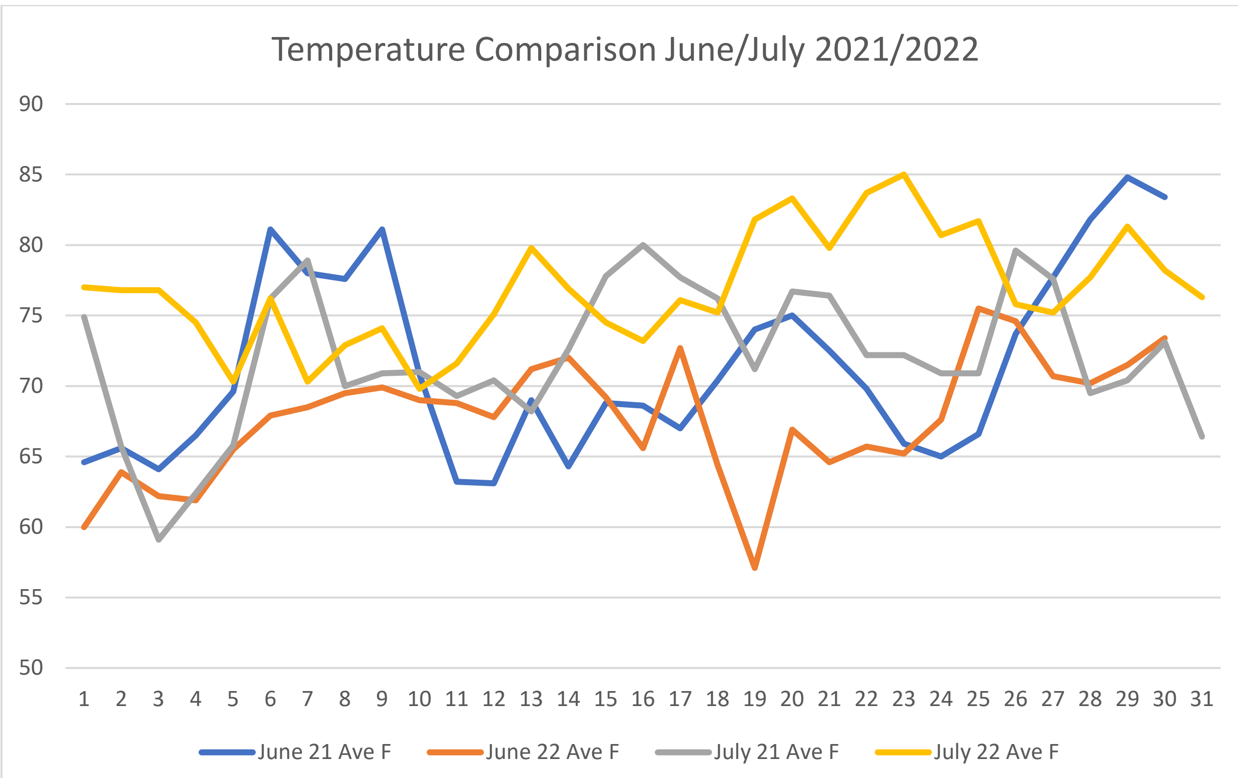

Figure 8: temperatures by day between June and July 2021 and 2022.

June 2021 average humidity was 60% and July was 58.5% while average humidity in 2022 was 56% and 66.3% respectively. With average temperatures and humidity being much higher as the neutral currents continued to drop, and reduced loading the year prior, the overall savings appear to fall in at over 12.7% from the installation of the single device in one panel.

CONCLUSION

As noted in this study using a new version of the Onics neutral harmonics filter that a direct energy savings is possible. This supports prior research (see foot notes on the first page) indicating the losses associated with harmonic conditions in the neutral. Additionally, the body of work associated with this study also has indicated that 5^{th} and 7^{th} (negative and positive sequence) harmonics also contribute to neutral energy losses when the values are unbalanced outside of theortical expectations. Once filtered the overall value of current in the neutral dropped to less than half of the original findings.

Additional research into the harmonic content associated with ground and neutral is being pursued. The findings in this report are consistent with results from both commercial facilities with lighter three phase loads and industrial facilities with larger three phase loads. The benefits have been found in neutral and ground current harmonics which have a direct impact on the neutral and ground loads at the transformer. The additional benefit being evaluated is the impact on the reliability of electrical equipment and improved operation of electrical and electronic equipment that uses the neutral and ground as reference.