Informational Document from Harmonics Limited IDHL-14

Subject: Mitigation of 3rd Harmonic Currents in Electrical Distribution Systems

The Wye Distribution System

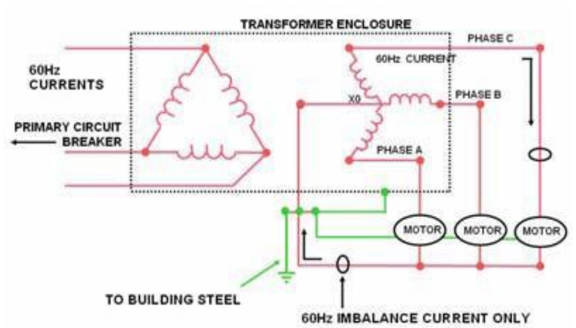

Figure 1. Wye distribution system with linear loads.

The 3-phase 4-wire 208/120 volt (wye) distribution system, found in most commercial and industrial facilities, is designed to serve both three-phase connected loads and phase-neutral connected single-phase loads. Due to the properties of this type of distribution, when the phase-neutral loads are balanced, there is no 60 Hz current flowing in the combined neutral, as shown in Figure 1 the only current flowing in the neutral is imbalance current.

Until 1991, the National Electrical Code permitted down-sized neutral wires to be used since the neutral was not considered to be a load- carrying wire. However, with the advent of large numbers of computers, connected phase-neutral, the picture changed due to harmonic currents.

Harmonic Currents

Harmonics in an electrical distribution system are caused by the types of loads connected to the system. Modern electronic equipment and controls, particularly PC computers, draw current with a non- linear waveform, as shown in Fig. 2. This waveform is rich in 3rd harmonic current – such currents can be as high as 120% of the fundamental. Resultant rms phase currents have been observed as high as 1.5 times the 60 Hz portion of the current.

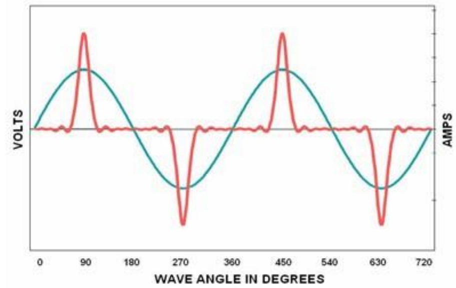

Figure 2. Voltage and current waveform for a typical computer power supply.

When circuits are heavily loaded with computers high rms currents can cause random tripping of panel breakers. Either the number of computers connected to a given circuit must be reduced or the capacity of the system must be increased by running new circuits to handle the desired computer load.

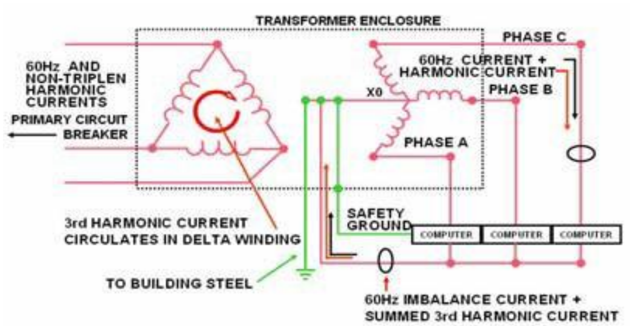

Figure. 3. Wye distribution system with non-linear loads.

Current flow in a wye distribution system serving non-linear loads is shown in Fig. 3. Third harmonic currents can overload the neutral wire. Unlike 60 Hz currents, 3rd harmonic currents do not cancel in the neutral wire of a wye distribution system, but, rather, are additive. The neutral wire for a wye system in which all three phases are fully loaded with switching power supplies could be carrying rms current as much as 1.73 times the individual phase currents. The neutral wire is not protected by breakers or fuses (it cannot be so protected according to code) and high neutral currents often go undetected until wire overheating leads to failure of connections or even fires.

High 3rd harmonic currents in a wye distribution system can also cause problems with the transformers feeding the system. Third harmonic currents return to the X0 connection on the transformer secondary. They are reflected into the primary, where they are trapped. Balanced 3rd harmonic currents cannot flow through a delta-connected transformer primary. Instead they circulate in the delta winding . Since these circulating currents do not flow into the primary connecting wires, they are not seen by the breakers or fuses protecting the primary and the overloaded, and unprotected, transformer can overheat and fail.

Accommodation of Harmonic Currents

Several methods of avoiding consequences of neutral overheating have been used. Doubling the neutral wire size or running a separate neutral wire for each phase will permit the wires to handle the extra current. As an alternative, current sensor connected to the neutral can be used to operate a shunt trip on the phase circuit breakers, turning the circuits off when neutral overload occurs, thus turning off all the computers. (While the latter solution protects the wiring, it is usually not a satisfactory solution from the viewpoint of the computer users.) Many engineers specify double neutral wires to avoid any problems with overheating.

Transformer overheating is avoided by using specialty transformers. One specialty transformer is the “k-rated” transformer. A k-rated transformer is specially designed to be able to handle high harmonic loading without burning up. The neutral connection lugs are oversized and doubled so that two neutral wires can be connected. The transformer core contains more iron to reduce flux density and multiple wires are used in the windings to handle extra currents. The resulting transformer will not overheat when subjected to high harmonic loading. However, the k-rated transformer does nothing to remove harmonic currents. They still flow throughout the distribution system.

A second specialty transformer is called a phase-shifting or “zig-zag” transformer. The zig- zag transformer contains multiple windings connected so as to present a low impedance to 3rd harmonic currents and a high impedance to 60 Hz currents. Connection and current flow for a zig-zag transformer is shown in Fig. 4. When a zig-zag transformer is used to power a wye distribution system, 3rd harmonic currents are canceled in the secondary winding and never reach the primary winding. Thus the transformer primary is now protected by its breaker or fused and will not burn out due to primary overload.

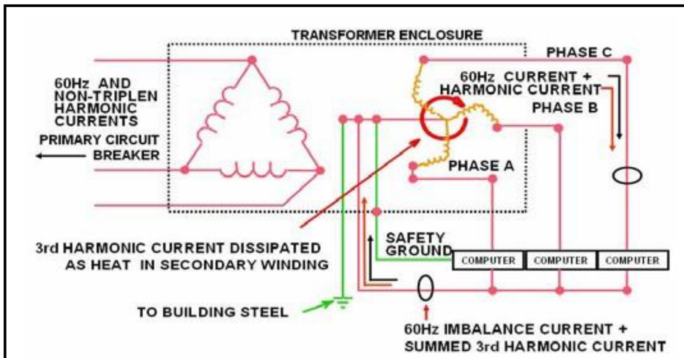

Figure 4. Zig-zag transformer powering a wye distribution system

However, with a zig-zag transformer providing power, 3rd harmonic currents still flow throughout the distribution system. Double neutrals are still recommended to carry extra current. Because the 3rd harmonic currents in the transformer secondary are partially dissipated as heat, most zig-zag transformers come with thermal switches to provide an overheating alarm.

Suppression of Harmonic Currents

Harmonic accommodation schemes dissipate harmonic currents as heat and allow the system to function without failing. A different type of harmonic mitigation device, the series blocking filter, or Harmonic Suppression System (HSS) actually relieves harmonic overloading on the distribution system by preventing the formation of harmonics.

The filter consists of a passive LRC network, tuned to have an almost infinite impedance at the 3rd harmonic while the 60 Hz impedance is low. When placed in series with a switching power supply load, the filter prevents the supply from drawing 3rd harmonic current. Since the normal current waveform for such loads, shown in Fig. 2, is rich in 3rd harmonic, and this frequency is forbidden by the filter, the load must now draw its current with a different waveform. This revised waveform is shown in Fig. 5. The peak current is reduced and current draw is spread out over a longer period of time than when the load is operated without the filter. Current waveform determines the harmonic spectrum and the more sinusoidal the waveform the lower the harmonic content. Therefore it is not surprising to discover that in addition to being low in 3rd harmonic, due to the blocking action of the filter, this current waveform contains reduced quantities of other harmonics.

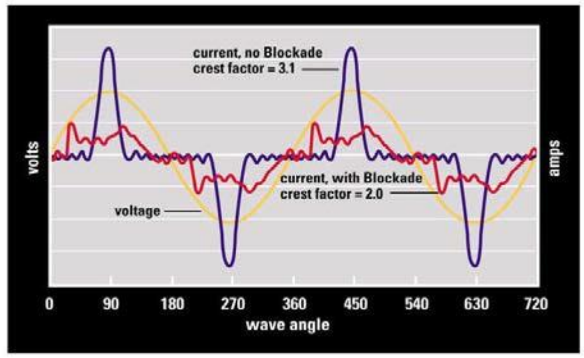

Figure 5. Effect of HSS on the computer current waveform.

The filter has no measurable effect on operation of the computer power supply. However the effect on the power distribution system is significant. Since the 3rd harmonic is never formed, there is nothing to remove or dissipate as heat. Any current drawn through the filter is free of 3rd harmonic. Therefore the system is free of this harmonic from the transformer out to the furthest load. Third harmonic currents simply do not exist anywhere in the distribution system!

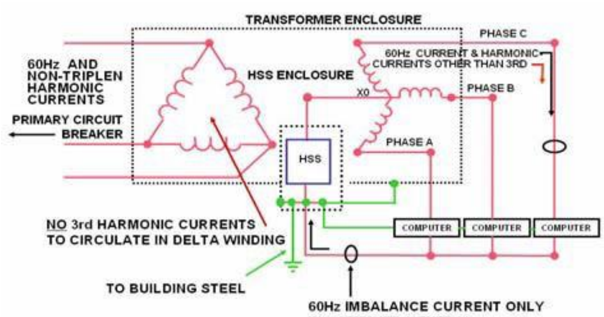

Fig. 6. Wye distribution system with HSS in the neutral to suppress 3rd harmonic currents

Figure 6 illustrates the application of an HSS in the neutral of a 208/120 volt wye distribution system serving single-phase computer loads. Since all current that flows in the phases must return through the neutral, the placement of a near-infinite 3rd harmonic impedance in the neutral prevents 3rd harmonic currents from being drawn by the switch-mode power supplies.

The filter has a low impedance at 60 Hz for minimal losses at the frequency at which power is delivered to the loads. Since the HSS is rated for the full load current of the transformer, it is protected against secondary phase-neutral or phase-ground short circuits by the main secondary breakers.

The neutral and safety ground are tied together and connected to building steel or a suitable grounding electrode as required by the National Electrical Code. The only effect on the electrical distribution system of installing the HSS is complete elimination of system overheating and other problems caused by 3rd harmonic currents.

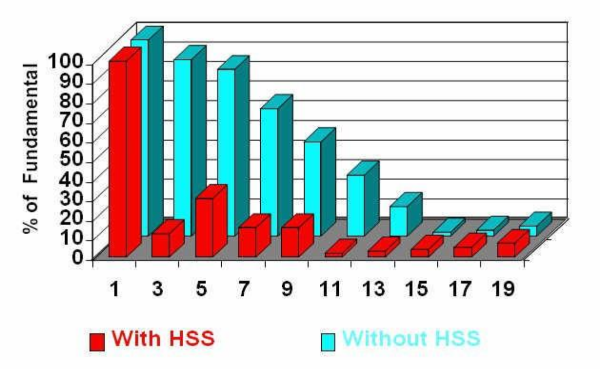

Figure 7. Phase current with and without HSS.

Figure 7 shows, in graphical form, data obtained from a 3-phase system with an HSS installed in the neutral. The loads consisted of multiple computers in a data center. Note changes in the harmonic spectrum when the HSS is installed. Third harmonic currents are almost totally eliminated and other harmonics are reduced as well. The reduction of other harmonic currents is a result of the computer, prevented from drawing 3rd harmonic current, drawing current with its preferred waveform. This preferred waveform, in addition to containing almost no 3rd harmonic current, is also lower in harmonics other than the 3rd.

Figure 8 shows, in graphical form, neutral current data. Before application of an HSS the transformer neutral was carrying more than 200 amps of 3rd harmonic current, the transformer was too hot to touch, and a strong odor of overheated insulation was evident. Following installation of the HSS 3rd harmonic current in the neutral dropped to 5 amps and transformer temperature was significantly reduced.

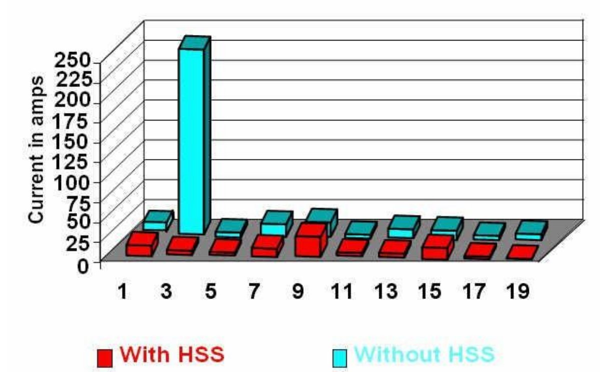

Figure 8. Neutral current with and without HSS.

Conclusion

Oversized neutrals, K-rated transformers, zig-zag transformers and other such harmonic-accommodating schemes are simply “band aids” which minimize system damage caused by 3rd harmonic currents. The Harmonic Suppression System is a true “surgical” solution to the problem. It eliminates damaging harmonic currents by preventing them from ever forming. The benefits of the HSS are easily seen and include the following:

- Phase rms currents can be reduced by up to 30%, reducing load on the electrical system and providing more useable capacity without increasing the size of the system.
- Neutral rms currents can be reduced by as much a 98%, eliminating the necessity of doubling or over sizing the neutral wires.
- Third harmonic current is removed from both phase and neutral wires starting at the transformer and going out to the furthest outlet.
- Transformer, switchgear, and wire overheating are eliminated throughout the system.
- The reduction in heat losses throughout the system (due to reduction of I^2R heating) provides energy savings and a lowering of in energy bills.

It should be evident that the Harmonic Suppression System is the most effective harmonic mitigation device for mitigation of harmonic currents in three-phase 4-wire wye connected distribution systems powering multiple computer loads.

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