Harmonics

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The Problem: Harmonics

To begin, when discussing the topic of harmonics, it is important to note that we almost exclusively are discussing three-phase power systems. Harmonics found within single-phase power systems are typically ignored due to their small size.

Stated previously, harmonics are electric voltages and currents that appear on the electric power system because of non-linear electric devices. A non-linear device is one in which the current is not proportional to the applied voltage. Examples of non-linear loads include:

- Arcing devices such as arc furnaces
- Power electronic equipment such as variable-speed drives, battery chargers and rectifiers
- Office equipment such as photocopiers, laser printers and fax machines

Ideally, voltage and current waveforms are perfect sinusoids. With non-linear loads, these waveforms are often distorted. This deviation from a perfect sine wave can be represented by harmonics which are sinusoidal components having a frequency that is an integral multiple of the fundamental frequency.

Thus, a pure voltage, or current sine wave, has no distortion and no harmonics; a non-sinusoidal wave has distortions and harmonics. To quantify the distortion, the term Total Harmonic Distortion (THD) is used. THD expresses the distortion as a percentage (%) of the fundamental (pure sine) of voltage and current waveforms.

High harmonic currents can have several negative effects on a facility. High levels of distortion can lower power factors, overheat equipment, and lead to penalties from the local utility for exceeding recommended limits. Each of these effects can result in higher cost to the facility.

Poor Power Factor

The harmonic currents caused by the non-linear loads do not carry any real power (kW) even though they increase the volt-amperage (kVA). Because true power factor is equal to the watts divided by the volt-amperes:

$$Factor = \frac{W}{VA}$$

with any increase in volt-amperes without a corresponding increase in watts will lower the power factor. A lower power factor will affect facilities in two ways: Losses inside the facility will increase due to the higher level of current required to perform the work.

Utilities will charge a penalty if the power factor falls below a predetermined level. Both of these will increase utility bills.

Overheating of Transformers

Overheating of transformers is another issue associated with harmonic currents. Overheating shortens the life of the transformer. ANSI/IEEE Standard C57 states that a transformer can only be expected to carry its rated current if the current distortion is less than 5%. If the current distortion exceeds this value, then some amount of de-rating is required. The overheating is primarily due to the higher eddy-current losses inside the transformer than were anticipated by the designer. The overheating can be avoided by either de-rating the transformer or by specifying a “k-rated” transformer that is designed for the higher levels of eddy currents.

Large Currents in Neutral Wires

Another effect of harmonic currents on the power system is the overheating of neutral wires in wye-connected circuits due to the third harmonic and any multiples thereof that do not cancel in the neutral, as do other harmonic currents. The result is a large 180-Hz current in the neutral conductor—if there are significant non-linear loads connected to the wye source. Usually the higher multiples of the third harmonic are of small magnitude. The attended increase in the RMS value of the current, however, can cause excessive heating in the neutral wire. Currents as high as 200% of the phase conductors have been seen in the field. This large level of current can easily burn up the neutral creating an open neutral environment with very serious consequences.

Voltage Distortion

Harmonic currents can distort the voltage waveform and cause harmonic voltages. Voltage distortion affects not only sensitive electronic loads but also electric motors and capacitor banks. In electric motors, negative sequence harmonics (i.e. 5^{th}, 11^{th}, 17^{th}), are so called because their sequence (ABC or ACB) is opposite of the fundamental sequence, produce rotating magnetic fields. These fields rotate in the opposite direction of the fundamental magnetic field and could cause not only overheating but also mechanical oscillations in the motor-load system.

Problem with Capacitor Banks

On facilities with capacitor banks, the reactance (impedance) decreases as the frequency increases. This causes the capacitor bank to act as a trap for higher harmonic currents from the surrounding utility system. The effect is an increase in current, in heating and an increase in dielectric stresses that could lead to capacitor bank failure.

- Other Problems Caused by Harmonics:
- Unacceptable neutral-to-ground voltages
- Breakers and fuses tripping
- Interference on phone and communications systems
- Unreliable operation of electronic equipment
- Erroneous register of electric meters
- Wasted energy/light electric bills - kW & kWh
- Wasted capacity - inefficient distribution of power
- Increased maintenance of equipment and machinery

The Solution: The Phase-Shift Transformer

Phase Shift Transformer is a distinct kind of transformer that has a special winding that changes the angular displacement between primary and secondary, also commonly called Harmonic Mitigating Transformers. Unlike a K-rated transformer, which only prevents the transformer and neutral conductor from overheating, a Phase-Shift Transformer uses a technique known as “phase shifting” to displace harmonic currents so that they cancel each other out. Harmonic treatment is provided entirely by electromagnetic flux cancellation; no filters, capacitors, or other such devices are used. It is important to remember that the harmonic currents still flow on the secondary windings.

How Does a Phase-Shift Transformer Eliminate Harmonics?

It involves separating the electrical supply into two or more outputs, each output being phase shifted with respect to each other with an appropriate angle. The concept is to displace the harmonic current pairs in order to bring each other to a 180° phase shift thereby cancelling each other out.

So an angular displacement of 60° between two three-phase outputs will cancel the 3rd harmonic currents, an angular displacement of 30° between two three-phase outputs will cancel the 5th and 7th harmonic current pairs, and an angular displacement of 15° between two three-phase outputs will cancel the 11th and 13th harmonic current pairs.

For example, using a Phase Shift Transformer solely by itself (either 0° or 30°), can reduce the 3rd, 9th and 15th harmonic currents. When used in pair with both 0° and 30° Phase Shift Transformers, it can eliminate all 3rd, 5th, 7th, 9th, and 15th harmonic currents.

In summary, harmonics need to be controlled and should be reduced as much as possible—especially when they become a problem. A Phase Shift Transformer eliminates specific harmonics and attenuates the distortion to minimum values, providing protection against these electrical disturbances. Using Quality Transformer and Electronics' Phase Shift Transformers will solve the problems mentioned above ensuring that your power distribution systems are completely compatible with each other.

Quality Transformer and Electronics is your source for all your transformer needs. Our Engineering Team can assist you in specifying, designing, and manufacturing your needed transformers. We want to help you understand more about transformers and how we can assist in your selection of Phase Shift Transformers.

References

- Pacific Gas and Electric Company (January 1993). Power System Harmonics
- International Journal of Advanced Technology & Engineering Research (IJATER) (Volume 2, Issue 2, May 2012). Harmonic Effects and Its Mitigating Techniques For A Non-Linear Load