

System Problems and Electronic Loads: Harmonics, Resonance, and Commutation



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With the increased use of electronic loads such as variable frequency drives (VFD) and uninterruptible power supplies (UPS), power quality problems are becoming more common. These power quality problems can be difficult to identify and can be even more difficult to correct. Acceptable power is more than just a good rms voltage; it is a signal with a defined strength and shape. Power quality problems are distortions of that shape.

When you have electronic loads such as VFDs and UPS systems, those types of loads can cause current distortion through their normal operation. Current distortion in itself is not a problem; however, if the strength of the signal is low, then current distortion creates voltage distortion. The strength of the signal is the amount of current the system can produce under a short-circuit condition. It is affected by the strength of the utility supplying it, the size of the supplying transformer, and the length of cable run to the load. The smaller the supplying transformer and longer the cable run, the more likely current distortion will result in voltage distortion. Many designers, incorrectly, do not consider the possibility of voltage distortion when sizing a transformer. A transformer that is properly rated to supply a normal load may not be capable of sustaining an acceptable voltage if that particular load is completely supported by VFDs or UPS systems. Voltage distortions can cause issues throughout the power system and even be carried back to the grid. These problems cause failures to computers, transformers, capacitor banks, motors, and even the VFDs or UPS systems themselves. This article will lay out three specific problems caused by electronic loads, harmonics, resonance, and commutation. It will also cover what they are, how to spot them, and how to solve them.

Harmonics

Harmonics are basically a repeated ripple in the power wave form. The ripple has a definable frequency that is a multiple of the fundamental (normal) frequency of 60 Hz. For example, a 3rd order harmonic has a frequency of 60 Hz times 3 or 180 Hz. Harmonics are formed by the rectifiers found in electronic loads. These rectifiers are designed to turn ac into dc. They are present in all types of electronic devices, from the largest VFD to the laptop computer you carry. Electronic loads don't consume power as a steady signal. Instead they pull pulses of current at the voltage peaks. This repeated pull of current produces a small ripple in the voltage. The number of pulses per cycle defines what type of

harmonics that a device will produce. The most prevalent order of harmonic on an unfiltered system is equal to the number of pulses that device pulls per cycle plus and minus one. For instance an unfiltered traditional six-pulse drive will produce mostly 5th and 7th order harmonics. A laptop computer will pull two pulses per cycle (one on the voltage peak and one at its trough) so it will produce mostly 3rd order. These voltage harmonics may only be a few volts; however, they can lead to a number of different power problems.

The harmonics can be calculated as follows:

$$h = n \times K \pm 1$$

where

h is the harmonic order the equipment produces,

n is an integer, typically from 1 to 4,

and k is the number of pulses the equipment draws.

A six-pulse drive will produce the 5th, 7th, 11th, 13th, 17th, 19th... order harmonics, a 12-pulse drive will produce 11th, 13th, 23rd, 25th... order harmonics, and a single-phase, full-wave rectified source will produce 3rd, 5th, 7th, 9th, 11th, 13th... order harmonics.

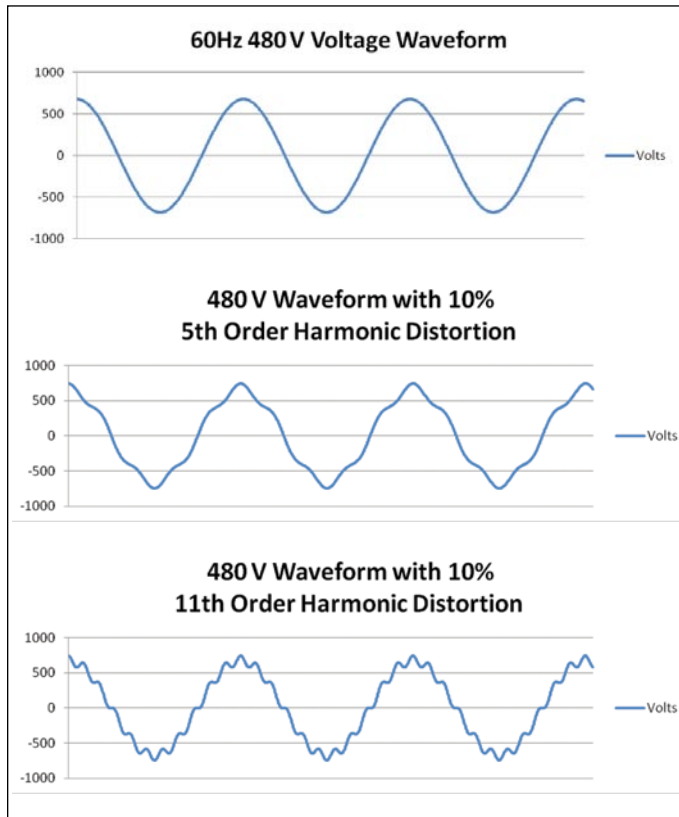


Figure 1

Transformer and motor losses increase with the frequency of the power supplying them. Harmonics are higher frequency than 60 Hz; therefore, they increase the losses in those devices. This decreases equipment life span and can even be the direct cause of equipment failure. The increased use of electronic loads resulted in the creation of the transformer K-factor rating. The K-factor is to allow for increased heating that harmonics produce. Excessive voltage harmonics can cause equipment to shut off randomly or to fail entirely. It is possible to see harmonic problems through thermography. Transformers that may be properly rated for the load that are showing high heat losses can be a clue to high levels of harmonics on a system. However, the best way to know what harmonics are on a system is through the use of a power recording meter. This meter will record the voltage and current as well as calculate the harmonics for a particular waveform. This information can then be used to either design a filter or to ensure the system is properly rated for the harmonics present.

Harmonic issues can be corrected through the use of tuned or partially tuned capacitor banks. These capacitors are designed to filter out a specific band of harmonics. However, this system should be designed by an engineer familiar with filtered capacitor banks, as the presence of these devices can cause additional problems. An improperly designed filter system can result in system resonance and increased commutation. These problems can be much greater than the harmonics that produced them.

Resonance

System resonance is a difficult problem to diagnose. It is typically caused by harmonics along with the misapplication of capacitors either for power-factor correction or harmonic filtering. Resonance produces large spikes of current and voltage on the system which cause the operation of protective devices or the failure of equipment, however, the events that cause these failures can be difficult to reproduce. This leads to speculation on how and why the problems occurred in the first place. For example, a motor lineup with power factor correction, if started in a specific order, may have no issues. However, if the same lineup is started in a different order, resonance may occur.

The impedance of capacitor banks, transformers, and motors is related to the frequency of the power supplying them. For transformers and motors, the impedance increases as the frequency increases. For capacitor banks, the impedance decreases as the frequency increases. The fundamental frequency of power produced in the USA is fixed at 60 Hz. Without harmonics, the impedance of those devices is fixed based on that frequency. On systems with harmonics there are several frequencies acting on the system at the same time the resonant point of the system is the frequency at which the capacitive reactance is equal to the inductive reactance. If the resonant point of a system falls on a harmonic frequency present in the system, the system will likely fail.

Impedance is calculated by;

$$X_L = 2\pi fL, \quad (1)$$

$$X_C = \frac{1}{2\pi fC} \quad (2)$$

where:

- X_L is the reactive impedance of an inductive load
- X_C is the reactive impedance of a capacitive load
- f is the frequency

The resonant frequency is calculated as follows:

$$f_R = \frac{1}{2\pi\sqrt{LC}} \quad (3)$$

where

- L is the inductance of the load
- C is the capacitance of the load
- f_R is the resonant frequency

Series resonance is most often caused by the tuning of a capacitor bank too close to a common harmonic frequency. This results in a nearly direct short circuit for the resonant frequency. This creates a surge in current through the capacitor bank that may be tuned to absorb this frequency. It can

lead to the operation of a capacitor bank's protective device or destruction of the capacitor bank itself. Series resonance occurs when X_{EQ} is equal to zero. X_{EQ} is calculated by:

$$X_{EQ} = X_L + X_C \quad (4)$$

where

- X_{EQ} is the equivalent total reactive impedance
- X_L is the reactive impedance of the inductive portion of the load
- X_C is the reactive impedance of the capacitive portion of the load

Parallel resonance occurs when the combined reactive impedance for a given system goes to infinity. This occurs when the capacitive impedance of the system is equal to the inductive impedance. For an ideal system with no resistance, this makes the impedance at a particular frequency infinite. This acts as a block to the resonant harmonic frequency.

$$X_{EQ} = \frac{X_L \times X_C}{X_L + X_C} \quad (5)$$

where

- X_{EQ} Is the equivalent total reactive impedance,
 - X_L Is the reactive impedance of the inductive load,
- and
- X_C is the reactive impedance of the capacitive load.

Parallel resonance occurs when $X_L + X_C = 0$.

Resonance is difficult to spot and many times should not be considered until other possible problems are eliminated. However, there are clues that an experienced technician can spot, such as if the site has newly installed capacitor banks. If the capacitor banks are not tuned or not staged correctly, resonance could result. Many times the only way to know for sure is to either perform the calculations by hand or to model the system in a software program designed to look for resonance. Electrical system modeling software is the most efficient method for determining a system's resonant point. This allows for the rapid calculation of various scenarios to determine potential problems.

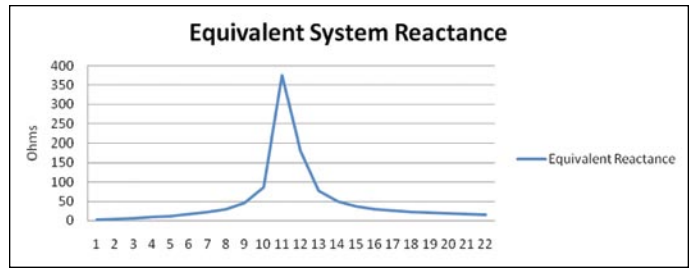


Figure 2
This systems resonates near the 11th order harmonic. If this system had a VFD or UPS, dangerous overvoltages could occur.

The possibility of cheap and fast power-factor correction has many facilities chasing low bid designers to install fixed capacitor banks. These designers often do not consider system resonance. The problems they cause may never be attributed to the capacitor installation. However, the problems they create can cause a catastrophic failure to a facility's power system. The design of power-factor correction or tuned capacitors should only be completed by an experienced engineer.

Commutation

Another reason to avoid fixed, unfiltered capacitor banks is commutation. As the inverters of electronic loads switch on and off to draw current there is sometimes an overlap between the phases. When this happens, even for a very brief period, there is a direct short between the phases being switched. This period is called commutation. It appears as a notch in the voltage waveform. This notch is a very quick drop in voltage and can cause damage to other loads. The best way to detect commutation is with the use of a power recording meter or oscilloscope. Currently manufactured electronic equipment does not have the commutation problems that older drives had but commutation problems are still found in equipment that was designed to run on generators such as drilling rigs. Commutation is usually easy to eliminate as the installation of an in-line reactor will prevent this from occurring. However this in-line reactor will have a voltage drop and heat losses proportional to current flow. Other benefits from the reactor is reduction of the short-circuit current at drive and a decrease in the magnitude of voltage harmonics that the drive generates in the power system. Therefore, in-line reactors should be installed with careful consideration of all these issues.

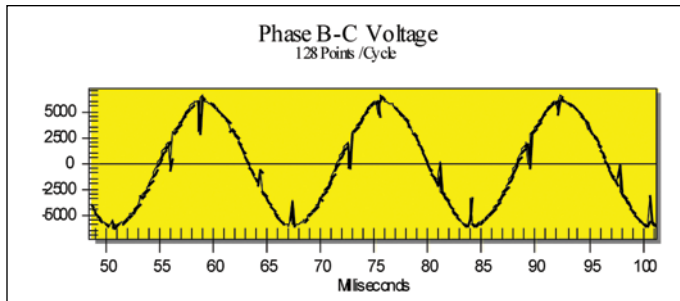


Figure 3
Recorded voltage notching from drilling rig VFD

As more motors operate from VFDs and more critical equipment operate from UPS systems, the problems associated with this equipment are becoming more common. The addition of power-factor correction capacitors can increase these problems. Designers and technicians must realize that electronic loads have unique issues. Transformers that are rated properly for the quantity of load may not be rated properly if that load contains a significant portion of VFDs or UPS systems. Electronic loads have the ability to cause harmonics, system resonance, and voltage notching. If the cause cannot be readily determined, unexplained protective device tripping should be examined on a system wide level. With the proper understanding of these problems, these issues can be detected in the field, verified in the office, and corrected without introducing other problems. Without skilled and knowledgeable technicians and engineers, problems are often not diagnosed, much less corrected. These issues, specific to electronic load, have systemwide symptoms and can cause system-wide failures. 🌐

Todd Stroik graduated with a Bachelor of Science in Electrical Engineering from the University of Texas at Arlington in 2004. Since then he has been working in the electrical testing industry. He has been employed by Shermco Industries since 2006. Todd has performed considerable work in substation design, protective device coordination and power quality.