Total Harmonic Distortion and Effects in Electrical Power Systems

Associated Power Technologies

Introduction

The power quality of distribution systems has a drastic effect on power regulation and consumption. Johan Lundquist of the Chalmers University of Technology in Goteberg, Sweden put it best, stating "The phrase 'power quality' has been widely used during the last decade and includes all aspects of events in the system that deviates from normal operation."[1] This has been especially true after the second half of the 20th century when new types of electronic power sources caused distortion in waveforms of the power system.

Power sources act as non-linear loads, drawing a distorted waveform that contains harmonics. These harmonics can cause problems ranging from telephone transmission interference to degradation of conductors and insulating material in motors and transformers. Therefore it is important to gauge the total effect of these harmonics. The summation of all harmonics in a system is known as total harmonic distortion (THD). This paper will attempt to explain the concept of THD and its effects on electrical equipment. It will also outline the low THD of the Associated Power Technologies (APT) line of programmable sources and how these can be used to more effectively test equipment.

What is Total Harmonic Distortion?

Total harmonic distortion is a complex and often confusing concept to grasp. However, when broken down into the basic definitions of harmonics and distortion, it becomes much easier to understand.

Imagine a power system with an AC source and an electrical load (Figure 1).

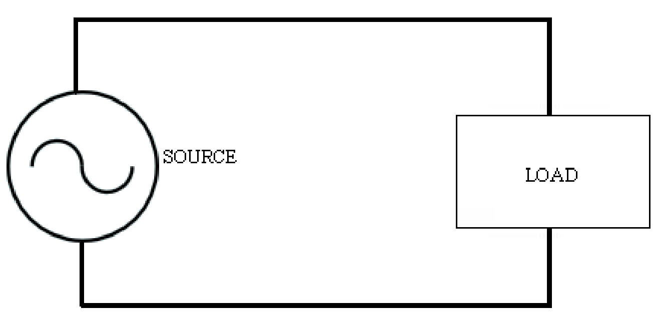

Figure 1: Power System with AC source and electrical load

Now imagine that this load is going to take on one of two basic types: linear or non-linear. The type of load is going to affect the power quality of the system. This is due to the current draw of each type of load. Linear loads draw current that is sinusoidal in nature so they generally do not distort the waveform (Figure 2). Most household appliances are categorized as linear loads. Non-linear loads, however, can draw current that is not perfectly sinusoidal (Figure 3). Since the current waveform deviates from a sine wave, voltage waveform distortions are created.

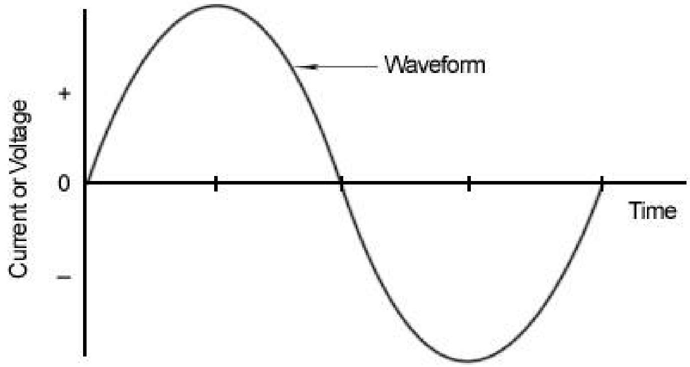

Figure 2: Ideal Sine wave

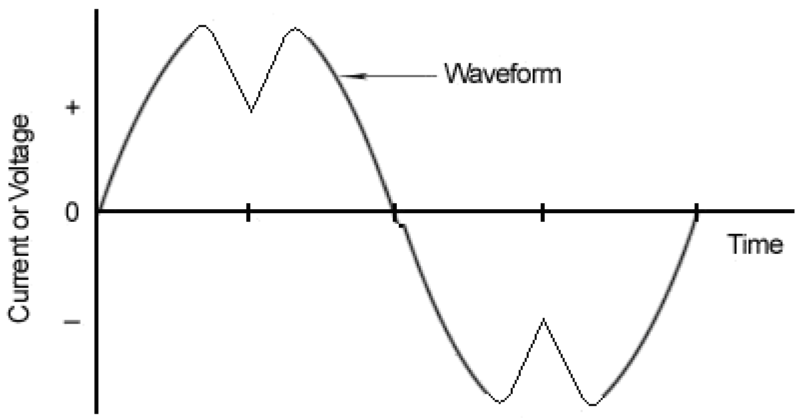

Figure 3: Distorted Waveform

As can be observed from the waveform in Figure 3, waveform distortions can drastically alter the shape of the sinusoid. However, no matter the level of complexity of the fundamental wave, it is actually just a composite of multiple waveforms called harmonics.

Harmonics have frequencies that are integer multiples of the waveform's fundamental frequency. For example, given a 60Hz fundamental waveform, the 2nd, 3rd, 4th and 5th harmonic components will be at 120Hz, 180Hz, 240Hz and 300Hz respectively. Thus, harmonic distortion is the degree to which a waveform deviates from its pure sinusoidal values as a result of the summation of all these harmonic elements. The ideal sine wave has zero harmonic components. In that case, there is nothing to distort this perfect wave.

Total harmonic distortion, or THD, is the summation of all harmonic components of the voltage or current waveform compared against the fundamental component of the voltage or current wave:

$$\mathrm{THD} = \frac{\sqrt{\left(V_2^2 + V_3^2 + V_4^2 + \cdots + V_n^2\right)}}{V_1} * 100\%$$

The formula above shows the calculation for THD on a voltage signal. The end result is a percentage comparing the harmonic components to the fundamental component of a signal. The higher the percentage, the more distortion that is present on the mains signal.

The Usual Suspects

Harmonics have existed on power systems from the time of the very first generators. However, the harmonic components were so small that their effects on systems were negligible. This was due to the lack of non-linear loads before the 1960s. As associated professor of the University of Wollongong, V.J. Gosbell wrote, "Harmonic distortion is not generally due to the operation of the power system, and was largely absent before the 1960s. At about this time, a different type of customer load with electronic power supplies became popular."[2] This was the beginning of the era of non-linear loads which now include electronics ballasts, computer power supplies, fax machines, arc furnaces and variable frequency drives (VFDs).

Harmonic distortion can have detrimental effects on electrical equipment. Unwanted distortion can increase the current in power systems which results in higher temperatures in neutral conductors and distribution transformers. Higher frequency harmonics cause additional core loss in motors which results in excessive heating of the motor core. These higher order harmonics can also interfere with communication transmission lines since they oscillate at the same frequencies as the transmit frequency.[3] If left unchecked, increased temperatures and interference can greatly shorten the life of electronic equipment and cause damage to power systems.

Importance of Mitigating THD

While there is no national standard dictating THD limits on systems, there are recommended values for acceptable harmonic distortion. IEEE Std 519, "RECOMMENDED PRACTICES AND REQUIREMENTS FOR HARMONIC CONTROL IN ELECTRICAL POWER SYSTEMS" provides suggested harmonic values for power systems:

> *"Computers and allied equipment, such as programmable controllers, frequently require ac sources that have no more than 5% harmonic voltage distortion factor* [THD], *with the largest single harmonic being no more than 3% of the fundamental voltage. Higher levels of harmonics*

result in erratic, sometimes subtle, malfunctions of the equipment that can, in some cases, have serious consequences."[4]

The limits on voltage harmonics are thus set at 5% for THD and 3% for any single harmonic. It is important to note that the suggestions and values given in this standard are purely voluntary. However, keeping low THD values on a system will further ensure proper operation of equipment and a longer equipment life span.

Associated Power Technologies: Keeping a low THD

With the use of non-linear loads on the rise globally, isolation for poor quality distribution systems and mitigation of harmonics will become increasingly important. The limits per IEEE Std 519 are not enforced limits but suggestions on acceptable levels. As a result, THD on certain power systems could be much higher, especially considering the difficulty in attaining harmonic measurements. The APT line of programmable AC power sources isolates electronic equipment from a distorted mains supply while maintaining low THD during testing and measurement. Below are THD specifications for the full APT line of sources. THD is maintained below 2% for full frequency range:

Associated Power Technologies THD Rating	
300XAC Series	<1% (Resistive Load) at output voltage 80 - 140 V & 160 - 280 V, <1.5% (Resistive Load) at 501-1000Hz and output voltage within the 100~140Vac at Low Range or the 160~280Vac at High Range.
6000 Series	< 1% (Resistive Load) for low range voltage 80V – 140V and high range voltage 160V - 280V
5000 Series	< 1% (Resistive Load) for low range voltage 80V – 140V and high range voltage 160V – 280V
LS Series*	<0.5% @ 45-500Hz (Resistive Load)
VariPLUS	<1% (Resistive Load) at output voltage within the 80~140Vac at low range or the 160~280Vac at high range.
* The LS Series are linear sources which partially accounts for the lower THD. Linear sources do not have added distortion due to the fast switching relays in switch mode power supplies.	

APT power sources are measured for THD up to the 40th harmonic for the various frequency outputs of the source (mains frequency up to 1000Hz). This ensures a low THD value over the entire operating frequency range of the instrument. Utilizing an APT source will provide a clean signal with low THD and isolation from local supply interference.

References

[1] Lundquist, Johan. On Harmonic Distortion in Power Systems. Chalmers University of Technology: Department of Electrical Power Engineering, 2001.

[2] Vic Gosbell. "Harmonic Distortion in the Electrical Supply System," PQC Tech Note No. 3 (Power Quality Centre), Elliot Sound Products, http://sound.westhost.com/lamps/technote3.pdf

[3] "Harmonics (electrical power)." *Wikipedia, The Free Encyclopedia*. Wikimedia Foundation, Inc. 4 April 2011. Web. 5 April 2011.

[4] IEEE Std 519-1992, *IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*, New York, NY: IEEE.