HARMONICS - Understanding the Facts - Part 1

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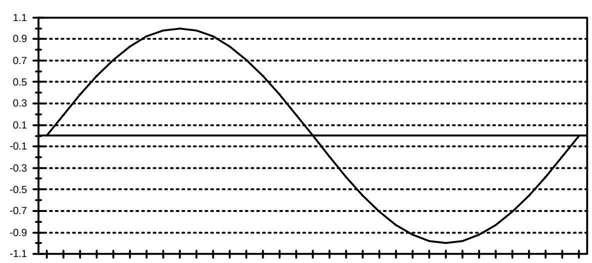
Abstract

Understanding what is important to know about harmonics can be challenging for those without extensive electrical engineering backgrounds. In this three part series, this first article will review what a harmonic is, the second will help to clarify what those important facts are, and the third will provide details on what causes harmonic problems and suggested solutions.

Why a Sine Wave

Before defining what a harmonic is, it is useful to review why electrical power is generated in the form of a sine wave, as shown in Figure 1. In much of the world, an AC generator is used to produce power. AC, or alternating current, was chosen back in the 1800s over DC, or direct current, due to its ease of generation and the ability to change amplitude using transformers. [1] The key to understanding a sine wave is in understanding what it is that is "alternating."

Figure 1. Sine Wave

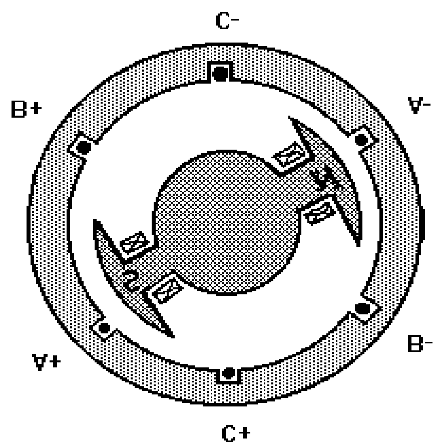


The principle in most AC generators is that by rotating a magnetic field over coils or windings, an alternating electric current will be induced into the windings. The current (or electrical force) is proportional to the magnetic flux (magnetic force), and the voltage (electrical potential) is proportional to the rate of change of the current. If there was no change or alternating of the magnetic flux and hence no change in the current, then there would be no voltage produced.

A mechanical force, such as water, steam or wind, is used to provide the rotation to produce this changing flux. Figure 2 is a cross-section of a three phase, 2 pole generator. Half of the windings for each phase are located on opposite sides of the stator, or stationary part of the generator. When these coil pairs (A+/A-, B+/B-, C+/C-) are joined together, the current can flow through the circuit of the windings. In the center is the magnet, which has a north and south pole. The magnetic flux gets stronger as the rotating pole gets closer to the coil, and then reduces in intensity as it goes past. The north pole makes the current flow into one coil and the south makes it flow out of the other. In some generators, the magnets are actually electromagnets, not permanent magnets.

Figure 2. Cross section of three phase, two pole generator.

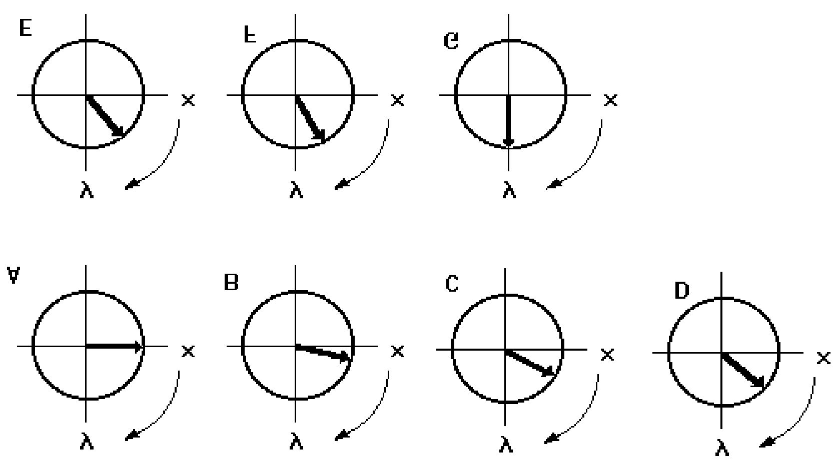
Why the voltage is illustrated by diagrams in Figure rotates around the magnets rotating the position of the the y axis is shown done in 15 degree to save space.



a sine wave is best looking at the phasor 3. As the phasor circle (like the inside the generator), end of the phasor in in Table 1. This is steps in this example

Figure 3. Phasors

Position	**Phase Angle**	**Y axis value**
A	0 degrees	0
B	15 degrees	0.259
C	30 degrees	0.5
D	45 degrees	0.707
E	60 degrees	0.866
F	75 degrees	0.966



G	90 degrees	1

Table 1. Phase Angle and Magnitude values.

The rotational position (in degrees) is related to an incremental step in time. Plotting the y axis values corresponding to the position steps over a complete 360 degree circle results in an approximation of a sine wave that was shown in Figure 1. This sine wave function occurs in many natural phenomena, such as the speed of a pendulum as it swings back and forth, or the way a string on a guitar vibrates when plucked.

The frequency of the sine wave is proportional to the number of poles (or magnets) and the speed of the rotation, usually expressed in 'rpm' (revolutions per minute). The equation is $f = (p / 2) * rpm$. This frequency is referred to as the fundamental frequency. In the North America, this frequency is 60 Hz, or cycles per second. In European countries and other parts of the world, this frequency is usually 50 Hz. Aircraft often use 400 Hz as the fundamental frequency. At 60 Hz, this means that sixty times a second, the voltage waveform increases to a maximum positive value, then decreases to zero, further decreasing to a maximum negative value, and then back to zero.

What is a Harmonic

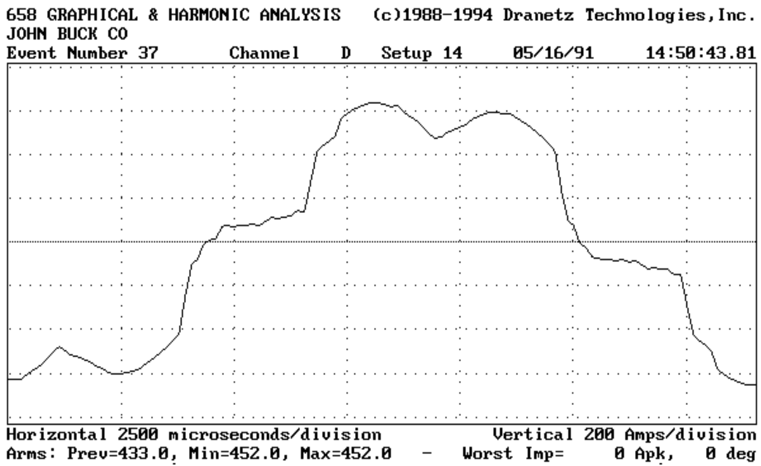
The knowledge of harmonics has been around for a long time. In fact, musicians have been aware of such since the invention of the first string or woodwind instrument. Harmonics (called "overtones" in music) are responsible for what makes a trumpet sound like a trumpet, and a clarinet like a clarinet. It can be shown that any complex waveform, whether it is produced by a musical instrument or a power system, can be broken up into harmonic components.

The typical definition for a harmonic is "a sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency." [2]. Some references refer to "clean" or "pure" power as those waveforms without any harmonics. Today, such clean waveforms typically only exist in a laboratory.

The harmonic frequencies are integer multiples [2, 3, 4, ...] of the fundamental frequency. For example, the 2nd harmonic on a 60 Hz system is 2*60 or 120 Hz. At 50Hz, the second harmonic is 2* 50 or 100Hz. 300Hz is the 5th harmonic in a 60 Hz system, or the 6th harmonic in a 50 Hz system. Figure 5 shows how a signal with dominant 5th and 7th harmonics would appear on an oscilloscope-type display, which some power quality analyzers provide.

Figure 5. Fundamental with 5th and 7th harmonics

Frequencies that are not integer multiples of the fundamental frequency are called "interharmonics". There is also a special category of interharmonics, which are frequency values less than the fundamental frequency, called sub-harmonics. The presence of sub-harmonics is often observed by the lighting flicker.



One other parameter to be aware of is the phase angle of the harmonic relative to the fundamental. In Figure 6, a third harmonic with an amplitude of 33% of the fundamental is combined with the fundamental. In the left hand picture, the fundamental and the third harmonic are in phase. In the right hand picture, they are 180 degrees out-of-phase with each other. Obviously, the resulting waveform looks quite different.

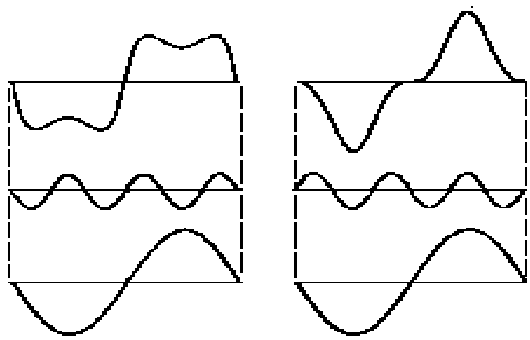


Figure 6. Effect of Harmonic Phase. [4]

References

[1] Fitzgerald, A.E. et al, Electric Machinery, McGraw-Hill Company, 1971.

[2] IEEE 519 Recommended Practices and Requirements for Harmonic Control in Electric Power Systems

[3] Kerchner, Russel M. And George F. Corcoran, Alternating-Current Circuits, John Wiley & Sons, NY, 1 943.

[4] Powerline Harmonic Problems - Causes and Cures, Dranetz Technologies, December 1994.

About the Author

Richard P. Bingham is currently the Chief Technologist for Dranetz Technologies, Inc., having previously been the Vice-President of Engineering and Strategic Planning. He has been with the company since 1977, following completion of his BSEE at the University of Dayton. Richard also has an MSEE in Computer Architecture and Programming from Rutgers University. He is a member of IEEE Power Engineering Society and Tau Beta Pi, the Engineering Honor Society. Richard is currently working with the NFPA 70B committee on Power Quality and several IEEE committees related to IEEE 1159, and has written and presented numerous papers and seminars in the electric utility and power quality instrumentation fields.