APPLICATION NOTES **Ultra-K - UK#12**

Ukharma2
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HARMONICS

General

In today’s electrical environment, power is used quite differently and consumed 10 times more than a few decades ago. The electrical devices used today are “high tech” and more plentiful. Compounding quality and quantity issues lead to sophisticated high technological problems. Before 1970, the typical office consisted of very few electrical devices. There may have been an electric typewriter, calculator and of course incandescent lights. These devices of the past (also called loads) are known to be linear loads; where the current waveform is the same as the voltage waveform. The utility company provides power in sine waves (Figure 1 shows a typical sine wave) at a rate of 60 cycles per second. This is the fundamental frequency, measured in Hertz.

The proliferation of electronic controls and specialty electronic equipment has automated the offices of today. Typically in every office there is a minimum of personal computers, telephone system, copier machines, fax machines, and laser printers. These new loads are non-linear. Figure 2 shows a comparison between the way linear and non-linear loads draw current.

The current waveform of the non-linear load has the same period as the fundamental frequency but is not sinusoidal. The non-linear waveform is comprised of the fundamental frequency as well as others. The current waveform approaches the appearance of a square wave, thus it is rich in odd order harmonics (even order harmonics produce triangular waves). A non-linear load distorts the sine wave by introducing higher frequencies than the fundamental 60 Hertz.

The distortion of the normal sine wave by non-linear loads is created by harmonics. Harmonics are related to the fundamental frequency and are defined as whole number multiples of the fundamental frequency, thus the 3rd harmonic is 3 times the fundamental frequency (60 Hertz) which is 180 Hertz. Even ordered harmonics (2nd, 4th, 6th, etc.) pose little to no threat on the distribution grid, therefore they won’t be discussed.

The transmission distribution grid was designed to carry the fundamental 60 Hertz frequency. A problem exists with higher frequencies (harmonics), that is, they do not fully penetrate the conductor. They travel on the outer edge of the conductor. This is called skin effect (Figure 3). When skin effect occurs, the effective cross sectional area of the conductor decreases; increasing the resistance and the I^2R losses, which in turn heats up the conductors and anything connected to them. This heating effect causes circuit breakers to trip, neutral and phase conductors to heat up to critical flash over temperatures, and premature failure of motors and transformers. This is costly in terms of down-time, loss of production, repair, and possible reconstruction.

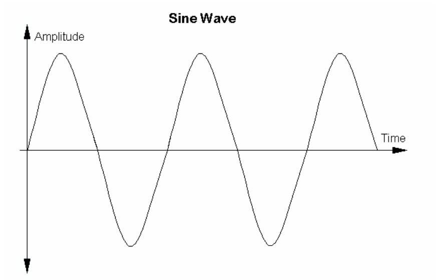

Figure 1

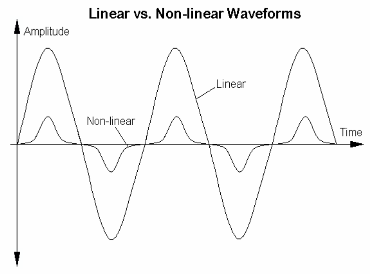

Figure 2

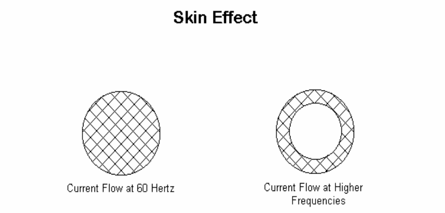

Figure 3

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“World's recognized authority in power treatment”

Three Phase Applications

Harmonics get more complicated in three phase applications. Here not only do you have to deal with phase conductors, but also the neutral conductor, triplen (odd multiples of 3) harmonics, and sequence harmonics.

The triplen harmonics (3rd, 9th, 15th, etc.) are the major cause of heat because they add together in the neutral conductor. The magnitude of the harmonic current produced by the triplens can approach twice the phase current. This causes the neutral conductor to overheat because neutral conductors were historically designed with the same ampacity as the phase conductors.

A situation that produces abnormal amounts of heat in motors is the combination of positive and negative sequenced harmonics. The positive sequenced harmonics are the fundamental, 7th, 13th, 19th, etc. They tend to apply an additional forward force in the direction of the motor rotation. The negative sequenced harmonics are the 5th, 11th, 17th, etc. They present a force that opposes the motor rotation and tries to make the motor rotate in the opposite direction. The force of these harmonics acting upon each other creates heat which leads to premature failure.

Transformers configured with a delta - wye connection help to reduce the effects of harmonics. The triplen harmonics are trapped and circulate in the delta primary of the transformer. Since most loads produce high levels of the 3rd harmonic (one of the triplens), the harmonic content reflected back to the source is reduced.

The circulating harmonics in the primary of the transformer creates heat because of their higher frequencies. For this reason, a transformer that can handle the excess heat is needed. This transformer is called a K-rated transformer.

K-rated Transformers

The *Ultra-K* K-rated transformer manufactured by Controlled Power Company is designed specifically to handle the heat generated by the high frequencies caused by harmonics. The neutral conductor is double sized and the transformer uses additional copper, more air ducts, and sophisticated geometric windings than a normal transformer to assure dissipation of the heat.

The *Ultra-K* has an associated value called K-factor that Underwriter's Laboratory (UL) developed to determine how much harmonic current a transformer can handle without burning up. Sometimes it is not possible to know how much harmonic current is produced from a certain load, so a guideline has been introduced to help determine how much K-factor a transformer needs. This guideline is shown in table 1.

Load	**K-factor**
Incandescent lighting (with no solid state dimmers)	K-1
Electric resistance heating (with no solid state heat controls)	K-1
Motors (without solid state drives)	K-1
Control transformers/electromagnetic control devices	K-1
Motor-generators (without solid state drives)	K-1
Electric-discharge lighting	K-4
UPS w/optional input filtering	K-4
Welders	K-4
Induction heating equipment	K-4
PLC's and solid state controls (other than variable speed drives)	K-4
Telecommunications equipment (e.g. PBX)	K-13
UPS without input filtering	K-13
Multi-wire receptacle circuits in general care areas of health care, facilities and classrooms of schools, etc.	K-13
Multi-wire receptacle circuits supplying inspection or testing equipment on an assembly or production line	K-13
Mainframe computer loads	K-20
Solid state motor drives (variable speed drives)	K-20
Multi-wire receptacle circuits in critical care areas and operating/recovery rooms of hospitals	K-20
Multi-wire receptacle circuits in industrial, medical, and educational laboratories.	K-30
Multi-wire receptacle circuits in commercial office spaces	K-30
Small mainframes (mini and micro)	K-30
Other loads identified as producing very high amounts of harmonics (especially in higher orders)	K-40

Table 1

It is possible to determine the K-factor needed when measurements can be obtained from the load. To do this, measurements of the harmonic currents need to be taken. The harmonic current at each harmonic needs to be found, which can easily be done using a harmonic analyzer. If a current value is given for each harmonic, simply divide that value by the total current value. This will yield a per unit value for that given harmonic. If a percentage of the overall current is given, multiply that number by 100, which will also give a per unit value. Then take these values and plug them into the formula:

$$K = \Sigma\, [Ih_{n(pu)}^{2}\,(h_n^{2})]$$

where $Ih_{n(pu)}^{2}$ is the value of the harmonic current squared (in the per unit form), h_n^2 is the order of the harmonic (3rd, 5th, 7th, etc.) squared. Multiply these two numbers together for each harmonic order. The sum of these numbers gives the K-factor rating. This procedure may look difficult, but it is actually pretty simple. An example is demonstrated in Table 2. Column 1 shows the harmonic orders present, column 2 shows the harmonic current on a per unit basis, columns 3 and 4 show the square of the harmonic orders present and the harmonic order respectively, and column 5 shows the product of columns 3 and 4. The K-factor is found by summing all the numbers in column 5. A K-factor of 9.802 is formulated. This means that 9.802 times as much heat is produced by the non-linear current than would have been produced by the same value of linear current.

While K-factor shows how much more heat is produced from a non-linear load, it doesn't portray anything about distortion of the sine wave.

K-FACTOR CALCULATION

h_n	$Ih(pu)$	h_n^2	$Ih(pu)^2$	$[Ih(pu)^2 h_n^2]$
1	0.879	1	0.7726	0.7726
3	0.568	9	0.3226	2.904
5	0.376	25	0.1414	3.5344
7	0.198	49	0.0392	1.9210
9	0.091	81	0.0083	0.6708
				$\Sigma = 9.81$

Table 2

Total Harmonic Distortion (THD) and Power Factor

Harmonics work together in distorting the fundamental waveform. The representation of the harmonic current with respect to the fundamental waveform is called total harmonic distortion (THD). There is a THD for both voltage and current. I will talk about current THD since it pertains to this discussion better than voltage THD. The THD of a waveform is calculated by taking the square root of the addition of the squares of the harmonic currents, and dividing them by the fundamental current. As a formula:

$$I_{THD} = \sqrt{(I_3^2 + I_5^2 + I_7^2 + I_9^2 + \ldots) / I_1},$$

where $I_1, I_3, I_5, I_7, I_9, \ldots$ are the currents at their respective harmonics.

Linear loads have very low values of THD because they have little to no harmonic current. Non-linear loads have large values of THD, and cause considerable distortion to the normal sine wave. The more the sine wave gets distorted, the lower the total power factor becomes. Usually, total power factor is associated only with the phase displacement of the voltage waveform to the current waveform, but harmonics also affect the total power factor. The most common formula for power factor is:

$$PF_{DISP} = \cos\theta,$$

where θ is the angle between the voltage and current waveforms. This is only one part of the total power factor, known as the displacement power factor. What is typically overlooked is that it is possible to have a power factor less than one even though there is no phase shift between the voltage and current waveforms. The other part of the total power factor, called the distortion power factor, is due to harmonics. The formula for distortion power factor is:

$$PF_{THD} = \sqrt{[\,1 / (\,1 + THD^2)]}.$$

The total power factor the product of the displacement power factor and the distortion power factor.

Summary

Harmonics are more of a concern now than ever before because of the way the high-tech devices we use now draw current. They draw current in a non-sinusoidal fashion creating harmonics. Harmonic currents travel on the outer edge of the conductors (skin effect) creating heat. This heat causes circuit breakers to trip, neutral and phase conductors to heat up, and motors and transformers to fail prematurely. Because all of these causes of harmonics are a nuisance to the user, the *Ultra-K* has been developed. It is designed to handle the heat generated by harmonics. The *Ultra-K* has a K-factor rating which determines how much heat the transformer is able to withstand. Controlled Power Company manufactures the *Ultra-K*, which is a K-rated transformer, with K-ratings of K-4, K-7, K-13, and K-20. The *Ultra-K* also comes with double or triple shielding (your choice) for the highest level of noise attenuation.