Application Note:

HARMONICS MONITORING

HOW HARMONICS ARE GENERATED AND WHY THEY SHOULD BE REGULARLY MONITORED

Utilities generate virtually pure sinusoidal power. Nonlinear loads, such as frequency inverters, switching power supplies and UPSes consume nonlinear power. Figure 1 shows a simple electrical network with pure source and single load. When the switch is connected, there is a voltage drop due to the supply line impedance. The result is that pure voltage in the source leads to distorted voltage and current in the main service (Figure 2).
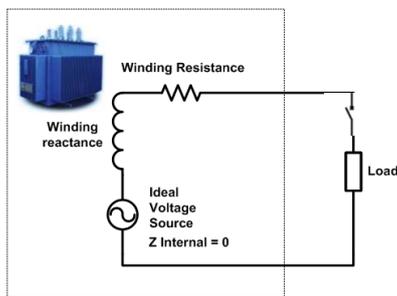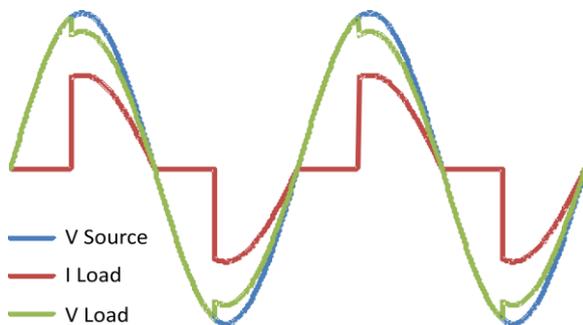

Figure 1: Simple Electrical Network

Figure 2: Distorted Waveform

Measurement of Harmonics

In order to analyze the influence of the harmonics, a Fast Fourier Transform (FFT) is performed. FFT divides the waveform into several waveforms, each one in another frequency which is a multiplication of the fundamental one, as shown in Figure 3. Each waveform has its own amplitude and phase shift.
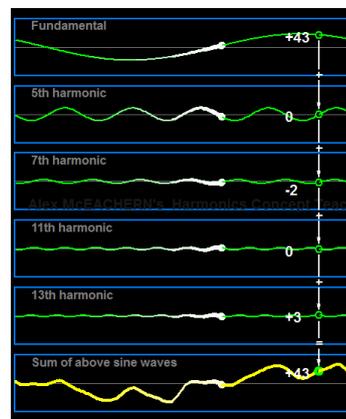

Figure 3: Adding Waveforms

In order to enable analysis of the harmonic distortion, the parameter THD, which stands for Total Harmonics Distortion, is defined as $THD = \frac{100\% \cdot \sqrt{(x_2^2 + x_3^2 + ... + x_n^2)}}{x_1}$. There are two different THD values for the voltage (THDv) and current (THDi).

Harmonics Standards and Practices

Harmonics can cause significant damage. A comprehensive research, conducted in Europe at 1400 sites in 8 countries, reports that 20% experience the following:

- Computer lockouts (20%)
- Light flickering (22%)
- Electronic card failures (18%)
- Power Factor correction system failures (17%)
- Failures in high load switching (16%)
- Neutral conductor overheating (12%)
- Unexpected breaker operation (11%)
- Power meters inaccurate readings (6%)

And of course excess losses and downtime.

Various standards, such as the American IEEE 519, European EN50160 or the British standard P5/4, specify limits for the THDv and some of them also THDi. While for the voltage the levels are defined as an absolute value in each standard/network (typically between 3% to 8%), the current is a more fluctuating value which presents another challenge. For example, a site with computer servers causing 100A distorted current out of a total of 1000A has 10% THDi. At night, most of the loads are down with total current of 200A but the computers continue to work, resulting in 50% THDi. It would seem that at night the problem is worse than during the day, but it is rather the other way around; the level of polluted current is the same, but since the network is less loaded at night, the case is better than during daytime. Using another parameter enables estimation of the current harmonics during different loading conditions. TDD (Total Distortion Demand) is

defined as $TDD = \frac{100\% \cdot \sqrt{(I_2^2 + I_3^2 + ... + I_n^2)}}{I_{max\ demand}}$. It is defined for the current only and its common levels are similar to the voltage (3% to 8%).

Affects on all loads

Affect on Transformers

Transformers are a major source of losses in the electrical network. The losses in transformers include four different types:

- No load losses (core losses), which are fixed and do not change with the load
- Copper losses, equals to I^2R (all harmonics have same affect)
- Winding eddy current losses, linear with the square of the harmonic index - $P_{EC} \alpha\ I^2h^2$
- Stray losses (in clamps, tanks, etc.), includes various losses and in estimation is linear with the 0.8 power of harmony: $P_{SL} \alpha\ I^2h^{0.8}$

As can be seen from the above formulas, there is a difference in the losses caused by the current in each harmonic order. Since THD and TDD parameters provide equal importance to each harmonic order, they are not suitable of analyzing the losses.

There a several formulas to estimate the losses and help designing the network for harmonics. The most common one is K factor, which is calculated as $K\,\text{factor} = \frac{\Sigma(I_n \cdot n)^2}{\Sigma I_n^2}$. Especially design K-transformers are used to cope with harmonics, according to the K factor. For example, a K4 transformer works with harmonics up to K factor of 4 similarly to regular (K1) transformer with pure sinusoidal waveforms.

The additional losses in the transformer are converted to heat and increase their operational temperature. According to Arrhenius law, each 10 Deg. Celsius reduce the life expectancy in half, which means that harmonics shorten the lifetime of transformers and other loads.

Affect on Motors

Three phase motors (squirrel cage) design is based on the rotating of the three phase network. Harmonic voltage runs N times faster (N – order of harmonic). The result is that they create a force reversed to the motor force that is generated by the fundamental harmony and slow down the motor. The harmonic current increases the motor heat, reducing its life expectancy.

Affects on Power Factor Capacitors

Capacitors are short circuit for high frequencies. Power factor correction capacitors are designed for the fundamental harmony. In presence of harmonics, their impedance is lower which result in increasing the amount of harmonics, capacitor overheating, potentially permanent damage to capacitors and resonance between the capacitors and transformers. The solution is installing series reactor to each capacitor that limit these phenomenon but increase the system losses.

Directions of Harmonics

As the rule of thumb above, utilities deliver voltage harmonics to the consumers and consumers inject current harmonics toward the power source. However, voltage and current harmonics increase each other, particularly in situations of resonance. This makes it complicated to identify which part has a higher responsibility for the higher harmonics.

Precise analysis of source of harmonics is based on impedances and network simulation. However, there are two practices that allow reasonable evaluation of the direction:

- Monitoring the harmonic energy flow direction (negative sign means load generates harmonics)
- Comparing the THDv and TDD – If THDv > TDD the source is the utility

Recommendation

Any electrical installation must take into account the harmonics. It is important to continuously monitor the harmonies levels and take action shall they are exceeding certain limits.

Recommendations for new installations:

- Estimate the level of harmonics
- Install power meters that can measure accurately at least 40 harmonics, THD, TDD and K-Factor
- Specify limits for alerts and configure the power meters accordingly
- Consider harmonics filtration solutions (low harmonic pollution loads, passive filers, active filters, retuned power factor etc.)

Recommendation for existing installations:

- Perform harmonics study for a week and compare to international standards. Check the levels of at least 40 harmonics, THD, TDD and K-Factor. It is possible to use temporary handheld meters. However, permanent installation is preferred.
- Specify limits for alerts and configure the power meters accordingly
- Consider harmonics filtration solutions (low harmonic pollution loads, passive filers, active filters, retuned power factor etc.)

Harmonics in SATEC devices

All SATEC meters from PM130EH and up provides details about the harmonics, including:

- Measurement of THD as well as TDD with local display and via communication
- Measurement of K Factor for transformer performance monitoring and design
- Measurement of individual harmonics for depth analysis (up to 40th in the basic meters, 50th in mid-range and 63rd in high end)
- Automatic comparison to International power quality and harmonics standards, such as IEEE 519
- Programmable controller logic on harmonics such as in cases of high harmonic level, PF control application or high losses detection

Figure 4 shows a basic powermeter model EM133 that is equipped with complete harmonic measurements – up to 40th harmonics, THD, TDD and k-Factor. It has built in relay that can be freely programmed with up to 16 different setpoints, each one with its own hysteresis of values and time. Figure 5 provides an example of setpoint configuration for harmonic protection that includes all three parameters – THD, TDD and K-Factor. The powermeter has internal "or" logic that makes sure that exceeding any value will activate its relay. By connecting the relay to a notification system, the operator receives a warning for excessive level of harmonics.

Figure 5: Harmonics Setpoint Example

Figure 4: EM133 with Harmonic Monitoring

Summary

Harmonics is an important issue in the modern electrical network, becoming increasingly more important as more switching and smart loads are present. Harmonics must be monitored regularly in order to verify its level and prevent potential failures or high losses. The use of SATEC meters simplifies the operation by measuring all required parameters from the fundamental THD values, through TDD and K-Factor as well as individual harmonics. With the custom control logic, the monitoring becomes an automatic process.