Engineer's Notebook

Power & Power Quality Measurements

Understanding Power & Power Quality Measurements

The threatened limitations of conventional electrical power sources have focused a great deal of attention on power, its application, monitoring and correction. Power economics now play a critical role in industry as never before. With the high cost of power generation, transmission, and distribution, it is of paramount concern to effectively monitor and control the use of energy.

For economic reasons, electric power is generated by utility companies at relatively high voltages (4160, 6900, 13,800V are typical). These high voltages are then reduced at the consumption site by step-down transformers to lower values, which may be safely, and more easily used in commercial, industrial and residential applications.

Personnel and property safety are the most important factors in the operation of electrical system operation. Reliability is the first consideration in providing safety. The reliability of any electrical system depends upon knowledge, preventive maintenance and subsequently the test equipment used to monitor that system.

TYPICAL VOLTAGE CONFIGURATIONS

Single-Phase Systems

Single-phase residential loads are almost universally supplied through 120/240V, 3-wire, single-phase services. Large appliances such as ranges, water heaters, and clothes dryers are supplied at 240V. Lighting, small appliances, and outlet receptacles are supplied at 120V. In this system the two "hot" or current carrying conductors are 180 degrees out-of-phase with respect to the neutral.

Three-Phase, 3-Wire Systems

In this type of system, commonly known as the "DELTA" configuration, the voltage between each pair of line wires is the actual transformer voltage. This system is frequently used for power loads in commercial and industrial buildings. In such cases, service to the premises is made at 208V, three-phase. Feeders carry the power to panel boards supplying branch circuits for motor loads. Lighting loads are usually handled by a separate single-phase service. The 480V distribution is often used in industrial buildings with substantial motor loads.

Three-Phase, 4-Wire Systems

Known as the "WYE" type connection, this is the system most commonly used in commercial and industrial buildings. In office or other commercial buildings, the 480V three-phase, 4-wire feeders are carried to each floor, where 480V three-phase is tapped to a power panel or motors. General area fluorescent lighting that uses 277V ballasts is connected between each leg and neutral; 208Y/120 three-phase, 4-wire circuits are derived from step-down transformers for local lighting and receptacle outlets.

Typical voltage:
phase-to-phase = 208/480V
phase-to-neutral = 120/277V

Balanced vs. Unbalanced Loads

A balanced load is an AC power system using more than two wires, where the current flow is equal in each of the current-carrying conductors. Many systems today represent an unbalanced condition due to uneven loading on a particular phase. This often occurs when electrical expansion is affected with little regard to even distribution of loads between phases or several nonlinear loads on the same system.

RMS vs. Average Sensing

The term RMS (root-mean-square) is used in relation to alternating current waveforms and simply means "equivalent" or "effective," referring to the amount of work done by the equivalent value of direct current (DC). The term RMS is necessary to describe the value of alternating current, which is constantly changing in amplitude and polarity at regular intervals. RMS measurements provide a more accurate representation of actual current or voltage values. This is very important for nonlinear (distorted) waveforms.

Until recently, most loads were "linear"; that is, the load impedance remained essentially constant regardless of the applied voltage. With expanding markets of computers, uninterruptable power supplies, and variable speed motor drives, resulting nonlinear waveforms are drastically different.

Measuring nonsinusoidal voltage and current waveforms requires a True RMS meter. Conventional meters usually measure the average value of the amplitudes of a waveform. Some meters are calibrated to read the equivalent RMS value (.707 x peak); this type calibration is a true representation only when the waveform is a pure sine wave (i.e., no distortion). When distortion occurs, the relationship between average readings and True RMS values changes drastically.

Only a meter which measures True RMS values gives accurate readings for a nonsinusoidal waveform. RMS measuring circuits sample the input signal at a high rate of speed. The meter's internal circuitry digitizes and squares each sample, adds it to the previous samples squared, and takes the square root of the total. This is the True RMS value.

DEMAND

The amount of electrical energy consumed over time is known as demand. Demand is the average load placed on the utility to provide power (kilowatts) to a customer over a utility-specified time interval (typically 15 or 30 minutes). If demand requirements are irregular, the utility must have more capability available than would be required if the customer load

requirements remained constant. To provide for this time-varying demand, the utility must invest in the proper size equipment to provide for these power peaks. Brief high peaks such as those present when large equipment initially comes on line are not critical in the overall equation because the duration is short with respect to the demand averaging interval.

CONSUMPTION

Watts and vars are instantaneous measurements representing what is happening in a circuit at any given moment. Since these parameters vary so greatly within any period, it is necessary to integrate (sum) electrical usage over time. The fundamental unit for measuring usage is the watthour (Wh), or more typically the kilowatthour (kWh). This value represents usage of 1000W for one hour. Typical costs in the United States for one kilowatthour range from 8 to 15 cents.

POWER FACTOR

Power factor is the ratio of ACTUAL POWER used in a circuit to the APPARENT POWER delivered by a utility. Actual power is expressed in watts (W) or kilowatts (kW); apparent power in voltamperes (VA) or kilovoltamperes (kVA). Apparent power is calculated simply by multiplying the current by the voltage.

$$\textbf{Power Factor} = \frac{\textbf{Actual Power}}{\textbf{Apparent Power}} = \frac{\textbf{kW}}{\textbf{kVA}}$$

Certain loads (e.g., inductive type motors) create a phase shift or delay between the current and voltage waveforms. An inductive type load causes the current to lag the voltage by some angle, known as the phase angle.

On purely resistive loads, there is no phase difference between the two waveforms; therefore the power factor on such a load will be 0 degrees, or unity.

Understanding Power & Power Quality Measurements continued...

ELECTRICAL HARMONICS

Until fairly recently, power quality referred to the ability of the electric utilities to supply electric power without interruption. Today, the phrase encompasses any deviation from a perfect sinusoidal waveform. Power quality now relates to short-term transients as well as continuous state distortions. Power system harmonics are a continuous state problem with dangerous results. harmonics can be present in current, voltage, or both. It is estimated that as many as 60% of all electrical devices operate with non-linear current draw.

Utility companies invest millions of dollars each year to ensure that voltage supplied to their customers is as close as possible to a sinusoidal waveform. If the power user connects loads to the system which are resistive, such as incandescent light bulb, the resulting current waveform will also be sinusoidal. However, if the loads are nonlinear, which is typically the case, the current is drawn in short pulses and the current waveform will be distorted. Total current that is then drawn by the nonlinear load would be the fundamental as well as all the harmonics.

Harmonic distortion can cause serious problems for the users of electric power, from inadvertent tripping of circuit breakers to dangerous overheating of transformers and neutral conductors, as well as heating in motors and capacitor failure. Harmonics can cause problems that are easy to recognize but tough to diagnose.

Loads which produce harmonic currents include:

- Electronic lighting ballasts
- Adjustable speed drives
- Electric arc furnaces
- Personal computers
- Electric welding equipment
- Solid state rectifiers
- Industrial process controls
- UPS systems
- Saturated transformers
- Solid state elevator controls
- Medical equipment

Harmonics can cause a variety of problems to any user of electric power. For large users, the problems can be intense. For electronic equipment that relies on the zero crossing of the sinusoidal waveform, such as clock timing devices, heavy harmonic content can cause a zero crossing point offset.

Odd number harmonics (third, fifth and seventh) cause the greatest concern in the electrical distribution system. Because the harmonic waveform usually swings equally in both the positive and negative direction, the even number harmonics are mitigated.

False tripping of circuit breakers is also a problem encountered with the higher frequencies that harmonics produce. peak sensing circuit breakers often will trip even though the amperage value has not been exceeded. Harmonic current peak values can be many times higher than sinusoidal waveforms.

Most harmonic problems result when the resonant frequency is close to the fifth or seventh harmonic. These happen to be the largest harmonic amplitude numbers that adjustable speed drives create. When this situation arises, capacitor banks should be resized to shift the resonant point to another frequency.

Detection and Measurement

In harmonic analysis, field measurements are performed to identify frequency and magnitude of harmonic currents generated by susceptible equipment (e.g., electronic equipment, variable speed motors, etc.). Remember that most distribution systems are designed specifically to carry 60 Hz.

Most nonlinear harmonic problems can be detected at the electrical panel. Excessive current flow on the neutral can be detected with a True RMS current meter, but may be indicated by a resonant buzzing sound or by discolored connections on the neutral buss.

Beginning at the service entrance panel, measure and record the True RMS current in each phase, as well as the neutral of the distribution transformer secondary. Compare this measured neutral current to the anticipated current due to phase imbalance. If the phase currents are equal, the vector sum of the neutral currents will add to zero. If there are excessive amounts of triplen harmonics in the neutral, neutral current may exceed phase current. Consult the NEC® for the maximum ampacity for each of the tested conductors.

Effects on the System

To compound the problems that harmonic currents present to the system, nonlinear harmonic load also have an Ohm's law relationship with the source impedance of the system to produce voltage harmonics. Consider a heavily loaded transformer that is affected by one branch circuit feeding a non-linear load. The creation of voltage harmonics can then be passed down to all the remaining circuits being fed by that transformer.

Voltage harmonics may cause havoc within the electrical system. Motors are typically considered to be linear loads; however, when the source voltage supply is rich in harmonics, the motor will draw harmonic current. The typical result is a higher than normal operating temperature and shortened service life.

Different frequency harmonic currents can cause additional rotating fields in the motor. Depending on the frequency, the motor will rotate in the opposite direction (counter-torque). The fifth harmonic, which is very prevalent, is a negative sequence harmonic causing the motor to have a backward rotation, shortening the service life.

Transformer Derating

Most generators and transformers base their operating characteristics on undisturbed 60Hz waveforms. When the waveforms are rich in harmonics, shortened service or complete failure often follows.

The derating K factor can be applied specifically to transformers to ensure that dangerous heating will not result due to the transformer supplying load currents rich in harmonic content.

The K factor is basically an index of the transformer's ability to handle nonlinear load current without abnormal heating. Some distribution transformers are now being designed with magnetic cores and windings to accommodate harmonic content. A K-rated transformer is specifically designed to handle nonlinear loads. The higher the K factor value, the better the transformer's ability to handle nonlinear loads.

Meter Readings

Harmonic problems can be analyzed more easily when the proper test equipment is used.

The term "True RMS", or Root-Mean-Square, relates to the equivalent DC heating value of the current or voltage waveform. If a pure sine wave and a distorted sine wave were both applied to a resistive load, the point where they both create the same heating value is the point where they both have the same RMS value.

True RMS capability is required to accurately measure systems where harmonic current is present. Average responding instruments will yield erroneous measurement results from 25 to 40% below the actual value when harmonic distortion is present.

Crest Factor

Crest factor is the ratio of the Peak value of a sinusoidal waveform to its RMS value.

$$\text{Crest Factor (CF)} = \frac{\text{Peak Value}}{\text{RMS Value}}$$

Crest factor indicates the level of peaking which an instrument can handle without measurement errors. For a perfect sine wave the crest factor would be 1.414. This relates to the Peak amplitude that an instrument can measure accurately. Typical crest factor ratings are from 2.0 to 6.0. The higher the factor, the more capable the instrument of measuring a complex waveform correctly. When harmonics are present crest factors may be less than (CF of a square wave = 1) or greater than 1.414.

Limiting the Effects of Harmonics

Derating certain types of electrical equipment is the easiest way to limit the effects that increased heating has on the equipment. A 25% derating for transformers and generators is commonly employed in industry.

Filtering is currently the most common method used to limit the effects that harmonics present to the rest of the system. Filters typically consist of tuned series L – C circuits. Filter impedance is negligible with respect to the rest of the system, limiting its interaction effects for harmonic control. Filters are sized to withstand the RMS current as well as the value of current for the harmonics.

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