

Power Quality Issues, Impacts, and Mitigation for Industrial Customers

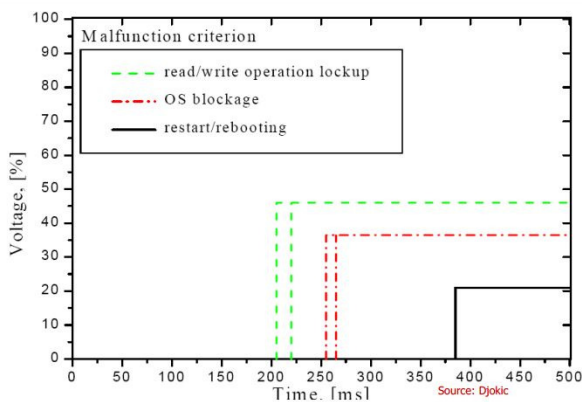
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Now, more than ever, electronic equipment and computing devices are used in all types of industrial processes. This has been pivotal in making these processes more productive, efficient, and safe. However, this trend also makes manufacturing processes and equipment more vulnerable to real-world power quality conditions. Power quality is related to fluctuations in the electrical supply in the form of momentary interruptions, voltage sags or swells, transients, harmonic distortion, electrical noise, and flickering lights, among others. The electrical power grid is designed for delivering power reliably, namely maximizing power availability to customers. However, power quality events are largely untracked, and as a result, can take out a process as many as 20 to 30 times a year, costing industrial customers millions of dollars. To minimize these costs, it is critical for industrial customers to understand how power quality is impacting their system and how to mitigate its effects.

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Costs show up in the form up plant downtime, lost work in process, additional labor, and possibly missed shipment dates.

Industrial customers are becoming more aware of the direct costs associated with the electrical energy consumed by their machines and processes as it shows up every month on their utility bill. However, the indirect costs associated with poor power quality, or voltage quality to be more precise, while just as significant, are less obvious. These costs show up in the forms of plant downtime, equipment replacement, lost work in process, additional labor, and possibly missed shipment dates. Without the ability to monitor and gain a comprehensive understanding of the impact power quality has on industrial

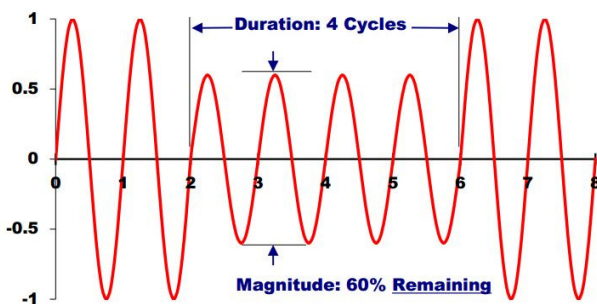


processes, these costs will continue to go unaddressed. However, with the knowledge to identify and mitigate power quality events, process reliability can be significantly improved.

The utility is responsible for the reliability of power, not the quality of power. The supplied power by the utility generally does not have an ideal sinusoidal voltage, and the customer is responsible for protecting their sensitive equipment at their own expensive. Moreover, the electrical equipment and machinery within the plant floor can worsen the quality of power being distributed. There are numerous types of power quality problems; however, the three types that impact industrial customers the most are voltage sags, harmonics, and transients.

Sags

Voltage sags are an RMS voltage reduction by at least 10% of the nominal voltage that lasts between half a cycle and a minute. IEEE 1159, "Recommended Practice for Monitoring Electric Power Quality," classifies sags as instantaneous (0.5 cycles to 30 cycles), momentary (30 cycles to 3 seconds), and temporary (>3 seconds to 1 minute).



In a study done by the Electric Power Research Institute (EPRI), an average of 66 voltage sags was experienced by industrial customers per year.

Example 60% sag with a duration of 4 cycles (Instantaneous)

What are the causes and effects of sags?

A common cause of sags for industrial customers is turning on large loads such as large motors. If using an across-the-line motor starter, the current draw when turning on a motor can be six times or more of its normal running current. The large and sudden current draw results in downstream voltage drops. Weather factors, such as lightning, wind, and ice, are also significant

contributors to voltage sags. From an electric utility perspective, a fault on the transmission system can produce a sag to electricity users downstream of that location, and depending on the system topology, users upstream or even on connected distribution circuits can be affected as well.

Depending on the ride through capability of a variable frequency drive, a sag can create an undervoltage condition on a drive's DC bus, tripping the drive and potentially stopping critical process lines.

Often times, process controls use 120 VAC relays in the emergency stop circuit of control circuits. Sags can contribute up to 20 shutdowns a year by tripping these relays.

Programmable logic controllers (PLC) and other industrial computers can be very susceptible to voltage sags. All computing equipment requires a power supply to provide a low DC voltage in order to operate. Without sufficient ride through capability, computing equipment can be disrupted during sags, severely impacting industrial controls and causing data corruption. Moreover, if using digital I/O, a logical "high" can be read by the PLC as a logical "low" if the input voltage drops significantly, potentially causing process disruption.

How do I mitigate sags?

Uninterruptible Power Supplies (UPS) is the most common solution for all types of RMS voltage variations (sags, swells, undervoltages, overvoltages, and interruptions). A UPS uses stored energy in a battery to provide load power when the normal power supply falls outside a defined voltage range.

If the sags a customer is experiencing are largely in the instantaneous or momentary classification, an alternative to a UPS is an Electronic Sag Compensator. An electronic sag compensator uses a capacitor instead of a battery for energy storage. As a result, electronic sag compensators are lower maintenance and have higher rated lifetimes. In addition, electronic sag compensators are generally more lightweight. However, electronic sag compensators don't have the same ride-through capability as a UPS for longer duration sags.

Voltage sags can also be addressed by using constant voltage transformers (CVT), which are generally suited for constant, low power loads. By saturating the transformer core with magnetic flux, differing from most transformer applications, a relatively constant output voltage is maintained.

Sags that result from the starting of large motor loads can be addressed by using drives or soft starters to minimize in-rush current at start-up.

Harmonics

Harmonics are a form of voltage or current waveform distortion. A harmonic refers to a component of a waveform of a frequency that is a multiple of the fundamental, general 50 or 60Hz. For example, the third harmonic for US electrical distribution systems would be 3 * 60Hz = 180 Hz. Harmonics are a relatively steady state condition, unlike momentary conditions such as sags or transients. A common measurement of the cumulative amount of harmonic distortion is Total Harmonic Distortion (THD), which is calculated by IEEE as follows:

$THD(\%) = \sqrt{ID_1^2 + ID_2^2 + \dots + ID_n^2}$, where ID_n is the magnitude of the nth harmonic as a percentage of the fundamental frequency. IEC calculates THD in a similar fashion, except ID_n represents the percentage of the true RMS magnitude.

IEEE 519, "IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems," is the standard for harmonics in North America. Within this standard, recommended limits are provided for individual harmonics and total distortion. This standard aims to limit harmonics at the Point of Common Coupling (PCC), defined as the utility/customer connection point, focusing on current distortion limits for the user and on voltage distortion limits for the supplying utility.

[Harmonics] over time can result in increased power demand, system loss, and shorter equipment lifetime.

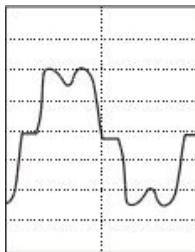
What are the causes and effects of harmonics?

Harmonics are caused by non-linear loads in the electrical system, meaning that the loads draw non-sinusoidal current from a sinusoidal voltage source. Examples of non-linear loads that produce harmonics are AC or DC motor drives, electric arc furnaces, static VAR compensators, inverters, and switch-mode power supplies, such as those found in computers, lighting ballasts, and industrial electronic gear. Industrial customers are increasingly using drives for more

precise motor control and to improve energy efficiency. Consequently, the potential for greater harmonic distortion rises.

For example, the AC current at the input to a rectifier begins to resemble a square wave as opposed to a sine wave. Dependent on the system impedances, corresponding voltage harmonics are generated as a result of current harmonics. Variable frequency drives also produce harmonic content at the output of the inverter, seen by the motor. Sometimes, interharmonics, which are non-multiple frequencies of the fundamental, can be present at the input or the output of the drive.

High levels of harmonic distortion can result in increased transformer, capacitor, motor, or generator heating. In addition, electronic equipment that relies on voltage zero crossing detection, or is sensitive to voltage wave shape, can malfunction. Other potential effects include incorrect readings on meters, misoperation of protective relays, and interference. Devices in parallel with harmonic sources will see a distorted voltage waveform, and consequently, these electronic devices can trip, potentially causing plant shutdown.



Typical 6-Pulse Rectifier Input Current Waveform

Moreover, harmonic currents produce additional efficiency losses, and consequently, system components such as cables, circuit breakers, and transformers may have to be oversized. In a 3-phase wye system, triplen harmonics, defined as odd harmonics that are multiples of three (i.e. 3, 9, 15, 21, etc), sum together in the neutral conductor, creating a large neutral current. This can result in efficiency losses and requires an oversized neutral conductor.

The probability of these effects increases dramatically when the harmonic frequency coincides with a power system natural frequency, known as a resonant condition. This condition sometimes occurs when combining drives with power factor correction capacitors. Resonance results in substantial amplification of the harmonic current and can lead to a blown capacitor fuse or transformer overheating.

The negative impact of harmonics may not be immediately evident, but over time can result in increased power demand, system loss, and shorter equipment lifetimes.

How do I mitigate harmonic distortion?

Harmonic mitigation can result in roughly a 15% Capital Expenditure (CAPEX) reduction and a 10% Operational Expenditure (OPEX) reduction.

Harmonic filters, passive or active, can be added to the system to suppress harmonic frequencies. Passive filters are tuned to filter a specific frequency or group of frequencies. While this is a lower cost option, passive filters have diminishing benefit for varying loads. Active filters measure the harmonic currents present in the system and generate opposite harmonics to cancel those produced by the harmonic sources.

[Transients] can result in data loss or even physical damage to equipment.

If the problems arising are a result of harmonic resonance, it could be worthwhile adding or subtracting a small level of power factor correction capacitance to shift the overall system natural frequency.

When looking to reduce the harmonic distortion that is the result of a variable frequency drive, options include using a rectifier with a higher pulse than 6. While a 6-pulse rectifier will produce roughly

25% current THD, a 12-pulse rectifier will produce about 12% THD, and an 18-pulse rectifier will produce about 5% THD. Another method is to place AC line reactors in series with the incoming AC power line, which, along with the DC link chokes, help to smooth out the flow of current to the drive. Reduced harmonic distortion can also be achieved by using a Pulse Width Modulated (PWM) rectifier that uses switching devices instead of diodes. PWM rectifiers can use control algorithms to minimize the current distortion produced at the drive input.

Transients

Transients are sub-cycle disturbances in the AC waveform and can be categorized as either impulsive or oscillatory. Transients are possibly the most damaging type of voltage disturbance.

What are the causes and effects of transients?

Impulsive transients are frequently referred to as surges. The most common cause of impulsive transients is lightning strikes. Other causes include electrostatic discharge (ESD), poor grounding, switching of inductive loads, switching of power factor correction capacitors, and utility fault clearing. This can result in a large amount of energy transfer with very short rise and decay times. IEEE 1159, "Recommended Practice for Monitoring Electric Power Quality," further categorizes impulsive transients by the speed at which they occur. "Fast" transients can have a 5 ns rise time and have duration of less than 50 ns.

An impulsive transient can damage a wide variety of equipment that's not rated for such high voltage levels, with computing equipment being especially vulnerable. Even if the amplitude of the transient isn't very high, the rise and fall rate of voltage can damage solid-state equipment. Moreover, repeated transients can have a cumulative impact on electronic equipment, leading to failure in time with no evident cause. Consequently, the damage from impulsive transients can lead to data loss and process faults.

Capacitive or inductive load switching is the most common cause of oscillatory transients. Often times for active power factor correction, capacitors will switch on or off, changing the steady state of the electrical system. Oscillatory transients can also occur by abruptly turning off a motor load. In these situations, the system voltage will oscillate at a high frequency that decays within an electric cycle. IEEE 1159 further classifies oscillatory transients by its frequency content, ranging from less than 5 kHz as low frequency and

between 0.5 and 5 MHz as high frequency.

The voltage overshoot that is a product of the oscillation can affect equipment such as variable speed drives. In addition, the oscillation in the AC voltage can impact the voltage level of a drive's DC bus, potentially causing it to exceed its overvoltage trip point.

How do I mitigate transients?

Equipment can be protected from impulsive transients by removing sources of potential ESD and using surge suppression devices (SPD). SPDs use metal oxide varistors (MOV) to suppress impulsive transients, swells, and other high voltage conditions, and can be used in conjunction with circuit breakers to help protect equipment. The MOV has the ability to dissipate a large amount of the energy from an impulsive transient and clamps its voltage to a level that doesn't damage equipment. MOVs can degrade with usage, so it's important for the SPD to have the ability to break the circuit if the MOV is unable to function as expected.

Good wiring practices can also help reduce the impact of impulsive transients. This includes separating the power, control, and communications wiring, as well as crossing different classes of circuits at 90 degree angles.

To help prevent oscillatory transients from impacting variable speed drive performance, a common solution is to install line reactors or chokes that damp the oscillatory transient to a manageable level. High frequency filters can also suppress oscillatory transients.

Conclusion

The vast majority of power quality issues experienced by industrial customers can be attributed to sags, harmonics, and transients. However, several other power quality conditions can also disrupt processes and equipment, such as swells, undervoltages, overvoltages, interruptions, DC offsets, notching, noise, voltage fluctuations, and frequency variations. Solutions exist for all of these types of conditions, but the biggest step that needs to be taken to reduce the capital and operational expenditures that are a direct result of power quality is to have the capability to measure, detect, and visualize your power quality events and conditions.

Power quality monitors are similar to energy monitors in that they measure voltage and current. However, there are much higher processing and computational requirements in order to detect, capture, and measure power quality events that can be of high frequency and sub-cycle duration. Moreover, in order to plan mitigation strategies, visualization software is necessary to view waveforms and analyze the captured data. An orthopedic surgeon is unlikely to take any kind of action without taking an X-ray first. Similarly, in order to know the correct power quality mitigation actions to take, proper measurement is required. Power quality events can last microseconds and happen sporadically, but these same events can be extremely detrimental to the reliability of production. To "prescribe" a solution, the complete picture is required.

Resources

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