In the United States, more than 14,500 Water and Wastewater Treatment Plants (WTP/WWTP) rely upon properly designed electrical distribution systems to supply clean, stable power to equipment that runs the gamut from DC motors to control instrumentation. In this white paper, we will address Power Quality (PQ) as the first step in recognizing opportunities to improve WTP/WWTP operational reliability and energy efficiency. WTP/WWTPs are some of the largest consumers of electrical power in the world. Approximately 4 percent of US electricity usage is linked to water treatment, corresponding to 30.2 billion kWh per year and more than 21 million metric tons of greenhouse gas emissions.

From a strictly monetary standpoint, it makes sense for WTP/WWTPs to adopt a strict PQ policy because it allows them to dramatically cut rising operational costs while increasing profitability. From a sustainability perspective, it translates into a smaller carbon footprint for the plant, along with the reduced potential for incidents requiring the discharge of contaminated wastewater into local streams and rivers. Power quality is key for continuous, safe, cost-effective, and sustainable treatment services throughout a plant's lifetime.

Power Quality Problems in WTP/WWTPs

PQ refers to power characteristics, or more specifically, the determining of the quality of current and voltage using performance-based criteria like frequency, symmetry, and magnitude. Desired characteristics would be clean sinusoidal waveforms free of harmonics, sags, swells, unbalances, or fluctuations. In WTP/WWTPs, the most common power quality problems are harmonics, voltage sags or swells, and noise.

Prevention against **harmonic distortions** is important because variable speed drives have made WTP/WWTPs highly vulnerable to their damage. For instance, compressors are frequently paired with variable frequency drives (VFDs) to maximize motor efficiency, yet VFDs present power quality issues on the input and output side, especially harmonic distortions. Besides VFDs, other low- and high-power nonlinear electronic switching loads like computers, power controllers, servers, telecom equipment, and switched-mode power supplies, force conductors to carry currents at frequencies other than 60 hertz. In other words, these loads draw nonlinear current at specific points along the voltage sinewave instead of drawing current all across the sinewave.

Low harmonic frequencies (e.g. 180, 300, or 420 hertz) are caused by low-frequency distorted currents and phase-shifted currents flowing through the power system. High harmonic frequencies (between 1 and 3 kHz) are caused by switching of high currents in high-power, nonlinear electronically switched loads. This problem is growing progressively worse as the power levels of electronic switching power supplies continue to increase, and more high-power electronic switching-based equipment is added to plant electrical systems.

Another harmonics phenomenon, line notching, is caused by the switching of current rectifiers in the WTP/WWTP's DC motor drives, motor starters and power supplies. Line notching can produce high frequency harmonics destructive to capacitor banks and electronics.

Besides harmonics, WTP/WWTPs are highly vulnerable to voltage sags (undervoltage) brought about by large loads coming online. The sag typically lasts at least one half cycle but can endure for up to several cycles. In severe cases of more than a 15 percent sag, PLCs and PCs can crash and other equipment can abruptly shut down. During a sag, for instance, water pumps using AC motors on constant torque load will draw more current, reducing efficiency and sometimes tripping overload relays. These same issues can occur because of a voltage swell (transients, spikes, impulses). The opposite of a voltage sag, swells are caused by large loads going offline or by a lightning strike, resulting in a sudden massive increase in voltage. In cases of more than a 10 percent swell, sensitive electronic components may be damaged. System lock-up or failure can corrupt valuable operational data.

When small motors are started in a WTP/WWTP they are not likely to cause any major problems for the equipment itself. However, switching noise occurs and produces rapid voltage variations whenever equipment is turned on or off using electrical contactors. This noise will affect the operation of sensitive equipment that controls and monitors the plant's processing equipment. In severe cases, when high enough voltage spikes are produced, they can damage or destroy the sensitive equipment.

Another potential problem for the WTP/WWTP is a compromised grounding network. Common in aging electrical systems, a compromised grounding network will permit leakage current to travel paths not engineered to act as grounds (i.e., building structure, piping, sensor wiring) because the mechanical joints of conduit and rigid pipe have become less capable of maintaining low-impedance ground paths. Compromised plant grounding systems with high impedance that provide a "clearing house" for disturbance currents are incapable of supporting nonlinear switching loads. Such grounding systems cannot dissipate and expel harmful low and high frequency disturbance currents into the Earth ground, leaving them available to create high-differential transient voltages, which cause damage to machines. To compound these growing power quality

deficiencies, machinery is increasingly dependent on low-impedance grounding systems to deal with internal plant power quality problems.

Older electrical systems can be further compromised by thermally hardened electrical conductors, overloaded circuits, and loose connections in electrical panels. The EPA recommends that WTP/WWTP electrical systems be replaced every 15-20 years. However, budget restraints have prevented many WTP/WWTPs from upgrading critical components. In the United States the average WTP/WWTP is over 25 years old.

Energy Efficiency in WTP/WWTPs

Electricity costs may account for up to 40 percent of a WTP/WWTP's operating budget. An aging plant experiencing reduced energy efficiency, combined with higher maintenance costs, can create financial headaches and even potential hazards. Further complications arise from the fact that most treatment plants were designed to meet effluent standards established decades ago. As industry standards have grown more stringent, these plants struggle to stay compliant because their older processes require higher energy consumption than newer technologies offer.

WTP/WWTPs that strategically invest in equipment such as variable frequency drives (VFDs), LED lighting, electronically switched industrial power supplies, and high-efficiency processing equipment will save energy and generate less heat. Bringing down operating temperatures, reducing maintenance costs, and increasing plant-wide energy savings translate into a lower total cost of ownership.

Mitigation Solutions

Eighty percent of electrical disturbances that cause poor power quality originate internally. Powering on and off very large equipment, wiring errors, poorly specified or improperly-serviced power conversion equipment, grounding loops and even normal daily operations can foster power quality issues that lead to production disturbances and lost data. Severe weather, utility fault clearing, power line accidents and other external network issues like grid switching or power-factor correction capacitors represent the remaining twenty percent of power quality problems. These disturbances often generate spikes or power interruptions that can instantly damage equipment. Unfortunately, these incidents are completely unpredictable and beyond anyone's control.

PQ mitigation products — surge protective devices (SPDs), filter-based SPDs, isolation transformers, power conditioners, active tracking filters, and uninterruptible power supplies (UPS), among others — are required to re-establish power quality throughout the WTP/WWTP, therefore reducing the strength of harmonics, surges, sags, and transients, while re-establishing the ground reference needed by equipment to function properly. Due to the numerous sources and types of power disturbances, maintaining PQ effectively requires a multi-tiered approach.

Harmonics Mitigation

As mentioned earlier, harmonics are created whenever a non-linear load draws current in pulses. Harmonics represent trouble for equipment throughout WTP/WWTPs by overheating neutral conductors and transformers, tripping breakers, creating a high neutral current, reducing system capacities, and even loosening electrical connectors.

Transformers are a primary means to address harmonics. These types of transformers are designed for variable speed motor drive applications where a transformer is needed to magnetically isolate the motor drive from the main plant power. When large drives are used, equipment-level protection is recommended. Drive isolation and k-factor transformers perform three basic functions: voltage change, reduction of drive-induced ground currents, and reduction of common-mode noise, whether they are being used with DC drives or variable-frequency AC drive applications. Drive isolation transformers must be able to withstand the heat of non-linear loads. They offer extra advantages over reactors since their wye-connected secondary can be grounded. A k-factor transformer features a higher magnetic to resistive property than a standard transformer, which enables it to handle the heat generated by harmonic currents. K-factor transformers are sized appropriately to handle this additional heat and tested to UL 1561 rigid standards.

A power conditioner is another means of harmonics mitigation. It is used for harmonic correction by recreating a smooth, pure sinewave. It also maintains a constant voltage against spikes and sags, while providing electrical isolation when the application requires it.

Emerson's Solution

SolaHD™ Drive Isolation Transformers by Emerson are specifically designed to handle the mechanical stresses, voltage demands, and harmonics associated with Silicon Control Rectifier (SCR) applications. Created to magnetically isolate the incoming line from the motor drive, it provides a voltage change to match the required voltage of the SCR Drive. Standard designs are delta primary and wye secondary to match the common power sources required in most three phase circuits. SolaHD Transformers meet applicable industry standards, are Listed in accordance with UL 5058 and UL 1561 specifications, and are available from 7.5 to 440 kVA, 3 Phase, 60 Hz.

SolaHD K-Factor Ventilated Distribution Transformers feature conductors capable of carrying the harmonic currents of non-linear loads without exceeding the temperature rating of the insulation system. The basic design takes into account the increase in naturally occurring "stray" losses caused by non-linear loads that can cause standard transformers to dramatically overheat and fail prematurely. Core and coil design is engineered to manage the DC flux caused by triplen harmonics. They are UL 1561 Listed up to K-20 rated protection, DOE 2016 compliant, and shielded for quality power.

SolaHD CVS Hardwired Series Power Conditioners by Emerson provide superior voltage regulation of ±1%, setting the CVS Series apart from other power conditioning technologies on the market. Extremely tight regulation is accomplished by the patented ferroresonant transformer technology, enabling the CVS Series to recreate a well-regulated sinusoidal waveform that is well isolated from input disturbances.

In addition, SolaHD MCR Hardwired Series Power Line Conditioning with Voltage Regulation provides excellent noise filtering and surge protection to safeguard connected equipment against damage, degradation, or malfunction. This protection, combined with ±3% output voltage regulation, can significantly increase the MTBF of protected equipment.

MCR Hardwired Series Power Line Conditioning with Voltage Regulation

Voltage Sags (Undervoltage) Mitigation

Voltage sags are a result of large load start-up and utility switching. While short-lived, these disturbances reduce the efficiency and lifespan of electrical equipment. Repeated exposure to voltage sags will result in damage to SCADA (supervisory control and data acquisition) networks, programmable logic controllers (PLC), remote terminal units (RTU), sensors and variable speed drives.

UPS and power conditioners are deployed in a WTP/WWTPs to protect critical process systems against voltage sages. UPS provide additional protection from power interruptions. Only industrial UPS with rugged components should be specified for harsh environments subject to environmental challenges including wide temperature extremes, humidity, and moisture. Voltage regulators and power supplies with sag immunity also provide protection against sags.

Emerson's Solution

The SolaHD S4K Industrial On-Line UPS by Emerson are true online industrial uninterruptible power systems that provide flexible output voltage. Online design means zero transfer time from external to internal power, so when utility power fails, your critical load remains supported by a seamless flow of power. Models can be configured with an integrated maintenance bypass switch, external bypass switch, internal or external batteries, and feature double conversion topology to provide the ultimate in protection against a wide range of potential power problems.

In addition, engineers can rely on the SolaHD SOLATRON™ Plus Three Phase Power Conditioner to protect equipment from chronic over- and undervoltage, switching transients, lightning, and induced surges. Leveraging a precision-designed surge suppression circuit linked to a shielded isolation transformer, the SOLATRON will regulate output voltage to ±3 percent, even when input voltage varies from +10% to –25%. Response time to any line variation is 1.5 cycles regardless of power factor.

SOLATRON Plus Three Phase Power Conditioner

Voltage Swells (Surge) Mitigation

Voltage swells can originate inside the WTP/WWTP from short circuits, tripped breakers, and the start-up of heavy equipment, or from outside due to a lightning strike or grid switching. Common problems associated with surges are failure to microprocessor-based controllers, circuit boards, flow and other meters, reduced energy efficiency for lighting systems and motors, as well as memory loss and erratic operations of PCs.

Surge protection devices (SPD) or “suppressors” can be installed at the service entrance, branch panels or dedicated sensitive electronic loads. When voltage surges or spikes, the SPD diverts the extra electricity into the grounding wire. Power is effectively short-circuited to ground for transient pulses exceeding the threshold, while the flow of normal current is unaffected.

STC-SLAC Series Surge Protection Devices

Emerson’s Solution

Designed for the water and wastewater industry, SolaHD STC-SS Series Surge Protection Devices by Emerson address overvoltage transients with gas tube and silicon avalanche technology. In addition, sneak and electrical fault currents are mitigated with positive temperature coefficient (PTC) devices that consist of solid-state resettable fuses. The units are encapsulated in stainless steel pipe nipples making them suitable for use in severe environments.

The SolaHD STC-SLAC Series Surge Protection Devices are surge suppressors specifically designed for WTP/WWTPs to protect sensitive electronics that contain both low-voltage control circuit signal lines and 120 volt AC power. It combines the technologies found in the SolaHD STC-642 Series Data/Signal Line Surge Protective Devices and the SolaHD STC-SLAC Series Surge Protection Devices advanced three-stage hybrid solid state power line protector. The rugged waterproof NEMA 4X polycarbonate enclosure is suited for installation in the most severe environments. The AC power suppressor features filtering of common and normal mode noise and metal oxide varistor (MOV) protection for nanosecond response time. The signal line protector incorporates a design consisting of gas discharge tubes (GDT), thermal resettable fuses (PTC) and silicon avalanche diode components (SAD) for premium protection of signal lines up to 36 volts.

Mitigating Lightning Strikes

Lightning strikes are an extreme example of a power surge. Predictably, they are also the most damaging. WTP/WWTPs are built on large, exposed surface areas in isolated locations, and are equipped with vast amounts of metal and electronic equipment, making them "sitting ducks" when it comes to lightning strikes. Most equipment failures at WTP/WWTPs are reported during or shortly after electrical storm activity, indicating that these problems stem from poor surge protection within the distribution system. Lighting strikes can occur within the facility or nearby ground. Overvoltage from lightning directly impacts instrumentation, communications, and sensitive electronic equipment such as gauges, meters, and PLCs.

It is important to note that for direct lightning strikes, SPDs alone are not a replacement for a comprehensive lightning protection system (refer to UL96A Master Lightning Certification). For additional information, Emerson recommends carefully reviewing NFPA (National Fire Protection Association) 780, "Standard for the Installation of Lightning Protection Systems" (United States) and BS EN (European Norm)/IEC (International Electrotechnical Commission) 62305 "Protection Against Lightning" that informs the standards for lighting protection globally.

Emerson's Solution
For hardwired surge protection at the service entrance, branch panel, or a dedicated sensitive electronic load, the answer is SolaHD Series Surge Protective Devices. The STV100K Series features all mode protection, LED and audible alarm status indication, sinewave tracking, and form C dry contacts. They deliver unsurpassed built-in safety with thermal fusing and a fault current fusing level of 100 kAIC. The SPD50K Series can be installed via 3/4" NPT, DIN-Rail, or bracket mount anywhere in any electrical distribution system; line-side or load-side of main disconnect. The LED is visible from multiple sides and angles to allow for better viewing of the status from any of the tri-mount options. The visual diagnostic system is easy to see and easy to diagnose.

The SPD200K and SPD300K Series offers continuous protection from damaging voltage transients and electrical noise commonly found at the service entrance or distribution panel. The robust design allows for installation flexibility in the most severe exposure locations. The SPD200K and SPD300K utilizes circuitry to monitor the status of all protection modes, including neutral to ground. In addition, high isolation form C dry contacts provide remote monitoring of protection system failure, under voltage, phase, and power loss. The protection integrity monitoring indicates failure for both shorted or opened protection components.

Lightning protection for low voltage data requires SolaHD STC-642 Series Data/Signal Line Surge Protective Devices. These compact suppressors address overvoltage transients with gas tubes and silicon avalanche components. In addition, sneak and fault currents are mitigated with resettable fuses that increase resistance several orders of magnitude when over currents exceed safe levels. A normal state resumes when over currents are removed. The ability to self-restore significantly increases performance and survivability.

Mitigating Noise

Typical noise sources can be generated from any piece of equipment when it is turned on or off because of the influx or efflux of voltage or current. This process produces undesirable effects in the electronic circuits such as very rapid or large amplitude changes. In general, noise is a more serious problem on signal and data circuits because these circuits operate at faster speeds and with low voltage levels. The lower the signal voltage, the less the amplitude of the noise voltage that can be tolerated. Electronic solid-state sensors and controls found in WTP/WWTPs use circuit board technology that operates using integrated circuit (IC) components operating at extremely low power levels, meaning that even less noise is required to negatively affect the printed circuit board (PCB) technology. A power filter provides clean AC power by eliminating lower voltage noise, therefore keeping equipment safe and functioning efficiently.

Emerson's Solution
The SolaHD Active Tracking Filters (STFE and STFV Series) guards against lower energy transients. Offering excellent noise reduction, it continuously tracks the input AC power line and responds instantly upon detecting extraneous high frequency noise. The filter eliminates low voltage/high frequency noise via a low-pass or L-C filter. Filters are used for low energy, high frequency noise reduction and consist of a series of inductors, capacitors, and resistors. They are load dependent, meaning the inductors located on each phase and neutral conductors are sized to handle the maximum current draw on the line. These inductors, together with the capacitors and resistors, form a circuit capable of absorbing a large bandwidth of noise.

STFE Series Series Surge Protection Device

Special Considerations

Corrosion: Aggressive chemicals and gases, combined with the constant presence of moisture, create a highly corrosive environment inside WTP/WWTPs. Exposure to corrosive elements prematurely deteriorates unprotected devices, forcing owners to perform frequent repairs and replacements. Given these circumstances, devices in WTP/WWTPs must be specifically engineered to resist corrosion, as well as extreme temperatures, humidity, shock, and vibration.

Corrosion-resistant, NEMA-rated metal enclosures featuring electrostatically applied epoxy coatings have proven to be effective, as have polycarbonate cases and stainless steel pipes. These enclosures must be fully sealed to prevent the ingress of corrosive vapors and liquids, even during high-pressure hose washdowns, as well as dust and dirt that could degrade electronic components. According to NACE International (National Association of Corrosion Engineers), corrosion costs the U.S. water/wastewater processing industry an estimated $1.3 billion annually.

Cascading Protection: Power quality throughout a WTP/WWTP typically requires more than a single PQ device located at the service entrance. Depending on the size of the plant, proper protection may require dozens of devices strategically located throughout the electrical distribution system. Installing PQ devices at all levels of the electrical distribution system is known as cascading (or layering), or as IEEE (Institute of Electrical and Electronics Engineers) refers to it, Protection in Depth. The closer to the service entrance, the more robust the device should be rated.

Summary

Given the sensitivity of today's advanced processing equipment, WTP/WWTP operations managers must take the proper steps to ensure continuous, reliable power quality before malfunctions and delays occur. If malfunctions are already taking place, this should be taken as a clear indicator that poor power quality is present in a plant's electrical system. Additionally, plants with outdated electrical systems or those who are looking to upgrade, should consult with PQ experts so that devices they incorporate offer the optimal protection, feature industrial-grade engineering, and are compliant with local codes and standards. With improved mitigation devices, a plant's profitability and performance will be protected for years to come.

From the service entrance to point-of-use, Emerson has the SolaHD power quality solutions you need to constantly protect industrial operations from the threat of disturbances and secure the highest level of power quality throughout the plant. Learn more at www.solahd.com.

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