IMPLEMENTING INDUSTRY ACCEPTED STANDARDS TO PREVENT THE RESTORING, REPAIRING AND REPLACEMENT OF ELECTRICAL EQUIPMENT (PRRR)

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Abstract: Power disturbances will cost United States companies an estimated $126-$229 billion dollars in 2008. Power disturbances typically are classified as total or partial power failure, power outage, equipment failure and power quality phenomena. 72% of all companies have an average of three (3) power disturbance issues each year. Generally total cost of the restoration process is seldom logged or tracked the focus is always to restore the equipment ASAP. Management accepts these electrical equipment failures as a normal cost of doing business. Preventing (P) power disturbances from causing the restoring of power to the device (R), repairing the device (R) or total replacement of the device (R) PRRR within facilities could have saved companies $100-$183 billion dollars in 2008. Where the holistic approach has been used return on the investment is typically less than two (2) years.

Key Words: Equipment failure; power disturbance; power failure; power quality; power outage.

1. Introduction: Power disturbance issues have been present since the first electrical device was developed. Since electrical device circuitry over the years has developed from analog type devices to digital type devices, these devices have become more susceptible to power disturbances as the device operating voltage has decreased. A power disturbance occurs when the designed characteristics of electrical voltage to a device changes unexpectedly. Different types of power disturbances includes: voltage transients, voltage interruptions, voltage sags, voltage swells, voltage waveform distortions, and voltage frequency variations. These power disturbances are caused by lightning strikes, utility lines failing, accidents to power lines and transformers, incompatible equipment within a facility, human intervention, etc. Any of these power disturbances can cause an electrical device to fail. An electrical device usually fails because conditions stress it beyond its maximum ratings. The way a device fails is called a failure mechanism. Typically, electricity, heat, chemicals, radiation, mechanical stresses, and other environmental factors caused the failures. It is important to draw a distinction between mechanisms and causes. For example, a device might fail due to an electrical mechanism caused by mechanical stress.

Presently the relatively small footprint of the modern control devices and the reduction of manpower needed to operate these devices have caused industries of all types to embrace this new technology. In most cases the technology was incorporated directly into existing facilities without upgrading or evaluating the electrical infrastructure. If the electrical infrastructure is not evaluated or upgraded before the new devices are installed, it is highly likely that the new equipment could be placed into a hostile environment where it is more susceptible to failure. Facility owners need to acknowledge that power disturbances are going to happen at some point in time, and that they have choices that need to be considered regarding power disturbances. One choice is to ignore the power disturbances completely, and live with the downtime costs and equipment failures as they occur while simultaneously ignoring or disregarding that remedies do exist to repair these problems. Another choice is to be aware that corrective measures for power disturbances do in fact exist, and after the proper design and implementation of these corrective measures, outages and equipment failures from power disturbances will drastically be reduced or eliminated.

By facilities choosing to take corrective actions they create the opportunity to prevent (P) power disturbances from causing the restoring (R) of power to the device, repairing (R) the device, or total replacement (R) of the device, also known as PRRR. The first step to create PRRR within a facility is to view the electrical infrastructure of the facility as a whole. Through utilization of a holistic inspection approach that addresses: building protection, equipment protection, equipment compatibility, arc flash labeling, short circuit analysis, bonding, grounding, cable protection, cable routing and lightning protection for both AC and DC equipment, facility managers can use industry recognized standards to bring facilities up to par. After creating a design and taking corrective measures, facilities will be safeguarded against power disturbances, and at the same time, protection and safety for personnel, facility, and equipment will be increased.

2. Cost of Power Disturbances: Every year 72 percent of U.S. businesses are interrupted from power disturbances [1] and on average every business experiences 3.9 power disturbances per year [2] Out of these 3.9 power disturbances per year, 49 percent last less than 3 minutes [2] while 20 percent last one hour or more [2]. Some of these power disturbances are unavoidable such as power outage from the utility, lightning and other power grid disturbances such as, auto accidents involving utility poles, and an electrical utility company’s inability to meet user demand. Lightning storms have interrupted 33.7 percent of U.S. companies’ business operations [1]. Utility power accounts for about 20 percent of power disturbances, even though they deliver power to customers about 99.5 - 99.95 percent of the time in the United States, the other 80 percent of power disturbances are caused by the wiring or equipment within the facility. If a facility is not properly equipped to manage and protect against power disturbances, the inability of a building’s electrical infrastructure to handle demand on circuits can cause systems and network crashes (outages and equipment failure), PC lockups, and corruption or loss of valuable data from servers, workstations and PLC’s. On average 45.3 percent of the failures reported are attributed directly to power disturbances.

Power disturbances cost companies billions of dollars of lost profit every year. One reliable source for the cost of power disturbances to U.S. businesses was completed by the *Consortium for Electric Infrastructure to Support a Digital Society in June 200 [2]1.* The data collected estimated that companies within the United States are losing between $104 billion and $188 billion a year due to power disturbances [2]. Since 2001, the U.S. inflation rate has increased by 21.85 percent. When you factor the inflation rate into the 2001 study, in 2008 the same losses would range from $126.7 billion to $229.1 billion. This estimate does not take into consideration the higher susceptibility of modern equipment to power disturbances which could increase these numbers drastically.

3. Power Disturbance Events and the Effects they have on Electronic Circuitry and Devices: Electrical Line Noise: By definition, electrical line noise is a high frequency waveform caused by radio frequency interference (RFI) or electromagnetic interference (EMI). These common interferences in a power supply can be generated by local or remote influences. Equipment such as transmitters, welding devices, SCR driven printers, lightning, and electrical equipment, etc. can generate RFI and EMI conditions. Varying degrees of damage can occur from simple keyboard lock-ups to program failures, data crashes and data corruption.

Electromagnetic Compatibility: Also known as EMC and is the term used to describe how well a device system is able to function in an electromagnetic environment without introducing electromagnetic disturbances that interfere with the operation of other electrical products in the environment. Electronic devices that can function and meet the criteria are called electro-magnetically compatible devices. In most systems, some or all of the following situations may occur: file corruption; hardware damage; data loss; data corruption; firmware damage or loss; or malfunction of the computer.

Electromagnetic Interference (EMI) Issues: EMI can be caused by electrical storms, noisy electrical equipment (e.g., motors, welding equipment, etc.), fluorescent lighting, and even radio transmitters. EMI has caused events such as system lockups, temporary lapses in computing, circuit connection termination, data transmission errors, and even data corruption or loss. Statistically, about 80 percent of EMI issues are from internal sources. Studies have found that 99.9 percent of failures in electronic equipment from EMI occur due to noise on a power line that is under 300 volts.

Earth Potential Rise (EPR): An EPR is caused by electrical faults that occur at electrical substations, power plants, or high-voltage transmission lines. Short-circuit current flows through the plant structure, equipment and into the grounding electrode at station. The resistance of the earth is finite, so current injected into the earth at the grounding electrode produces a potential rise with respect to a distant reference point. The resulting EPR or GPR (ground potential rise) can cause hazardous voltage in the form of step and touch potentials, many hundreds of feet away from the actual fault location. Many factors determine the level of hazard, including: soil conditions, clearing time, and the amount of current entering the earth.

Equipment Failure: Equipment failure is the failure of an electrical device for any reason. In most systems, some or all of the following situations may occur: file corruption; hardware damage; data loss; data corruption; firmware damage or loss; or malfunction of the computer.

Ground Potential Rise (GPR): GPR's occur when a large current flows to the earth through an earth grid impedance. The potential relative to a distant point on the earth is highest at the point where current enters the ground, and declines with distance from the source. Ground potential rise is a concern in the design of electrical substations because the high potential may be a hazard to personnel or equipment. The potential gradient (drop of voltage with distance) may be so high that a person could be injured due to the voltage developed between two feet, or between the ground on which the person is standing and a metal object. Any conducting object connected to the substation earth ground, such as telephone wires, rails, fences, or metallic piping, can also be energized by the ground potential in the substation. This transferred potential is a hazard to personnel and equipment outside the substation. A GPR can cause a power disturbance in a building from a lightning strike nine miles away in any direction – which is within 257 square miles from the strike.

Harmonic Distortion: By definition, harmonic distortion is the distortion of the normal line waveform. Harmonic distortion is, generally, transmitted by nonlinear loads. Harmonics are a definitive presence in power. Their distortions can be caused by mundane and ubiquitous equipment found in any pharmaceutical plant. Switch mode power supplies, variable speed motors and drives, copiers, fax machines, variable speed pumps are examples of non-linear loads. Harmonic distortions can cause communication errors, overheating, and hardware damage. Common maladies and failures are CPU clock errors, overheating, and premature failure of electrical components.

Over Voltage: By definition, under voltage is when line voltage is increased for duration of time. Over voltage is a fairly infrequent occurrence but occurs in instances of rapid reduction in power loads, shut-off of heavy equipment, or by utility switching. Over voltage can incur extensive hardware damage including burned-out circuit boards, component stress or loss, memory loss, data loss and data errors.

Partial Power Failure: Partial loss of power serving the facility or a loss of one or more power phase legs serving the building. In most systems, some or all of the following situations may occur: file corruption; hardware damage; data loss; data corruption; firmware damage or loss; or malfunction of the computer.

Power Factor Below 1: With low power factor loads, the current flowing through electrical system components is higher than necessary to do the required work. This will result in excess heating, which can damage or shorten the life of equipment. A low power factor can also cause low-voltage conditions, resulting in dimming of lights and sluggish motor operation.

Power Failure: By definition, a power failure is a total loss of power from the utility provider. Utility power losses are caused by numerous events including lightning strikes, downed power lines, transformer malfunctions, over demands on the grid, accidents, weather anomalies, and natural disasters. In most systems, some or all of the following situations may occur: file corruption; hardware damage; data loss; data corruption; firmware damage or loss; or malfunction of the computer.

Power Outage: Is a complete or partial loss of electrical power within the facility at any AC service panel, circuit or electrical device. In most systems, some or all of the following situations may occur: file corruption; hardware damage; data loss; data corruption; firmware damage or loss; or malfunction of the computer.

Power Quality Phenomena: Deviation of the voltage level or current waveform from its ideal norm. These small deviations from the nominal or desired value are called "voltage variations" or "current variations." An equipment failure can take place from long-term conditions such as past lightning strikes, voltage sags, surges, transients, harmonics and phase voltage imbalances. Several symptoms of power quality phenomena are: flickering lights, excessive equipment heating, higher equipment failure rates for computers, electrical bridges, HVAC, lighting, motors, telecommunications, servers, printers, routers, and network controllers. Typical problems situations may occur: file corruption; hardware damage; data loss; data corruption; firmware damage or loss; or malfunction of the processor controlled equipment.

Power Sag: By definition, power sag is a short-term, low voltage supply, from the utility. The duration of power sag can be extremely short or may last for a few seconds. Power sag can be triggered by various load and utility switching mechanisms. When a large load is started, the grid will yield to the load while stressing the existing supply and load on the grid. Utility equipment failure, utility switching, lightning, large load start-up, and demand that are greater than the power service can handle can all be contributing factors to power sags. Power sags can cause crashes to equipment and hardware damage. Typically, the hardware damage may entail memory loss, data errors, flickering lights; equipment shut-off or malfunctions with automatic shut-off.

Power Surge: By definition, power surge can be a short-term high voltage 110% above the nominal supply voltage. Power surges can be caused by lightning strikes sending line voltages above 6,000 volts. Power surges, also known as "power spikes," invariably result in both data loss and hardware damage. Typically, the hardware damage may entail memory loss, data errors, flickering lights; equipment shut-off or malfunctions with automatic shut-off.

Service Entrance Voltage Ranges: The *ANSI C84.1-1989 American National Standard Voltage Ratings for Electric Power Systems and Equipment (60 Hz)* [3] has listed voltage ranges from the utility to the voltage point of service entrance from to be acceptable from high of 1.058% of nominal voltage to a low of 91.7 % of nominal voltage. Thus, a 480 volt three phase service voltage can range from 440 -508 volts as supplied by the power utility. This wide deviation from 480 volts is only one possible problem. Power surges, sags, electrical noise, harmonics, load, and other interferences can damage sensitive electrical components and accessories. Microprocessor-based devices in the pharmaceutical process including controllers, programmable logic controllers (PLCs), PC controllers, and servers are susceptible to power interruptions and fluctuations. This can result in violation of process parameters, loss of real-time data, loss of process control, loss of archiving data, loss of batch, loss of revenue, etc.

Service Utilization Lighting Voltage Ranges: The *ANSI C84.1-1989 American National Standard Voltage Ratings for Electric Power Systems and Equipment (60 Hz)* [3] has listed voltage ranges from the of service entrance point to the point of utilization from a high of 1.058% of nominal voltage to a low of 86.7 % of nominal voltage. Thus, a 480 volt three phase service voltage can range from 410 -508 volts as supplied to the utilization point within the facility. This wide deviation from 480 volts is only one possible problem. Power surges, sags, electrical noise, harmonics, load, and other interferences can damage sensitive electrical components and accessories. Microprocessor-based devices in the pharmaceutical process including controllers, programmable logic controllers (PLCs), PC controllers, and servers are susceptible to power interruptions and fluctuations. This can result in violation of process parameters, loss of real-time data, loss of process control, loss of archiving data, loss of batch, loss of revenue, etc.

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Switching Transients: By definition, switching transients is an instantaneous under voltage condition. Normal duration of this anomaly is less than a “voltage spike,” typically in the range of nanoseconds. Damage may be incurred in both hardware and software resulting in burned circuitry, component stress or failure, memory and data losses.

Time-dependent Dielectric Breakdown (TDDB): By definition is the destruction of dielectric layers of semiconductor-based micro-electronic devices occurring over time. Electromigration (EM), hot carrier injection (HCI), corrosion, electrostatic discharge (ESD), oxide breakdown and negative bias temperature instability (NBTI) some processes that cause the destruction of these devices.

Under Voltage: By definition, under voltage is when line voltage is reduced for an extended period of time—from a few minutes to as long as a few days. Is also known as “brownout”, is a condition that may be intentionally induced by the utility. The utility may enact a “brownout” during peak demand periods to conserve power. Supply due to heavy loads exceeding the capacity can necessitate an under voltage condition. The effect of the under voltage can predicate premature hardware failure, data loss and corruption.

4. Power Disturbance Solution Methods: Different methods are used by facility managers to bring off-line equipment back on-line. In this paper we are only showing two methods.

Typical Solution Method: Many managers have accepted electrical equipment failures as a normal cost of doing business. In many cases the electrical utility has been blamed for delivering dirty power to the facility which caused the equipment to fail in the first place. The normal restoring procedure is to restore power to the device (R), repair the device (R) or totally replace the device (R) that failed as quickly as possible. This method is referred to as the RRR method. Unfortunately this method will only benefit the facility for a short amount of time. If nothing is done to correct the source of the problem that caused the device to either have its power restored (R), the device repaired (R), or total replacement of the device itself, it is only a matter of time before the problem will occur again.

Preferred Solution Method: The preferred method for electrical equipment failures is to manage power disturbances and to prevent them from causing outages and equipment failures in the first place. When the power disturbance is controlled you can prevent most (P) power disturbances from causing the restoring of power to the device (R), repairing the device (R) or total replacement of the device (R), otherwise known as the PRRR method.

5. PRRR Holistic Inspection Approach: The holistic inspection approach includes all items under section 5.

Calculate Probable Component Failure Rate: In most cases, electrical components have historical failure rates and life cycle calculations. If a component has a probably failure rate of 10 percent that means it could fail anytime within a ten year period of time. The risk factors of repair cost, downtime and loss of productivity should be taken in consideration for maintenance and purchasing of every electrical component.

Calculate Protection Device Failure Rate: The frequency and duration of unknown events that cause switching devices or protection systems to fail should be calculated. The risk factors of repair cost, downtime and loss of productivity should be taken in consideration for maintenance and purchasing every component.

Calculate Service Outage Cost: The cost of downtime should be calculated to the minute, hour or day. Every different business model requires a different method to track their costs. One method is to first calculate total employees at that location for direct and indirect labor costs by the hour, make sure you add in all overhead expenses. Normal income or production value by the hour also needs to be calculated. Once that number is calculated it is quite simple to determine how long the outage occurred and what percentage of personnel were affected by the outage.

> **Example:** Labor costs $1,230 per hour and sales/production costs $6,000 per hour. A two hour outage would cost $2,460 in labor and $12,000 in sales/production loss. If the outage affected only 50 percent of the people and 50 percent of sales/production the amount would be $1,230 ($21.50 per minute) in labor and $6,000 ($100.00 per minute) in production losses.

Calculate Service Redundancy Cost: If only one service entrance of supplied power to the facility exists, a method of improving the reliability performance is to determine the cost of adding a redundant service entrance system. A cost feasibility study would need to be completed to justify the addition of the redundant system.

Calculate Yearly Planned Scheduled Outage: Contact the facility maintenance manager to determine when, if any, scheduled preventative maintenance procedures are scheduled that would cause a total or partial power interruption in any area of the facility. Calculate the scheduled downtime duration and effect on the facility's normal operations. Determine all planned scheduled outages for all departments.

Codes and Standards Compliance: Many facility owners in the United States believe that the National Electrical Code (NEC) is the only code or standard needed or required for electrical service and reliability for service in their facility. Many facility owners do not know that the National Electrical Code (NEC) is and always has been a safety code. Article 90 of the National Electrical Code states the purpose of the code under 90.1 (A) Practical Safeguarding, 90.1 (B) Adequacy and 90.1 (C) Intention. The facility manager should determine which codes and standards are going to be implemented for the facility. At a minimum the following codes and standards should be included in the selection process: *NFPA 70 National Electrical Code® 2008 Edition NFPA 70B [4], Recommended Practice for Electrical Equipment Maintenance 2006 Edition [5]and NFPA 70E Standard for Electrical Safety in the Workplace 2009 Edition [6].*

Determine Type and Power Quality Required for all Areas: According *to the 1100™ IEEE Recommended Practice for Powering and Grounding Electronic Equipment ™-2005 (Revision of IEEE Std 1100-1999) page 324 section 9.8.1 Power classifications [7]* Both AC and DC power systems may be classified into types of power availability or suitability. Classifications for AC are often found described as nonessential, protected, back-up, emergency, uninterruptible, conditioned, etc. Classifications for DC are often found described as centralized, rack or enclosure specific, filtered, converter based, on-board, point-of-use, etc.

Establish the Existence of a One electrical Line Drawing for Facility: The facility manager needs to make sure that a current one line electrical drawing exists for the facility. If this drawing does not exist one should be created.

Establish third party commissioning: With third party commissioning required on new and major electrical device upgrades the facility manager gets an independent inspection with a punch list of any violations of codes, standards or workmanship of the new installation or upgrade of electrical devices.

Evaluate all Backup or Emergency Power Systems: The back up generator should be tested in an on line condition to verify that all of the equipment that is required to be on the back up generator does work when the generator is operational. The findings should be included in a report detailing problems found and recommendations for corrective measures.

Evaluate all Cable Systems Entering the Facility: All cable systems entering the building should be inspected for proper grounding, cable routing, cable support, cable connection and cable protection (both sheath protection and surge protection.)

Evaluate all DC Storage Batteries: All storage batteries should be inspected and when possible load tested to determine the life cycle condition of the batteries. All batteries should be labeled with the battery installation date clearly visible on the battery. The findings should be included in a report detailing problems found and recommendations for corrective measures.

Facility Power System Evaluation: An assessment of the facility must be completed to determine if the facility has met all National Electrical Code requirements and to establish the fact that personnel will be safe and free from any electrical safety from shock hazard.

Grounding Evaluation Internal and External: The evaluation should be completed to determine the overall design and effectiveness of all grounding grids internal and external to the facility including location of ground faults. The findings should be included in a report detailing problems found and recommendations for corrective measures.

Lightning Protection Evaluation: When a lightning protection system exists the evaluation should be completed to inspect for any damage from past lightning strikes and to determine the overall design and effectiveness of all lightning protection system components to the facility. The findings should be included in a report detailing problems found and recommendations for corrective measures.

Monitor Power Entering the Facility: A data logging monitoring system should be used to measure the service feeders from the service provider. The monitoring system should, at a minimum, be capable of logging the following: voltage, current, frequency, waveform, date and time. The monitoring system should be in place for a minimum of one week.

Power Evaluation: This evaluation should be completed throughout the facility to determine the quality of the power and to verify the overall design and footprint of the power grids. Temporary AC and DC power monitors should be used during the evaluation to determine if any power fluctuations exist in the facility. The findings should be included in a report detailing problems found and recommendations for corrective measures.

Service Interruption Analysis: The first step in any electric service interruption analysis study should be a careful assessment of the reliability of the service entrance power from the service provider. This assessment should analyze any historical power interruptions from the service provider for frequency and duration time frames. If no historical data is available for the facility, an assessment analysis should be created from data collected from a similar nearby facility.

Short Circuit and Arc Flash Analysis: A short circuit and arc flash analysis of all AC service panels should be completed. The analysis will be used to create a current one line AC power drawing for the facility. Depending on the size of the equipment and utility connection, the amount of detail required to perform these calculations can vary greatly. The findings should be included in a report detailing problems found and recommendations for corrective measures.

Switches, fuses, and breakers that need to interrupt or close into a fault are of special concern. Cables and buswork also have short-circuit withstand limitations, and a thorough study will examine non-interrupting equipment, as well as switches and breakers. Standards such as *C37.010-1999 Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis* [8] and *ANSI/IEEE C37.13-1990 IEEE Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures* [9] outline the recognized calculation methods for these equipment-rating analyses. Short-circuit calculations are required for the application and coordination of protective relays and the rating of equipment. All fault types can be simulated.

Surge Protection Device (SPD) Evaluation AC/DC: Surge-protection studies examine transient over-voltages that may result from lightning and equipment switching. Surge-protection studies are required in locations that have a high incidence of lightning exposure or where capacitors are switched frequently. These transient problems may become evident after an installation is complete and equipment is in operation. In such cases, significant constraints on solutions are common.

Thermal Imaging Inspection: Every AC and DC service panel should be inspected during a thermal imaging inspection. The thermal imaging inspection is used to find hot spots in the AC and DC service panels. Thermal imaging can determine loose connections and hot spots in service panels, equipment frames and circuit conductors. The findings should be included in a report with digital and thermal imaging pictures detailing problems found and recommendations for corrective measures.

6. PRRR Holistic Protection Devices: Other protection devices exist however; the length of this paper requires us to include the most common protection devices.

Capacitor Bank: Designed to control the level of the voltage (power factor) supplied to the facility by reducing or eliminating the voltage drop in the system caused by inductive reactive loads.

Constant Voltage Transformer: Constant voltage transformers are excellent at controlling voltage sags, surges, brownouts, noise, and distortion through providing a continuous output voltage. Constant voltage transformers allow for high isolation and fast response time. Many constant voltage transformers have input voltages that will range from +15 percent to -25 percent of nominal voltage. As a result, input voltage variations do not pass through the transformer.

Generators: Generators are machines that convert mechanical energy into electrical energy. They are normally used as a backup power source for a facility's critical systems, such as elevators and emergency lighting, in case of blackout; however, they do not offer protection against utility power problems such as overvoltage and frequency fluctuations. Although most can be equipped with automatic switching mechanisms, the electrical supply is interrupted before switching is completed, so it cannot protect against the damage that blackouts can cause to expensive equipment and machinery.

Harmonic Filter: Designed to limit the periodic or continuous distortions of the normal voltage wave pattern (sine wave) caused by non-linear loads. Non-linear loads (like all electronic equipment) draw electricity differently than linear loads and distort the normal voltage pattern.

Isolation Transformers: Isolation transformers protect sensitive electronic equipment by buffering electrical noise. They effectively reject common mode line-to-ground noise, but are limited in their rejection of normal mode line-to-line or line-to-neutral noise. Isolation transformers do provide a "separately derived" power source and permit single point grounding.

Motor Generators: Motor generators consist of an electric motor driving a generator. They convert incoming electrical energy into mechanical energy and back again into electrical energy. The mechanical shaft isolates the electrical load from incoming disturbances such as voltage impulses, surges and sags. The motor generator rides through many short “momentary interruptions,” but it will not protect against sustained outages.

Surge Protection Devices (SPD’s): SPD’s are the most basic form of power protection. They are passive electronic devices that protect against transient high-level voltages. SPD’s are available for AC, DC and coaxial equipment.

Uninterruptable Power Supplies: There are three basic types of UPS: Standby (or Offline), Line Interactive, and Double Conversion (or Online).

> **Standby (Offline):** The Standby UPS consists of a basic battery/power conversion circuit and a switch that senses irregularities in the electric utility. The equipment to be protected is usually directly connected to the primary power source, and the power protection is available only when line voltage dips to the point of creating an outage. Some off-line UPS include surge protection circuits to increase the level of protection they offer.
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> **Line Interactive:** Line Interactive UPS are hybrid devices that offer a higher level of performance by adding better voltage regulation and filtering features to the standby UPS design. Like standby models, a line interactive UPS protects against power surges by passing the surge voltage to the equipment until it reaches a predetermined voltage, at which point the unit goes to battery backup. The line interactive UPC can also provide moderate protection against high voltage spikes and switching transients, although, not with complete isolation.
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> With power sags, a line interactive UPS may use a tapped transformer to provide the voltage levels needed to maintain output voltage. Essentially, the unit switches to battery to adjust the tap location at set intervals to maintain the output voltage as the input voltage falls. It will eventually go to battery full-time once the input voltage reaches a pre-selected level. This system offers adequate protection as long as the power sags aren't continuously changing, which may reduce battery time. If it is frequently going to battery, the risk of not having the batteries fully charged for use during a power outage exists.
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> **Double Conversion (Online):** A double conversion UPS, often called "online," will provide the highest level of power protection and are an ideal choice for

> shielding a facility's most important computing and equipment installations. This technology uses the combination of a double conversion (AC to DC/DC to AC) power circuit and an inverter, which continuously powers the load to provide both conditioned electrical power and outage protection. An online UPS offers complete protection and isolation from all types of power problems, such as: power surges, high-voltage spikes, switching transients, power sags, electrical line noise, frequency variations, brownouts and blackouts. In addition, they provide digital-quality power not possible with offline systems. For these reasons, they typically are used for mission critical applications that demand high productivity and system availability.

Voltage Regulators and Power Conditioners: Regardless of the term used, these devices are all essentially the same in that they provide voltage regulation and one or more additional power quality related functions. They can correct and/or provide protection from power problems such as: voltage fluctuations, sags, dips, line noise, swells, phase imbalance, short circuits, brownouts and surges

7. Five Nine’s (99.999) Uptime Calculations: Many manufacturers of electrical equipment are marketing products by stating that their product will have “five nines” of service uptime. Five nines mean that using the manufacturer’s method of calculation, equipment will be on line 99.999 percent of the time. If we review the table below, it clearly shows that five nines of service, 99.999 percent, would only permit five minutes and thirty-five seconds of downtime for each real work year.

First we must understand just what the manufacturer’s definition of uptime means. Second, any scheduled maintenance is counted as downtime. Third unless the entire system is totally down, that time is not factored into downtime either.

Using the World Wide Web to access power distribution utility web sites in the United States, it was discovered that utilities vary between 99.5%-99.95% uptime to their customers each year. Unless the facility has a power system that can ride through these times of no utility from the utility company for those systems of “five nines” of service reliability that means we need to calculate between 262 to 2620 minutes every year of no utility power to the facility, depending on the utility. Typically some electronic systems are under a maintenance contract. Most maintenance contracts have a four hour time allowance for response time. Just one four hour response call in a year reduces uptime by 0.046%. Once we calculate and add in scheduled interruption of power for electrical maintenance for the facility we also effect the five nine uptime. For every eight hours of scheduled maintenance, uptime will be reduced by about 0.1 percent, so the likelihood of achieving five nines, 99.999 percent, of uptime for equipment within a facility is very unlikely to occur.

The table clearly shows, when uptime ranges between 90-99 percent, one can expect between 4–36 days of 24/7 downtime. Depending on the operation and productivity of the facility having the downtime, these expenses can cost the company huge sums of money.

To show the effects of downtime on the bottom line we take a company with $7.5 million in payroll with a total overhead cost of $2.5 million dollars. Their annual volume sales from production are $54.3 million dollars. The average labor and overhead cost per hour is $1,144. The average production per hour is $6,250. If the total plant uptime was 99.95 percent it would result in $5K in lost labor and overhead cost and $27,319 in loss production (Downtime of 4.37 hours per year.) If the total plant uptime was 99.5 percent it would result in $50K in lost labor and overhead cost and $273K in loss production (Downtime of 43.7 hours per year.) If the total plant uptime was 98.5 percent it would result in $150K in lost labor and overhead cost and $819.5K in loss production (Downtime of 131 hours per year.)

Table 1: Five Nine's Uptime and Maximum Downtime:

Uptime	**Uptime**	**Maximum Downtime per Year**
Five nines	99.999%	5 minutes 35 seconds
Four nines	99.99%	52 minutes 33 seconds
Three nines	99.9%	8 hours 46 minutes
Two nines	99.0%	87 hours 36 minutes
One nine	90.0%	36 days 12 hours

8. Case Studies: SPGS has agreements with our customers not to publish their names or exact locations of their facilities; however, they do permit us to use equipment failure data for our case studies. In most cases income and productions losses were never tracked by the customer. Our case studies have proven equipment failures from power disturbances are drastically reduced or totally eliminated after these designs, standards and practices are implemented. In many cases our customers were losing over $100K in equipment replacement every year just from lightning damage alone. Our typical customer equipment failures are reduced on an average of 92 percent. In some cases over ten years have past without another equipment outage. In other cases our customers have elected to not implement all of our recommendations and have continued to experience minor equipment failures.

Cost of implementation varies with such factors as building size, type and quantity of equipment and facility location. Implementation of preventative procedures before the location is populated could add between 1-8 percent to the original design cost. Naturally, to assess and implement changes to the facility after the facility is populated, and power disturbances have already caused losses, would typically result in much higher costs to inspect and implement corrective measures. The majority of our case studies have been of facilities that are corrected after being populated and on line for an extended period of time. Since hardware has experienced degradation from past power disturbances, it is common during the first six months, after corrective measures are implemented, that some equipment failures may still take place.

In many case studies, power disturbance issues have occurred for years before someone actually addresses the problem for what it is, and not just apply the RRR method. The greatest savings would occur when these designs, practices and procedures are incorporated into the original design of the facility. Our case studies have shown that when the holistic approach has been used on a facility, the return on the investment is usually less than two (2) years.

9. Conclusion: In this paper, we addressed using a holistic approach (PRRR) to prevent power disturbances from causing costly downtime from electrical equipment outages and electrical equipment failures utilizing proven industry-recognized recommended standards and practices. Savings from downtime and equipment restoration differs from one facility to another; however, the PRRR method has the ability to improve the electrical systems within facilities for: personnel safety, building protection, equipment protection, lightning protection, equipment compatibility, equipment reliability, equipment performance and equipment lifecycles. The holistic PRRR approach assures that performance goals can be met for equipment installation, performance and reliability. By incorporating the holistic PRRR approach at facilities, ongoing electrical equipment failures and costly downtime losses from power disturbances can be reduced and possibly eliminated.

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