LEONARDO POWER QUALITY INITIATIVE

Power Quality and Utilisation Guide

Section 1 – Introduction

PQ In Continuous Manufacturing*

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Loads such as Programmable logic controllers, relays, power suppliers, contactors, and motor drives pepper the automation floor in a continuous manufacturing process. A power quality induced upset in the process can quickly lead to a cascading shutdown of the entire process. Such downtime is costly and can result in lost product. This application note will examine the typical problems of continuous processes and effective, proven solutions that can harden these processes with minimal investment.

Introduction

A minor voltage dip to 70 percent of nominal (30% Dip), lasting only 100 milleseconds, can cause today's industrial automated systems to grind to a halt. It is estimated that €10 Billion are lost yearly when automated control systems are upset by voltage dip events. Although power quality problems can be expensive for process-intensive industries, sweeping solutions to those problems can be expensive as well, both for end users of electric power and the utilities that serve them. For manufacturers, whole-facility power quality solutions can cost between €388 and €1 165 per kilowatt (kW), not including installation. For utilities, redesigning distribution systems or making other investments in power delivery infrastructure may also be prohibitively costly. Given that the cost of the events and plant level solutions can be very expensive, electric utilities and their industrial customers search for ways to ease the financial burden of dip-proofing manufacturing processes.

Fortunately, these systems can be made much more robust to voltage dip phenomenon with proper electrical and software design techniques. Such efforts entail identifying the particular types of electrical disturbances experienced at a manufacturing facility, finding the specific discrete components within each process machine that are susceptible to those disturbances, and then 'surgically' dealing with the sensitive components, either by replacing them with more robust alternatives or somehow cost-effectively protecting them from electrical disturbances. This application note explores typical problems and these control systems and the solutions for improving the overall response to voltage dips.

Voltage Dip Basics

To begin to understand why automated equipment is susceptible to these events, it is important to understand the voltage dip. Industrial manufacturers almost always incorrectly assume all events that affect electrical equipment are 'power surges' since the shutdown may have occurred during a lightning event. Although overvoltage conditions (known as voltage swells and surges) can occur, short duration reductions in voltage (voltage dips) lead to the most frequent complaints from industrial customers . These events typically occur when a line-to-ground fault has occurred on the utility grid instigated by weather, trees, or animals. The depth of the event that is seen by the industrial customer is determined by the magnitude of the fault current, stiffness of the grid, and how close the customer's facility is to the site of the fault. The duration of the event is related to the breaker-clearing time on the utility system. Typically described in terms of magnitude and duration (see Figure 1), voltage dip events can affect the operation of sensitive production equipment leading to shutdown, malfunctions, lost product, and diminished revenue. When a voltage dip results in equipment shutdown or malfunction during normal power system operation, the equipment is said to be incompatible with its electrical environment, or to have poor system compatibility.

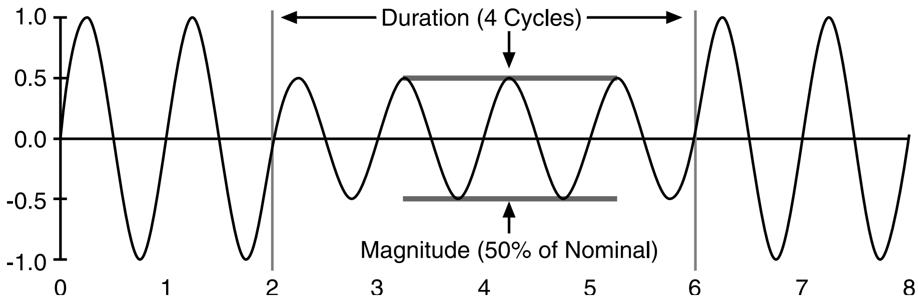

Figure 1: Voltage Dips are described by Magnitude and Duration

Typical voltage dip durations typically range from ten of milliseconds to less than 1 second depending on whether the facility is fed from the transmission system, which is somewhat stiff, or a distribution, which typically cannot supply as much fault current.

How Often Do Voltage Dips Occur?

Studies have been done in Europe and the U.S. to understand how often voltage dips occur. An examination of the similarities of the data will aid in the understanding of the typical environment.

EPRI Distribution Power Quality Study

In 1990, EPRI initiated a power quality monitoring project at the distribution level known as the EPRI DPQ Project. During this project, twenty-four utilities monitored power quality levels on their distribution circuits. Nearly 300 sites were monitored for a period of approximately two years [1]. The data gathered were characterized and analyzed to form a baseline of power quality on U.S. distribution circuits.

Uniped DISDIP Survey

The Distribution Study Committee of UNIPEDE appointed a group of experts, DISDIP, to improve the knowledge of the rates of occurrence and severity of voltage dips and short interruptions in public electricity supply networks. This group arranged a coordinated series of measurements in nine countries (Austria, France, Italy, Netherlands, Norway, Sweden, Switzerland, United Kingdom, and Germany) which provide statistical information based on over 80 system-years of monitoring experience covering a wide range of environmental and geographical conditions [2].

The measurements were performed at 85 sites on medium voltage networks. Of these, 33 sites were cable systems and 52 sites were mixed overhead-cable systems.

Norwegian EFI Survey

The EFI survey. The Norwegian Electric Power Research Institute (EFI, recently renamed 'SINTEF Energy Research') has measured voltage dips and other voltage disturbances at over 400 sites in Norway. The majority (379) of the sites were at low-voltage (230V and 400V), 39 of them were at distribution voltages, and the rest at various voltage levels [3]. The low voltage data is presented herein as it is most relevant to the environment that would be seen in plant's automated control system.

Voltage dip data for the DPQ, DISDIP, and EFI studies are summarized in Tables 1-3 for all events between 10 milliseconds and 60 seconds. The data is presented in percentage of events that fall into each category so that a comparison of the similarities can be made.

Table 1: Voltage Dip Table for EPRI DPQ Data, All 277 Sites, Based on Events Per Site Per Year (59.32 total dip events per site per year between 10ms – 60 Sec)

Remaining Voltage	10-100ms	100-500ms	500ms-1sec	1-3sec	3-20sec	20-60sec
70-90%	42%	22%	3%	1%	0%	0%
40-70%	10%	7%	1%	0%	0%	0%
10-40%	2%	1%	0%	0%	0%	0%
0% (Interruption)	1%	2%	1%	3%	2%	0%

Table 2: Voltage Dip Table for EFI Data, All Low-Voltage Networks, Based on Events Per Site Per Year (74.7 total dip events per site per year between 10ms – 60 Sec)

Remaining Voltage	10-100ms	100-500ms	500ms-1sec	1-3sec	3-20sec	20-60sec
70-90%	32%	6%	21%	4%	1%	1%
40-70%	10%	2%	1%	0%	0%	0%
10-40%	8%	2%	0%	0%	0%	0%
0% (Interruption)	1%	1%	0%	1%	1%	8%

Table 3: UNIPEDE DISDIP Survey, All Sites, Based on Events Per Site Per Year (84.6 total dip events per site per year between 10ms – 60 Sec)

Remaining Voltage	10-100ms	100-500ms	500ms-1sec	1-3sec	3-20sec	20-60sec
70-90%	27%	27%	3%	1%	0%	0%
40-70%	3%	15%	1%	0%	0%	0%
10-40%	0%	6%	1%	0%	0%	0%
0% (Interruption)	0%	3%	7%	1%	1%	2%

Reviewing of the data from Table 1 indicates similar characteristics. Namely, most events are less than 1 second in duration. This ranges from 84% for EFI study to 94% for Unipede study (See Table 4). Therefore, if equipment hardening strategies can handle events that are less than 1 second in duration, many shutdowns can be avoided. As will be discussed in this application note, batteryless power conditioners can provide this type of coverage without the maintenance and disposal issues of the common UPS. EPRI voltage dip testing experience shows that unprotected control systems can be upset for voltage dips in the 70 percent of nominal range. As shown in the table, between 25 to 36 percent of all voltage dips measured in these studies fall below 70 percent and last less than 1 second. A typical site will see from 59 to 84.6 events that are between 10milliseconds and 60 seconds in duration.

Furthermore, if the equipment can be hardened to withstand voltage dips by selection of robust components (relays, contactors, power supplies, etc.) down to 40 percent of nominal as suggested in IEC 61000-4-11 and IEC 61000-4-34, then only 8 to 17 percent of the events would likely cause shutdowns. This approach alone would equate to reducing the number of events that are likely to cause a shutdown by a factor 2 to 3.

Table 4: Comparison of DPQ, EFI, and Unipede data (For events between 10ms – 60 Sec)

Study	< 1 sec	< 70% &<1Sec	< 40%& <1 sec
DPQ	93%	26%	8%
EFI	84%	25%	12%
Unipede	94%	36%	17%

Voltage Dip Standards

There are several important standards that can be used as to measure the robustness of an industrial process to voltage dips. One of the most visible is the SEMI F47 standard. Originally released in February 2000, this standard was developed as a benchmark for testing equipment used by the semiconductor industry. The goal of the standard was to lead to more robust equipment designs that are less susceptible to voltage dips. The implementation of this standard has led to more robust semiconductor tooling and facility support equipment. Furthermore, the standard has been used in the automotive and food processing industries in the U.S. as a benchmark as well. SEMI F47-0706 was revised in July 2006 to reflect the knowledge gained after six years of experience in compliance testing and to better align the standard with the IEC 61000-4-11 and IEC 61000-4-34 standards. The requirements of the standard are shown in Tables 5

Table 5: SEMI F47-0706 Test Points (Single and Two-Phase Voltage Dips Only)

Voltage Dip Duration at 50Hz	Duration at 60Hz	
50%	10 Cycles	12 Cycles
70%	25 Cycles	30 Cycles
80%	50 Cycles0	60 Cycles

Voltage Dip is expressed in percent of remaining nominal voltage. For example, during a 70% dip on a 200 volt nominal system, the voltage is reduced during the event to 140 volts (not 60 volts).

The IEC 61000-4-11 and IEC 61000-4-34 are voltage dip and short interruption testing standards for equipment less than and greater than 16 Amps, respectively. These standards apply to electrical equipment that is to be sold in Europe. The requirements of the standard are multifaceted depending on what type of equipment is to be evaluated. The basic requirements of the standard are shown in Table 6. In contrast to SEMI F47, the worst case voltage dip at the 10 cycle (at 50 Hz) test point is 40 % of nominal versus 50% of nominal for SEMI F47. Furthermore, there are short interruption tests point requirements at ½ and 1 cycle duration and a long duration 250 cycle (at 50Hz), 80 % of nominal requirement. SEMI F47 has similar short duration and long duration test points, but they are 'recommended' versus required for the IEC standards. The IEC 61000-3 series standards are typically regarded as mandatory. Furthermore, IEC 61000-4-11 (equipment less than 16 Amps) is considered mandatory as it is also issued as CENELC EN 61000-4-11. CIGRE and CIRED have formed a joint working group (see www.jwgc4-110.org) to look at the applicability of the current IEC voltage dip standards and advocated test methods. This working group will make recommendations to the IEC regarding updates of the voltage dip standards. At this point it is unclear if IEC 61000-4-34 will be a mandatory requirement as it will require adoption via CENELEC.

Table 6: Preferred Test Levels and Durations for Voltage Dips (IEC 61000-4-11, IEC 61000-4-34)

Class[a]	Test level and durations for voltage dips (t_s) (50Hz/60Hz)				
Class 1	Case-by-case according to equipment requirements				
Class 2	0 % during ½ cycle	0 % during 1 cycle	70 % during 25/30[c] cycles		
Class 3	0 % during ½ cycle	0 % during 1 cycle	40 % during 10/12[c] cycles	70 % during 25/30[c] cycles	80 % during 250/300[c] cycles
Class X[b]	X	X	X	X	X

a	Classes per IEC 61000-2-4, See Annex B
b	To be defined by product committee. For equipment connected directly or indirectly to the public network, the levels must not be less severe than Class 2.
c	'25/30' cycles means '25 cycles for 50 Hz test' and '30 cycles for 60 Hz test'.

Effects of Voltage Dips on Continuous Manufacturing Equipment

When companies design manufacturing equipment, most do not always take into consideration that their products or systems will be subject to electrical environments that are prone to voltage dips. Most equipment is designed to operate under steady-state power conditions, with some allowances, usually ±10%. Common electrical disturbances can adversely affect process equipment. Dips can cause equipment with sensitive microprocessors, such as programmable logic controllers (PLCs), to shut down or send out faulty control signals. On the other hand, dips can also affect unsophisticated electro-mechanical equipment, such as simple control relay, causing the relay to open long enough to upset processes or unlatch safety circuits.

The tolerance of process equipment is often conveyed with a graph called a dip-tolerance curve. For example, consider the dip-tolerance curve of a sensitive PLC is shown in Figure 2. The area under the curve represents the area in which voltage dips cause the PLC to shutdown.

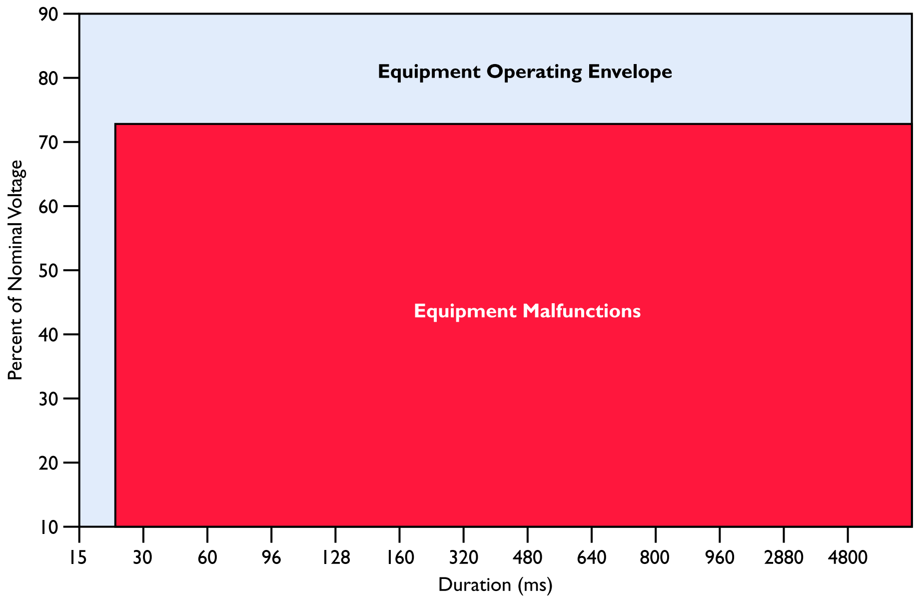

Figure 2: Dip-Tolerance Curve of a Sensitive PLC

If we impose this curve over a coordination chart, we can make assumptions about the number of times per year that the PLC will shutdown due to a voltage dip event. A coordination chart can be created by examining the power quality data from a given site. As described in IEEE 1346, Annex D from the depth and durations of the power quality events, contour lines can be drawn that represent the number of events that are likely to occur within areas of the chart [4]. For example, the tolerance curve overlaps an area of the coordination chart that indicates 25 events per year. On average, then, the PLC will trip the process as many as 25 times per year, leading to equipment malfunction (Figure 3).

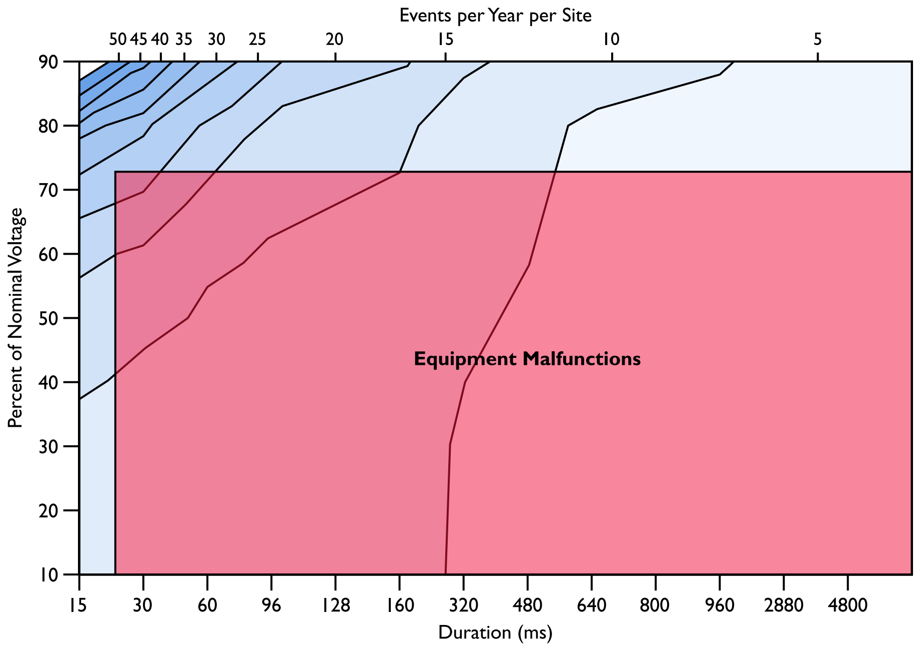

Figure 3: Dip-Tolerance Curve Imposed on the Voltage-Dip Contour Chart

Many different methods of increasing equipment immunity to voltage dip have been developed. Large-scale power conditioners such as static series compensators and backup stored-energy supplies protect entire facilities against electrical disturbances, but the cost is so high that capital expenditure may be difficult to justify for many manufacturers. Properly sized, strategically placed power conditioners can also be used to protect entire process or single pieces of equipment. Existing process equipment can be protected at the Control Level through the use if small power conditioners and/or component replacement. Equipment protection from dips and brief interruptions can also be embedded during manufacture without the use of power conditioners, through the benefits of the design, use of robust components, and/or modified programming techniques.

All methods for extending the operating envelope of equipment—from the macro-scale solutions implemented at the transmission or distribution level to embedded solutions—have their advantages and disadvantages. For example, utility-scale solutions can be very expensive, as shown in Figure 4. However, solutions applied at the equipment require extensive knowledge of each piece of equipment, and embedded solutions can increase the initial cost of equipment. Nevertheless, it is generally accepted that embedded solutions are the most cost-effective methods for improving voltage dip immunity of equipment.

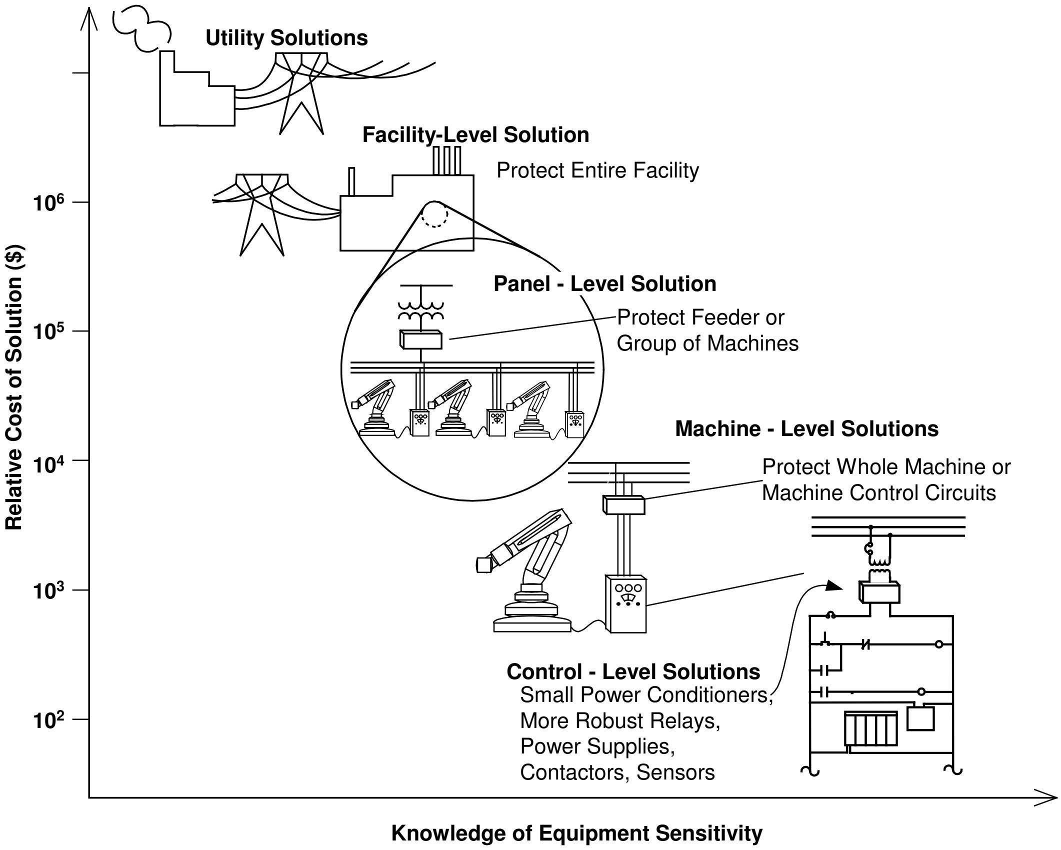

Figure 4: Dip-Tolerance Curve Imposed on the Voltage-Dip Contour Chart

In manufacturing plants with existing process equipment, there are two common approaches to improving the voltage dip ride-through. Both have their advantages and disadvantages when it comes to installation, understanding of the application, and cost. The two approaches are the Panel Level and the Control Level approach.

Panel Level Approach

The Panel Level approach involves installing a power conditioner between the equipment and the power supply. The voltage dip ride-through of entire processes or groups of process equipment can be protected using this method of protection. The drawing in Figure 5 shows examples of the Panel Level approach for a single-line or group of manufacturing lines.

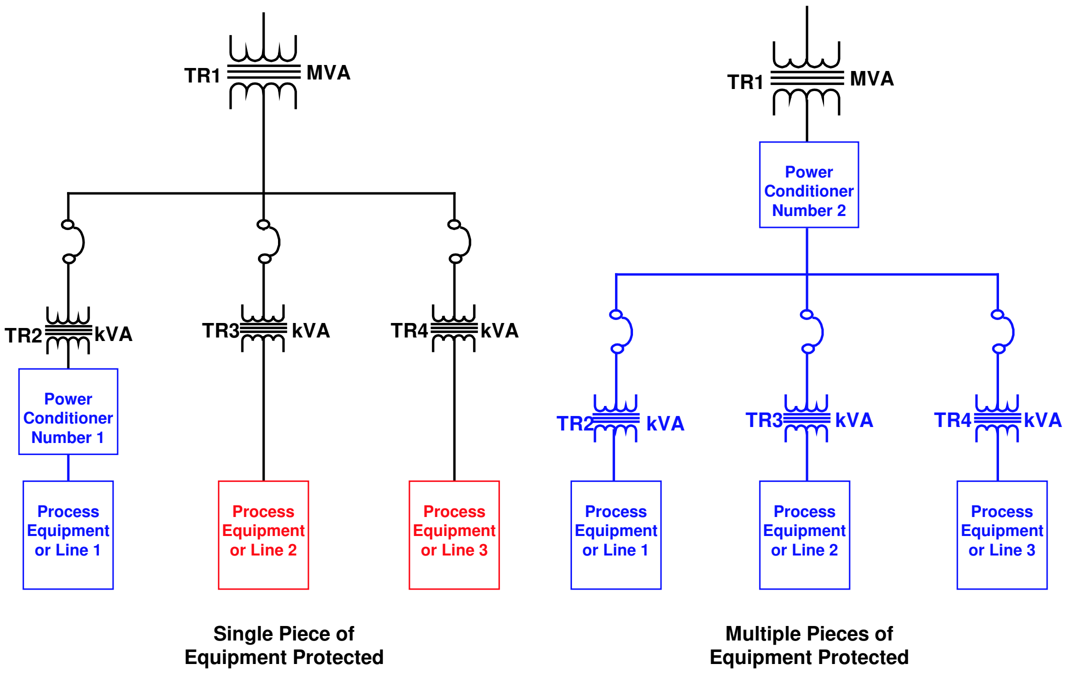

Figure 5: Example Panel Level Approach

Control Level Approach

The Control Level approach involves identifying voltage dip sensitive components or circuits within the manufacturing process equipment and only protecting those areas against voltage dips. The theory behind this is that when process equipment shuts down as a result of a voltage dip, it's usually a sensitive control component that caused the shutdown. Research has shown that certain control components and circuits, if protected correctly can enable the manufacturing equipment to ride-through most voltage dips [5]. The cost of the control level solution hardware is typically about $1/10^{th}$ to $1/20^{th}$ the cost of the panel level solution. However, consideration for the cost of installation must be considered as well since this approach may entail protecting several circuits located throughout the production line to achieve the desired voltage dip hardening.

The Control Level method requires an understanding of electrical schematics, plus a basic knowledge of power conditioners, an understanding of how voltage dips affect electrical components and the techniques to protect them against voltage dips. The following information is included to help plant engineers learn how to implement Control Level solutions.

Power Conditioners

Many of the voltage-dip related shutdowns could be overcome when small power conditioning devices are applied to the critical circuitry within process equipment. The critical items for most process equipment are the Emergency Off circuits, the control power, critical instrumentation, DC power supplies and the controller (computer) power and I/O. Often fed by single-phase voltage, there are several options for improving the ride-through in these areas. The most recommended types of power conditioner for the industrial environment, is the family of Batteryless Ride-Through Devices (BRTDs). Unlike the conventional battery-based UPS solution, these units utilize a variety of configurations that make use of the full range of power electronics technology. Magnetic components such as transformers and inductors as well as electronic devices such as diodes, power switches, and capacitors are used to control and shape electrical energy into a form that improves the ability of the load to tolerate variations in utility power. AC BRTDs have several different design topologies. Select BRTD topologies, best suited for the Control Level solution are; Standby Capacitor Based, Injection Technology, Coil Hold-In Device and the Constant Voltage Transformer (CVT).

Standby Capacitor Based

Standby capacitor based BRTDs operates only when the voltage dip is detected (off-line technology) it only needs to be sized for the nominal load. The device basically continually rectifies incoming AC voltage to charge the DC bus capacitors. When a voltage dip is detected that drops below an adjustable threshold, the line to the incoming power to the device is opened and the BRTD supplies rectified output to the load for the specified time duration, which will vary from manufacturer to manufacturer. The amount of time that the load will be supplied can be calculated based on the real power and the energy storage of the particular BRTD. Typically, these units can supply conditioned power to the load for up to a 1 second interruption. These include products such as the DIP Proofing Inverter (DPI) manufactured in South Africa (www.dipproof.com) and the Momentary Line Drop Protector (MLP) manufactured in Japan (www.densei-lambda.com). A typical 1kVA single-phase conditioner will range in cost from €1 200 to €1 500.

Injection Technology

There are BRTDs that correct voltage dips down to 50 percent of nominal, supplying a sine-wave output. By drawing power from the remaining voltage, these BRTDs injects a series voltage to regulate the output for voltage dips as low as 50 percent of nominal lasting from 3 to 12 cycles. These products come in single and three phase designs in power levels ranging from 250VA to several MVA. For control level solutions, single-phase units are often The available operating voltage levels are 120,208, 240,277, and 480Vac depending on the model used. Such products include the U.S. made Dynamic Dip Corrector (DySC) (www.softswitch.com) and three-phase only versions are made in New Zealand and marketed under the Active Voltage Conditioner (www.vectek.co.nz). The single-phase 1kVA DySC is about € 1 250.

Coil Hold-In Devices.

Coil hold-in devices are also BRTD designed to mitigate the effects of voltage dips on individual relays and contactors. Typically, the coil hold in device is connected in line with the incoming control signal for the relay or contactor. Available for coil voltages of 120Vac, 230Vac, and 480Vac, the best application for this device is to prop up relays and contactors that are in an EMO, master control relay, or motor control center circuits. Costing typically from €80 to €195, these units are very economical to support an individual contactors and relays. Typical coil hold-in devices allow a relay or contactor to remain engaged when the voltage drops to around twenty-five percent of nominal. The unit installs between the relay or contactor coil connection terminals and the incoming AC control line. Currently, these products include the Coil-Lock (www.pqsi.com) and Know-Trip (www.scrcontrols.com), both manufactured in the U.S.

Constant Voltage Transformer (CVT).

The CVT (a.k.a. ferroresonant transformer) is a ferroresonant transformer is a device that maintains two separate magnetic paths with limited coupling between them. The output contains a parallel resonant tank circuit and draws power from the primary to replace power delivered to the load. The transformer is designed so that the resonant path is in saturation while the other is not. As a result, a further change in the primary voltage will not translate into changes in the saturated secondary voltage, and voltage regulation results. These devices will allow for much better voltage dip ride-through if they are sized to at least two and a half the nominal VA requirement. Oversized in this manner, CVTs can supply a 100 percent of nominal voltage when the input voltage has dropped to as low as 40 percent of nominal. CVTs are available from multiple manufacturers world-wide (www.sola.com, www.uppi-ups.com). For a 1kVA load, a 2kVA CVT is required to get the desired voltage dip ride-through. The cost of such a unit is about €950.

Battery Based UPS

Power conditioners with batteries, like the UPS (Uninterruptible Power Supply) must be given careful consideration when used to harden control circuits. When small 1-3kVA UPS systems are utilized to power sensitive components in a control panel, one must ensure that the output is a 'true' sine wave rather than a simulated sine wave (which is normally a square wave output). Typically designed for PC applications, off-line models may not switch in fast enough to keep the automation hardware from tripping. Furthermore, the 3-5 year life span of the batteries require a dedicated maintenance program in order to keep the UPS systems running – which are located in various control cabinets. If the PQ Environment warrants the use of a UPS, manufactures are better off utilizing centralized UPS systems to provide a 'critical power' bus to the sensitive circuits throughout the facility rather than installing multiple small units. With proper maintenance, this approach is acceptable.

Understanding and Protecting Individual Dip-Sensitive Components

Two requisite steps to achieving a control-level solution are:

- Identifying components sensitive to voltage dips
- Investigating techniques for protecting those components against voltage dips.

The most common voltage dip sensitive components found in control circuits are AC Relays and Contactors, DC power Supplies, Controllers and Programmable Logic Controllers (PLC).

AC Relays and Contactors

These electromechanical devices are used extensively in control systems of process equipment. Relays are typically used as logic elements to switch control circuits, large starter coils, and light electrical loads. Contactors are electro-magnetically operated switches that provide a safe and convenient means for connecting and interrupting power circuits. Motor Starters basically have the same function as contactors but they also provide over current protection for the motor. Figure 6 shows an example tolerance curve of these types of devices.

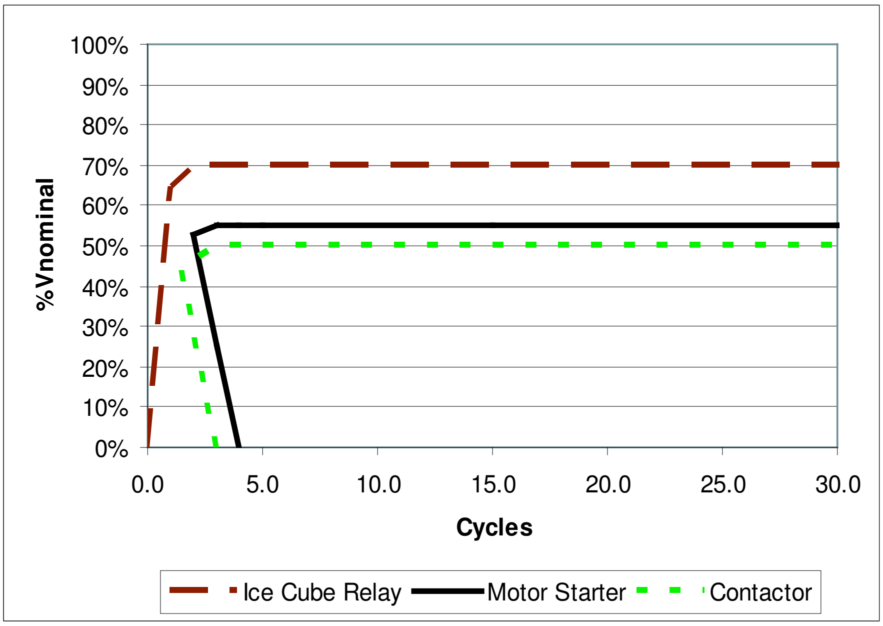

Figure 6: Example Dip-Tolerance Curves for Relays, Contactors, and Motor Starters

During voltage dips, the state of the relay reverts back to the de-energized state. For example, if the relay is part of a motor control circuit and the contacts are used to 'hold-in' the starter contacts, as shown in Figure 6 a voltage dip with a magnitude and duration below the sensitivity curve of the relay would cause the motor to stop. Relays can be protected against voltage dips by conditioning the power to the relay's coil using a coil hold-in device, as shown in Figure 7. In this case, the most sensitive element (CR1) is hardened by adding the coil hold-in device. The larger, less sensitive motor starter (SC1) could also be protected with another coil hold-in device as well if desired. Another approach is to add a battery-less power conditioner to the entire circuit containing the AC relay and motor starter as shown in Figure 8.

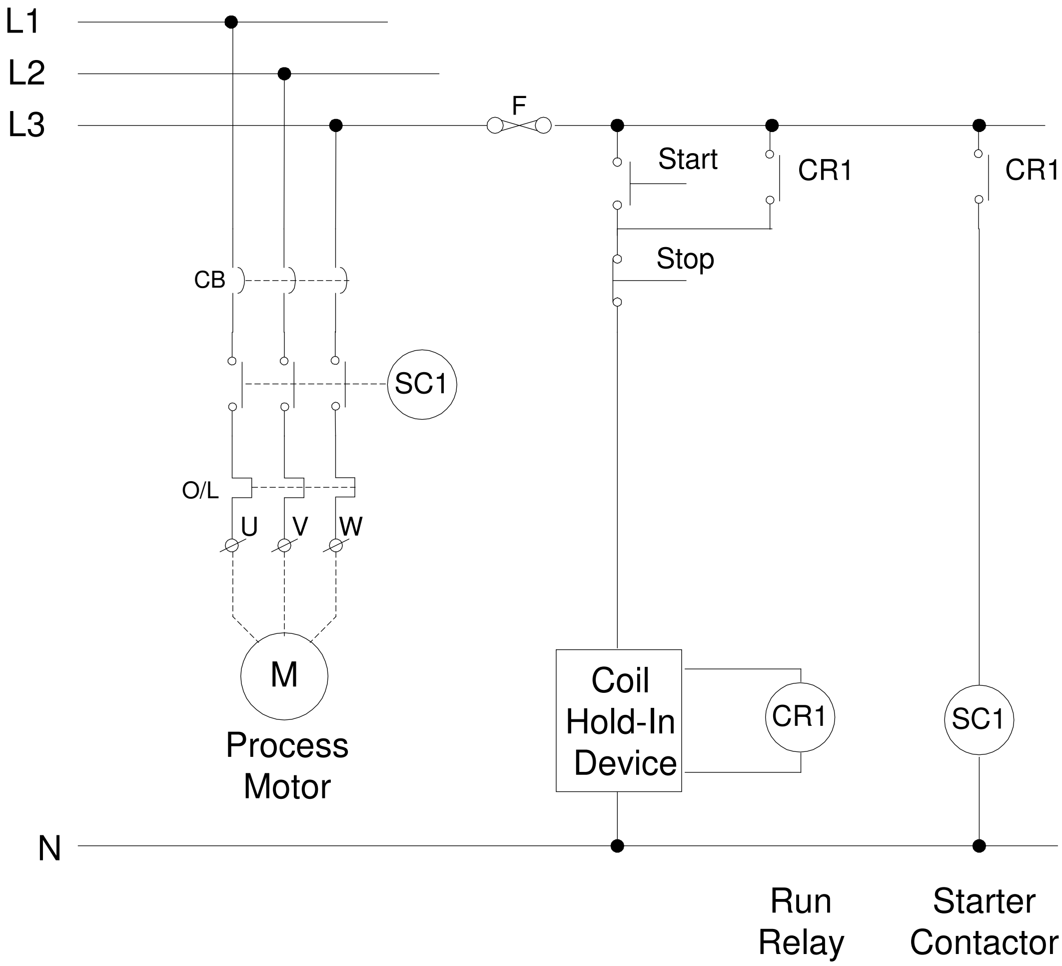

Figure 7: Relay or Contactor Circuit with Coil Hold-In Solution

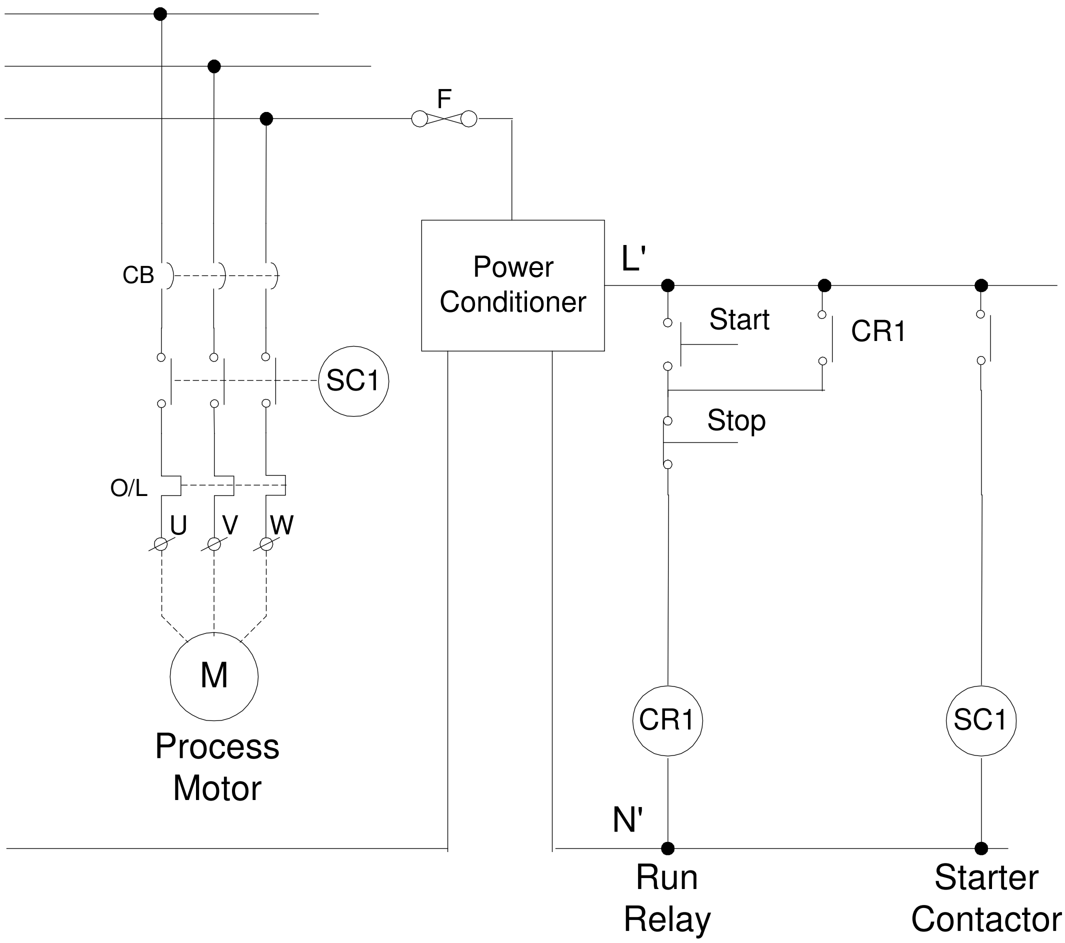

Figure 8: Relay or Contactor Circuit with Power Conditioner Solution

DC Power Supplies

The response of a DC power supply to voltage dips can vary greatly depending on the supply topology and loading. Figure 9 shows an example response of five different power supply topologies installed in a 400Vac power system for single-phase voltage dips (between L3 and Neutral for this example). In each case, a example sensitivity curve is shown for the power supplies in which the output voltage can be expected to deviate from the rated specification. The example considers that the supplies are loaded to 100% rated output.

Topology 1 – Unregulated DC Supply

For an unregulated DC power supply that consists of a transformer and diode-bridge, the output voltage will begin to drop for short duration, shallow voltage dips. For this reason, there is a large region in which this type of power supply will be upset by voltage dips.

Topology 2 – Regulated DC Supply

For a regulated DC power supply, capacitor(s) and a voltage regulator are typically used. Given the potential for the capacitors to store energy, the response of this supply will be better than its unregulated counterpart.

Topology 3 – Switch Mode Power Supply

A Switch-Mode DC power supply (SMPS) can be expected to perform better during voltage dips than the equivalently sized linear power supply. When the input voltage drops during voltage sag or momentary outage, the Pulse-Width Modulation will be increased to compensate the voltage drop until the supply voltage of the PWM control IC is lower than its designated threshold voltage [6]. This active compensation can help the power supply maintain output better than the equivalent linear unit.

Topology 4 – Universal Input Power Supply

The universal input DC power supply is a switch-mode unit with a wide-ranging input voltage that typically ranges from 85 to 264Vac. Installed phase-to-neutral in a 230Vac system, the unit can withstand voltage sags as low as 36 percent of nominal before the output voltage will drop out.

Topology 5 – Three-Phase Input Power Supply

One of the most robust methods is to use a three-phase input, DC output power supply. These units employee a three-phase diode bridge on the front end of the power supply. Multiple tests on many brands of these units reveal that many of these units are immune to single-phase voltage sags and interruptions lasting up to 1 second in duration. Some units can hold the DC output for two-phase dips as low as 10 percent of nominal. For severe three-phase voltage sags, this type of power supply has been known to ride-through events as low as 50 percent of nominal.

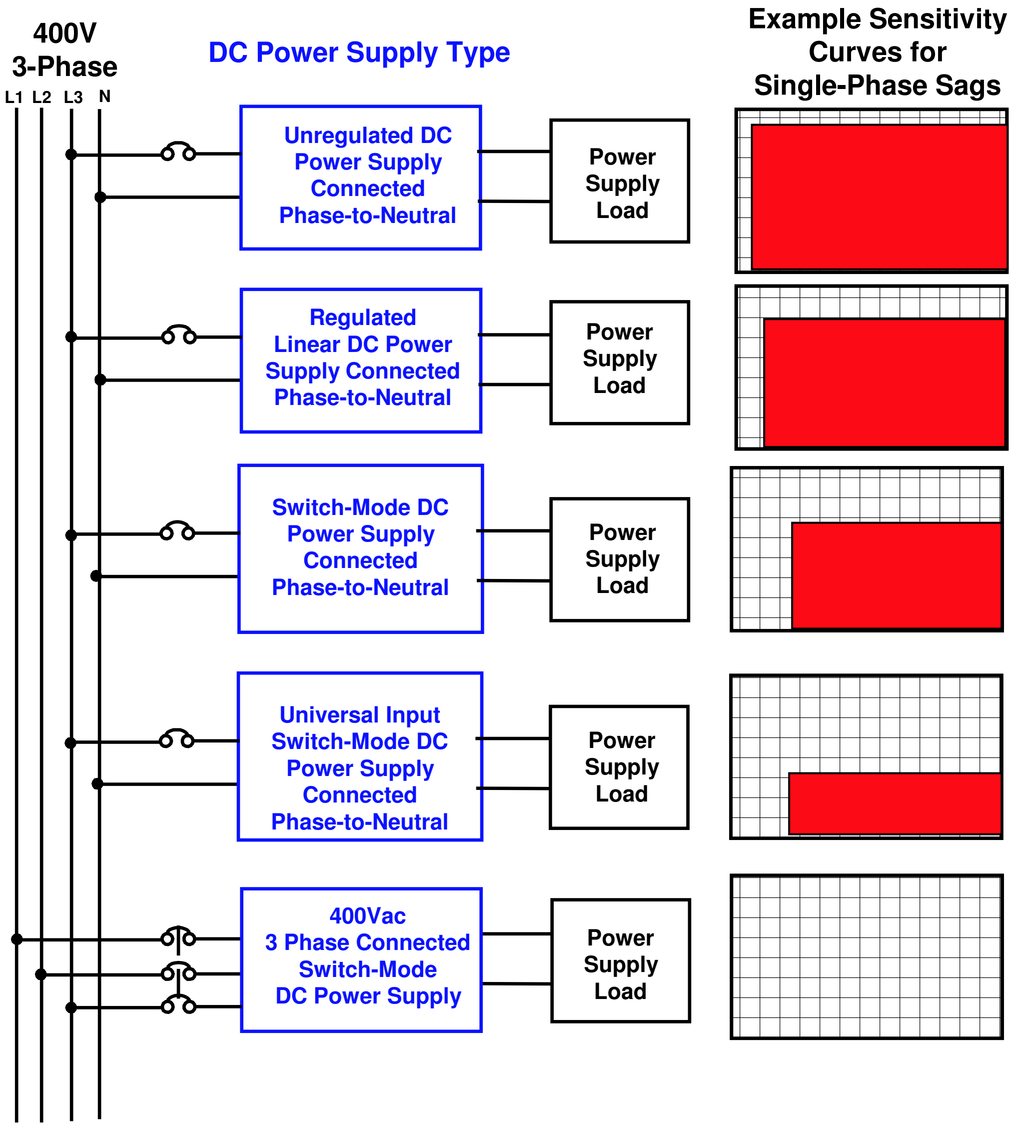

Figure 9: DC Power Supply Selection - With Respect to Voltage Dip Response, Worst (Top) to the Best (Bottom)

Programmable Logic Controllers (PLCs)

Programmable logic controllers (PLCs) are the backbone of industrial automation. PLCs are used extensively in automated processes. There are so many different types of PLCs and methods of process equipment, but all types of controllers seem to have the same basic elements. They all have a CPU that is usually powered from an internal DC power supply through an AC input; all PLCs have I/O, which give the CPU the means to interpret and manipulate electrical control signals. If the power supply and I/O of the controller uses AC voltage, voltage dips can affect the controller through the I/O or CPU power supply. There are many different types of controllers and configurations and each one requires a different power conditioning solution. For example, the power supply modules could be powered from an AC or a DC source and the I/O could be AC or DC, resulting in four possible configurations. Figure 10 shows the optimal solution for each configuration.

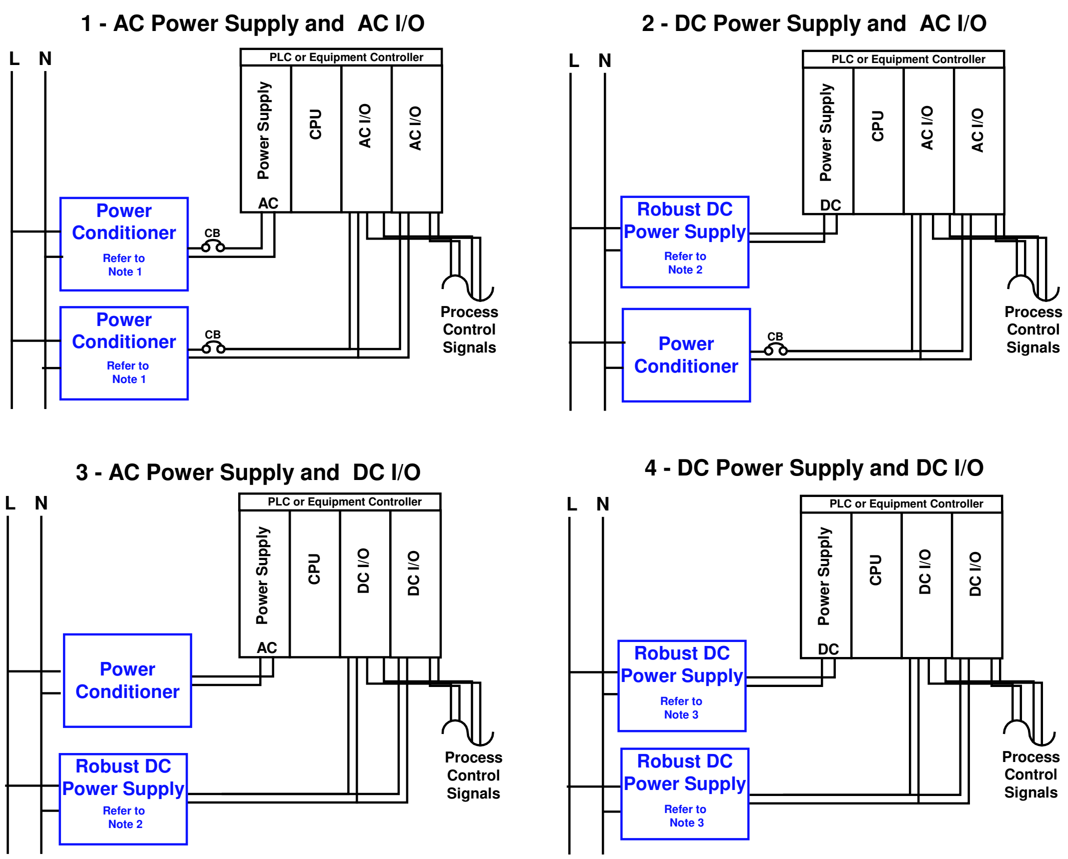

Figure 10: PLC Voltage Dip Hardening Solutions [8]

Notes:

1. Consider sourcing the controller and I/O power supply from one power conditioner. If the power supply and I/O power are close in distance and fed from the same power source, both could be fed from a common power conditioner.
2. To select a robust DC power supply, refer to Figure 9.
3. Consider sourcing the controller's power supply and I/O from one DC power supply with a second one as a redundant back-up. Refer to Figure 9 to select the primary and secondary power supply types.

Locating and Protecting the Common Power Source

The control circuits of process equipment are often powered from a common circuit breaker or a control power transformer. The control circuit is made up of electro-mechanical devices (relays) used for safety and logic circuits such as EMO (Emergency Machine Off), Start/Stop and the process equipment's controller or PLC. Process equipment can be protected easily if the sensitive components are all powered from a common circuit breaker or a control power transformer. For example, the circuit shown in Figure 11 shows a control system with an EMO circuit, and a PLC with both AC and DC I/O devices. There is also a separate DC power supply for the analog instrumentation. Locating the power conditioner at the main control power protects all of the control loads associated with the cabinet. Many designers make the mistake of placing the PLC and DC power supply on a conditioned power source, but do not include the AC I/O devices or associated relays in the cabinet. By protecting all control loads, the voltage dip response of the system can be greatly improved.

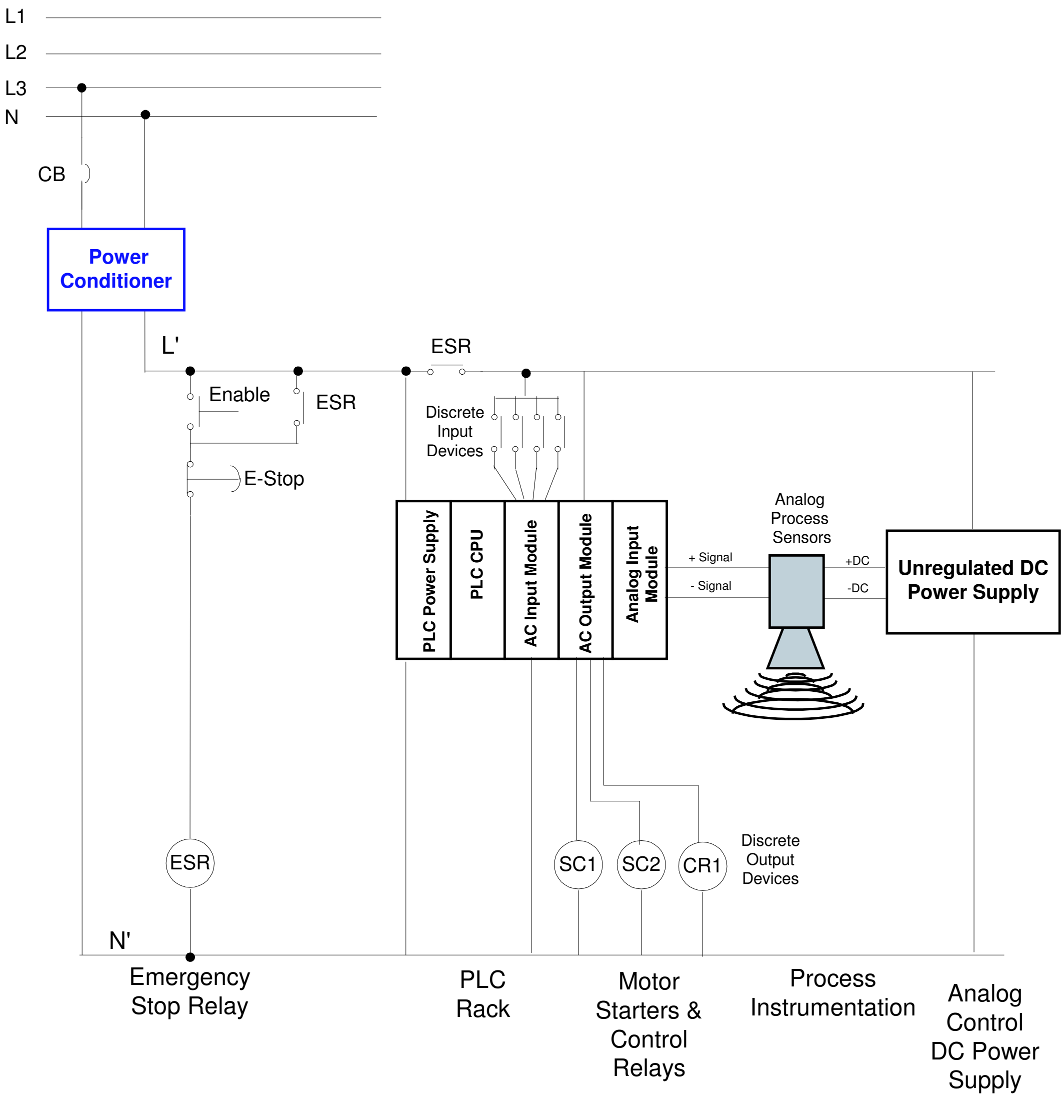

Figure 11: Common Power Source Power Conditioning Solution

Voltage Dip Mitigation Strategies

In order to stave-off future voltage dip related power quality problems, plant engineers can implement certain types of design strategies in existing systems. Furthermore, Original Equipment Manufactures (OEMs) and control systems designers can build robustness into their designs by considering the following strategies in future and current designs.

1. Use components that are certified to meet power quality standards such as IEC 61000-4-11, IEC 61000-4-34 or SEMI F47. Hundreds of control relays, safety relays, contactors, motor starters, power supplies, and motor drives have been certified as compliant with power quality standards. An Internet search will reveal possibilities.

2. Avoid mismatched equipment voltages. If the components used in an equipment design does not match the expected nominal input voltage, the machine or process will be more susceptible to voltage dips. This can occur when transformer secondary voltages do not match the rated voltage for the connected equipment, or when a subsystem such as a servo controller or power supply is rated for a higher voltage (i.e., 240 Vac equipment is used in a 208 Vac environment). For relays and contactors, a mismatch of 10% of voltage equates to an increase in susceptibility by 10%. However, in DC power supplies, the energy stored in the internal capacitors can be as much as 18% lower when the input voltage is mismatched by as little as 10% — directly equating to a reduction in ride-through time [9][8]. Furthermore, the amount of ride-through time available to the DC power supply can be effected by the lower input voltage as well.

3. Use three-phase switching power supplies in every location possible. This type of power supply can survive single- and two-phase voltage dips while maintaining the output DC voltage. This type of supply should be specified for power safety circuits as well as DC power supplies for instrumentation and controls.

4. Avoid the use of AC-powered 'ice cube' general purpose relays. Instead use a robust AC relay or use a DC power supply to power the control circuits as mentioned above.

5. Consider Circuit Breaker Characteristics. For equipment to be compliant with the power quality standards, circuit breakers and fuses should be selected to allow for higher inrush currents due to power quality variations. This must be considered for constant power loads such as power supplies and variable frequency drives. Where possible, do not select breakers that have instantaneous trip characteristics.

6. Do not use phase monitoring relays in the interlock circuit. These devices will easily trip during a voltage dip and can lead to tool shutdown. Instead use these devices to log that a voltage dip or phase problem exists. If the concern is that a motor might run in the wrong direction, interlock only with motor controls.

7. Use a non-volatile memory. This type of backup technique for tool controllers ensures that the control system will not lose its place in the event of a voltage dip. Utilizing non-volatile memory in combination with state-machine programming techniques can enable some batch processing equipment to pick up a the step where it was shut down as a result of a voltage dip.

8. Do not overload DC power supplies. Since the amount of voltage dip ride-through time available from a DC power supply is directly related to the loading, DC power supplies should not be running at their maximum capacity. Oversizing by at least two times the expected load will help the power supply to ride-through voltage dips. This is not as critical for robust power supply designs such as the 3-phase input DC power supply mentioned in Strategy 3 above.

9. Use robust ASDs. When using adjustable-speed drives in the tool design, specify models that have good voltage dip ride-through. Check with drive supplier to make sure the drive firmware will support voltage dip ride-through. Flying restart, kinetic buffering, and the ability to have a low DC bus level trip point (50% of nominal is ideal) are essential. Be sure to configure the drive to take advantage of these features. Also make sure that any relays and control signals that interface with the drive are hardened to voltage dips.

10. Consider the software and control program issues. System software developers should consider process variable fluctuations during voltage dips. Widening the bandwidth for certain process variables or adding time filter delays can help avoid tripping the process when voltage dips occur.

11. Consolidate control power sources. When designing the layout of process equipment, try to consolidate the control power feed such that they are fed from a common source or breaker where possible. If a small power conditioner is required to make the equipment or process robust to voltage dips, this will make the implementation less painful.

12. Use a targeted voltage conditioning approach as the last resort. Apply only targeted voltage conditioning devices to prop up weak link components on the tool that cannot be retrofitted with comparable robust components. As discussed in this application note, several types of products are available which are batteryless in nature and will require lower maintenance than the traditional battery-based UPS.

Conclusion

This application note has shown techniques for using power conditioning on control circuits to improve the overall robustness of continuous manufacturing processes to voltage dips. This approach is based on the fact that most voltage dip sensitive components are typically found in the control circuit. Since power users such as motors are not ultra-sensitive to voltage dips, many times these devices do not need to be placed on conditioned power. EPRI has a wealth of experience in proving that protecting the controls section of process equipment will greatly improve the voltage dip robustness of the overall process. The cost of this approach is typically much less than cost of placing the entire machine or process on conditioned power.

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