Leonardo ENERGY

Power Quality and Utilisation Guide

Introduction

1.5 PQ in Continuous Manufacturing

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Introduction

PQ in Continuous Manufacturing

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PQ in Continuous Manufacturing

Introduction

Loads such as programmable logic controllers, relays, power suppliers, contactors and motor drives are common in automated continuous manufacturing processes. A voltage dip induced error in the process can quickly lead to a cascading shutdown of the entire process. The resulting downtime can be costly and can result in lost production. This application note examines typical problems in continuous processes caused by voltage dips and suggests economic, effective and proven measures to 'harden' these processes.

A minor voltage dip to 70% of nominal (i.e. a 30% reduction), lasting less than 100 milliseconds, can cause automated systems to fail, accounting for an estimated annual loss of 10 billion Euro in Europe. Although the effects of 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 1165 Euro per kilowatt (kW), excluding installation. For utilities, redesigning distribution systems, or making other investments in power delivery infrastructure, may also be prohibitively costly.

Fortunately, automatic systems can be made much more robust with respect to voltage dip phenomena by the use of proper electrical hardware and software design techniques. These techniques involve identifying the particular types of electrical disturbances likely to be experienced at a particular facility, finding the specific components and equipment that may be susceptible to those disturbances, and then dealing with these sensitive items, either by replacing them with more robust alternatives or protecting them.

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 often 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 surges or swells) can occur, short duration reductions in voltage (voltage dips or sags) are the most frequent cause of 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. Voltage dips are described in terms of magnitude and duration as shown in Figure 1. The depth of the event seen at the facility 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. 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.

Typically, the duration of a voltage dip ranges from 10 milliseconds to less than 1 second, depending on whether the facility is fed from the transmission system, which is somewhat stiff, or a distribution network, which cannot supply so high a fault current.

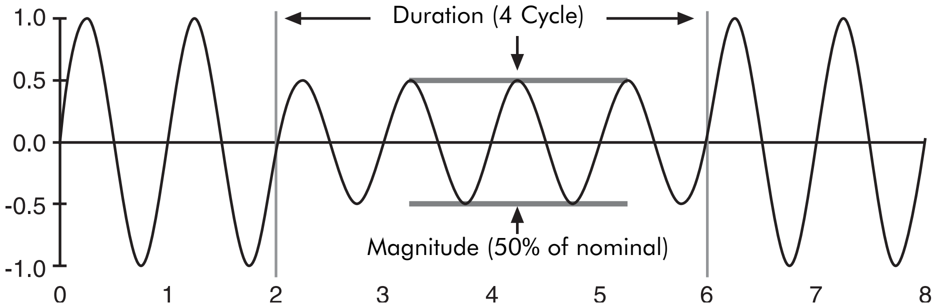

Figure 1 - Voltage dips are described by magnitude and duration

How often do voltage dips occur?

Many studies have been carried out in Europe and the US to quantify the frequency and characteristics of voltage dips. Some of these studies are described below. An examination of the results, especially the similarities, is helpful in understanding the typical environment.

EPRI distribution power quality study

In 1990, EPRI initiated the DPQ project to monitor power quality at the distribution level. Twenty-four utilities were monitored at nearly 300 sites for a period of approximately 2 years [1]. The data was characterised and analysed to form a baseline of power quality on US distribution circuits.

Retained voltage	10 -100 ms	100 - 500 ms	500 ms -1 s	1 s - 3 s	3 s – 20 s	20 s – 60 s
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 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 10 ms – 60 s)

Norwegian EFI survey

The Norwegian Electric Power Research Institute, EFI, (recently renamed SINTEF Energy Research) 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 [2]. The low voltage data is presented here, as it is most relevant to conditions inside a plant.

Retained voltage	10 – 100 ms	100 – 500 ms	500 ms - 1 s	1 s – 3 s	3 s – 20 s	20 s – 60 s
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 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 10 ms – 60 s)

UNIPEDE 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 9 countries (Austria, France, Germany, Italy, Netherlands, Norway, Sweden, Switzerland and United Kingdom) which provided statistical information on over 80 system-years of measurements covering a wide range of environmental and geographical conditions [3].

Retained voltage	10 – 100 ms	100 – 500 ms	500 ms - 1 s	1s – 3 s	3 s – 20 s	20 s – 60 s
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%

Table 3 - UNIPEDE DISDIP data: All sites, based on events per site per year (84.6 total dip events per site per year between 10 ms – 60 s)

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.

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

From the data in Tables 1 to 3 (summarised in Table 4) it can be seen that most events have a duration of less than 1 second. As will be discussed in this application note, battery-less power conditioners can provide coverage for this duration without the maintenance and disposal issues of the batteries used in the common UPS systems. Experience shows that most unprotected control systems can usually survive if the retained voltage is above 70% of nominal (1 second duration). Table 4 shows that a significant proportion of the <70%, <1 second dips have a retained voltage of 40% or more. Therefore, if strategies can be developed that 'harden' equipment to survive events of 40% magnitude and less than 1 second duration, many shutdowns will be avoided and only about 8 to 17% of the events would be likely to cause shutdowns. A typical site will see from 59 to 84.6 events that are between 10 milliseconds and 60 seconds in duration. This approach alone would equate to reducing the number of events that are likely to cause a shutdown by 50% to 30%.

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

Table 4 - Comparison of DPQ, EFI, and UNIPEDE data
(for events with durations of 10 ms - 60 s)

Voltage dip standards

There are several important 'standards' that can be used to represent the resilience of equipment and components to voltage dips. Basically, these standards are presented in the form of a retained voltage/time plot showing the boundary between normal operation – the area above the line – and abnormal operation – below the line. The original curve was developed in the early 1980s by CBEMA, now the Information Technology Industry Council (ITIC), and represented the *de facto* performance of a power supply. More recently it has been simplified and modified. Although very widely recognised, these curves were not standards at all. They were merely useful representations of what may be reasonably expected of equipment and, by extension, what might be required of a supply – although the original developers of the curves expressly excluded their use as a specification for either equipment or supply design. Nevertheless, most power quality monitors can superimpose the recorded data over the standard curves.

It should be noted that all these standards also describe the voltage/time limits for acceptable supply overvoltages and transients. However, in the context of voltage dips, only the under voltage boundary is relevant to this discussion.

In practice, the curve is unrealistic as a design standard – equipment that meets the ITIC limits will not ride-through all supply system dips. The SEMI F47 standard, originally released in February 2000, is more stringent than the ITIC curve. It was developed as a benchmark for testing equipment used by the semiconductor industry. This industry is very sensitive to downtime and the goal of the standard was to lead to more robust equipment designs that are less susceptible to voltage dips. The implementation of SEMI F47 has led to the wide availability of more robust semiconductor production equipment and facility support equipment. SEMI F47 has also been applied in other sensitive industries such as the automotive and food processing industries.

SEMI F47-0706 was revised in July 2006 to incorporate the knowledge gained during six years of compliance testing and to align it more closely with the IEC 61000-4-11 and IEC 61000-4-34 standards.

The requirements of SEMI F47-0706 are shown in Table 5.

Voltage Dip[1]	Duration at 50 Hz	Duration at 60 Hz
50%	10 cycles	12 cycles
70%	25 cycles	30 cycles
80%	50 cycles	60 cycles

Table 5 - SEMI F47-0706 test points (single and two-phase voltage dips only)

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 current rating, respectively. The requirements of the standard depend on the class of equipment under consideration as shown in Table 6.

Class[a]	Test level and durations for voltage dips (ts) (50 Hz/60 Hz)				
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

Table 6 - Preferred test levels and durations for voltage dips (IEC 61000-4-11, IEC 61000-4-34)

Notes for Table 6:

a Classes per IEC 61000-2-4, 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 servere than Class 2.

c '25/30' cycles means '25 cycles for 50 Hz test' and '30 cycles for 60 Hz test'

Comparing with 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 and the short and long interruption test points (at ½, 1 and 250 cycle durations) are required rather than recommended. When IEC standards are adopted by CENELEC as EN standards, they become mandatory for equipment that is CE marked and offered for sale in the European Union. IEC 61000-4-11 has already been adopted as CENELEC EN 61000-4-11 and so compliance is required in Europe. CIGRE and CIRED have formed a joint working group to consider the applicability of the current IEC voltage dip standards and proposed test methods. (see www.jwgc4-110.org) This working group will make recommendations to the IEC regarding updates of the voltage dip standards. At this point it is unclear whether IEC 61000-4-34 will be adopted by CENELEC.

Effects of voltage dips on continuous manufacturing equipment

Unless required to do so by their customers, most equipment designers and manufacturers do not take sufficient account of the electrical environment in which their products will be used. Most equipment is simply designed to operate under steady-state power conditions, with the normal allowances for long-term voltage tolerance.

Common electrical disturbances can adversely affect process equipment. Dips can cause all sorts of equipment to malfunction; not only sensitive equipment such as programmable logic controllers (PLCs), but also unsophisticated electro-mechanical equipment, such as simple control relays, affecting the operation of actuators or safety circuits.

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[1] *The magnitude of a voltage dip is expressed as a percentage 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).*

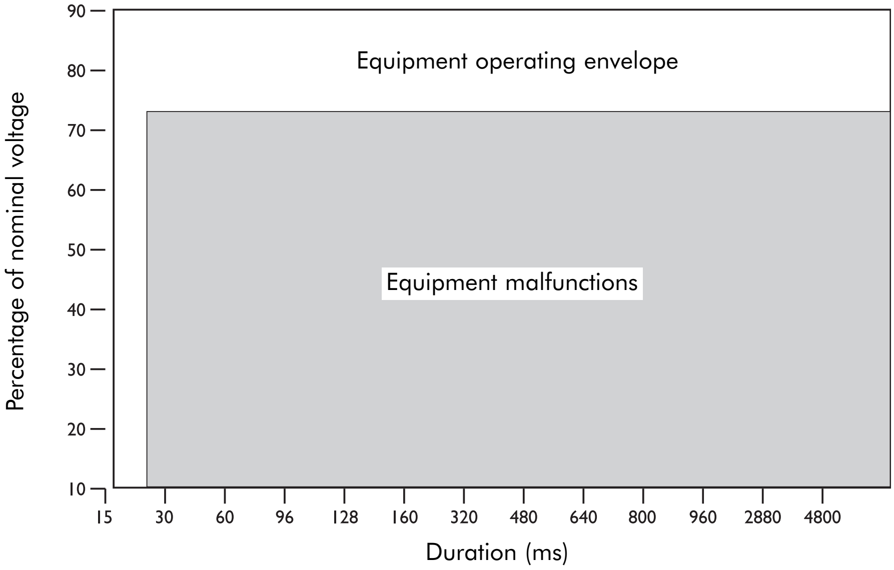


Figure 2 - Dip-tolerance curve of a sensitive PLC

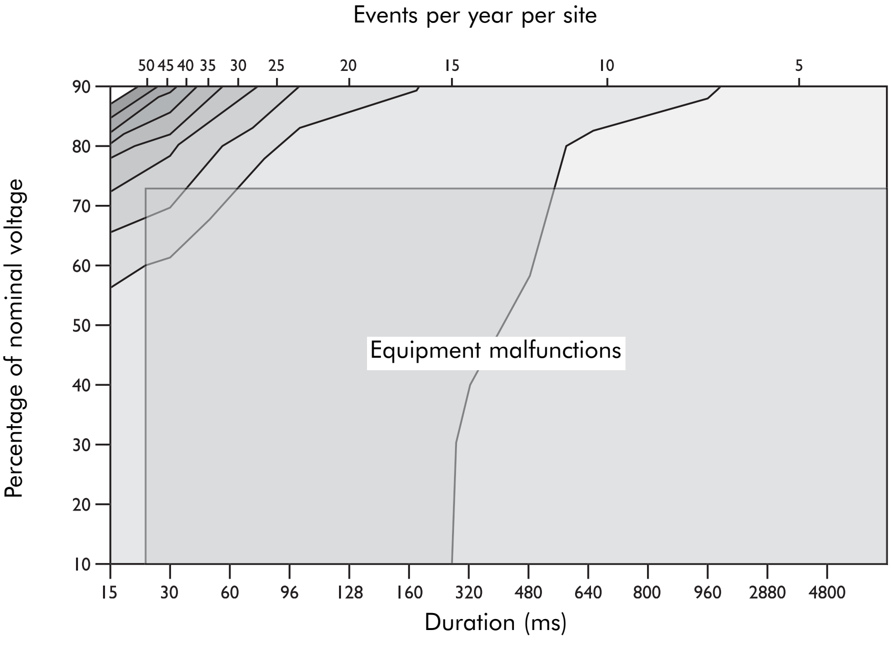


Figure 3 - Dip-tolerance curve imposed on the voltage-dip contour chart

The tolerance of process equipment is often illustrated using a graph called a dip-tolerance curve, such as that shown in Figure 2 for a PLC. The area under the curve represents the area in which voltage dips cause the PLC to malfunction.

A co-ordination chart can be produced by examining the power quality data from a given site. Each dip is plotted on the chart according to the retained voltage and duration. As described in IEEE 1346, Annex D, contour lines can be drawn that represent the number of events that are likely to occur [4]. If the dip tolerance curve is overlaid on the co-ordination chart (Figure 3), we can draw conclusions about the number of times per year that the PLC will malfunction. For example, the tolerance curve overlaps an area of the co-ordination chart that indicates approximately 25 events per year, each of which is likely to cause a malfunction.

During a voltage dip the energy available to the load is reduced and, unless corrective measures are taken, malfunctions may occur. There are several strategies for mitigating the effects of voltage dips, including:

- Large-scale power conditioners, such as static series compensators and stored-energy backup supplies, that can protect an entire facility. The cost of these solutions is very high and capital expenditure may be difficult to justify for many manufacturers.
- Properly-sized strategically-placed power conditioners can be used to protect a single process or individual pieces of equipment
- Existing process equipment can be protected at the control level by the use of small power conditioners
- Equipment can be made immune to dips of limited magnitude and duration by good design, the use of robust components and/or by modified programming techniques.

Each of these strategies for extending the operating envelope of equipment - from the macro-scale solutions implemented at the transmission or distribution level to embedded solutions implemented at the equipment level - have their advantages and disadvantages. For example, utility-scale solutions can be very expensive but require only limited knowledge about the detailed response of the equipment in the plant. Solutions applied at individual equipment level require extensive knowledge of each piece of equipment and how it interacts with others to determine the overall response of the process. Embedded solutions increase the initial cost of equipment, but it is generally accepted that embedded solutions are most cost-effective in improving voltage dip immunity of equipment. Figure 4 shows the spectrum of solutions mapped onto relative cost and the depth of knowledge required.

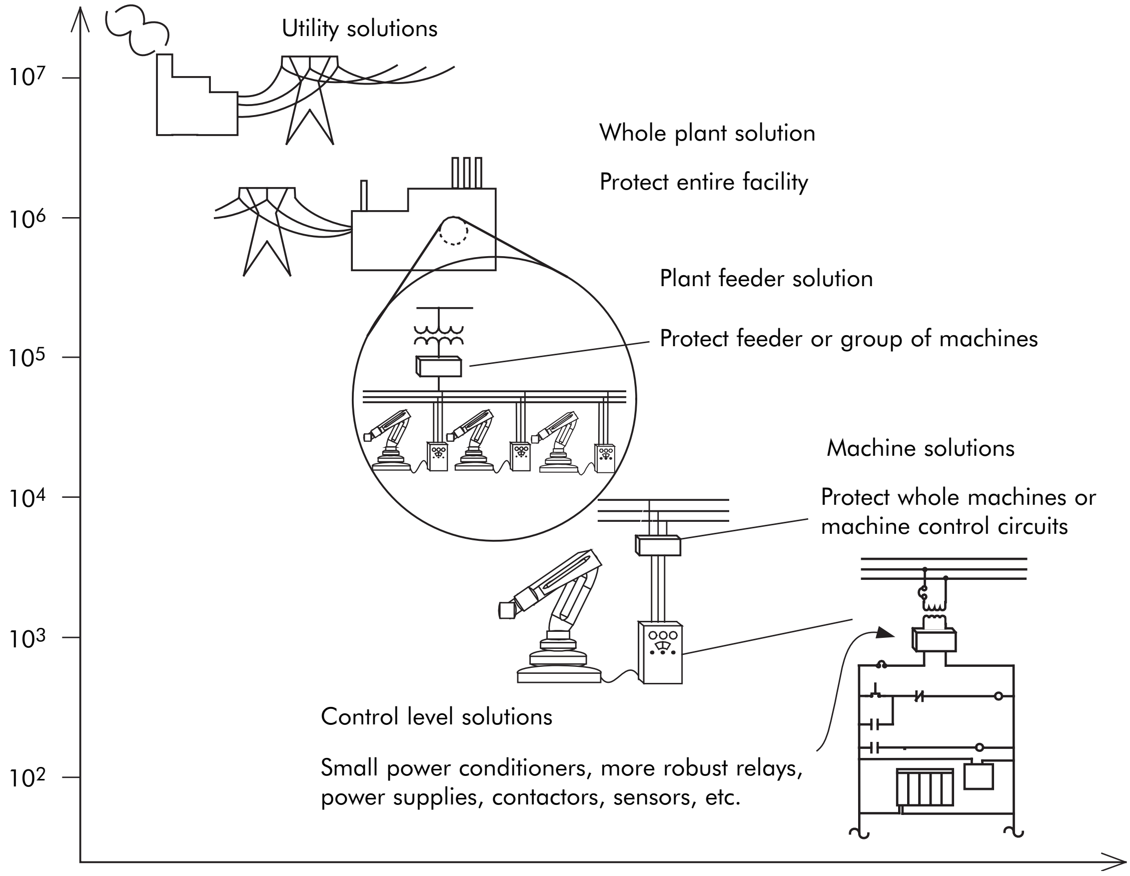


Figure 4 - Relative costs of solutions versus knowledge of equipment

In existing manufacturing plants there are two common approaches to improving the voltage dip ride-through. Both have their advantages and disadvantages when it comes to installation, design and management effort and cost. The two approaches are referred to here as the 'panel level' and the 'control-level' approaches.

Panel level approach

In the panel level approach a power conditioner is installed 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. Figure 5 shows examples of the panel level approach for a single-line or group of manufacturing lines.

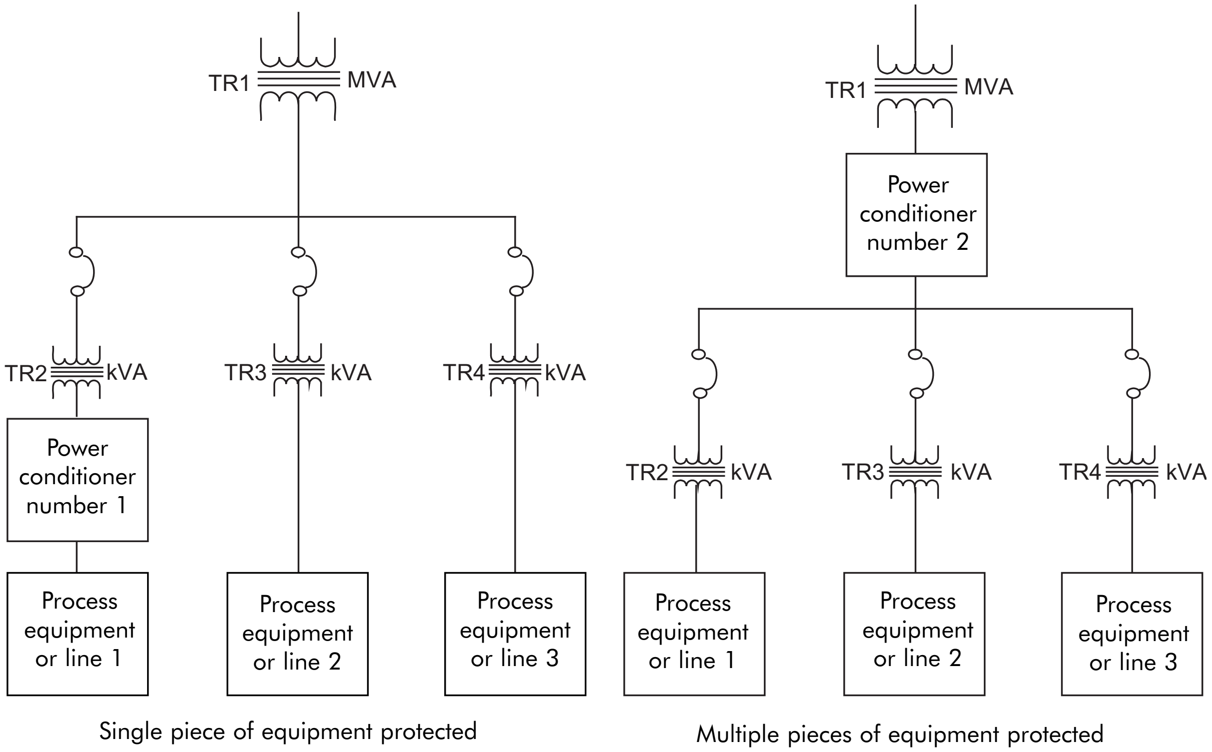


Figure 5 - Example of the panel level approach

Control level approach

The control level approach involves identifying those components or circuits within the manufacturing process equipment that are likely to be sensitive to voltage dips and protecting only those areas. The idea is that processes fail because of the failure of a single sensitive element in the control system. Research has shown correct protection can enable the manufacturing equipment to ride-through most voltage dips [5]. The cost of control level solution hardware is typically about 1/10th to 1/20th the cost of the panel level solution. However, the cost of installation must also be considered since this approach may require the protection of several circuits located throughout the production area.

Power conditioners

Power conditioners are designed to provide continuous power within the rated voltage range to the load during a dip in the power supply voltage. The energy supplied may be obtained by drawing an increased current from the residual voltage or from an energy store, such as a battery, inductor or capacitor. Where stored energy is used, the conditioner will often be effective against short interruptions, within the design parameters, as well as dips. Since this type of conditioner is used in relatively large numbers distributed across the production line, devices using battery storage, such as small UPSs, can pose a maintenance problem and it is often more effective to use passive storage devices, sometimes referred to as Battery-less Ride-Through Devices (BRTDs).

For most processes the critical areas are the emergency off circuits, instrumentation, dc power supplies and the power for the controller (computer) and its input/output circuits. Often fed by single-phase voltage, there are several options for improving the ride-through in these areas. Selected conditioner topologies are discussed below.

Standby capacitor-based conditioners

A standby capacitor-based conditioner is an off-line device that operates only when the voltage dip is detected. It is sized only for the nominal load. A capacitor bank is maintained in a charged state by a charging circuit fed from the raw supply. In the event of a dip the incoming power line to the device is opened and the load is supplied from the capacitor bank via a converter for a specified period. The time for which the load will be supplied can be calculated based on the actual load power and the energy storage capacity of the device; typically, these units can supply conditioned power to the load for up to 1 second. A typical 1kVA single-phase conditioner will range in cost from 1200 to 1500 Euro.

Injection technology-based conditioners

This type of conditioner has no storage. It operates by drawing a higher current from the reduced voltage source and generating a boost voltage in series with the supply to the load. It is capable of correcting dips down to 50% retained voltage for 3 to 12 cycles. Since they will draw ~200% current to support a 50% voltage dip, care has to be taken in specifying appropriate circuit rating and protection. Products are available in single- and three-phase designs at power levels ranging from 250VA to several MVA. For control level solutions, single-phase units are often used. A single-phase 1kVA unit costs about 1250 Euro.

Coil hold-in devices

Coil hold-in devices are designed specifically to mitigate the effects of voltage dips on individual relays and contactors. They are connected in line with the incoming control signal for the relay or contactor and are particularly useful in emergency-off circuits (EMO), master-control relay or motor control circuits. Typical coil hold-in devices cost between 80 Euro and 200 Euro and allow a relay or contactor to remain engaged when the voltage drops to around 25% of nominal.

Constant voltage transformer (CVT)

The CVT, also called a ferroresonant transformer, is a passive 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. (CVTs are described in more detail in Section 5.3.2.) CVTs have excellent voltage regulation, especially when operated at low loading – at 40% load the output is maintained within 5% for an input voltage down to 40% of nominal. The disadvantages of CVTs include a limited ability to supply high inrush currents (e.g. for switched mode power supplies), sensitivity of output voltage to supply frequency, a high external magnetic field and low energy efficiency. For a 1kVA load, the 2kVA CVT required for adequate voltage dip ride-through would cost about 950 Euro.

Battery-based UPS

Small uninterruptible power supply (UPS) systems - power conditioners with batteries - need careful consideration when used to harden control circuits. The output waveform of some older and cheaper units is far from a sine wave (in other words, the harmonic voltage distortion is very high) and such units should be avoided. Off-line UPS units, which are typically designed for PC protection, may not switch in quickly enough to prevent contactors, for example, from tripping – most PCs will survive for at least half a cycle but a contactor may not. On-line devices or off-line devices with known short transfer times should be preferred. The advantage of a UPS is that it has a relatively large energy store, in the form of a battery, to ride-through long and deep dips. However, the presence of the battery is also the greatest disadvantage in that it requires a carefully managed maintenance programme to ensure that batteries remain in good condition and are replaced before the end of their 3-5 year life. When small UPSs are distributed around a production line, maintenance can become a serious issue. If the PQ environment warrants the use of a UPS, it may be better to use a large centralised UPS system to provide a 'critical power' bus to the sensitive circuits, simplifying, but not eliminating, the maintenance requirement.

Understanding and protecting individual dip-sensitive components

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

- Identifying components sensitive to voltage dips
- Applying techniques to protect 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.

AC relays and contactors

These electromechanical devices are used extensively in process control systems. 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.

During a voltage dip a relay may revert to the de-energised 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.

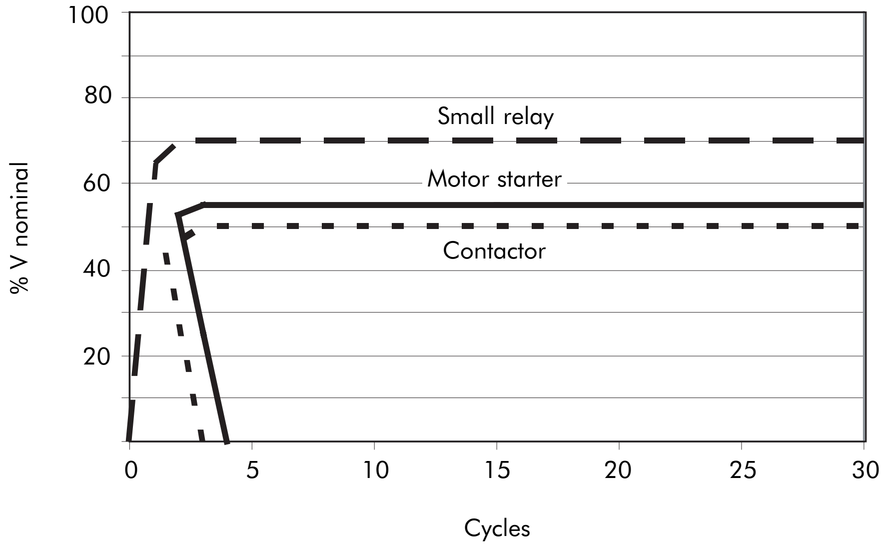


Figure 6 - Example dip-tolerance curves for relays, contactors, and motor starters

Relays can be protected against voltage dips by conditioning the power to the relay 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 if necessary. 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.

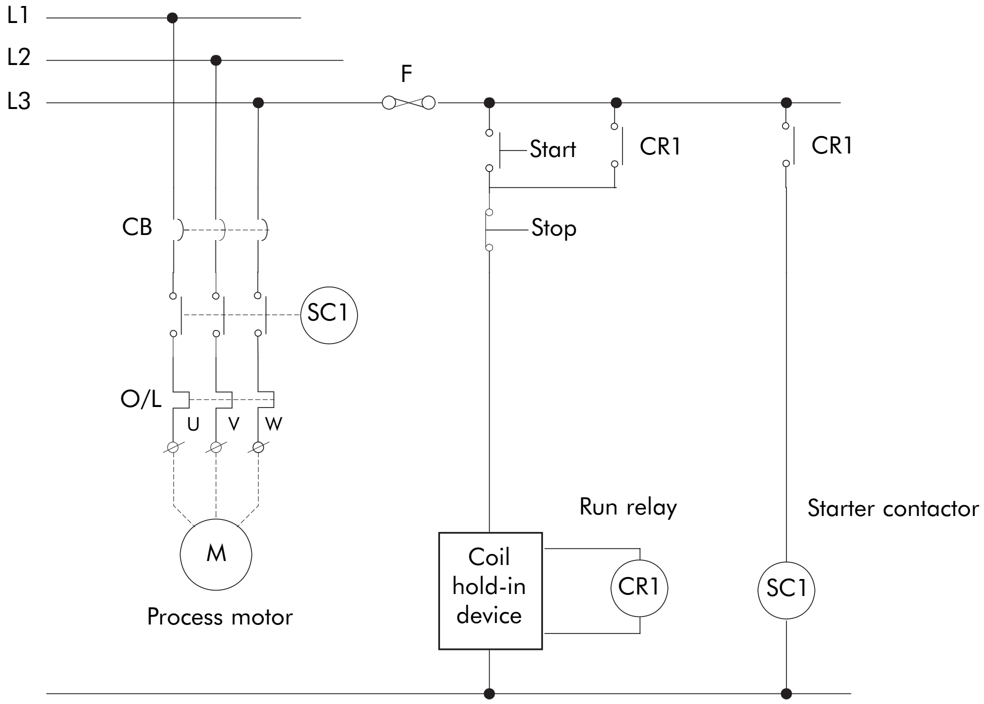


Figure 7 - Relay or contactor circuit with coil hold-in solution

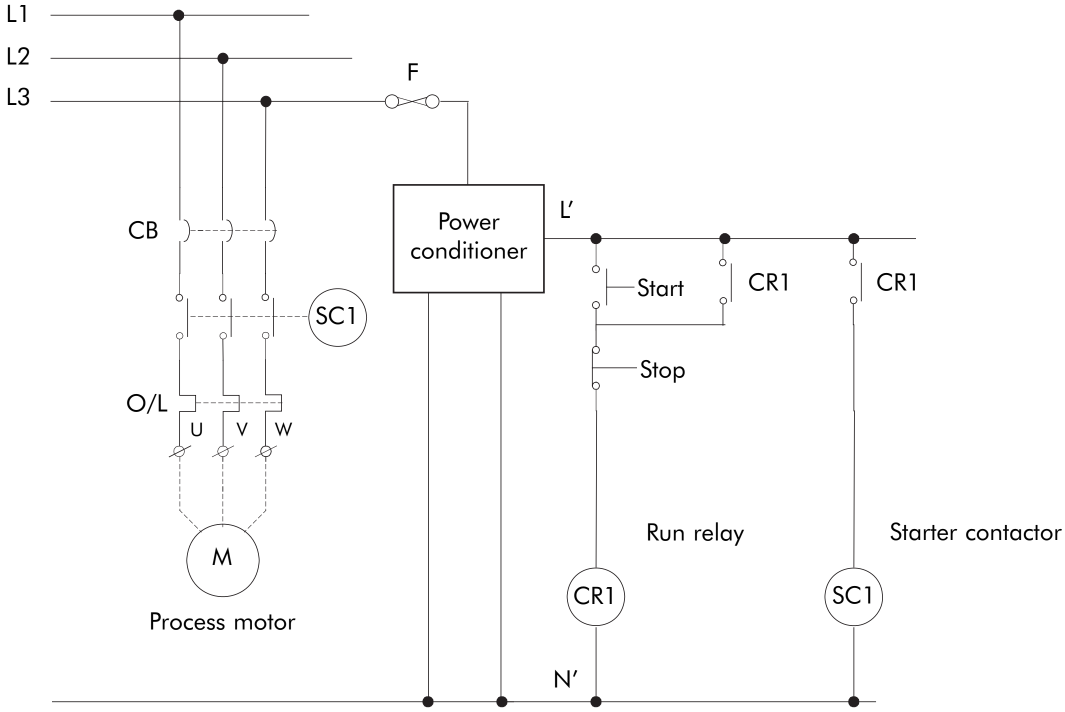


Figure 8 - Relay or contactor circuit with power conditioner solution

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, an illustrative sensitivity curve is shown. The supplies are assumed to be loaded to 100% of rated output.

Topology 1 – Unregulated dc supply

For an unregulated dc power supply, consisting of a transformer and diode-bridge without a capacitor, the output voltage will drop even for short-duration, shallow voltage dips. This type of supply provides no protection against voltage dips.

Topology 2 – Regulated dc supply

In a regulated dc power supply, a capacitor stores energy from the rectifier circuit and supplies a voltage regulator. The transformer and capacitor are dimensioned so that the input voltage of the regulator is maintained at a high enough level so that the regulator can maintain the correct output voltage during zero-crossings and dips. The higher the stored voltage, the better the ride-through capability, but at the expense of low efficiency.

Topology 3 – Switch mode power supply

A switch-mode dc power supply (SMPS) can be expected to perform better during voltage dips than an equivalently sized linear power supply. When the input voltage drops during voltage sag or momentary outage, the pulse-width will be increased to compensate the voltage drop until the supply voltage of the pulse width modulation control IC is lower than its designated threshold voltage [6]. This active compensation enables the power supply to maintain better output regulation than the equivalent linear unit.

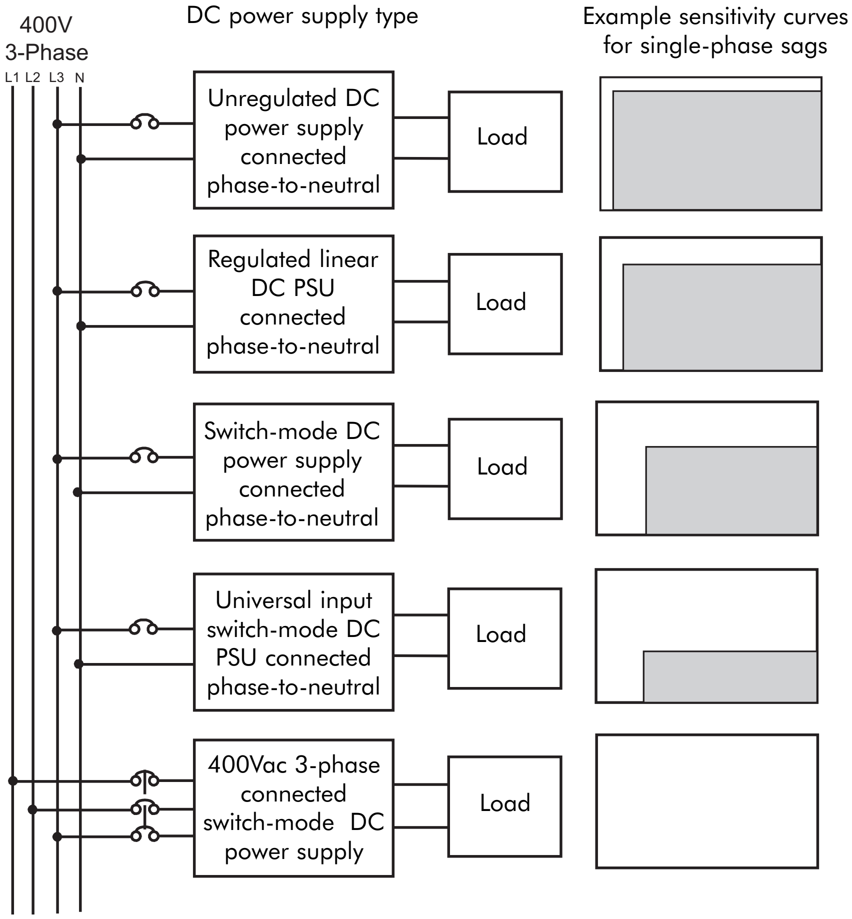


Figure 9 - DC power supply selection – with respect to voltage dip response

Topology 4 – Universal input power supply

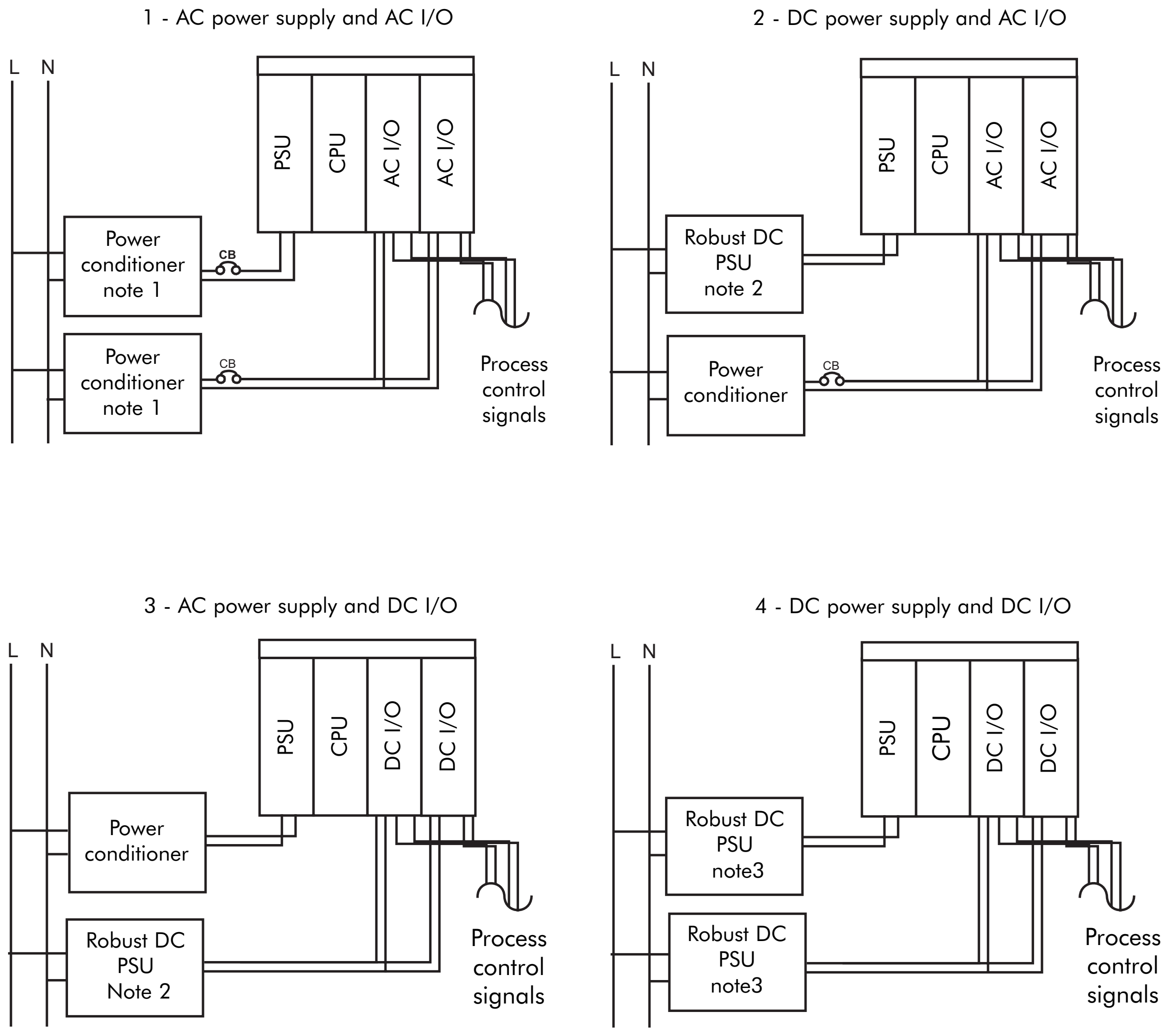
The universal input dc power supply is a switch-mode unit with a wide range of acceptable input voltage, typically from 85 to 264 Vac. In a 230 Vac system, the output voltage will be maintained during dips to 36% retained voltage.

Topology 5 – Three-phase input power supply

Voltage dips occur most often on one or two of the phases of a three-phase supply and three-phase dips are relatively rare. Using a three-phase input to a power supply therefore means that the number of dips that affect the dc output – only three-phase dips – will be much smaller and the system much more robust. Tests on many units of this type indicate that they are immune to single-phase voltage sags and interruptions lasting up to 1 second in duration and some can hold the dc output for two-phase dips as low as 10% of nominal. For severe three-phase voltage sags, this type of power supply has been known to ride-through events as low as 50% of nominal.

Programmable logic controllers

Programmable logic controllers (PLCs) are used extensively in industrial automation processes. The PLC consists of a central controller and power module and a set of input/output (I/O) circuits that interface between internal and external voltage levels. Each section is vulnerable to voltage dips to a degree dependent on how power is provided. For example, the power supply modules and the I/O could each be powered from an ac or a dc source, resulting in four possible configurations. Figure 10 shows the optimal solution for each configuration.



1 - AC power supply and AC I/O

2 - DC power supply and AC I/O

3 - AC power supply and DC I/O

4 - DC power supply and DC I/O

Figure 10 - PLC voltage dip hardening solutions [8]

Notes:

1. Consider supplying the controller and I/O power supply from one power conditioner if the power supply and I/O power are close to each other.
2. To select a robust dc power supply, refer to Figure 9.
3. Consider supplying the controller 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

Process equipment can be protected easily if the sensitive components are all powered from a common circuit. For example, the circuit shown in Figure 11 shows a control system with an EMO circuit, a PLC with both ac and dc I/O devices and a separate dc power supply for the analogue instrumentation. Locating the power conditioner at the main control power protects all 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 the associated relays. By protecting all control loads, the voltage dip response of the system can be greatly improved.

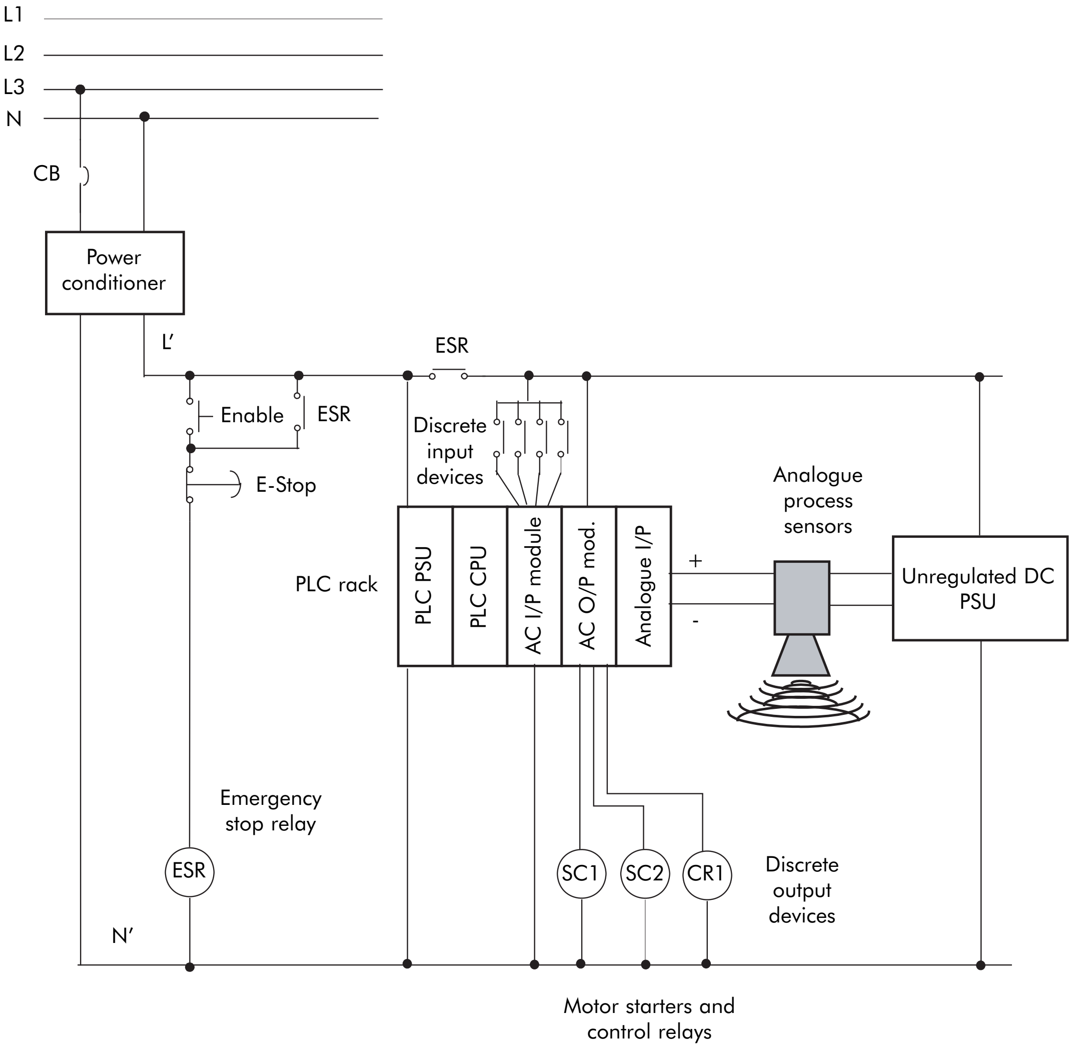


Figure 11 - Common power source power conditioning solution

Voltage dip mitigation strategies

In order to minimise the possibility of future voltage dip related power quality problems, plant engineers can implement best practice design strategies in existing systems. Original equipment manufacturers (OEMs) and control systems designers can build robustness into their designs by considering these strategies in future and current designs:

1. Use components that meet standards such as IEC 61000-4-11, IEC 61000-4-34 or SEMI F47. Hundreds of system components have been certified as compliant with these standards.
2. Avoid mismatched equipment voltages. If the components used in an equipment design do 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 (e.g. 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 of 10%. However, in dc power supplies, the energy stored in the internal capacitors can be 18% lower when the input voltage is mismatched by as little as 10% - directly equating to a reduction in ride-through time [9].
3. Use three-phase switching power supplies wherever 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 a dc power supply to power the control circuits as mentioned above.
5. Consider circuit breaker characteristics. Circuit breakers and fuses should be selected to allow for the higher inrush currents that may arise during voltage 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 interlock circuits. 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 has occurred. If there is concern that a motor might run in the wrong direction, interlock only with motor controls.
7. Select machine control systems that use non-volatile memory. This type of backup technique ensures that the control system will not lose its place in the event of a voltage dip. Utilising non-volatile memory in combination with state-machine programming techniques can enable some batch processing equipment to restart at the step where it was shut down.
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 twice the expected load will help the power supply to ride-through voltage dips. This is not so critical when robust power supply designs are used, as suggested in Strategy 3 above.
9. Use robust variable-speed drives. When using VSDs, specify models that have good voltage dip ride-through. Check with the 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. Ensure that the drive is configured to take advantage of these features. Also ensure that any relays and controllers that interface with the drive are hardened against voltage dips.
10. Consider the software and control program issues. System software developers should consider what process variable fluctuations might occur 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 feeds such that they are fed from a common source or breaker where possible. If a small power conditioner is subsequently required to make the equipment or process robust to voltage dips, implementation will be less painful.

12 Use a targeted voltage conditioning approach as the last resort. Apply targeted voltage conditioning devices only when the previous strategies are not applicable. As discussed in this application note, several types are available which are battery-less and so will require lower maintenance than the traditional battery-based UPS.

Conclusion

This application note has presented techniques for improving the overall robustness of continuous manufacturing processes to voltage dips by the use of power conditioning equipment. This approach is based on the fact that most voltage dip sensitive components are typically found in the control circuit. Since high power equipment, such as a motor, is not as sensitive to voltage dips as control equipment, it is often unnecessary to condition the power supply to it. The cost of this approach is typically much less than the cost of placing the entire machine or process on conditioned power.

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Notes

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