EPRI

technical update

Power Quality Impacts on Robotic Automation Systems

Power Quality for Customer Systems

Introduction

Robots are programmable electromechanical systems designed to perform repetitive tasks at lower cost and higher volume than humans. Many of the tasks done by industrial robots are performed to reduce injury caused by repetitive motion and enable work in hazardous environments. In addition to the benefits of protecting workers, robots can work 24 hours a day without fatigue. General Motors Corporation uses about 16,000 robots for tasks such as spot welding, painting, machine loading, transferring parts, and assembly. Assembly is one of the fastest growing industrial applications of robotics. It requires higher precision than welding or painting and depends on low-cost sensor systems and powerful but inexpensive computers. For example, robots are often used in electronic assembly where they mount microchips on circuit boards. Figure 1 shows an automotive robot in action.

Typically, robots are powered from an AC bus in a manufacturing facility. This bus has a voltage level compatible with the robot and possibly other process equipment. A transformer steps down the voltage level on this bus from a higher level (either a distribution or a transmission level). Because the robot is connected to the utility system through a transformer, it is exposed to common electrical disturbances such as voltage sags and momentary interruptions. For a company to realize the full benefit of robot technology, robots must be hardened to withstand these electrical disturbances.

Figure 1. Robot In Motion During Voltage Sag Testing (Courtesy Kuka)

Typical Applications of Industrial Robotics

In 1954, George Devol developed the first multi-jointed arm robot. Since then, robots have been introduced to many industries, including automotive, food-processing, semiconductor-manufacturing, and healthcare. Particularly over the last 20 years, the uses of robotics have grown rapidly. Table 1 shows just a few applications of robotic systems.

A Voltage-Sag Investigation of Robots

EPRI performed voltage-sag tests on two automotive industrial robots. General Motors provided access to the robots for testing. The voltage-sag tests were performed in an effort to measure the baseline effects of voltage sags on an industrial robot.

The basic electrical topology of the two tested robots is shown in Figure 2. A common DC bus fed both robots, which used DC-powered safety circuits.

As shown in Figure 3, each robot had six axes of motion. Table 2 compares other characteristics of the two robots.

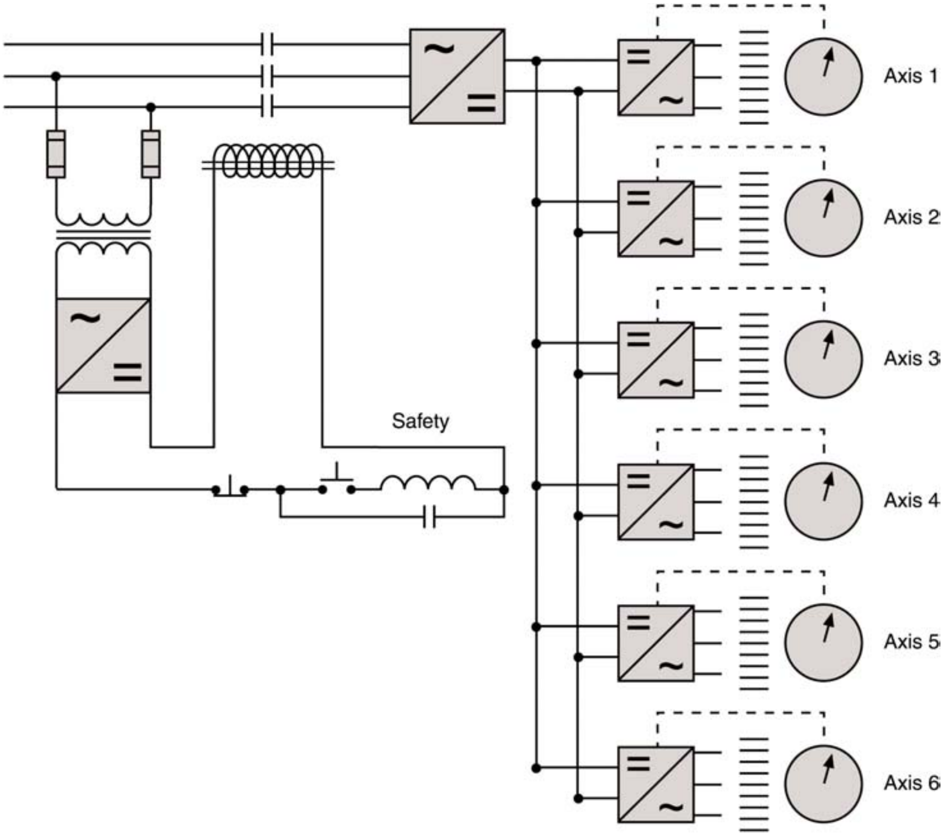

Figure 2. Basic Electrical Schematic of a Six-Axis Robot and Safety Circuit

Table 1. Applications for Robotic Systems

Function	Description of Use
Machine loading	The robot supplies a production machine with raw parts and/or unloads finished parts from the machine.
Material transfer	"Pick up and place" kinds of operations, transfer parts from one conveyor to another conveyor.
Processing operations	Other applications such as drilling, riveting, grinding, polishing, deburring, wire brushing, and water-jet cutting.
Spray coating	Greater safety, coating consistency, lower material usage and energy consumption, and greater productivity are possible.
Welding	Typically spot welding and arc welding.
Inspection	Dimensional checking and other inspection tasks.
Assembly	Assembly tasks require greater sophistication to account for variations in the position and orientation of assembly components, as well as out-of-tolerance and defective parts.

Voltage-Sag Test Procedure

To simulate voltage sags, a voltage-sag generator was temporarily installed in series with the main 480-V feed of the robots, as shown in Figure 4.

Single- and two-phase voltage sags were injected into the robot at varying magnitudes and durations to characterize the response of the robot. Single-phase sags were injected first, starting at 95% of nominal voltage with a duration of three cycles (50 ms). The magnitude was decreased in 5% increments until the robot tripped or until the magnitude reached 0% of nominal. This test was repeated at increasing durations in two-cycle increments until a duration of 60 cycles (1 second) was reached. This process resulted in a set of magnitude-versus-duration graphs called ride-through curves. In this way, the sensitivity of each robot was found for all single-phase sags (phase A-to-neutral, B-to-neutral, and C-to-neutral) and phase-to-phase sags (A-to-B, B-to-C, and A-to-C).

The robots were in two different operational states while tests were performed on the robots: stationary and moving.

Stationary Robot Test

The stationary-robot test was performed while the robot was powered but not moving. The servo drives were on and programmed to move to a position at which they were already positioned. Theoretically, results of this test should show how the robots would respond to voltage sags that occurred during a time when the robot was not doing work or waiting for material.

Moving Robot Test

The moving-robot test was performed while the robot was running and moving all six axes, as shown in Figure 3. The robots were programmed to run a continuous path from a point-to-point position.

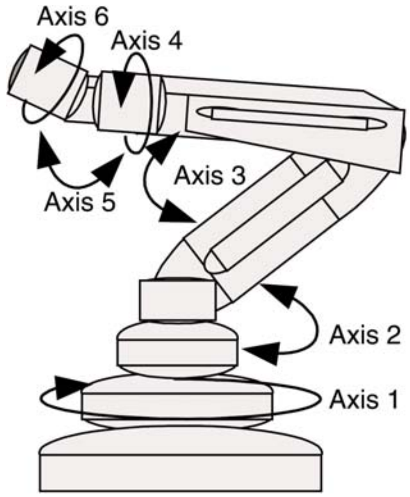

Figure 3. Robot Axis Identification

Table 2. Characteristics of the Two Robots

Robot	Payload	Weight	Arm Length	Rated Voltage	Rated Current
A	150 kg (331 lb)	1135 kg (2502 lb)	1.2 m (3.94 ft)	3-phase 480 V (50/60 Hz)	32 A
B	120 kg (265 lb)	2060 kg (4542 lb)	2.5 m (8.20 ft)	3-phase 480 V (50/60 Hz)	27 A

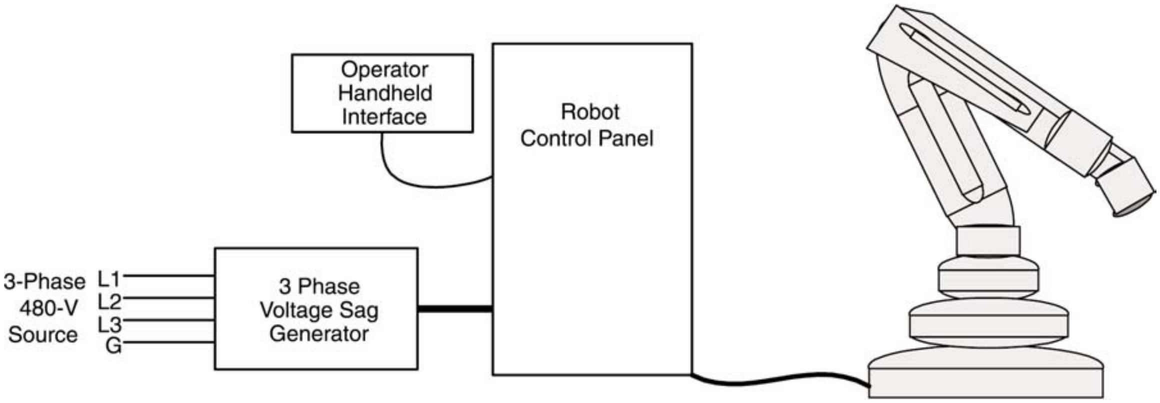

Figure 4. Voltage-Sag Test Setup

Positions 1 and 5 in Figure 5 are the beginning point (Point A) and end point (Point B) of the path. The robots were programmed to move from Position 1 to Position 5 and then back to Position 1. This point-to-point program was repeated while voltage single- and two-phase sags were injected into the supply voltage of the robot at Position 3 during the motion from Point A to Point B.

As shown in Figure 6, Robot B was also tested with and without a weight attached to the end of its arm. The weight matched the payload rating of the robot (120 kg or 264 pounds).

Results of the Voltage-Sag Tests

Stationary-Robot Tests

Results of the voltage-sag tests reveal that the two tested robots were very tolerant of voltage sags. Figures 7 and 8 show the ride-through curves for the two stationary robots. The SEMI F47 voltage-sag standard is imposed over the ride-through curves to provide a reference for the performance of the two robots. SEMI F47 is a very stringent voltage-sag standard developed by the Semiconductor and Equipment Materials International organization in 1999.

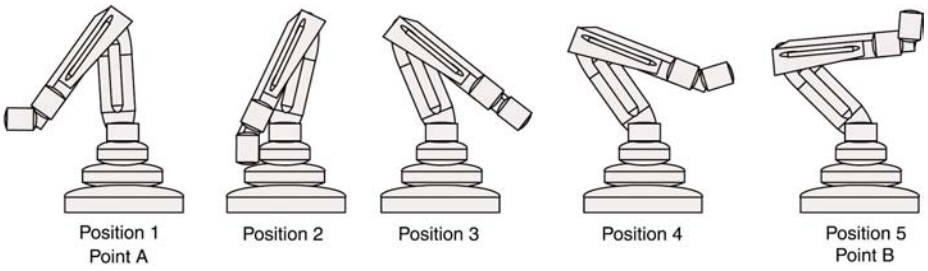

Figure 5. Moving-Robot Test (Point-to-Point Continuous Path)

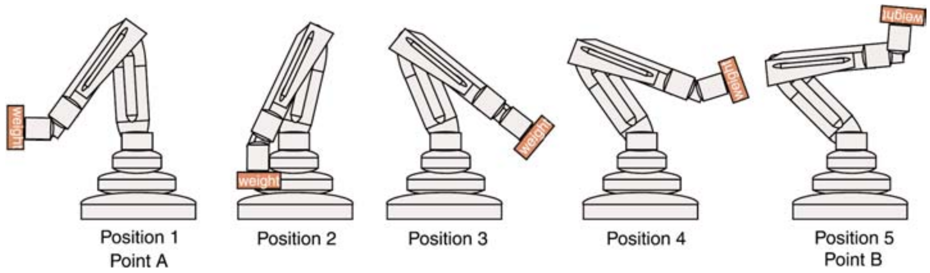

Figure 6. Moving-Robot Test With Rated Payload (Robot B Only)

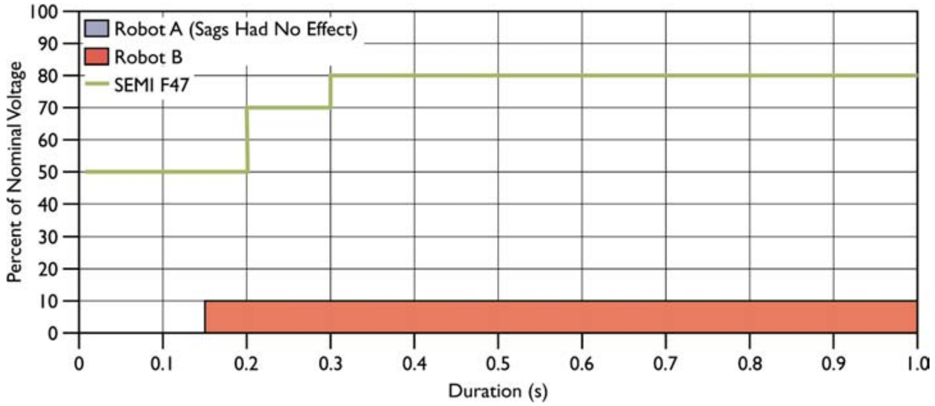

Figure 7. Ride-Through Curves for Stationary Robots During Single-Phase Voltage Sags

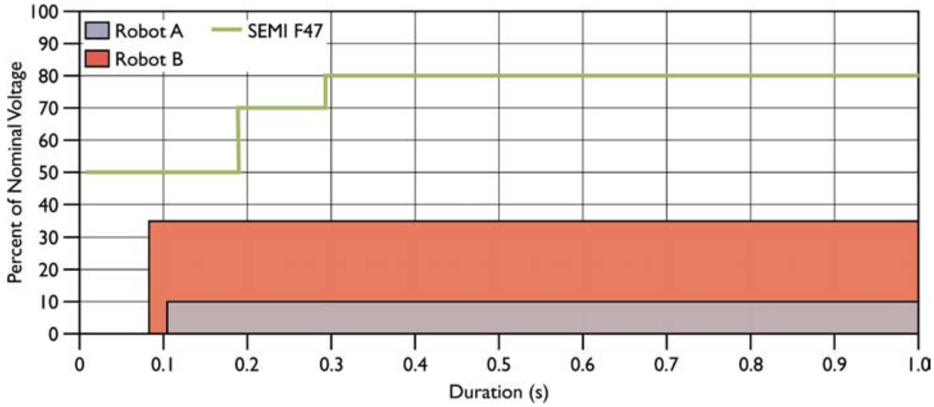

Figure 8. Ride-Through Curves for Stationary Robots During Phase-to-Phase Voltage Sags

Moving-Robot Tests

Even during motion, the two tested robots were tolerant of voltage sags. Figures 9 and 10 show the ride-through curves for the moving robots. The results of the tests reveal that the payload on Robot B made no difference to the ride-through ability of the robot. This result is not unexpected because the robot itself weighs about 17 times more than its maximum rated payload. Therefore, the servo controls are sized to precisely manipulate the robotic arms and carefully handle the maximum payload. Given this design criterion, it is not surprising that loading made no difference in the robot's ability to ride-through voltage sags.

Although not specifically verified by the testing reported in this technical brief, one might also expect the robots to handle deeper voltage sags during its traverse from point B to point A as the arm is moving downward with gravity from Position 5 to Position 3 (see Figure 5). In this motion scenario, extra kinetic energy has an effect on lowering the load of the system while the weight of the arm is traveling downward.

Reported Error Codes

When a robot shuts down as a result of an injected voltage sag, its controller reports error codes. Based on those alarm reports, it is apparent that the robots shut down due to a low voltage on the common DC link. Table 3 shows the shutdown levels and error codes given by each robot.

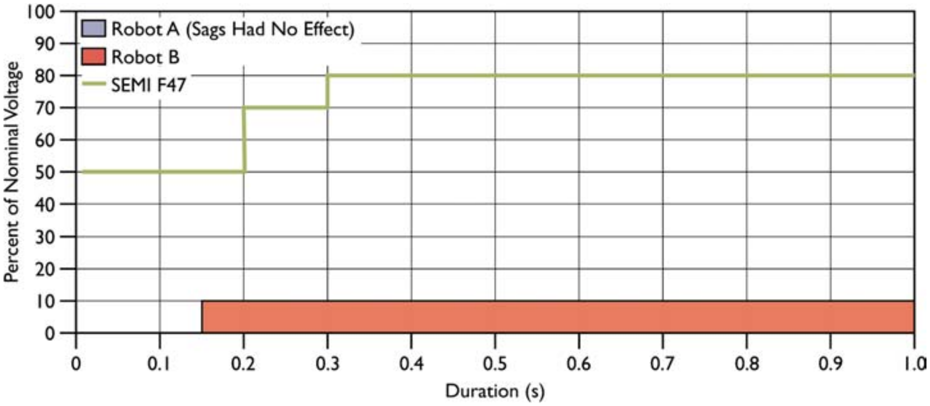

Figure 9. Ride-Through Curves for Moving Robots During Single-Phase Voltage Sags

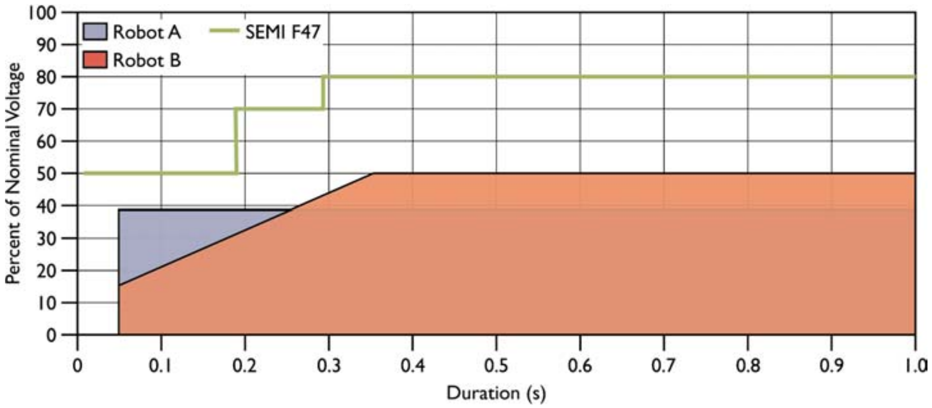

Figure 10. Ride-Through Curves for Moving Robots During Phase-to-Phase Voltage Sags

Table 3. Shutdown Level and Reported Shutdown Codes

Robot	Shutdown for 10-Cycle Phase-to-Phase Voltage Sag	Reported Error Code
A	10% of nominal voltage remaining	Power module unit undervoltage
B	35% of nominal voltage remaining	Mains missing: Incoming voltage to DC-link too low

Effect of Using AC-Powered Safety Circuits

Both of the tested robots were designed with DC control circuits and servo power supplies with a common DC bus. The servo drives of Robot A were fed from a separate three-phase DC power supply, while the servo drives of Robot B simply shared the DC bus. The DC design scheme of these robots and the way that they utilize the DC bus and power supplies for the servo drives are why their tolerance to voltage sags is so high. If the servo drives did not share a common DC bus but instead utilized AC control components, the robots would be more sensitive to voltage sags.

Consider the electrical schematic shown in Figure 11. This configuration has been observed by EPRI and member utilities in installed robot systems. The utilization of an AC-powered emergency-shutoff safety circuit makes the robotic system much more susceptible to voltage sags. In the circuit shown, when the operator presses the "machine on" pushbutton, a small pilot relay is utilized to hold in a larger contactor. Given the susceptibility of small pilot relays, which can range from 80 to 60% of nominal, the voltage-sag ride-through of the robotic system can be expected to be much worse, as shown in Figure 12. Because a robot in this scenario is at the mercy of the safety circuit, the robot will shut down during voltage sags to only 70% of nominal.

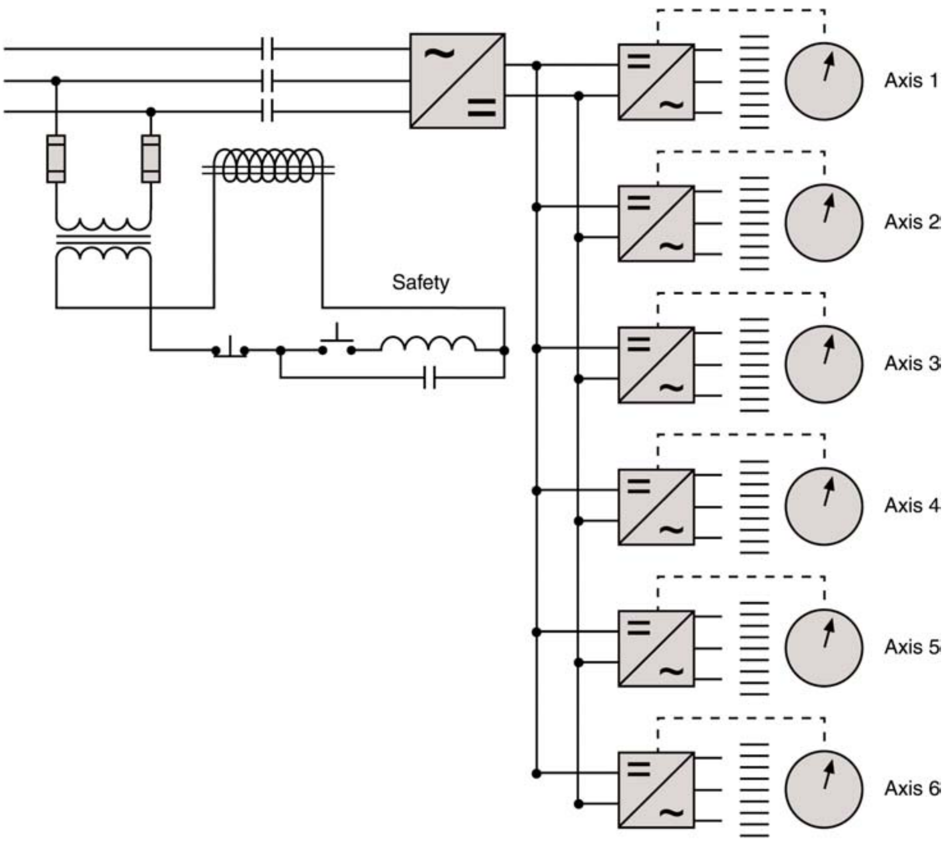

Figure 11. Robot Electrical Schematic With AC Powered Safety Circuit

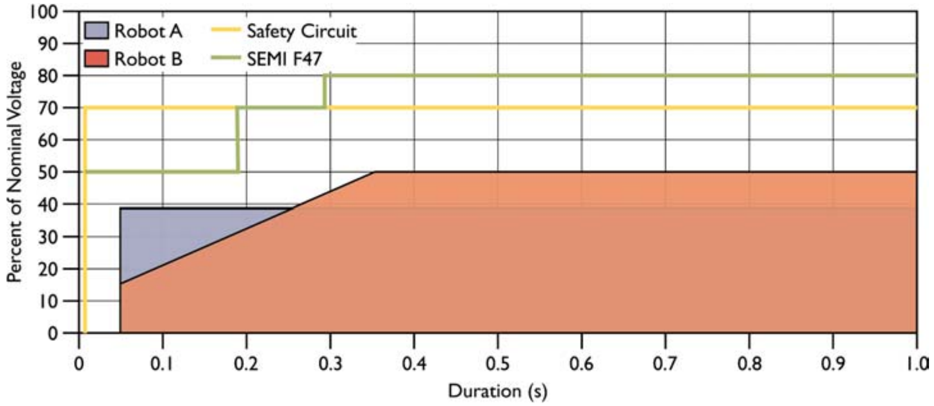

Figure 12. Ride-Through Curve of an AC-Powered Safety Circuit During Phase-to-Phase Voltage Sags

Conclusion

The two robots evaluated as a part of this effort were robust, riding through typical voltage sags. Furthermore, both systems passed the SEMI F47 requirements. The use of a common DC bus and sizing of the power electronics to precisely maneuver the 4500-pound (2041-kg) robots are a few of the reasons why the systems were so robust. Furthermore, both robots utilized DC-powered safety circuits, which made them more immune than AC-powered safety circuits found on some systems. When evaluating the ability of a robotic automation system to survive voltage sags and working to make the system more robust, one must consider the robotic cell as a whole. EPRI has well documented solutions and techniques for making programmable logic controllers, power supplies, drives, relays, and sensors more robust.

Further Reading

For information on hardening manufacturing equipment to voltage sags, review the following EPRI publications:

"PQTN Brief 39: Ride-Through Performance of Programmable Logic Controllers," EPRI, Palo Alto, CA: 1996. PB-107274.

"PQTN Brief 40: Ride-Through Performance of a Web Process Enhanced by a Constant-Voltage Transformer," EPRI, Palo Alto, CA: 1996. PB-107279.

"PQTN Brief 44: The Effects of Point-on-Wave on Low-Voltage Tolerance of Industrial Process Devices," EPRI, Palo Alto, CA: 1998. PB-111002.

"PQTN Brief 46: Performance of a Hold-In Device for Relays, Contactors, and Motor Starters," EPRI, Palo Alto, CA: 1998. PB-111613.

"PQTN Brief 49: Ride-Through Characteristics of PLC AC and DC Power Supplies," EPRI, Palo Alto, CA: 1999. PB-113724.

"PQTN Application Note 10: Sizing Constant-Voltage Transformers to Maximize Voltage Regulation for Process Control Devices," EPRI, Palo Alto, CA: 1997. TA-109233.

"PQTN Commentary 3: Performance of AC Motor Drives During Voltage Sags and Momentary Interruptions," EPRI, Palo Alto, CA: 1998. TC-112015.

"Extending the Operating Envelope of Process Equipment: Designing New Manufacturing Processes," EPRI, Palo Alto, CA: 2002. 1001663.

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