Guide for the Design of Semiconductor Equipment to Meet Voltage Sag Immunity Standards

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Abstract: This document summarizes the finding of testing to determine the immunity of semiconductor equipment to voltage sag events. Based in part on the findings, global standards have been adopted to define voltage sag immunity requirements for semiconductor equipment. As shown by the research, effective power conditioning and embedded design solutions can significantly improve the ability of equipment to ride through typical voltage sag events. The report conveys the basic findings of the research with regard to test results, standards development, and effective mitigation solutions. This document version contains corrected references to EPRI PEAC Corp.

Keywords: Equipment Performance, Equipment Reliability, Standards, Power Supply

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The authors would like to recognize the importance of workshops that brought together utilities, semiconductor manufacturers, semiconductor equipment suppliers, and other interested parties to find solutions to the issues of voltage sag immunity in the semiconductor industry. EPRI, SRP, and TXU Electric supported industry wide workshops while SRP, SEMI, and SEMI/SEMATECH supported equipment reliability workshops. Individual workshop organizers include Karen Forsten, EPRI PEAC Corp., Michele Negley, SRP, John Soward, TXU Electric, and Rick Koski, SEMI/SEMATECH.

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1 EXECUTIVE SUMMARY

This document summarizes the basic findings of a multi-organizational research project aimed at determining the immunity of semiconductor equipment to voltage sag events. This report also discusses resulting global standards that have been adopted to define voltage sag immunity requirements for such equipment. Additionally, it is shown that mitigation solutions, including effective power conditioning and embedded design procedures, can significantly improve the ability of equipment to ride through typical voltage sag events.

Efforts of this project focused on three main areas: equipment testing, power quality workshops, and SEMI standards. These are discussed below.

1.1 Equipment Testing

In recent system compatibility research work funded by select utility members of EPRI Electric, 33 different semiconductor tools were tested to determine their immunity to voltage sag events. Based on the findings of this research, a SEMI Task Force was formed to create standards that focus on improving the voltage sag immunity of semiconductor processing equipment. As a result of the task force work, two new standards documents have been adopted to define the desired voltage sag immunity of semiconductor processing equipment as well as the methodology for conducting voltage sag tests on this type of equipment. As proven by the EPRI research, effective off-the-shelf solutions and proper design guidelines can significantly improve the ability of semiconductor equipment to ride-through typical voltage sags and meet the new standard. The purpose of this document is to act as a vehicle to convey the basic findings of this work to the semiconductor equipment suppliers concerning the test results, new SEMI standards, and effective mitigation solutions.

1.2 Power Quality Workshops

The series of power quality workshops has been instrumental in bringing together utilities, semiconductor manufacturers, semiconductor tool suppliers, and other interested parties to better understand the issues facing one another in the quest to improve system compatibility. Four workshops were held by two electric utility companies. Texas Utilities Electric (TXU) hosted workshops in Dallas, TX in April 1997 and June 1998; and SRP hosted workshops in Tempe, AZ in September 1997 and in April 1999. The workshops brought together stakeholders to provide input and direction to the project. The outcome of these conferences heightened interest and directly led to standards development for semiconductor equipment, facilities, and the utilities that serve them.

1.3 SEMI Standards Efforts

SEMI is an international trade association representing semiconductor equipment and materials suppliers that develops standards for the semiconductor industry. Based on the input from the attendees at the Tempe power quality workshop, a SEMI Power Quality and Equipment Ride-Through Task Force was formed in October 1997. Six activities were defined for the task force, two of which are still ongoing at this time.

1.4 Conclusions

Major findings from the above-described work are as follows:

1. New global standards have been passed and published that considered the real electrical environment seen by semiconductor equipment.

2. The result will be improved tool ride-through and equipment immunity for the semiconductor industry.
3. Solutions are available through use of selective power conditioning and embedded designs to meet the standard.

2 INTRODUCTION

A March 30, 1998 Internet article in *Semiconductor Business News* stated that interruptions in semiconductor manufacturer processes can cost as much as $2 million in revenue per day. Such interruptions can be due to voltage sags caused by ice storms, floods, hurricanes, lightning, utility power distribution equipment failures, or other system anomalies. Typically described in terms of magnitude and duration (See Figure 1), voltage sag events can affect the operation of sensitive production equipment, leading to shutdown, malfunctions, lost product and diminished revenue. When a voltage sag 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.

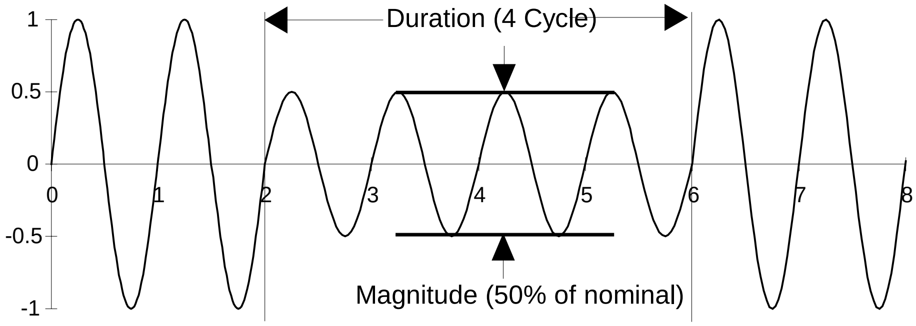


Figure 1 Voltage Sags Described by Magnitude and Duration

In recent System Compatibility Research work funded by select utility members of EPRI Electric, 33 different semiconductor tools were tested to determine their immunity to voltage sag events. Based on the findings of this research, a SEMI Task Force was formed to create standards that focus on improving the voltage sag immunity of semiconductor processing equipment. The task force included members from SEMATECH, SEMI, electric utilities, semiconductor manufacturers, semiconductor equipment suppliers and EPRI PEAC Corporation (formerly Electric Power Research Institute, Power Electronics Application Center). As a result of the task force work, two new standards documents have recently been adopted to define the desired voltage sag immunity of semiconductor processing equipment as well as the methodology for conducting voltage sag tests on this type of equipment. As proven by the EPRI research, effective off-the-shelf solutions and proper design guidelines can significantly improve the ability of semiconductor equipment to ride-through typical voltage sags and meet the new standard. The purpose of this document is to act as a vehicle to convey the basic findings of this work to the semiconductor equipment suppliers concerning the test results, new SEMI standards, and effective mitigation solutions.

The project efforts were focused in three main areas: Equipment Testing, Power Quality Workshops, and SEMI Standards Efforts. The EPRI research that developed the database of semiconductor equipment immunity was officially named Task 24: Power Quality in the Semiconductor Industry.

2.1 Equipment Testing

In order to understand the susceptibility of semiconductor equipment, extensive voltage sag testing was conducted. A portable voltage sag generator was used to test semiconductor equipment in semiconductor manufacturer clean rooms, at the tool supplier's facility, or at the Power Quality Test Facility (PQTF) located in Knoxville, TN. In all, 33 semiconductor tools were tested, and additional tests were conducted on tool subsystems such as robots, vacuum pumps and temperature control units. The breakout of the technological generation of the tested tools is best indicated by the wafer size processed. In general, the larger the diameter of the wafer, the newer the technology. As shown in Table 1, the Task 24 efforts led to the testing of four generations of semiconductor tool technologies.

Table 1 Breakout of Semiconductor Tools Tested by Wafer Size

Tool Wafer Size	Number Tested
100 mm	4
150 mm	16
200 mm	8
300 mm	5
Total	**33**

As shown in Figure 2, more tests were done on etch tools than any other type of equipment. Although most tool types tested exhibited susceptibility to voltage sags, the extensive number of tests done on etch tools is a direct indication of their problematic nature during voltage sag events.

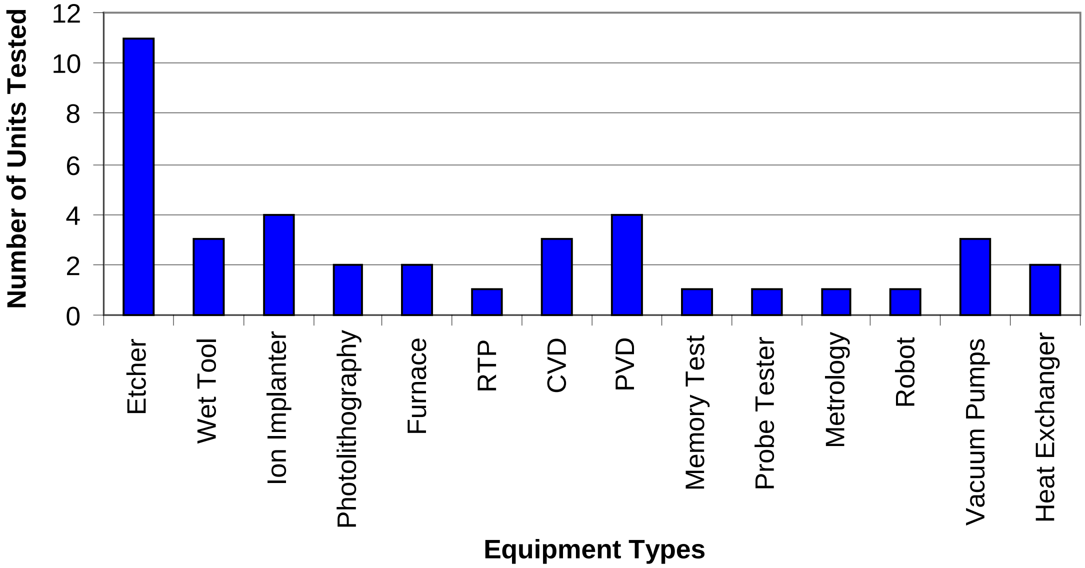


Figure 2 Breakout of Semiconductor Equipment Tested by Type

2.2 Power Quality Workshops

The series of power quality workshops has been instrumental in bringing together utilities, semiconductor manufacturers, semiconductor tool suppliers, and other interested parties to better understand the issues facing one another in the quest to improve system compatibility. The concept of a three-legged stool involving the utility, semiconductor manufacturer and tool supplier has been repeatedly used in this forum to indicate that only the combined efforts will make a difference (see Figure 3).

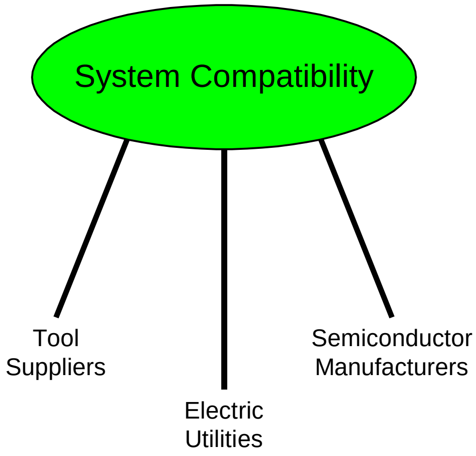


Figure 3 Three-Legged Stool Concept

Four workshops were held by two electric utility companies. TXU hosted workshops in Dallas, TX in April 1997 and June 1998. Salt River Project (SRP) hosted workshops in Tempe, AZ in September 1997 and in April 1999. The workshops brought together the stakeholders to provide input and direction to the project. The outcome of these conferences heightened interest and directly led to standards development for semiconductor equipment, facilities, and the utilities that serve them.

2.3 SEMI Standards Efforts

SEMI is an international trade association representing semiconductor equipment and materials suppliers that develops standards for the semiconductor industry. (Standards documents are available from SEMI at 805 E. Middlefield Road, Mountain View, CA, 94043; http://www.semi.org). Based on the input from the attendees at the Tempe power quality workshop, a SEMI Power Quality and Equipment Ride-Through Task Force was formed in October 1997. The six activities were defined for the task force, two of which are still ongoing at this time. A summary of the activities and progress to date is shown in Table 2.

Table 2 SEMI Standards Task Force Activity Summary

Activity	Activity Plan	Outcome
1	Review existing standards from IEEE, IEC, SEMI, CBEMA, and others	Internal task force report completed and approved in March 1998.
2	Review data collected on tools, facilities, and utilities	Internal task force report completed and approved in January 1998.
3	Develop Voltage Sag Immunity Standard for semiconductor equipment	SEMI F47, *Specification for Semiconductor Processing Equipment Voltage Sag Immunity,* was first printed in September 1999.
4	Develop a test methodology to confirm compliance to standard.	SEMI F42, *Test Method for Semiconductor Processing Equipment Voltage Sag Immunity*, was first printed in June 1999.
5	Develop performance guideline for power supplied to semiconductor factories.	SEMI document titled *Guide for Electric Utility Voltage Sag Performance for Semiconductor Factories* was approved in October 1999.
6	Develop guide for semiconductor factory power conditioning.	SEMI document titled *Guide for Semiconductor Factory Systems Voltage Sag Immunity* was approved in October 1999.

3 SUMMARY OF VOLTAGE SAG TEST RESULTS

Voltage sag tests conducted on 33 tools served to reveal the most common susceptibility problems for semiconductor manufacturing equipment. Using portable voltage sag test equipment developed by EPRI PEAC, the semiconductor tools were thoroughly characterized to understand their voltage sag susceptibilities. When examining the common “weak links” found in semiconductor tools, many of the same mechanisms are responsible for across-the-board tool immunity problems. Table 3 displays the most common reasons for the shutdown of the tools that were tested, and the percentage of the time that the particular “weak link” was found to be a problem when the tool shut down.

Table 3 Most Common Reasons for Voltage Sag Related Tool Shutdown for 33 Evaluated Tools

Voltage Sag Susceptibility Ranking	Weak Link	Overall %
1	EMO Circuit: Pilot Relay (33%) and Main Contactor (14%)	47%
2	DC Power Supplies: PC (7%), Controller (7%), I/O (5%)	19%
3	3 Phase Power Supplies: Magnetron (5%), RF (5%), Ion (2%)	12%
4	Vacuum Pumps	12%
5	Turbo Pumps	7%
6	AC Inverter Drives	2%

3.1 Emergency Machine Off (EMO) Circuits

Comprised of a pilot relay and a main contactor, the EMO circuit is typically the most vulnerable part of a semiconductor tool in relation to the overall equipment voltage sag immunity. As shown in Table 3, the EMO circuit was found to be the shutdown mechanism in 47% of the tests. The EMO circuit is used to power up the tool through the main contactor. Typically driven by the smaller EMO pilot relay (see Figure 4), the main contactor is used to apply power to the overall semiconductor tool. If either the EMO relay or main contactor are susceptible to voltage sags, the entire tool will shut down as a result. In the most sensitive circuits, a small general-purpose clear plastic case relay (an “ice cube”) was used for the EMO relay. Research shows that sags as minor as 78% of nominal, lasting less than one cycle in duration, can shut down an entire tool when these sensitive components are present. In contrast, other EMO circuits have been found to ride through voltage sags that are less than 50% of nominal voltage when robust relays and contactors are utilized in the design.

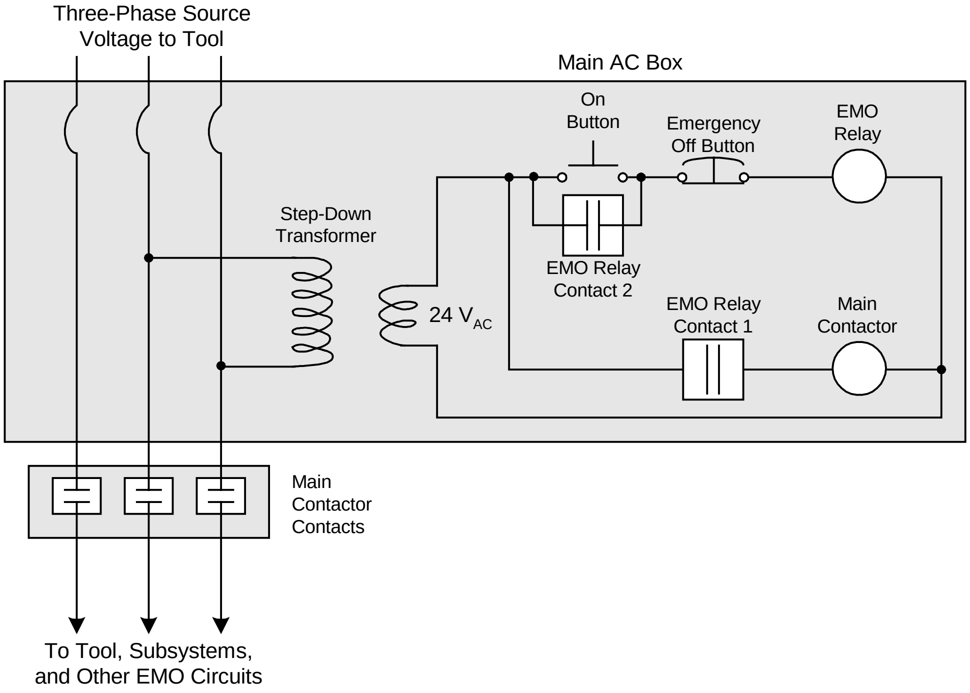


Figure 4 Typical Emergency Off Circuit (Simplified)

Another level of susceptibility in some semiconductor EMO circuits was found to be caused by the use of phase-monitoring relays in the EMO interlock circuit. These devices are designed to make sure that the incoming voltage has the correct phase rotation and is within a tolerance band. Figure 5 shows a typical unit.

Figure 5 Phase Monitoring Relay

The device typically protects against phase-unbalance and low voltage. Although the low voltage trip time is typically adjustable from 100 ms to 20 sec., the phase unbalance will trip immediately upon detection, leading to immediate tool shutdown when used in the EMO interlock circuit. Using a phase-monitoring relay as information only status input into the tool control system and graphical user interface (GUI) is suggested rather than interlocking the component in the EMO scheme.

3.2 DC Power Supply Response

The second most common reason for tool susceptibility to voltage sags hinges on the lack of stored energy and/or the control scheme of DC power supplies. DC Power supplies on semiconductor tools range from single-phase linear to switch-mode designs and are used to power user interface PCs, tool controllers, and instrument input/output (I/O) applications. The voltage sag ride-through of most power supplies designed for PC, tool controllers, and instrument I/O applications is directly related to the amount of stored energy and power requirement of the load. When these power supplies exhibit poor voltage sag ride-through, upsizing or the selection of a more compatible unit in a phase-to-phase connection scheme has shown to provide additional robustness. For example, utilizing a universal input (85–264 Vac) power supply in a phase-to-phase 208 Vac connection scheme will allow the power supply to continue operate for voltages down to 41% of nominal. The universal input supply can accomplish this while running at full load while still providing DC power within the desired ripple standards.

3.3 Three-Phase Power Supplies

Semiconductor tools use a variety of three-phase power supplies for high-voltage DC, microwave, and radio frequency (RF) applications. In order to suppress arcing in the process chamber, many of these units are designed with little stored energy. For this reason, some of these devices will shutdown when subjected to voltage sags. However, research has demonstrated that some of these units can continue to operate through the voltage sag event even though the output voltage may vary. Working closely with manufactures of these supplies, EPRI PEAC has learned that feasible changes in the control logic and power electronics can be made to make these units more robust.

3.4 Vacuum Pumps

Vacuum pumps are integral in the support of process chamber operations in many types of semiconductor tools. Closely coupled to the tool controller and EMO circuit operations, when the vacuum pump system is affected by a voltage sag event, the entire tool is likely to shut down. In one test case, a chattering EMO contactor from the main AC box was found to cause the vacuum pump system to shutdown, leading to an interruption in the tool operation. However, most of the vacuum pump related voltage sag immunity issues were found to originate from the vacuum pump package control circuit. Often, the vacuum pump control circuits utilize several AC powered “ice cube” general-purpose relays (see Figure 6). In fact, one manufacturer utilizes 27 such “weak” relays in their control scheme, 15 of which directly interfaced with the tool controller.

Figure 6 General Purpose AC Powered "Ice-Cube" Relay is a Common Weak Link Component in Vacuum Pump Control and Tool EMO Circuits

3.5 Turbo Pumps

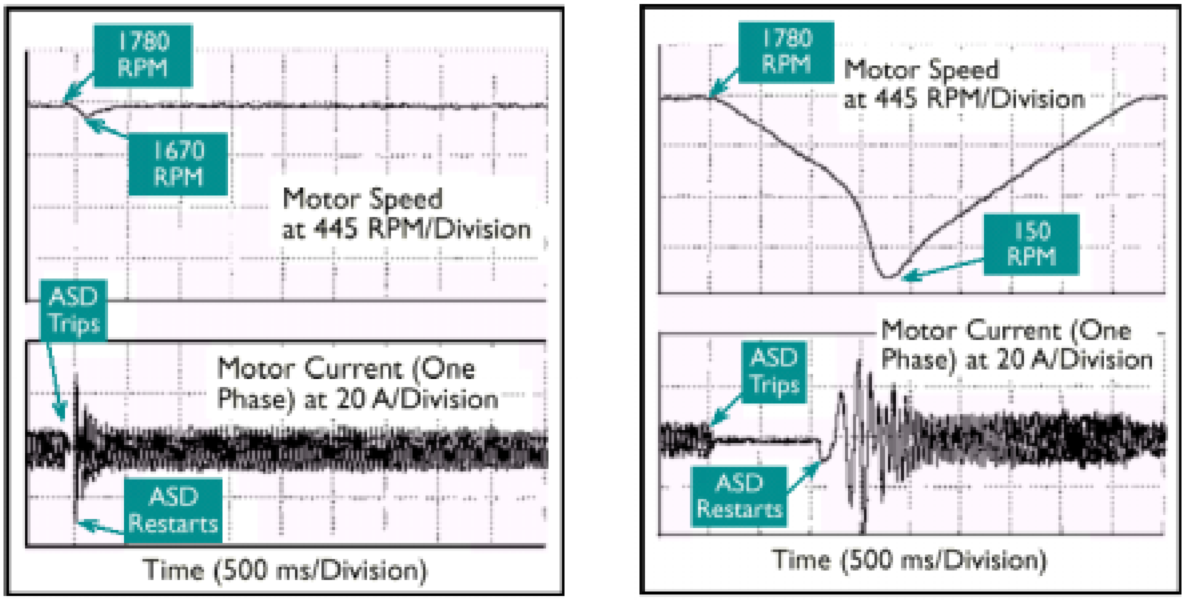
Typically powered from a single-phase source voltage, turbo pumps use magnetic-bearing technology to levitate the rotor on a magnetic field during high-speed turbine operation. The turbine turns at speeds up to 35,000 rpm. Previous generations of turbo molecular pumps used an AC motor and variable-frequency drive arrangement. To keep the rotor from crashing into the assembly during a power outage, a battery is used to keep the magnetic bearings energized until the rotor has spun down. With a properly maintained battery the turbo-pump controller will survive outages lasting up to 2 sec. If periodic battery replacement is not performed, the pump could be damaged during a power failure. During the voltage sag testing of etch tools, EPRI PEAC witnessed poor ride-through in installed vacuum pump controllers because of improper battery pack maintenance.

The newer generation of turbo molecular pumps, which are being used on some 300 mm tools, employ a DC motor and drive technology. A pulsed DC signal is used to rotate the field of a permanent-magnet motor. The kinetic inertia of the rotor acts as a motor-generator to power the magnetic bearing levitation circuit until the rotor has come to a stop, thus eliminating the need for a battery.

3.6 AC Inverter Drives

AC inverter drives, often referred to as adjustable speed drives (ASDs) are used in semiconductor tools and range in sizes from fractional to about 10 hp. These ASDs typically are employed in blower applications to keep air circulating in high temperature process applications.

Most ASDs that are used for semiconductor tools allow the user to tune a set of parameters that govern the operation of the unit. One common feature is called *flying restart* or *catch a spinning load*. With this parameter enabled, many drives are able to ride-through voltage sags without the motor speed dropping significantly. The restart algorithm that determines the motor speed at which the ASD restarts varies among manufacturers, with some having more accurate algorithms than others. Thus, one ASD model may afford smoother restarting than another. Figure 7 shows the motor speed during the shutdown and restart of two different ASD models (model A and model B) for a constant torque load. In both cases, motor speed slowed during the shutdown. However, the speed change of the motor connected to model A was minimal, whereas the speed change of motor connected to model B was significant. Before a semiconductor tool supplier purchases an ASD for a tool application, the user should consult with the ASD manufacturer to determine restart characteristics.



a) Model A **b) Model B**

Figure 7 Motor Speed and Current During a Five-Cycle Voltage Sag (“Flying Restart” Enabled)

4 ESTABLISHING A VOLTAGE SAG IMMUNITY STANDARD

In order to make a usable voltage sag ride-through standard, a SEMI standards task force developed both a specification that defined the voltage sag immunity requirements as well as a test method document.

The Computer Business and Equipment Manufacturers Association (CBEMA) curve was established in the late 1970s as a first attempt to determine the appropriate response of computer equipment to under-voltage conditions (sags and interruptions) and over-voltage conditions (swells). In the 1990s, EPRI benchmark studies in the nature of the electrical systems determined that voltage sags were by far the most common disruptive events in the power system. In addition, EPRI research on computer power supplies in 1995 led to a revised CBEMA curve known as CBEMA 96 or the Information Technology Industry Council (ITIC) curve. Existing electrical supply standards from IEC, CENELEC, IEEE, and SEMI were examined by the SEMI Power Quality and Equipment Ride-Through Task Force and documented in an internal task force report. Furthermore, a database of over 1000 voltage sag events was amassed from 15 different semiconductor sites. This voltage sag magnitude-duration data was plotted and statistically analyzed to determine the common voltage sags that are experienced at semiconductor manufacturing facilities. The scatter plot of the data is shown in Figure 8, with the CBEMA 96 curve overlaid on the graphic.

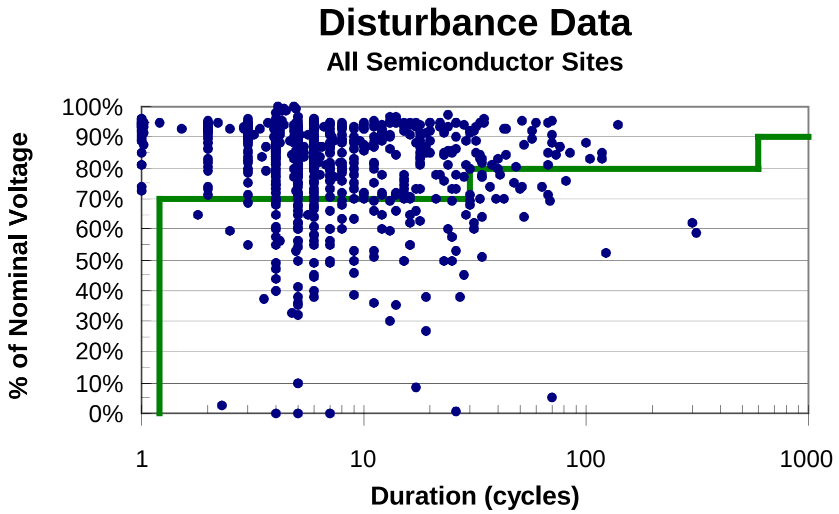


Figure 8 **Scatter Plot of Voltage Sag Event Data Considered by SEMI Task Force with CBEMA 96 Curve Overlaid**

Pertinent equipment electrical tolerance standards must reflect an understanding of equipment design as well as an understanding of the electrical environments in which equipment is expected to operate. The electrical disturbance data collected from the 15 different semiconductor sites provides a representation of the electrical environment for large semiconductor sites. Because relevant information on the susceptibility for semiconductor manufacturing equipment did not exist at the onset of the standards process, testing was performed to determine actual tolerance to voltage sags.

An analysis of 30.5 monitor-years of disturbance data collected at major semiconductor sites revealed that 166 (or 15.4%) of the events were below the CBEMA 1996 tolerance curve. Thirteen of the 15 semiconductor sites averaged at least one event below the CBEMA curve each year. Furthermore, the average number of occurrences below the CBEMA 1996 curve per site per year was 5.4. Given this information, it was apparent to task force members that application of the CBEMA 1996 curve would not yield satisfactory performance for semiconductor manufacturing equipment. The task force concluded that a higher standard was needed.

Semiconductor manufacturing equipment tests demonstrated that properly selected sub-components within the semiconductor equipment could consistently withstand voltage sags to 50% of nominal. The number of sub-components that were capable of withstanding voltage sags more severe than 50% declined abruptly. A 0.2-sec. duration for voltage sags of this magnitude was selected because of a requirement to have an even duration figure to accommodate 50-Hz rated equipment. The figure also was selected for compatibility with fault clearing times for common protective devices present on utility electrical systems.

Figure 9 shows a contour plot for the disturbance data collected at the 15 semiconductor sites. The plot represents the number of occurrences that a given equipment tolerance curve will be exceeded during a one-year period. Displayed on the plot is the tolerance curve that was proposed for semiconductor processing equipment. The contour plot illustrates that the transitions in the proposed tolerance curve for semiconductor equipment tracks the contour line that represents the fewest number of expected events.

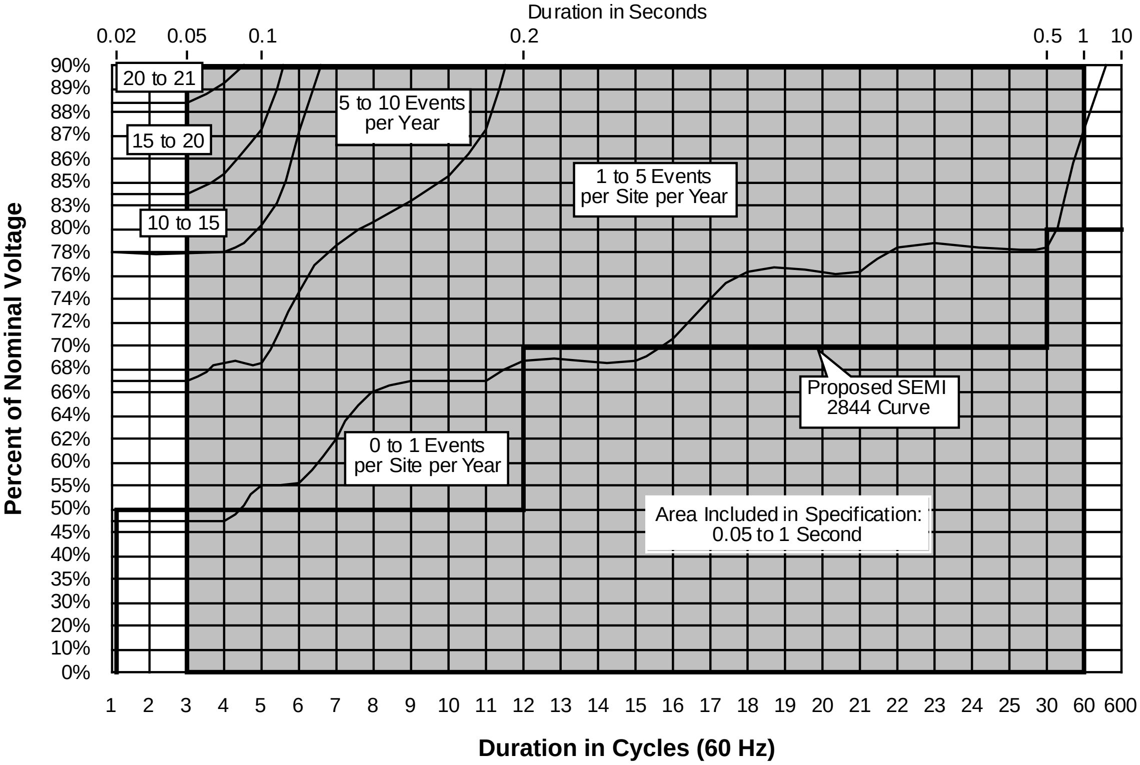


Figure 9 Disturbance Contour Plot with Equipment Tolerance Curves

The task force members developed a SEMI standard, *Specification for Semiconductor Processing Equipment Voltage Sag Immunity* (see Table 2). This document is the heart of the task force’s work, since it defines the threshold that a semiconductor tool must operate without interruption and it also provides a target for the facility and utility systems. Recognizing that semiconductor factories require high levels of power quality due to the sensitivity of equipment and process controls and that semiconductor processing equipment is especially vulnerable to voltage sags, this document defines the voltage sag ride-through capability required for semiconductor processing, metrology, and automated test equipment.

The requirements in this international standard were developed to satisfy semiconductor industry needs. While more stringent than existing generic standards, this industry-specific specification is not in conflict with known generic equipment regulations from all regions or generic equipment standards from other organizations. It is the intent of this standard to provide specifications for semiconductor processing equipment that will lead to improved selection criteria for sub-components and improvements in equipment systems design. While it is recognized that in certain extreme cases or for specific functions battery storage devices may be appropriate, it is not the intent of this standard to increase the size or use of battery storage devices provided with equipment. Focus on improvements in equipment component and system design should lead to a reduction or elimination in the use of battery storage devices to achieve equipment reliability during voltage sag events.

This specification specifies the minimum voltage sag ride-through capability design requirements for equipment used in the semiconductor industry. The expected equipment performance capability is shown graphically on a chart representing voltage sag duration and percent deviation of equipment nominal voltage. Standard evaluation test method references also are included.

The primary focus for this specification is semiconductor processing equipment—including, but not limited to, the following tool types:

- Etch equipment (dry and wet)
- Film deposition equipment (chemical vapor deposition [CVD] and physical vapor depostion [PVD])
- Thermal equipment
- Surface preparation and clean
- Photolithography equipment (stepper and tracks)
- Chemical mechanical polishing (CMP) equipment
- Ion implant equipment
- Metrology equipment
- Automated test equipment

The final proposed curve in the SEMI standard was amended slightly to make the curve break-points at even numbers for both 50 and 60 cycle power systems as well. The curve, which applies both to two-phase (phase-to-phase) and single-phase (phase-to-neutral) voltage sags, is shown in Figure 10.

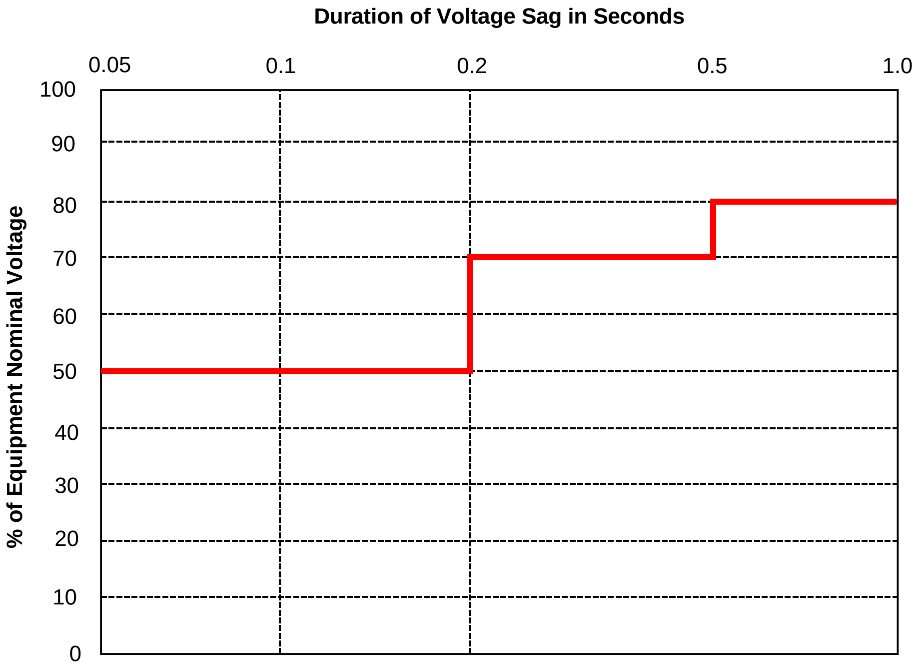


Figure 10 Voltage Sag Ride-Through Curve Proposed by the SEMI Standards Task Force

The specification simply states that semiconductor processing, metrology, and automated test equipment must be designed and built to conform to the voltage sag ride-through capability per the defined curve. Equipment must continue to operate without interrupt (per SEMI E10

Standard for Definition and Measurement of Equipment Reliability, Availability, and Maintainability) during conditions identified in the area above the defined line. In the context of SEMI E10, interrupt means any assist or failure. An assist is defined as an unplanned interruption that occurs during an equipment cycle where all three of the following conditions apply:

1. The interrupted equipment cycle is resumed through external intervention (e.g., by an operator or user, either human or host computer).
2. There is no replacement of a part, other than specified consumables.
3. There is no further variation from specification of equipment operation.

Furthermore, a failure is any unplanned interruption or variance from the specifications of equipment operation other than assists. Although no variation in the tool’s process is the goal, this standard addresses these issues as related to the equipment operation only. Since the process effect of such disturbances is tool-specific and is in the venue of the tool supplier, it was beyond the task force’s scope of work.

4.1 Companion Test Methodology

Realizing that a voltage sag immunity standard was only useful if a standardized test protocol were used to evaluate the equipment, the Task Force developed the SEMI F42 document. This document defines the test method used to characterize the susceptibility of semiconductor processing, metrology, and automated test equipment to voltage sags. The scope of the document is to define the testing procedures and the test equipment specifications that will be required to characterize the equipment’s response to voltage sags and qualifying the equipment to meet the industry standard. This methodology document is generic in nature in that it results in the characterization of the equipment voltage sag immunity which can then be measured against any defined ride-through standard. The document contains important sections that detail how to conduct voltage sag tests on semiconductor tools. These sections define the following:

- Test apparatus requirements
- Safety precautions
- Sampling and test specimens
- Test setup
- Test procedure
- Interpretation of results
- Reporting test results

5 EQUIPMENT DESIGN SOLUTIONS

Compliance with the SEMI standard can be obtained in three ways:

1. Use of selective power conditioners on susceptible loads
2. Embedded solutions through design and component selection strategies
3. A combination of options 1 and 2.

5.1 Selective Power Conditioning

Often the ride-through of a semiconductor tool is directly related to the ability of one or more small components to survive the voltage sag event. In this case, the use of selective power conditioning can lead to a great improvement in the overall tool's robustness to voltage sags. The idea of this approach is to prop up the single phase powered "weak links" in the tool. The premise of this approach is that all equipment power users are not ultrasensitive to voltage sags and thus do not need to be placed on conditioned power. The loads that typically are fed by selective power conditioning devices are single-phase devices with voltage requirements from 100–230 Vac. As one might imagine, the cost of this approach is much less than putting the entire tool on conditioned power.

Many of the voltage-sag related tool shutdowns can be overcome when power conditioning devices are applied to the critical circuitry. The critical items for most tools are the EMO circuits, control power, critical instrumentation, DC power supplies and the controller (computer) power. Often fed by single-phase voltage, there are several options for improving the ride-through in these areas. The most common selective power conditioning devices are shown in Figure 11 and discussed below.

Figure 11 Common Selective Power Conditioning Devices

5.1.1 Voltage Dip Proofing Inverter (DPI)

The DPI falls into a class of device referred to as batteryless ride-through devices (BRTD). Since the DPI operates only when the voltage sag is detected (offline 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 sag is detected that drops below an adjustable threshold, the line to the incoming power to the device is opened and the DPI supplies a square-wave output to the load for about 1–3 sec. 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 DPI.

5.1.2 Constant Voltage Transformer (CVT)

The CVT (also called 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 sag 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% of nominal voltage when the input voltage has dropped to as low as 40% of nominal.

5.1.3 The Uninterruptible Power Supply (UPS)

The UPS can come in three basic types: standby, line-interactive, and rectifier/charger. The standby UPS switches to a battery and provides an inverter output to the load once the voltage sag is detected. If the transfer is fast enough (< 1 cycle) and is in phase with the incoming voltage, typical control components are not likely to be affected by the sag event. Careful section of the this type of UPS is required in order to guarantee that sensitive control loads will not drop out before the unit switches to the inverter. The line-interactive UPS is an online type that employs a regulating transformer (CVT) when the incoming voltage is nominal. When a voltage sag is sensed, the unit then switches to the inverter to power the load. High inrush loads must be taken into account when using this unit since the CVT output can collapse from overloading. The rectifier/charger UPS is also an on on-line unit. The unit constantly rectifies the incoming AC line voltage. The resulting DC voltage is then used to charge the batteries and to feed the inverter circuit for the units output section. In the event of a voltage sag or outage, the unit switches to the battery for the source of the inverter’s power.

Ultimately, the determination of whether to use a UPS or some other voltage conditioning device depends on whether the load requires power during a brief outage and the end user’s willingness to perform periodic maintenance on the unit’s batteries.

5.1.4 The Dynamic Sag Corrector (DySC).

The DySC system is a new BRTD that corrects voltage sags down to 50% of nominal, supplying a sine-wave output. By drawing power from the remaining voltage, the DySC injects a series voltage to regulate the output for voltages as low as 50% of nominal lasting from 3–12 cycles. The units can be fitted with capacitors as well to allow for limited outage ride-through comparable to the DPI. This product comes is single and three phase designs in power levels ranging from 1.5–2000 kVA. The available operating voltage levels are 120, 208, 240, 277, and 480 Vac depending on the model used. This product was developed in tandem with the SEMI standard and is targeted toward the semiconductor industry.

5.1.5 Coil Hold-In Devices.

Coil hold-in devices are also BRTD that are designed to prop up individual relay and contactor loads. Two commercial brands are the KnowTrip and the Coil Lock. These units are designed to mitigate the effects of voltage sags on individual relays and contactors. Typically, the coil hold in a device is connected in line with the incoming control signal for the relay or contactor. Available for coil voltages of 120, 230, and 480 Vac, 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. Generally costing less than $50, these units are very economical to support contactors and relays. Typical coil hold-in devices allow a relay or contactor to remain engaged until the voltage drops to around 25% of nominal. The unit installs between the relay or contactor coil connection terminals and the incoming AC control line.

A comparison of the common selective power conditioners is shown in Table 4.

Table 4 Selective Power Conditioning Equipment Comparison

Type of Event	DPI	CVT	DySC	UPS	Coil Hold-In Devices
Spikes and surges	No	Solved	Solved	Solves	No
Sags to 80%	Solves	Solves	Solves	Solves	Solves
Sags to 50–80%	Solves	Solves depending on sizing of device	Solves	Solves	Solves
Sags to 25–50%	Solves	Solves depending on sizing of device	No	Solves	Solves
Below 25%	Solves	No	No	Solves	No
Outage	Up to 1 sec.	No	Up to 0.15 sec. only	Solves	No

5.2 Embedded Solutions

In general, these solutions involve fixing the individual “weak links” components of a tool in order to increase the overall ride-through of the entire system. Embedded solutions are attractive, since they in theory do not require add on power conditioning equipment, but instead involve using more robust or improved components in the tool design. Tips for embedded solutions to meet SEMI are discussed below.

Tip #1: Wire load devices in a phase-to-phase configuration where possible.

This includes EMO transformers, power supplies, PCs and tool controllers. Connected in this manner, a single-phase drop to 50% of nominal will equate to only 76% of nominal phase-to-phase. Furthermore, if the load components on the secondary side of the transformer can survive voltage sags to 50% of nominal, they will not drop out even if one phase of the primary voltage drops to 0 V. Table 5 illustrates the relationship between single and two-phase voltage sags.

Table 5 Phase-Neutral and Phase-to-Phase Voltage Sag Relationship

Given a Line-Neutral Sag Voltage of this:		The remaining Line-to-Line Voltage will be this:	
%	**Voltage**	**%**	**Voltage**
95%	263.3	97.51%	468.1
90%	249.4	95.04%	456.2
85%	235.6	92.60%	444.5
80%	221.7	90.18%	432.9
75%	207.8	87.80%	421.4
70%	194.0	85.44%	410.1
65%	**180.1**	**83.12%**	**399.0**
60%	166.3	80.83%	388.0
55%	152.4	78.58%	377.2
50%	138.6	76.38%	366.6
45%	124.7	74.22%	356.2
40%	110.9	72.11%	346.1
35%	97.0	70.06%	336.3
30%	83.1	68.07%	326.7
25%	69.3	66.14%	317.5
20%	55.4	64.29%	308.6
15%	41.6	62.52%	300.1
10%	27.7	60.83%	292.0
5%	13.9	59.23%	284.3
0%	0.0	57.74%	277.1

Note: For illustration calculations are shown for 277 Vac line-to-neutral and 480 Vac line-to-line voltage systems)

Tip #2: Avoid mismatched equipment voltages.

If the equipment used in the tool design does not match the expected nominal input voltage, the tool will be more susceptible to voltage sags. This can occur in the following circumstances:

- Transformer secondary voltages do not match the rated voltage for the connected equipment.
- A tool subsystem, such as a servo controller or power supply, is rated for a higher voltage (i.e. 240 Vac equipment is used with a 208 Vac supply).

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 a little as 10%—directly equating to a reduction in ride-through time.

Tip #3: Use universal input switching power supplies in every location possible.

The universal input type power supply typically has a voltage range of 85–264 Vac. When connected phase-to-phase in a 208 Vac system (tip #1), the power supply can continue to operate down to 41% of nominal. This type of supply should be specified for DC powered EMO circuit, tool DC power supplies, PCs, and tool controllers.

Tip #4: Avoid the use of AC powered "ice cube" general purpose relays.

Instead, use a robust AC relay or utilize a DC power supply to power the EMO or control circuit configured as mentioned in above.

Tip #5: Do not use phase monitoring relays in the interlock circuit.

These devices will easily trip during a voltage sag and can lead to tool shutdown. Instead, utilize these devices to log that a voltage sag or phase problem exists. If the concern is that a motor might run in the wrong direction, interlock only with motor controls.

Tip #6: Utilize a non-volatile memory.

This type of back-up technique for tool controllers ensures that the control system will not lose its place in the event of a voltage sag.

Tip #7: Do not overload DC power supplies.

Since the amount of voltage sag 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. Over-sizing by at least two times the expected load will help the power supply to ride-through voltage sags. This is only critical for systems that do not have a universal input front-end.

Tip #8: 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 can not be retrofitted with comparable robust components.

Tip #9: Use robust inverter drives.

When using ac inverter drives in the tool design, specify units that have good voltage sag ride-through. Flying restart 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 the features. Make sure the flying restart of the drive has the characteristic of model A in Figure 7.

6 CONCLUSIONS

Major findings from the above-described work are as follows:

1. New global standards have been passed and published that considered the real electrical environment seen by semiconductor equipment.
2. Solutions are available through use of selective power conditioning and embedded designs to meet the standard.
3. The result will be improved tool ride-through and equipment immunity for the semiconductor industry.

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