PQ TechWatch

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Making Equipment Immune to Voltage Sags: What You Need to Know about Standards and Voltage-Sag Testing Methods

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CONTENTS

Introduction 1

What to Expect from "Uncertified" Manufacturing Equipment 1

Voltage-Sag Standards 4

The ITIC Curve 4

The SEMI F47-0706 Standard 4

The IEC 61000-4-11 and 61000-4-34 Standards 7

What Difference Does a Method Make? 9

Including Voltage Sag Standard Compliance Language in the Purchase Specifications 13

Conclusion 13

Related Documents .14

Notes 14

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EXECUTIVE SUMMARY

Voltage sags are a proverbial thorn in the side of many industrial manufacturers. With losses that can cost many hundreds of thousands of dollars per voltage sag, the industrial manufacturer understands what voltage sags can do to their profitability. The cost to own manufacturing equipment must include equipment robustness or susceptibility to voltage sags in the calculation. Original equipment manufacturer equipment that is robust to voltage sags equates directly to profitability. Industrial manufacturers understand what it means to have equipment vulnerable to these common events on the electrical network. However, many do not know how to rectify the problem.

This *PQ TechWatch* describes how to properly specify voltage-sag immunity in equipment purchase specifications and how to ensure that voltage-sag tests are done in a way that will lead to system compatibility and ultimately robustness of the manufacturing process. This report reveals what to expect from equipment that has not been "certified" to a voltage-sag standard, describes voltage-sag standards, illustrates how to place language in a purchasing specification, reviews test documentation, and describes the process of matching industrial equipment to the electrical environment. It will lead you on a journey of ensuring that the equipment in your plant is hardened to common voltage sags.

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INTRODUCTION

From the manufacturing of automobiles to the production of indispensable medicines, from the mass production of plastic components to the machining of metal parts for control valve assemblies, industrial manufacturers find themselves battling the effects of unwanted downtime caused by voltage sags. If only the equipment and electrical system could "play well" together, the end-use manufacturers would be able to stave off unwanted and unplanned downtime caused by these events.

Many industries do not understand how to implement improved system compatibility in their manufacturing systems.

In the early 1990s, EPRI coined the term "system compatibility" to describe the concept of the electrical grid and the end-use systems playing well together. While some industries like the semiconductor-fabrication industry have taken ownership of their system compatibility issues via improvement of their manufacturing equipment, many others still lag behind and do not understand how to implement improved performance in their manufacturing systems.

Most industrial end-use manufacturers receive performance specifications of electrical equipment from original equipment manufacturers (OEM) rather than supplying criteria of their own. Often as a result, the only "specification" that the OEM complies with is that its equipment will operate in an electrical environment that is about ±10% of the expected environment. The large majority of manufactures do not ask for more. However, the electrical grid to which this equipment is connected will experience up to six voltage sags per year in which the service voltage drops below 50% of nominal and about 13 sags in which the service voltage drops below 70% of nominal.[1] Industrial manufacturers are typically not requiring OEM vendors to provide equipment that can ride through these conditions.

Figure 1. Semiconductor Fabricators Routinely Require Voltage Sag Testing at the OEM Site

To ensure that OEM-provided equipment is compatible with the electrical grid, the industrial end user must require that the equipment be evaluated against the probable electrical environment. Voltage-sag testing (as in Figure 1) is the most effective means of determining the compatibility of OEM equipment with the intended electrical environment. Knowing the equipment's ability or inability to ride through voltage sags can provide information that will lead to informed decisions related to the purchase, installation, and maintenance of the equipment. Only testing can reveal complex interactions between electrical components, process control algorithms, and voltage sags.

WHAT TO EXPECT FROM "UNCERTIFIED" MANUFACTURING EQUIPMENT

A major driver in a decision to purchase and install industrial equipment is *cost*. For the OEM, the cost of components that are used in a manufacturing machine weigh heavily in the design process and decision to

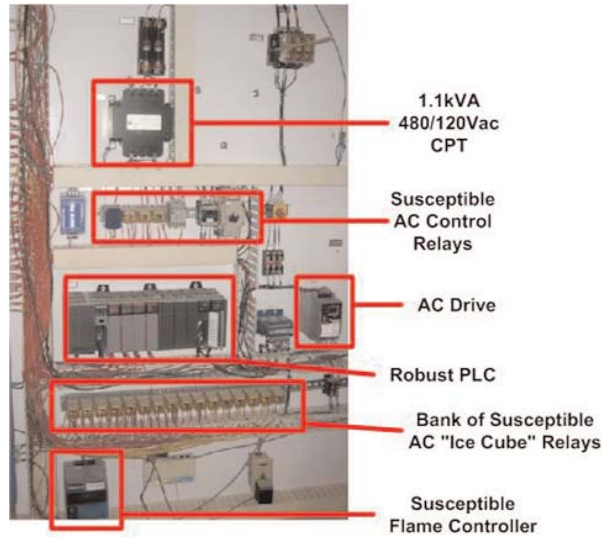
A typical process system will have at least one weak link that is sensitive to voltage sags.

include them in the final design of the machine. Another important driver is the function of the components used. In other words, the relay, contactor, power supply, programmable logic controller (PLC), and variable-frequency drive must be economical for the OEM to purchase and must meet the design criteria for the function required in the given process application. Because the functional criteria trump the ride-through criteria in many cases, it is possible for the manufacturer to have a mixture of components, some of which are robust to voltage sags while others are vulnerable to these events. Figure 2 shows such a case. The PLC in the system can ride through a voltage sag down to 50% of nominal for up to 20 cycles and the AC drive can ride through a single-phase interruption for 1 second. However, the choice of AC "ice cube" interposing relays and the flame-safety controller negates the potential robustness.

Figure 3 shows the ride-through curves for all of the components in the example system.

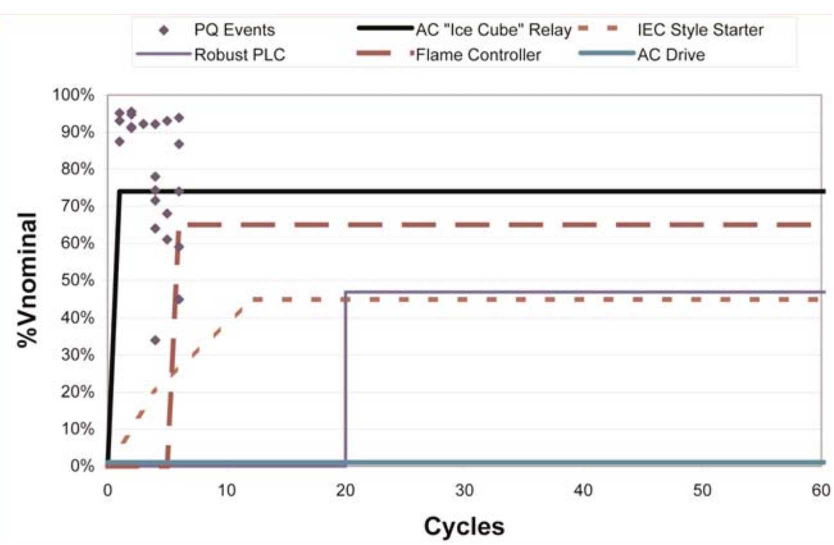
An unspoken rule in industrial environments is that a "typical" machine or process system will have at least one weak link that will make it sensitive to voltage sags. Again, such weak links are the result of noncompliance to voltage-sag standards and an absence of forethought with regard to power quality. As a result of the numerous power quality audits that EPRI conducts every year, a pattern related to such noncompliance emerges: Power conditioning is applied to certain parts of the control cabinet but not to all critical elements that need this conditioning. It is often the case that a constant-voltage transformer or even a battery-based UPS is applied on the local operator PC and the main PLC rack. However, this advantage of conditioned power is rarely extended to the AC I/O and various other AC components in the control cabinets such as the critical emergency-off circuit components and other various weak links such as the AC "ice cubes." This hodgepodge approach does little to increase the robustness of the overall machine or process system.

Figure 2. A Mixture of Control Components



Equipment that is not certified to a power quality standard is likely to wind up with a random mix of components that are highly robust to voltage sags and others that are susceptible.

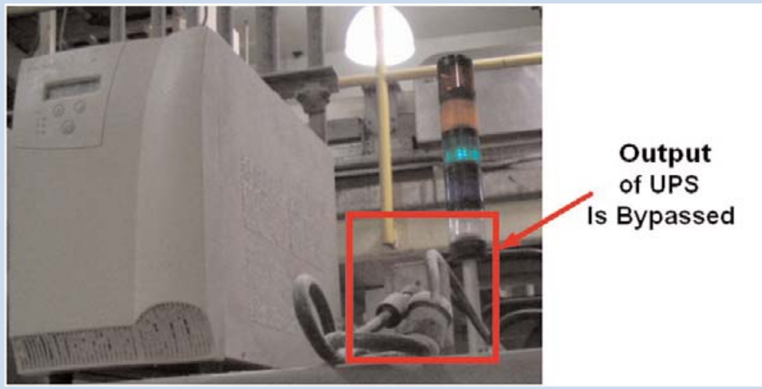
Figure 3. The Ride-Through Curves for the Components of an OEM Machine Noncompliant with Voltage-Sag Standards Vary Widely from Component to Component



Considerations for Using Small Battery-Based UPS systems

Battery-based UPS systems must be used with caution when applied in process systems running in a plant environment. These power conditioners are often either misapplied with respect to the power quality requirements of the load or the batteries are found to expire just at the time the next voltage sag occurs. When this occurs, the UPS may be "bypassed" and left abandoned in place (see Figure 4). For this reason, properly applied batteryless power-conditioning devices are often a better choice to support control loads in an industrial plant. If the end user chooses to use small UPS systems throughout the plant, they must be properly maintained and/or replaced on a scheduled maintenance program. If several seconds to minutes of power backup is truly needed, a better approach would be to bring conditioned "house power" from a centralized UPS system to the plant floor loads. Options include flywheel-based systems as well as the traditional battery-based UPS.

Figure 4. Compromised Protection Equipment



Even when sag-mitigating measures are installed, they must be maintained to be effective. In the case shown above, a control-cabinet UPS was bypassed because its battery had failed.

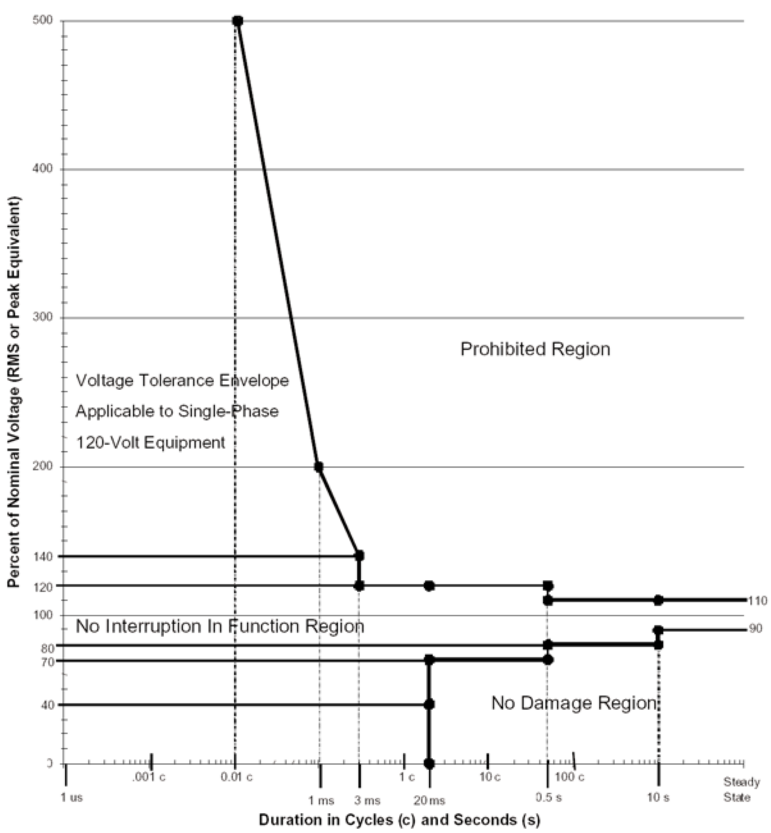
Systems that rely on motor drives also suffer when OEM drives are delivered on-site without certification to voltage-sag standards. Consider the power-loss ride-through functions for the example AC drive shown in Table 1. With the factory setting of "0," the drive's ability to ride through a voltage sag is disabled. Without setting up this parameter, the drive is likely to trip during a voltage sag even though it has features that allow ride-through to occur.

Table 1. Example AC Drive Power-Loss Ride-Through Function

Parameter	Parameter Name and (Display)	Description	Setting Range	Factory Setting	Recom-mended
L2-01	Momentary Power-Loss Detection Selection (**PwrL Selection**)	Enables and disables the momentary power-loss function. 0: Disabled — Drive trips on (UV1) fault when power is lost. 1: Power Loss Ride Thru Time - Drive will restart if power returns within the time set in L2-02. 2: CPU Power Active — Drive will restart if power returns prior to shut down of the control power supply.	0 to 2	0	Either 1 or 2
L2-02	Momentary Power-Loss Ride-Through Time (**PwrL Ridethru t**)	Sets the power loss ride-through time. This value depends on the capacity of the drive. Only effective when L2-01 = 1.	0 to 25.5 sec	Varies by kVA	At least 1 second

To obtain equipment that can ride through voltage sags, the manufacturer who procures the equipment must request that the equipment be evaluated against voltage-sag standards. Although it may seem too simple a solution to an otherwise intractable problem, a single strategically placed power conditioner, replacement of a simple component such as a relay, or properly setting up a motor drive can make an *entire* system robust to voltage sags. However, unless equipment is tested against voltage-sag standards and enhanced based upon the test results, system hardening will not occur. Because there are several voltage-sag standards that could be applied, it is important to have a better understanding of these standards, their use, and implications for the industrial manufacturer.

Figure 5. The Lower Part of the ITIC Curve Relates to Voltage Sags



VOLTAGE-SAG STANDARDS

There are several important standards that can be used to evaluate the robustness of an industrial process to voltage sags. These include the ITIC Curve, the SEMI F47-0706 lower part test points, and the IEC 61000-4-11 and IEC 61000-4-34 standards.

The ITIC Curve

The first industry-recognized standard that set boundaries for equipment performance related to voltage sags was the original CBEMA (Computer and Business Equipment Manufacturers Association) Curve. This standard set both an upper and lower voltage-tolerance recommendation for single-phase computer-based equipment fed from voltages that range from 120 V_{AC} to 240 V_{AC}.[2] In 1996, the curve was updated and renamed the ITIC Curve after the organization that sponsors the curve, the Information Technology Industry Council. The ITIC updated the curve again in 2000. With respect to voltage sags, the lower part of the 2000 voltage-tolerance envelope shown in Figure 5 is relevant.

The SEMI F47-0706 Standard[3]

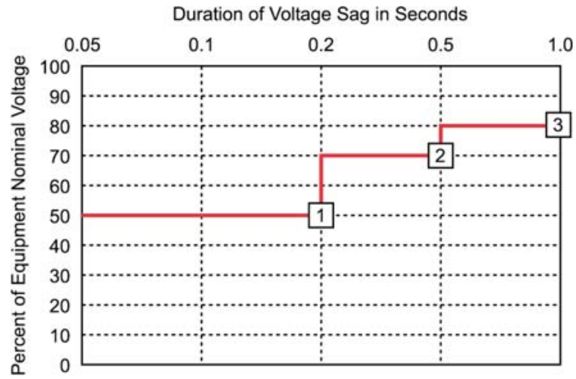
Although the ITIC Curve is a useful benchmark, it is limited in scope, applicable to only information technology (IT) equipment. Furthermore, for typical voltage sags, the ITIC Curve requires equipment to operate down to only 70% of nominal. Given the great losses in the semiconductor-manufacturing industry caused by voltage sags not addressed by the ITI Curve, a more stringent standard was need. The resulting standard is known as the SEMI F47 standard.

SEMI stands for Semiconductor Equipment and Materials International. "F47" came from the fact that this standard was the 47th facilities standard written by the organization to govern the operation of equipment in semiconductor factories. This standard was first published in 1999 and revised in 2000 and 2006. The standard defines the voltage-sag immunity requirements for equipment that is used in semiconductor factories. Unlike the ITIC Curve, which was written for single-phase IT equipment, the SEMI F47 standard is relevant for single-, two-, and three-phase manufacturing equipment. Such equipment includes common electrical devices, such as motor drives, PLCs, relays, power supplies, and instrumentation. In addition, there are unique devices that are included in this industry, such as specialized vacuum pumps, turbo pumps, RF generators, and plasma-generator power supplies.

The test points of the standard are shown in Table 2 and shown graphically in Figure 6. For each test point, the equipment must not be interrupted and must continue operation without manual intervention.

"Sag depth" in Table 2 is expressed in percentage of remaining voltage based on the nominal voltage rating. For example, during a 70% sag on a 480-volt system, the voltage is reduced during the sag to 336 volts (not 144 volts).

Figure 6. The SEMI F47 Standard Has Three Test Points That Define the Required Voltage-Sag Immunity



If the equipment has a neutral conductor, then single-phase testing is required in addition to phase-to-phase testing. An example of the vector diagrams for single-phase testing is shown in Figure 7 for a 70% of nominal phase-to-phase voltage sag.

Figure 7. Phase-to-Neutral Testing Must Be Conducted on Three-Phase Systems One Phase at a Time (Type A)

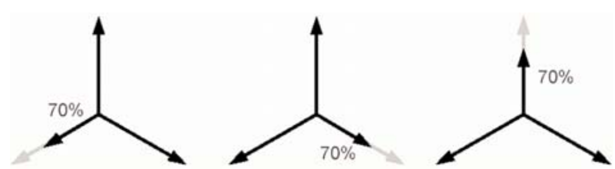


Table 2. Required SEMI F47-0706 Test Points (Single- and Two-Phase Voltage Sags Only)

Minimum Test Point No.	Sag Depth	Duration	Duration at 50 Hz	Duration at 60 Hz
1	50%	0.2 seconds	10 cycles	12 cycles
2	70%	0.5 seconds	25 cycles	30 cycles
3	80%	1.0 second	50 cycles	60 cycles

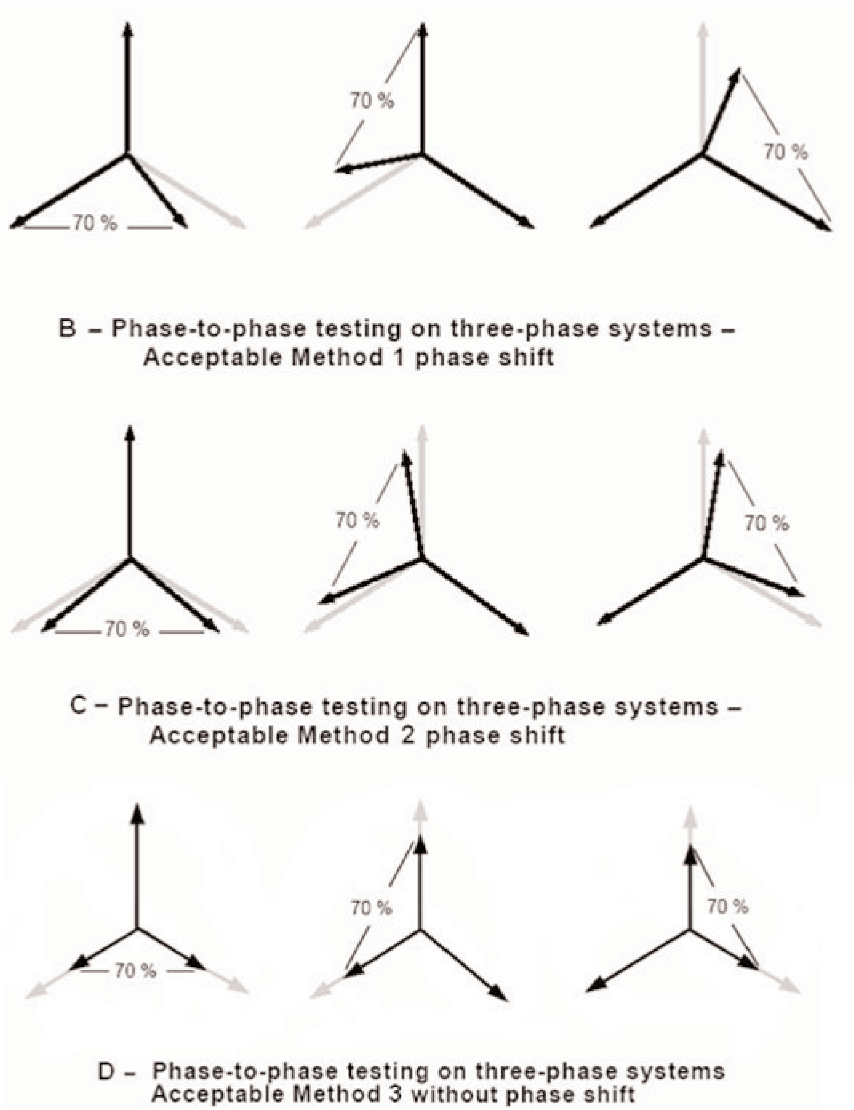
For single-phase testing, voltage sags are created on one phase at a time for the magnitudes and durations shown in the standard. Therefore, to determine whether the equipment passes the standard for single-phase events, three voltage-sag tests per phase are required as a minimum, for a total of nine voltage sags, as shown in Table 3. Although some component manufacturers conduct compliance tests at multiple frequencies, OEM machine tests are typically conducted at the voltage frequency available at the site.

To be SEMI F47 compliant, the equipment must also pass voltage-sag testing on phase-to-phase combinations. Because there are several possible methods for conducting phase-to-phase testing, SEMI F47-0706 allows the user to determine the method. The three types of methods for phase-to-phase testing are shown in Figure 8 for an example 70% of nominal phase-to-phase voltage sag.

Table 3. Typical Test Result Matrix for SEMI F47 Single-Phase Tests

Test No.	Sag Duration			V_{A-N}	V_{B-N}	V_{C-N}	Equipment Operation Interrupted?
	Seconds	60-Hz Cycles	50-Hz Cycles				
1	1.0	60	50	**80%**	100%	100%	Yes/No
2	0.5	30	25	**70%**	100%	100%	Yes/No
3	0.2	12	10	**50%**	100%	100%	Yes/No
4	1.0	60	50	100%	**80%**	100%	Yes/No
5	0.5	30	25	100%	**70%**	100%	Yes/No
6	0.2	12	10	100%	**50%**	100%	Yes/No
7	1.0	60	50	100%	100%	**80%**	Yes/No
8	0.5	30	25	100%	100%	**70%**	Yes/No
9	0.2	12	10	100%	100%	**50%**	Yes/No

Figure 8. SEMI F47-0706 Allows Equipment to Be Tested by One of Three Phase-to-Phase Sag-Testing Methods



For phase-to-phase testing, voltage sags are created in phase-to-phase pairs, one at a time, for the magnitudes and durations shown in Table 4. Again, there are nine test points required as a minimum to determine phase-to-phase compliance.

Table 5 shows the number of tests that are required for single- and three-phase equipment. The least number of test points is required for a single-phase load, while the most number of tests is required for a three-phase machine or process that has a neutral conductor.

The IEC 61000-4-11 and 61000-4-34 Standards

IEC 61000-4-11 and IEC 61000-4-34 are testing standards for voltage sags and short interruptions. IEC 61000-4-11 applies to equipment rated at less than 16 amps, while IEC 61000-4-34 applies to equipment rated at greater than 16 amps.[4,5] These standards primarily apply to electrical equipment that is to be sold in Europe. The requirements of the standard are multifaceted, depending on what type of equipment is to be evaluated. Table 6 shows the basic requirements of the standards. In contrast to SEMI F47, the worst-case voltage sag at the 10-cycle (at 50 Hz) test point is 40% of nominal versus 50% of nominal for SEMI F47 for equipment that is expected to operate in harsher electrical climates (Class 3). Furthermore, there are required tests for short interruptions at durations of 1/2 and 1 cycle, as well as a long-duration voltage sag to 80% of nominal for 250 cycles (at 50 Hz). SEMI F47-0706 has similar short-duration and long-duration test points, but they are “recommended” versus required for the IEC standards.

The key differences between the twin IEC standards and the SEMI F47-0706 standard are the lowest-magnitude test points and the allowable test methods. For single-phase sags, the allowable test vectors for the IEC and SEMI standards are the same (type A as shown in Figure 7). However, for phase-to-phase sags, these two IEC standards allow only test configurations Type B and C, as shown in Figure 8, while not allowing Type D. The phase-to-phase classifications correlate to the vectors shown in Figures 3A, 3B, 3C, and 3D in the IEC 61000-4-34 standard.

Table 4. Typical Test Result Matrix for SEMI F47 Phase-to-Phase Tests

Test No.	Sag Duration			V_{A-B}	V_{B-C}	V_{C-B}	Equipment Operation Interrupted?
	Seconds	60-Hz Cycles	50-Hz Cycles				
1	1.0	60	50	**80%**	X[a]	X[a]	Yes/No
2	0.5	30	25	**70%**	X[a]	X[a]	Yes/No
3	0.2	12	10	**50%**	X[a]	X[a]	Yes/No
4	1.0	60	50	X[a]	**80%**	X[a]	Yes/No
5	0.5	30	25	X[a]	**70%**	X[a]	Yes/No
6	0.2	12	10	X[a]	**50%**	X[a]	Yes/No
7	1.0	60	50	X[a]	X[a]	**80%**	Yes/No
8	0.5	30	25	X[a]	X[a]	**70%**	Yes/No
9	0.2	12	10	X[a]	X[a]	**50%**	Yes/No

[a] Phase vector magnitudes for the nontargeted phases naturally emerge depending on the test method that is chosen (i.e., Method B, C, or D in Figure 8).

Table 5. Equipment Type Versus Test Requirements

Equipment Voltage Requirement	Single-Phase Testing?	Phase-to-Phase Testing?	Three-Phase Testing?	Total Test Points Required to Pass for Compliance
Single-Phase	Yes	No	No	3
Three-Phase, No Neutral	No	Yes	No	9
Three-Phase with Neutral	Yes	Yes	No	18

Table 6. Preferred Test Levels and Durations for Voltage Sags (IEC 61000-4-11 and IEC 61000-4-34)

Class[a]	Test Levels and Durations for Voltage Sags (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 25/30c Cycles		
Class 3	0% during ½ Cycle	0% during 1 Cycle	40% during 10/12[c] Cycles	70% during 25/30[c] Cycles	80%during 250/300[c] Cycles
Class X[b]	X	X	X	X	X

[a]Classes per IEC 61000-2-4, Annex B.
[b]To be defined by product committee. For equipment connected directly or indirectly to the public network, the levels must not be less severe than Class 2.
[c]Cycles at 50 Hz/cycles at 60 Hz.

Specifying *any* voltage-sag standard in a purchase specification is better than not including one at all.

WHAT DIFFERENCE DOES A METHOD MAKE?

Specifying *any* voltage-sag standard in a purchase specification is better than not including one at all. So why should an end-use manufacturer be concerned with the way that the equipment is "certified"?

Consider again the three phase-to-phase test vectors shown in Figure 8 (Types B, C, and D). Test Method B does not naturally occur during typical voltage sags. This method approximates a voltage sag by reducing the phase-to-phase vector by drawing one phase toward the other "stationary" phase. Method B induces a large phase shift for the phase that is manipulated. Furthermore, one of the three phase-to-phase voltages will always remain at 1.0 per unit with Method B regardless of the value of the test voltage. In other words, only two of the three phase-to-phase vectors are shortened during the test.

Test Method C is the most commonly occurring scenario of the three. It represents the typical scenario that occurs on the secondary side of a delta-wye transformer when a fault from a single phase to ground occurs on the primary side. This method creates phase shifting as well as vector shortening on all three phases.

Test Method D can occur when there is a fault from phase-to-phase to ground on the electrical system. This method induces minimal phase shifts on the phase-to-phase vectors and no phase shift on the phase-to-neutral vectors (if applicable). Method D creates the shortest phase-to-phase vectors.

To understand why the different phase-to-phase test methods have different effects on typical three-phase loads, consider the passive front-end variable-frequency drive shown in Figure 9.

Figure 9. AC Drive with Diode Bridge Rectified Front-End

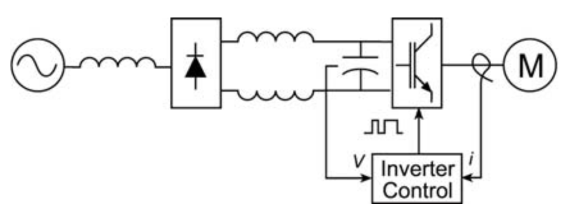


Figure 10. The Simulation Output Is the Result of a Phase-to-Phase Voltage Sag Conforming to Method B (Figure 3B in IEC 61000-4-34)

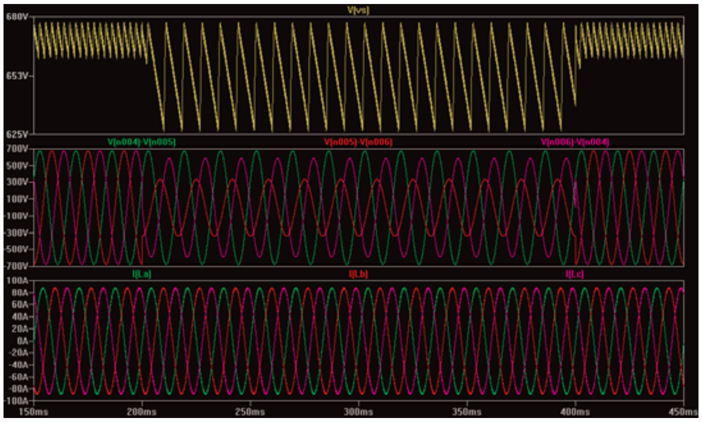


Figure 11. The Simulation Output Is the Result of a Phase-to-Phase Voltage Sag Conforming to Method C (Figure 3C in IEC 61000-4-34)

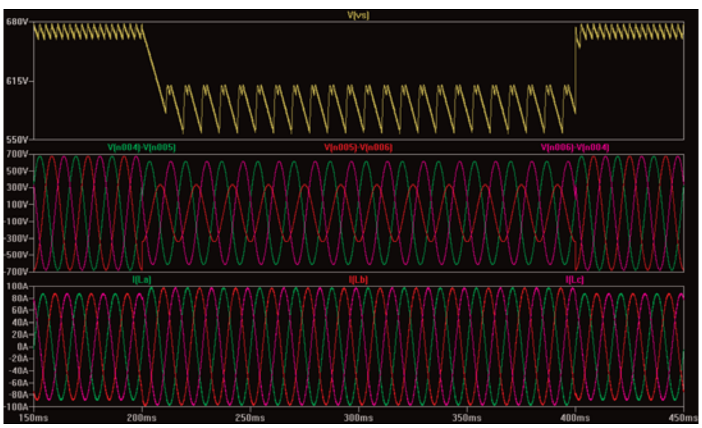
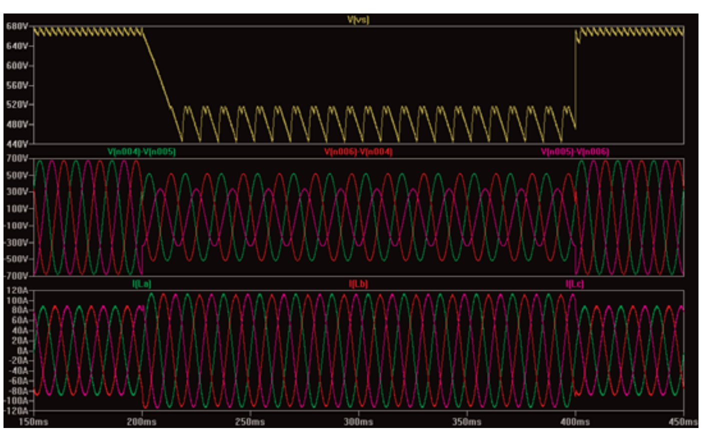


Figure 12. The Simulation Output Is the Result of a Phase-to-Phase Voltage Sag Conforming to Method D (Figure 3D in IEC 61000-4-34)



Three simulations were conducted for this drive: phase-to-phase test methods B, C, and D. Drives typically trip based on low voltage on the DC bus or on overcurrent. Figures 10, 11, and 12 show the simulated effect on the DC bus for a voltage sag down to the SEMI F47-0706 test point of 50% of nominal, 200 milliseconds. The three scenarios are modeled for an AC drive with a constant power output model. In each of the three figures, the DC bus, three-phase voltage, and currents are shown.

Key results of the simulations are shown in Table 7. Note that Method B does not typically cause a diode front-end drive to trip. Lab tests reveal that even when the voltage sag is reduced to as far as 0% of nominal during a 200 millisecond event, Method B has been shown not to upset a drive.[6]

Table 7. Summary of Simulation Result (50% Phase-to-Phase, 200 ms)

Sag Type	Nominal Max DC Bus Voltage	Minimum DC Bus	Approximate Percent "Sag" on DC Bus	Expected Result
Method B (IEC Type 3B)	680 V_{DC}	625 V_{DC}	92%	Drive will not trip.
Method C (IEC Type 3C)	680 V_{DC}	550 V_{DC}	81%	Drive may trip if voltage-sag ride-through parameter s are not enabled.
Method D (IEC Type 3D)	680 V_{DC}	440 V_{DC}	64%	Drive is likely to trip if voltage-sag ride-through parameters are not enabled.

Results from numerous lab tests on passive-input three-phase loads are similar to results shown the for the AC drive shown in Figure 9. Given the allowable test methods and the potential difference in test results, what method should the manufacturer recommend that the OEM use during certification testing?

For single-phase equipment, this question is irrelevant because testing is straightforward and there are no different types of test configurations. Single-phase tests must be conducted on single-phase equipment and on three-phase equipment with a neutral conductor. With regard to phase-to-phase testing on three-phase equipment, the most technically correct way to conduct the test is using Method C, as shown in Figure 8 and described in IEC 61000-4-34 (Figure 3C). If the OEM cannot obtain test equipment to conduct testing according to Method C, then either Method B or Method D can be used with caution, taking into account the strengths and weaknesses of each test method as summarized in Table 8.

Table 8. Test Method Considerations

Test Method (See Figure 8)	Voltage-Sag Characteristics at Defined Test Points	Strengths	Weaknesses	Notes
Method A (IEC Type 3A)	Single-Phase Voltage Sags	Will help determine weakness of equipment to single-phase events.	None	This testing is most relevant to single-phase equipment or three-phase equipment with a neutral.
Method B (IEC Type 3B)	Maximum Phase Shift*, Maximum Vector Magnitudes	Will reveal load susceptibilities to high phase shifts.	May not trip loads with diode front ends, such as power supplies or adjustable-speed drives, because one phase-to-phase vector stays at 1.0 per unit regardless of the voltage sag depth.	EPRI research revealed that voltage sags with phase shifts of this extreme occur infrequently on the electric power system.
Method C (IEC Type 3C)	Medium Phase Shift, Medium Vector Magnitudes	One of the most common types of actual voltage sags.	Commercial sag generators used to create this type of sag are available from fewer vendors.	This type of voltage sag represents what is typically seen on the secondary of a delta-wye transformer when a single-phase line-to-ground (SPLG) fault occurs on the primary. The SPLG fault is the most common type of fault.
Method D (IEC Type 3D)	Lowest Phase Shift, Minimum Vector Magnitudes	Most stringent test method with respect to voltage-sag magnitudes.	Least stringent test with respect to phase shift. May not trip a load that is susceptible to extreme phase shifts.	This type of voltage sag can occur when two phases are shorted to ground at the same time.

*The amount of phase shift created in the voltage sag is referenced with respect to the phase-to-phase vectors.

In the original System Compatibility Research Project, EPRI used Method D because the first generation of voltage-sag generators were based on referencing the voltage sag to a neutral conductor. This method has provided the most severe scenario for phase vector magnitudes during tests and has been proven to lead to improvements in voltage-sag immunity of end use equipment. However, Method D induces little phase-shift for the phase-to-phase vectors and no phase-shift for the phase to neutral vectors. For equipment with active front ends and phase-locked-loop controls, such as those shown in Figures 13 and 14, testing by Method D could possibly lead to a false sense of robustness for these types of loads because no phase shifting occurs.

Likewise, testing with Method B can lead to a false sense of robustness for certain three-phase loads in that they may not trip during the test but could trip during actual voltage sags. Again, this is most critical for loads such as the diode bridge AC drive shown in Figure 9.

As EPRI has continued research into this area, it has become apparent that test equipment should be built that allows for the most versatile testing scenarios. For this reason, EPRI now evaluates equipment against power quality standards such as IEC 61000-4-34 and SEMI F47-0706 using all allowable test methods. Although equipment is not required to pass all phase-to-phase test methods, testing in this manner reveals susceptibilities that might not have been caught otherwise. These methods are summarized in Figure 15.

Again, if the OEM does not have access to equipment that can conduct Method C testing or multiple-method testing, then the test equipment and sag types used should be documented as a part of the compliance documentation.

Figure 13. AC Drive with Active SCR Bridge Rectified Front-End

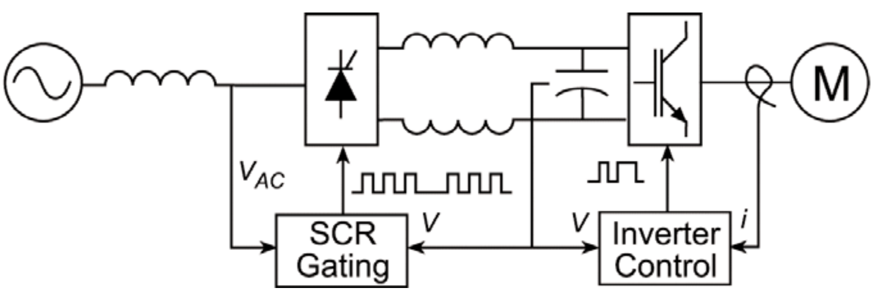


Figure 14. AC Drive with Active IGBT Bridge Rectified Front-End

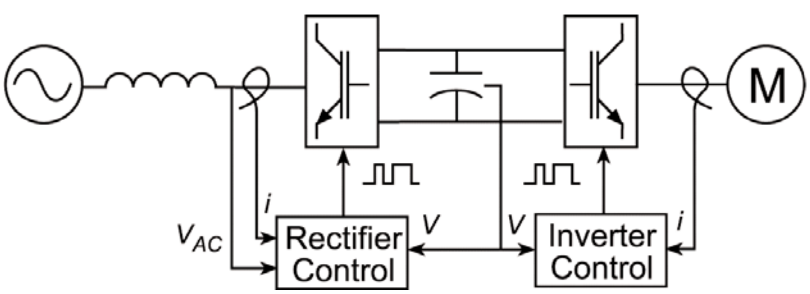
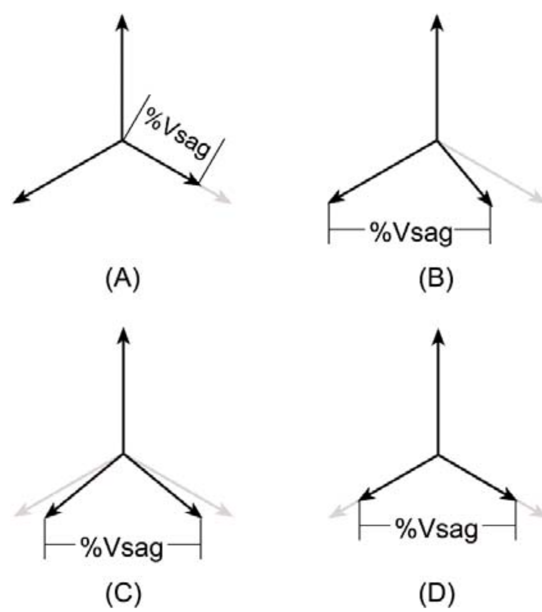


Figure 15. Multiple Test Methods Can Be Used to Best Ensure System Compatibility



INCLUDING VOLTAGE SAG STANDARD COMPLIANCE LANGUAGE IN THE PURCHASE SPECIFICATIONS

One reason that manufacturers do not receive equipment hardened to voltage sags is simply that this requirement is not spelled out in the purchase specifications. An example clause for inclusion in a purchase specification is shown in Figure 16 for equipment that is to be tested to the SEMI F47-0706 standard. This language is offered only as an example; each manufacture must construct its own purchase specifications as required by its specific needs and implement specific language it feels will best serve its particular needs.

Some manufacturers that buy OEM equipment also include a "retainer" clause in their purchase specifications, requiring that voltage-sag-compliance testing be conducted before the entire payment will be made for the equipment. Holding out 10% of the purchase price of the equipment is an incentive to have the testing done. Ideally, the equipment will be shown to be compliant or made to comply as a part of the testing effort. However, the value of the testing is paramount in that even if the equipment is shown not to be compliant with the standard, the resulting information can lead to informed decisions regarding design changes to incorporate robust components, the addition of power conditioning on selected circuits, or to help to facilitate the decision as to whether or not to place some portion or all of the equipment on facility UPS systems.

Figure 16. The Inclusion of a Requirement for Compliance with a Voltage-Sag Standard Enhances the Potential for System Compatibility (Example Only)

SEMI F47-0706 Compliance [or other voltage-sag standard]. The OEM shall provide documentation that proves that the provided equipment is in compliance with the **SEMI F47-0706** voltage-sag standard. The qualification testing shall be conducted and completed prior to the first scheduled shipment of new products to Buyer. Such testing shall occur, at the option of Buyer, either at Seller's facility or on the premises of Buyer and shall be at the expense of the Seller. Qualification testing shall determine the acceptability of the equipment in accordance with the **SEMI F47-0706** specifications and shall be conducted in accordance with the procedures outlined in the standard. In addition to the test results, the OEM must clearly document the test method and test equipment used for creating voltage sags. Upon written agreement of Seller and Buyer that the qualification tests have been successfully completed, the initial deliveries of production units of the equipment shall commence in accordance with the scheduled shipment established by issued Purchase Orders.

CONCLUSION

Industrial manufacturers often look at many factors when comparing OEM equipment from one OEM to that of another when deciding to purchase specific equipment. Some of the major factors include price, functionality, and maintainability. With fewer process upsets due to voltage sags, the cost of ownership (COO) of equipment that is compliant to a voltage-sag standard will be lower.

End-use manufacturers must realize that when purchasing equipment from OEM manufacturers, they have an opportunity to lower the COO by requiring that voltage-sag-compliance testing be conducted on the equipment. Without including this requirement in the language of the purchase specification, there is no assurance that the equipment will be robust to typical voltage sags. Experience indicates that some OEMs will comply with the request for compliance testing, while others will choose not to comply and hope to negotiate this requirement out of the final contract language. Because they will be required to live with the purchased equipment for possibly many years, equipment and facility engineers must insist upon compliance with a voltage-sag standard as part of the acceptance-testing regime before the equipment is "turned over" for use in production.

RELATED DOCUMENTS

PQ Tech Watch No. 2: *Minimizing PQ Costs by Taking Ownership*, EPRI, Palo Alto, CA: 2005.

PQ Tech Watch: *Hardening Manufacturing Processes against Voltage Sags*, EPRI, Palo Alto, CA: 2004.

NOTES

1. *Distribution System Power Quality Assessment: Phase II: Voltage Sag and Interruption Analysis*, EPRI, Palo Alto, CA: March 2003. 1001678.
2. ITIC (CBEMA) Curve Application Note, Information Technology Industry Council (ITIC) 1250 Eye Street NW, Suite 200, Washington, DC 20005, www.itic.org.
3. SEMI F-47-0706, *Specification for Semiconductor Processing Equipment Voltage Sag Immunity*, Semiconductor Equipment and Materials International, July 2006.
4. IEC 61000-4-11, Ed. 2, *Voltage Dips, Short Interruptions and Voltage Variations Immunity Tests*, March 2004.
5. IEC 61000-4-34, First Edition, *Voltage Dips, Short Interruptions and Voltage Variations Immunity Tests for Equipment with Input Current More Than 16A per Phase*, October 2005.
6. M. Stephens, M. McGranaghan, and M. Bollen, "Evaluating Voltage Dip Immunity of Industrial Equipment," 18th International Conference on Electricity Distribution, Turin, 6–9 June 2005.