Overview of:
IEEE P1668^{TM}/D1Q Draft Trial Use Recommended Practice for Voltage Sag Ride-through Testing for End Use Electrical Equipment Rated Less than 1,000 Volts

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IEEE P1668
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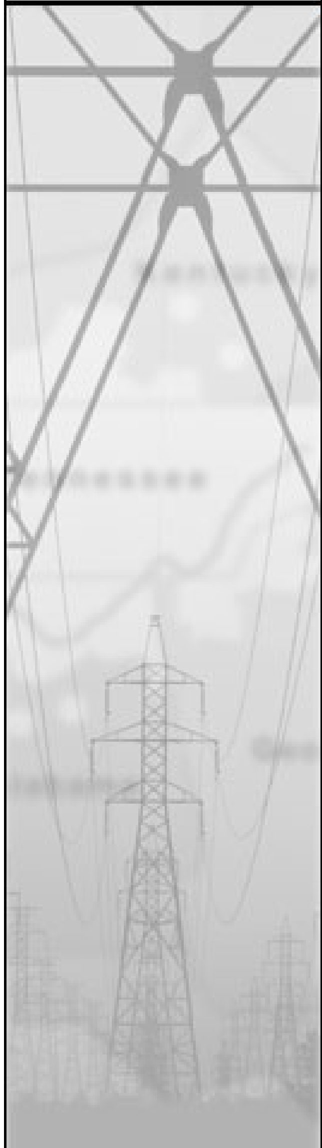

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IEEE PROJECT

P1668 - Recommended Practice for Voltage Sag and Interruption Ride-Through Testing for End Use Electrical Equipment Less than 1,000 Volts

This document is a non-industry specific recommended practice for voltage sag ride-through performance and compliance testing for all electrical and electronic equipment connected to low voltage power systems that can experience malfunction or shutdown as a result of reductions in supply voltage lasting less than one minute. The recommended practice includes defining minimum voltage sag immunity requirements based on actual voltage sag data. A section dedicated to the detailed analysis of voltage sags experienced by end users provides insight into real-world voltage sags. Testing procedures and test equipment requirements are clearly defined within this document to reflect this electrical environment including single-phase, phase-to-phase, three-phase, and unbalanced voltage sags. The recommended practice also defines certification and test reporting requirements, including voltage sag ride-through equipment characterization.

STATUS: Active Project

Working Group: 1668_WG - Voltage Sag Ride-through Working Group

Sponsor: IAS/PSE - Power Systems Engineering

Society: IAS - IEEE Industry Applications Society

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Who is on P1668 Working Group?

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Representatives from Utilities:
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Other PQ Industry Leaders:
EPRI, Soft Switching Technologies, University of Edinburgh

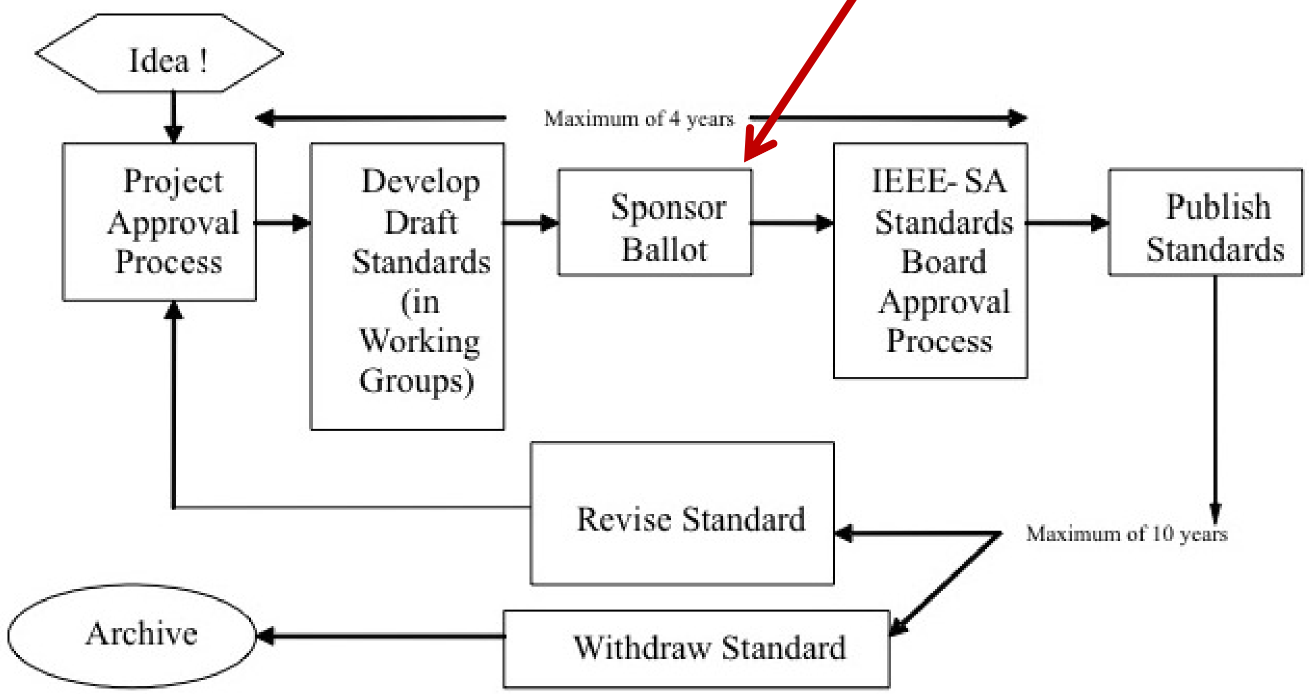
Working Group Developing P1668 For Over 5+ Years and Ready for Ballot

Group" First Web Meeting April 23, 2007 Following IEEE SA Process

SA Process

P1668 Ready for Ballot

Figure 1 - Overview



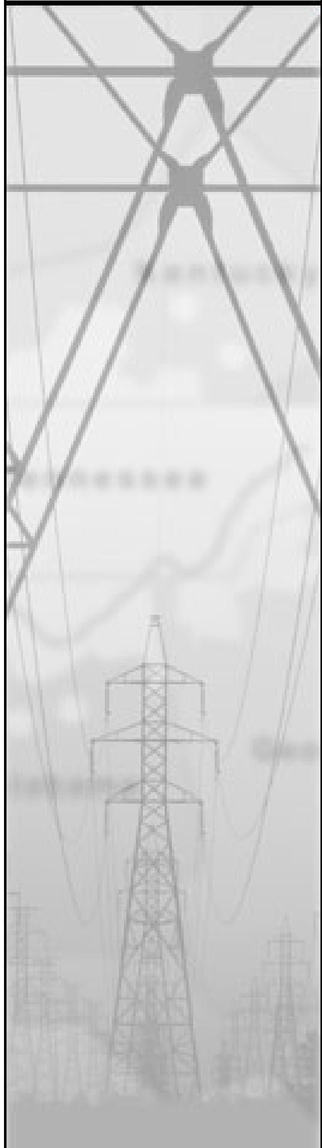
IEEE Standards Association Balloting Process

- Balloters usually fall into one of several interest categories (e.g. producers, users). No interest category can comprise over one-third of the balloting group.
- A standard will pass if at least 75 percent of all ballots from a balloting group are returned and if 75 percent of those bear a "yes" vote.
- Ballots usually last 60 to 90 days. Balloters can approve, disapprove, or abstain. The can also disapprove with comment. The ballot resolution group responds to all comments, whether submitted by those within or outside the balloting group.
- P1668 was set up with individuals each having the opportunity for a single vote.
- It is the Sponsor's responsibility to form the balloting group.

4.1 Type of Ballot: Individual

4.2 Expected Date of submission of draft to the IEEE-SA for Initial Sponsor Ballot: 08/2011

4.3 Projected Completion Date for Submittal to RevCom: 01/2012



IEEE Standards Association
Balloting Consensus

- What a balloting group is trying to achieve is the imperative principle of consensus.
- According to IEEE rules, consensus is defined as a minimum 75% return of ballots from the balloting group, and a 75% approval rate from that 75% return group.
- All negative comments will be addressed by the Working Group Chair even if consensus is reached.

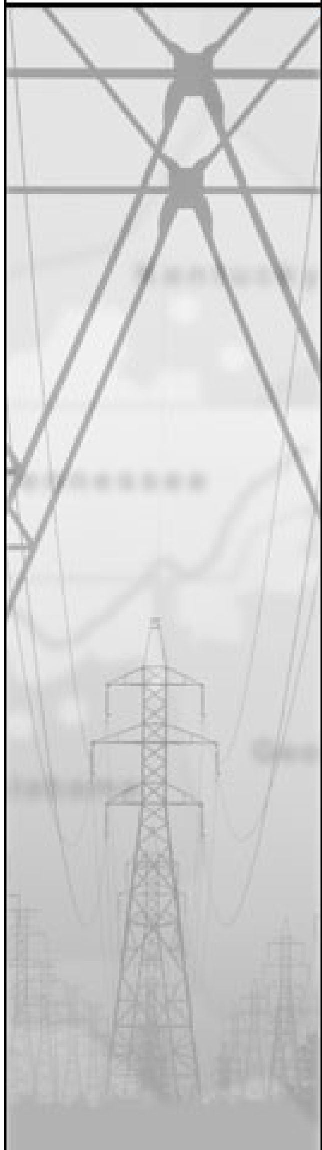
IEEE P1668 Contents

1. Overview
2. Limitations
3. Normative References
4. Definitions
5. A Primer on Voltage Sags
6. Recommended Voltage-Sag Test Requirements

Annex A Test Procedures and Guidelines
Annex B Test Equipment Requirements
Annex C Certification and Test Reports

Section 1
Overview of IEEE 1668

Section 1.1
IEEE P1668
Scope



- Recommended practice for voltage-sag performance and compliance testing for all electrical equipment ---<1000V
- Defines minimum voltage-sag immunity requirements
- Testing procedures and requirements for test equipment are clearly defined including the following voltage sag subtypes:
  - single-phase,
  - two-phase,
  - three-phase,
  - balanced
  - unbalanced voltage sags
- The recommended practice also defines requirements for certification and test reporting

Section 1.1 IEEE P1668 Purpose

- Establishes clearly defined test methods and ride-through performance for determining the sensitivity of electrical and electronic equipment to voltage sags.

- Analysis of real-world sags providing foundation for both the test methods and the performance criteria. The standard defines voltage sag characteristics in terms of the depths, magnitudes, durations, phase angles, and vectors.

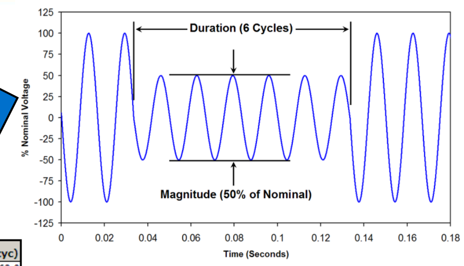
- The recommended practice shows how different voltage-sag testing methods can be used to simulate real-world sags.

- Provides end-use standard for purchase specifications to ensure the required level of equipment performance. In addition, end users can use the voltage-sag criteria as performance benchmark for existing equipment.

Section 5
A Primer on Voltage Sags

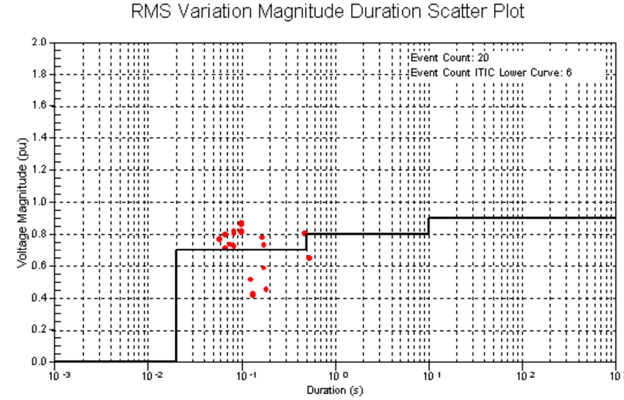
5.1 Voltage Sag Basics

Presents:
- Basic concepts
- Multiphase nature and complexity
- How we often over simplify in data presentation
- How to read a magnitude and duration scatter plot



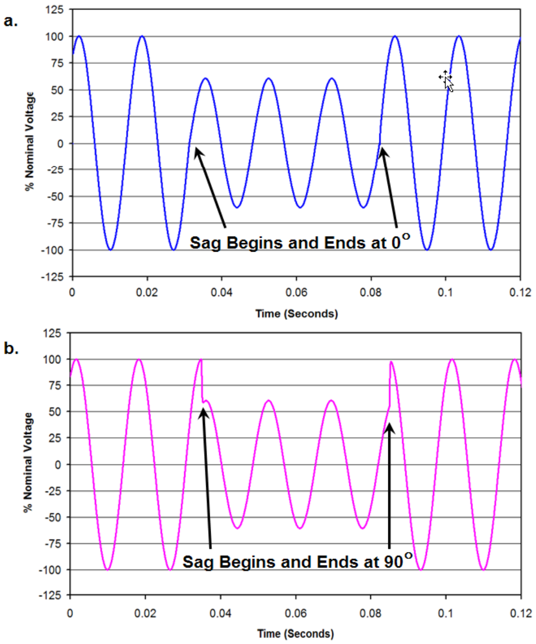
Time Stamp	Phase	Mag (kV)	Mag (pu)	Dur (s)	Dur (cyc)
9/4/2004 15:23:01.8870	C	0.004	0.000	2.799	168.0
5/12/2005 17:38:44.9620	CA	0.000	0.000	8.500	510.0
8/4/2006 11:56:05.6880	A	0.004	0.001	2.800	168.0
8/28/2006 09:47:30.0540	C	0.383	0.053	0.192	11.5
8/28/2006 09:55:35.5050	C	0.006	0.001	0.058	3.5
9/22/2006 16:29:37.1060	A	5.486	0.756	0.092	5.5
9/23/2006 10:36:26.0430	A	0.932	0.128	0.075	4.5
5/2/2007 15:47:42.8780	C	6.087	0.838	0.325	19.5
10/27/2007 06:20:58.5970	B	1.059	0.146	0.100	6.0
12/11/2007 22:43:41.2820	C	0.006	0.001	17.549	1053.0
4/4/2008 12:51:12.3990	A	0.004	0.001	118.934	7136.0
4/11/2008 07:57:19.2150	A	2.605	0.359	0.133	8.0
6/9/2008 09:32:32.2190	B	10.389	1.431	1.317	79.0
6/13/2008 18:23:43.7290	B	3.879	0.534	0.083	5.0
7/9/2008 05:01:16.0790	C	4.432	0.610	0.133	8.0
7/9/2008 05:15:54.9370	B	8.103	1.116	0.067	4.0
11/8/2008 12:21:40.2800	A	5.464	0.753	0.058	3.5
1/30/2009 03:12:25.8260	B	4.796	0.661	0.058	3.5
1/30/2009 05:00:01.0090	A	4.759	0.655	0.067	4.0
1/30/2009 23:29:24.8390	C	6.025	0.830	0.067	4.0
1/30/2009 23:31:11.1680	C	6.048	0.833	0.058	3.5
1/30/2009 23:32:32.4680	C	6.025	0.830	0.067	4.0
1/30/2009 23:45:58.9300	B	6.007	0.827	0.058	3.5
1/31/2009 04:32:14.0080	B	4.238	0.584	0.458	27.5
5/16/2009 01:38:35.9190	B	3.330	0.459	0.042	2.5
7/31/2009 08:08:40.9940	B	0.380	0.052	0.208	12.5
8/5/2009 07:54:42.4660	A	1.155	0.159	0.092	5.5

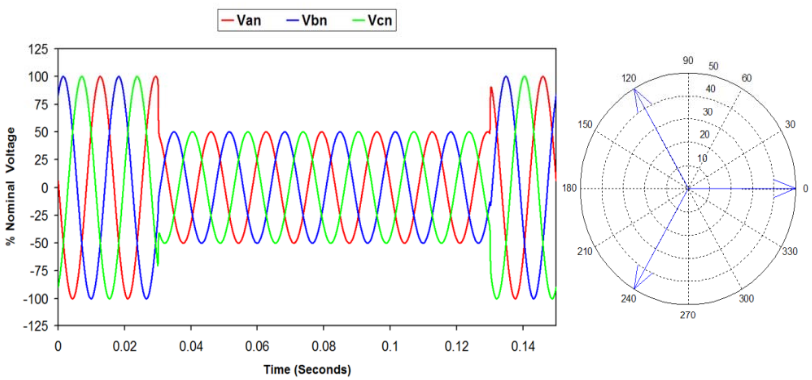
RMS Variation Magnitude Duration Scatter Plot



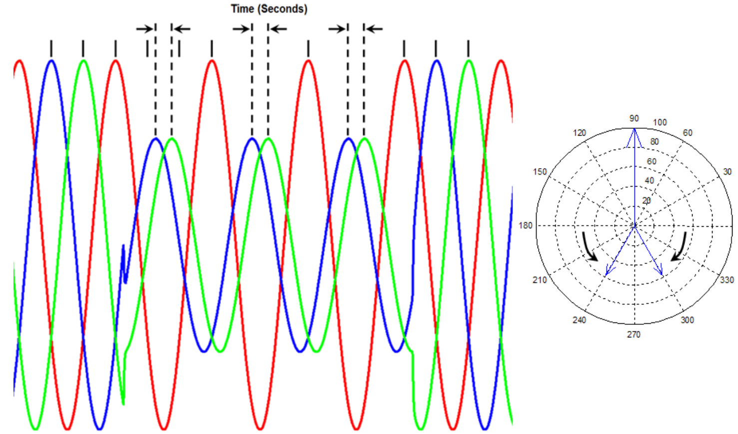
5.2 Other Key Voltage Sag Characteristics

Discusses Point on Wave For Fault Initiation





Balanced Voltage Sags

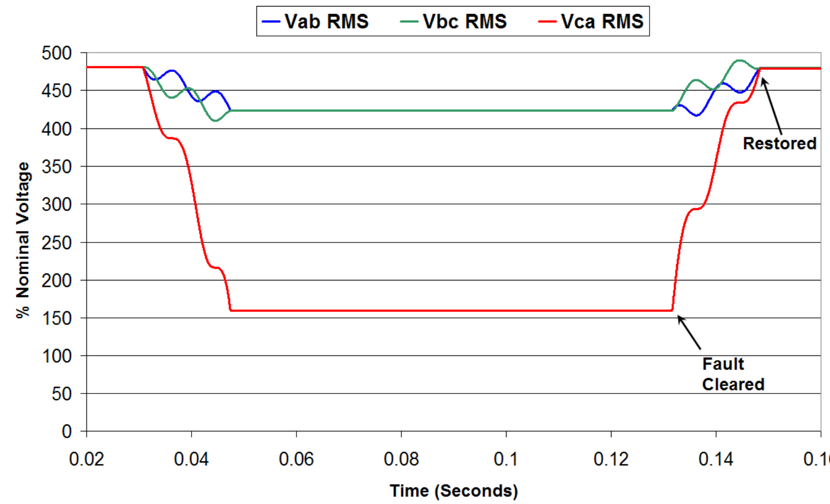


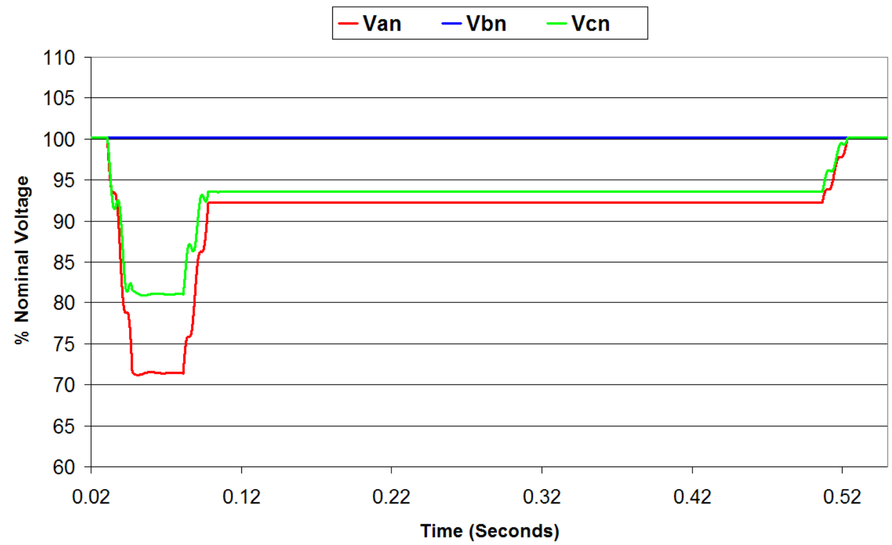
Unbalanced Voltage Sags

5.3 Fault (Characteristics) and Voltage Sags

Illustrates:

- Fault Clearing Times
- Voltage Recovery
- Slow Voltage Recovery

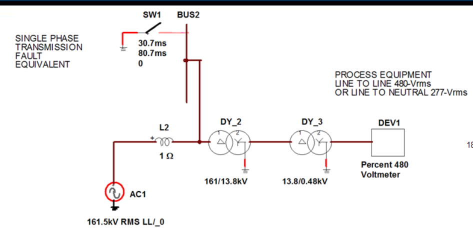


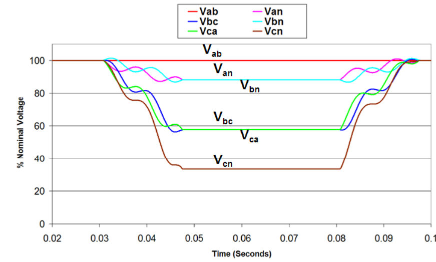


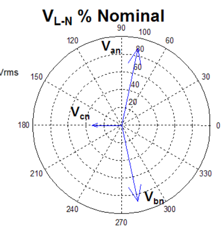
5.3 Faults and Voltage Sags (Continued)
Fault on Transmission System

Illustrates:

- Transmission fault influence on utilization voltage
- Effect of multiple transformations







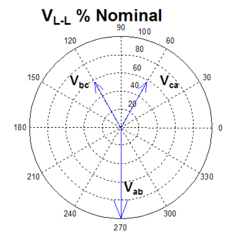


Table 2—Secondary transformer voltages (pu) and phase angles from a transmission-system fault (A-G)

Transformation #1	VLL (AB, BC, CA)	VLN (AN, BN, CN)	Transformation #2	VLL (AB, BC, CA)	VLN (AN, BN, CN)
Delta-Wye (g)	33% ∠ 180, 88% ∠ 79.1, 88% ∠ 280.9	58% ∠ 300, 58% ∠ 240, 100% ∠ 90	Delta-Wye (g)	58% ∠ 120, 58% ∠ 60, 100% ∠ 270	88% ∠ 280.9, 33% ∠ 180, 88% ∠ 79.1
Wye (g)-Wye (g)	58% ∠ 240, 100% ∠ 90, 58% ∠ 300	0%, 100% ∠ 240, 100% ∠ 120	Delta-Wye (g)	33% ∠ 180, 88% ∠ 79.1, 88% ∠ 280.9	58% ∠ 300, 58% ∠ 240, 100% ∠ 90
Wye (g)-Wye (g)	58% ∠ 240, 100% ∠ 90, 58% ∠ 300	0%, 100% ∠ 240, 100% ∠ 120	Wye (g)-Wye (g)	58% ∠ 240, 100% ∠ 90, 58% ∠ 300	0%, 100% ∠ 240, 100% ∠ 120
Wye -Wye (g)	58% ∠ 240 100% ∠ 90 58% ∠ 300	33% ∠ 0 88% ∠ 259.1 88% ∠ 100.9	Delta-Wye (g)	33% ∠ 180, 88% ∠ 79.1, 88% ∠ 280.9	58% ∠ 300, 58% ∠ 240, 100% ∠ 90
Wye (g) - Delta	33% ∠ 180 88% ∠ 79.1 88% ∠ 280.9	58% ∠ 300 58% ∠ 240 100% ∠ 90	Wye (g) - Delta	58% ∠ 120 58% ∠ 60 100% ∠ 270	88% ∠ 280.9 33% ∠ 180 88% ∠ 79.1

5.3 Faults and Voltage Sags (Continued)
Fault on Distribution System

Illustrates:

- Distribution fault influence on utilization voltage
- Effect of multiple transformations

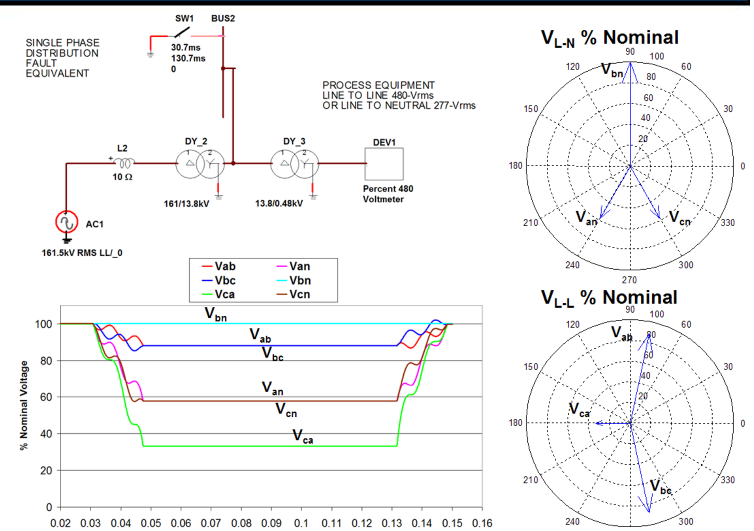


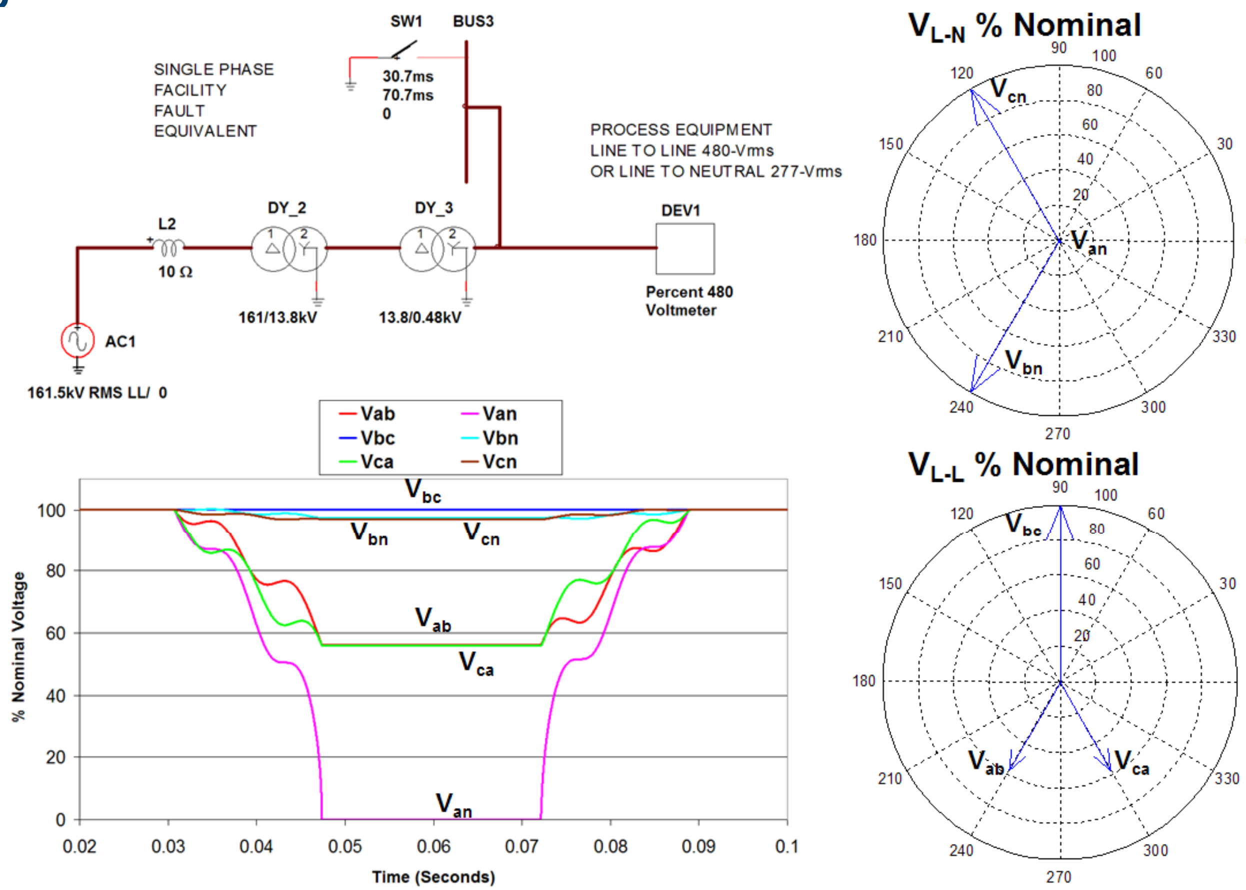
Table 4—Secondary transformer voltages (pu) and phase angle from distribution system fault (A-G)

Transformation	VLL (AB, BC, CA)	VLN (AN, BN, CN)
Delta-Wye (g)	33% $\angle$ 180, 88% $\angle$ 79.1, 88% $\angle$ 280.9	58% $\angle$ 300, 58% $\angle$ 240, 100% $\angle$ 90
Wye-Wye (g)	58% $\angle$ 240 100% $\angle$ 90 58% $\angle$ 300	33% $\angle$ 0 88% $\angle$ 259.1 88% $\angle$ 100.9
Wye (g) – Wye (g)	58% $\angle$ 240, 100% $\angle$ 90, 58% $\angle$ 300	0%, 100% $\angle$ 240, 100% $\angle$ 120
Wye - Delta	33% $\angle$ 180 88% $\angle$ 79.1 88% $\angle$ 280.9	58% $\angle$ 300 58% $\angle$ 240 100% $\angle$ 90

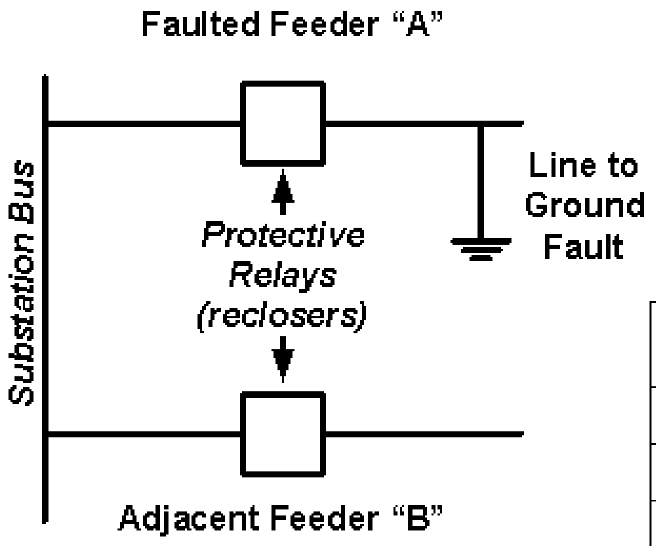
5.3 Faults and Voltage Sags (Continued)
On-Site Fault

Illustrates:

– Internal facility fault influence on utilization voltage



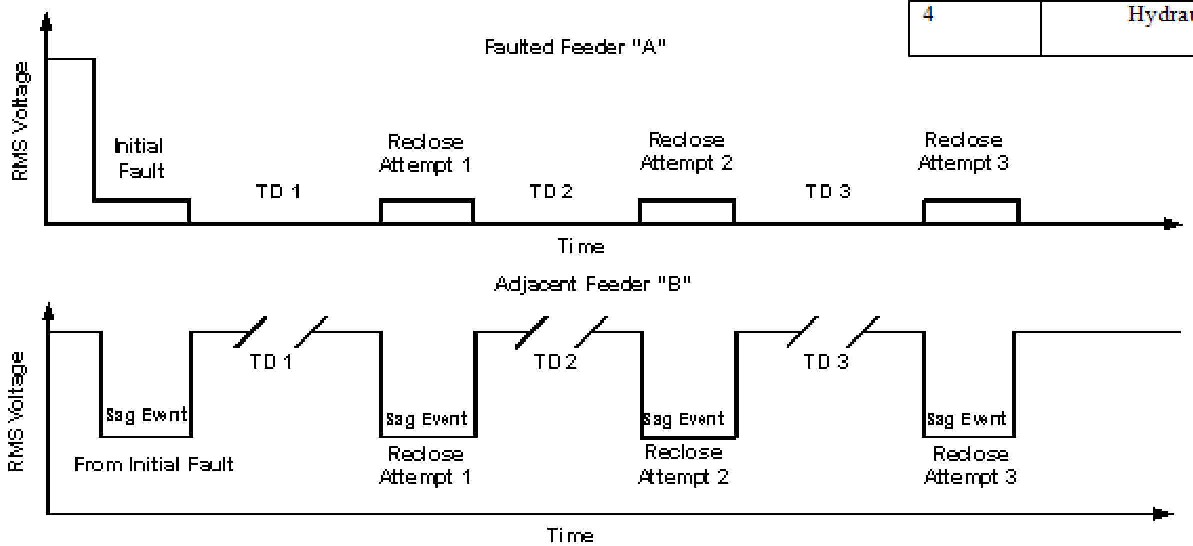
5.3 Faults and Voltage Sags (Continued)
Impact of Line Re-Closing



Illustrates: Re-closer Operations and Representative Schemes

Table 3—Four representative recloser schemes

Recloser scenario	Types of recloser schemes	Time delay 1 (TD1)	Time delay 2 (TD2)	Time delay 3 (TD3)
1	Instantaneous	30 cycles	15 seconds	30 seconds
2	Fast	2 seconds	15 seconds	30 seconds
3	Delayed	5 seconds	30 seconds	60 seconds
4	Hydraulic	2 seconds	2 seconds	2 seconds



5.4 Voltage Sags and Load Current Relationships

Discusses how current can vary during a voltage sag based on load types.

- Resistive – load current lowers proportionally
- Induction motors – load current generally increases
- Synchronous motors – inject reactive current toward fault
- Non-linear power electronic loads – may draw significant current on return of voltage

5.5 How Common Are Voltage Sags?

Discusses findings from benchmark voltage sag studies:

- EPRI DPQ Phase I
- EPRI DPQ Phase II
- CIGRE C4.110

How common are the events and how many phases are involved?

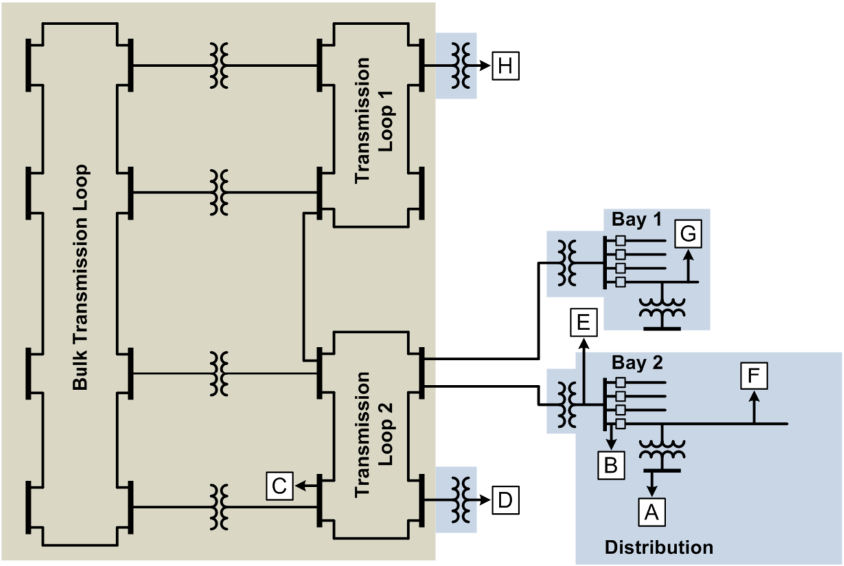
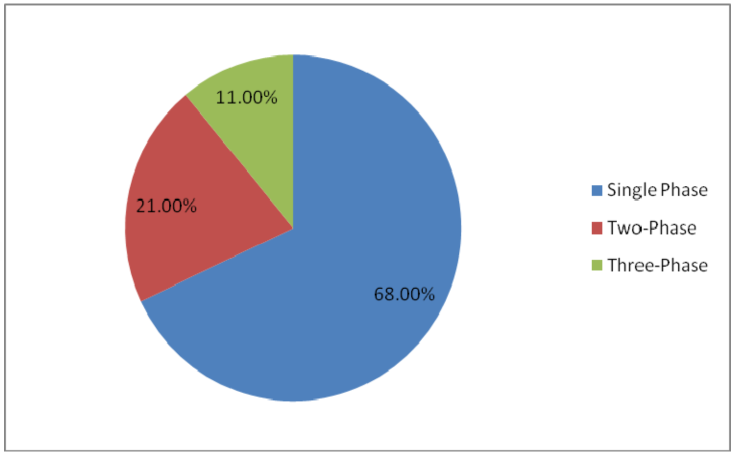


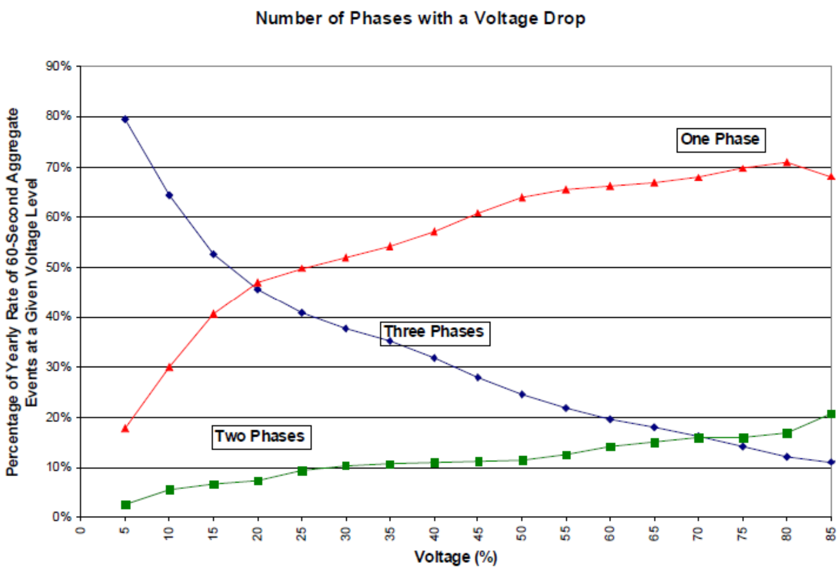
Table 6—Yearly SARFI rates
(60-Second Aggregate Period, DPQ I, DPQ II, and DPQ II Group 1 Sites)

SARFI level	DPQ Phase I	DPQ Phase II	DPQ Phase II Group 1 (A,F, and G Sites)
SARFI-70	23.4	13.7	22.4
SARFI-50	12.2	5.7	13.2
SARFI-10	5.8	0.9	3.4
SARFI-ITIC[12]	23.5	13.9	23.9
SARFI-SEMI[13]	17.0	8.3	19.9

5.5 Expected Voltage Sag Distribution
Previous EPRI Studies

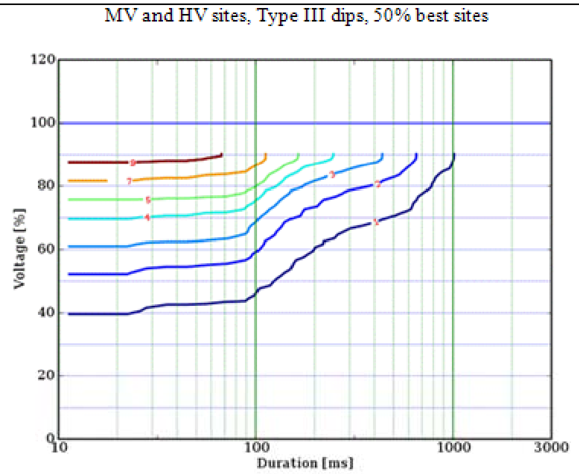


Number of affected phases (i.e., voltage sag types) for voltage sags with at least one remaining voltage below 85% of nominal from EPRI DPQ II
(1-Minute Aggregation, All Sites, All Days)

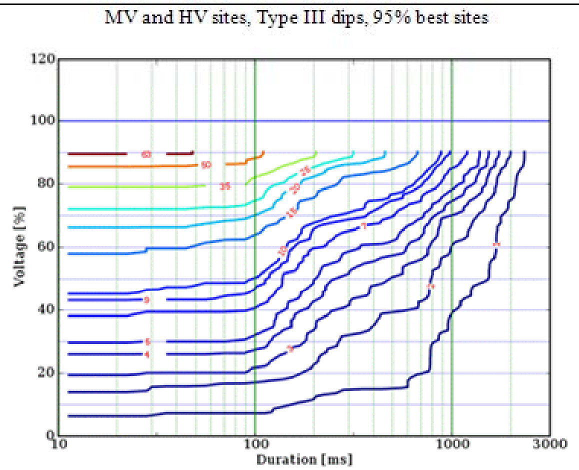


Percent residual voltage by type of sag from EPRI DPQ II Study

5.5 Expected Voltage Sag Distribution
International Statistics on Voltage Sags



Half of sites will have Type III events worse than this per year; half will have Type III events better.



Five percent of sites found will have Type III events worse than this per year; 95% will have Type III events that are better than represented numbers.

Figure 19—Three-phase (Type III) voltage-sag contour charts from C4.110 Working Group (969 sites, 40.86 Monitor Years)

Table 7—Breakout of voltage sag types from C4.110 Working Group Report

Sites	Voltage range	Number of sites	Single-phase (Type I)	Two-phase (Type II)	Three-phase Type III
MV & HV Sites	6 kV – 230 kV	969	27%	53%	20%
LV Sites	<1KV	206	64%	25%	11%

Section 6
Recommended Voltage Sag Test Requirements

- This section details the voltage-sag test requirements of this recommended practice.
- The recommended voltage-sag types and voltage-sag immunity levels are detailed in this section.

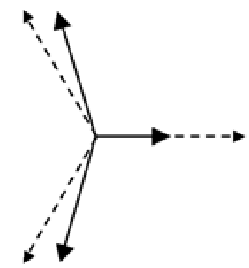
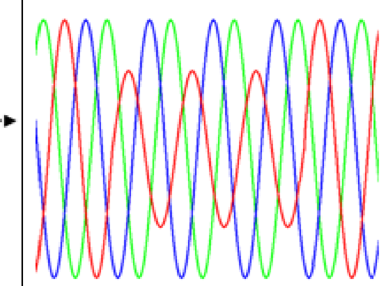
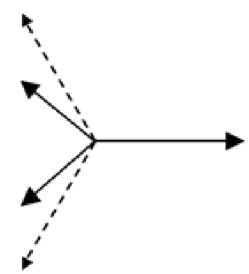
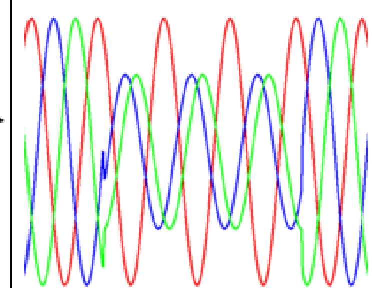
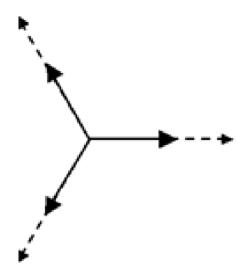
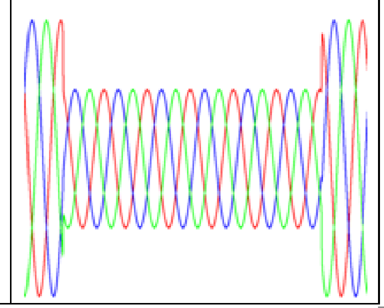
6.1 Classification of Voltage-Sag Types in Three-Phase Systems

Type 1
1 Phase Impacted
At Machine Level

Type 2
2 Phases Impacted
At Machine Level

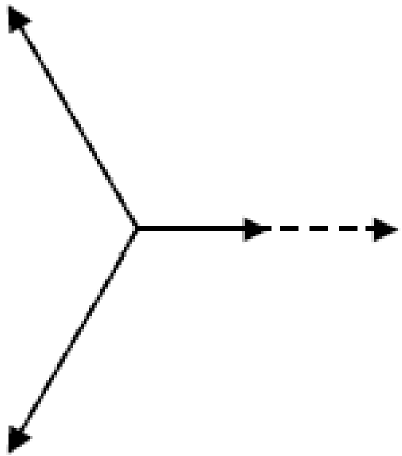
Type 3
3 Phases Impacted
At Machine Level

Table 8—Type I, II, and III voltage-sag classifications

Voltag-sag type	Description	Vector diagram	Waveform
Type I	This is a voltage sag in which a drop in voltage takes place mainly in one of the phase-to-ground voltages. $\overline{U}_a = \overline{V}$ $\overline{U}_b = -\frac{1}{2}\overline{V} - \frac{1}{2}j\overline{E}\sqrt{3}$ $\overline{U}_c = -\frac{1}{2}\overline{V} + \frac{1}{2}j\overline{E}\sqrt{3}$		
Type II	This is a voltage sag in which a drop in voltage magnitude takes place mainly in one of the phase-to-phase voltages. $\overline{U}_a = \overline{E}$ $\overline{U}_b = -\frac{1}{2}\overline{E} - \frac{1}{2}j\overline{V}\sqrt{3}$ $\overline{U}_c = -\frac{1}{2}\overline{E} + \frac{1}{2}j\overline{V}\sqrt{3}$		
Type III	This is a voltage sag in which there is a drop in voltage magnitude that is equal for the three voltages. $\overline{U}_a = \overline{V}$ $\overline{U}_b = -\frac{1}{2}\overline{V} - \frac{1}{2}j\overline{V}\sqrt{3}$ $\overline{U}_c = -\frac{1}{2}\overline{V} + \frac{1}{2}j\overline{V}\sqrt{3}$		

Where: V – characteristic voltage, E – pre-sag voltage, and Ua, Ub, Uc – phase-to-neutral voltages.

6.1 Classification of voltage-sag types in three-phase systems (continued)
Type 1 – One Phase Impacted



$$V_a = X$$

$$V_b = -\tfrac{1}{2}E - \tfrac{1}{2}jE\sqrt{3}$$

$$V_c = -\tfrac{1}{2}E + \tfrac{1}{2}jE\sqrt{3}$$

Figure 20—Recommended Type I test vector

6.1 Classification of voltage-sag types in three-phase systems (continued)
Two Phases Impacted

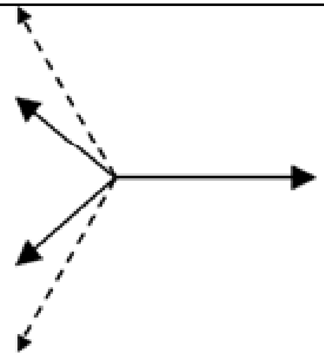
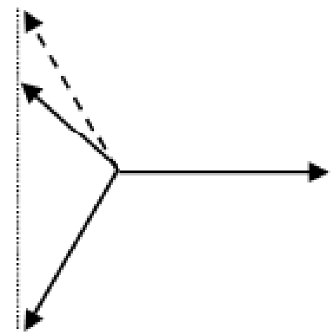
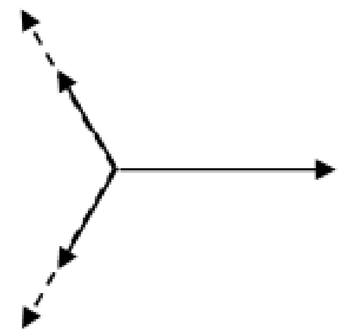
Type II (Recommended)	Type II.A1 (Alternate 1)	Type II.A2 (Alternate 2)
		
$V_a = E$ $V_b = -\frac{1}{2}E - \frac{1}{2}jV\sqrt{3}$ $V_c = -\frac{1}{2}E + \frac{1}{2}jV\sqrt{3}$	$V_a = E$ $V_b = -\frac{1}{2}E - \frac{1}{2}jV\sqrt{3}$ $V_c = -\frac{1}{2}E + \frac{1}{2}jV\sqrt{3}$	$V_a = E$ $V_b = -\frac{1}{2}E - \frac{1}{2}jV\sqrt{3}$ $V_c = -\frac{1}{2}E + \frac{1}{2}jV\sqrt{3}$

Figure 21—Recommended and alternative Type II test vectors

6.2 Recommended Voltage-Sag Immunity Levels One Phase Only and Two Impacted Phases

Table 10—Recommended test points for Type I and Type II voltage sags

Minimum test point No.	Residual voltage in percent nominal	Duration in seconds	Duration at 50 Hz	Duration at 60 Hz
1	50%	0.2	10 cycles	12 cycles
2	70%	0.5	25 cycles	30 cycles
3	80%	2.0	100 cycles	120 cycles

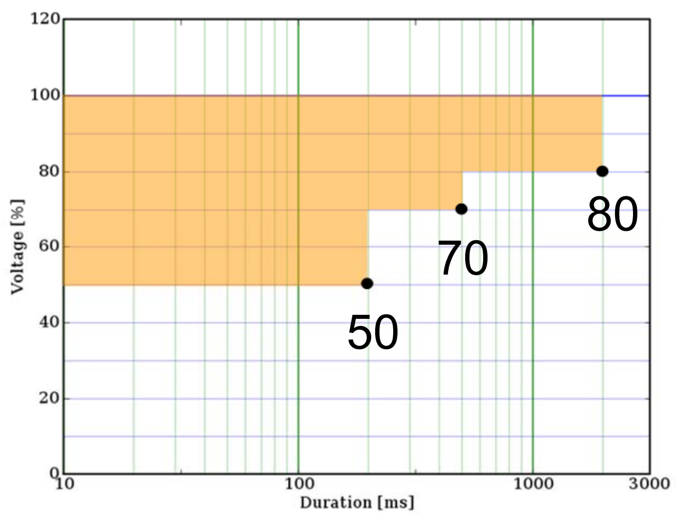


Figure 22—Recommended Type I & Type II test levels

6.2 Recommended Voltage-Sag Immunity Levels Three Phases Impacted

Table 11—Recommended test points for Type III voltage sags

Minimum test point No.	Residual voltage in percent nominal	Duration in seconds	Duration at 50 Hz	Duration at 60 Hz
1	50%	0.05	2.5 cycles	3 cycles
2	70%	0.1	5 cycles	6 cycles
3	80%	2.0	100 cycles	120 cycles

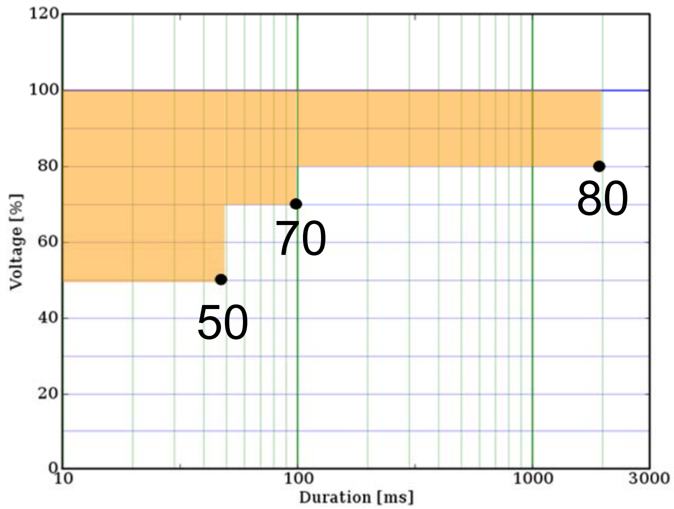


Figure 23—Recommended Type III test levels

When Published, Industries Can Specify Systems That Are IEEE 1668 Compliant!!!

6.2 Recommended Voltage-Sag Immunity Levels (continued)

Test Conditions:

- The EUT shall be tested in its most sensitive process states, as determined by the EUT manufacturer. For example, this may include robot movement, maximum power processing, and most sensitive measurement.
- Components and subsystems, when tested independently, shall be tested under load (for example, DC power supplies and AC drives).

6.3 Recommended Voltage-Sag Immunity Levels (continued)

6.2.4 Pass/fail criteria:

a) Full (normal) operation – Equipment performs as expected or intended, and all of its relevant parameters are within technical specifications or within allowed tolerance limits. Equipment performance should be expressed and measured against the set of relevant/critical “equipment outputs” (for example, speed, torque, and voltage level), which have to be defined as per the process requirements.

b) Self-recovery – Equipment does not perform its intended functions, or its outputs vary outside the technical specification/limits, but equipment is able to automatically recover after the end of a voltage sag without any intervention from the user.

c) Assisted-recovery – Equipment does not perform intended functions, or its outputs vary outside the technical specification/limits, and equipment is not able to automatically recover after the end of a voltage sag.

6.3 Recommended Voltage-Sag Immunity Levels (continued)

Table 12—IEEE P1668 equipment-immunity specification sheet
(for use with three-phase equipment)

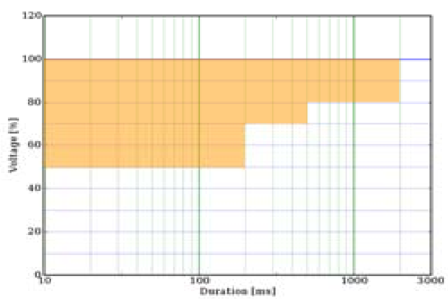
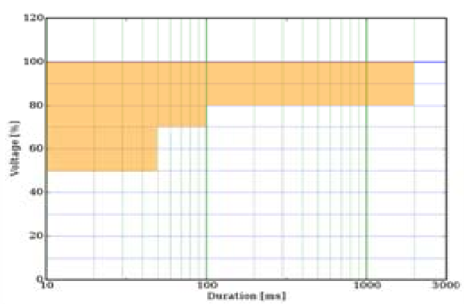
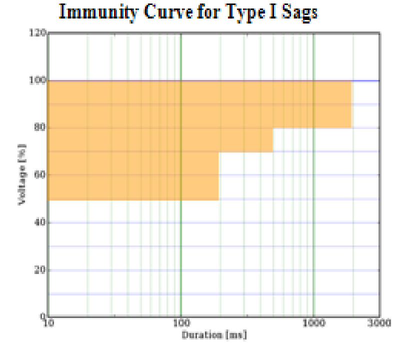
Equipment-Immunity Specification IEEE P1668 Voltage-Sag Immunity Requirement for Three-Phase Equipment					
Immunity Curve for Type I & Type II Sags			**Immunity Curve for Type III Sags**		
					
Type I and II voltage-sag test points: 80% for 2 seconds 70% for 500 milliseconds 50% for 200 milliseconds Repeat for test points for each phase-neutral and phase-to-phase combination.			**Testing for Type III voltage-sag required :** 80% for 2 seconds 70% for 100 milliseconds 50% for 50 milliseconds		
Desired Type II Test Vector					
Type II	**Type II.A1**	**Type II.A2**			
☐	☐	☐			
Pass/Fail Criteria			**Pass/Fail Criteria**		
Full Operation	**Self-Recovery**	**Assisted-Recovery**	**Full Operation**	**Self-Recovery**	**Assisted-Recovery**
☐	☐	☐	☐	☐	☐
Testing Procedure Requirements: IEEE P1668					

Table 13—IEEE P1668 equipment-immunity single specification sheet (for use with single-phase equipment)

Equipment-Immunity Specification IEEE P1668 Voltage-Sag Immunity Requirement for Single-Phase Equipment		
Immunity Curve for Type I Sags		
		
Type I voltage-sag test points: 80% for 2 seconds 70% for 500 milliseconds 50% for 200 milliseconds		
Pass/Fail Criteria		
Full Operation	**Self-Recovery**	**Assisted- Recovery**
☐	☐	☐
Testing Procedure Requirements : IEEE P1668		

6.3 Recommended Voltage-Sag Immunity Levels (continued)

- Advises how to use specification for procurement
  - With the establishment of the recommended voltage-sag test vectors, immunity levels, and desired equipment performance, it is possible for the equipment buyer/user to specify the desired equipment immunity in a purchase requisition. **A specification sheet for equipment immunity is provided in Table 12 and Table 13 for use by equipment buyers when purchasing three-phase or single-phase equipment.**
  - The equipment buyer may use this document to specify requirements for voltage-sag immunity to a system integrator/OEM. In turn, the system integrator/OEM may use this document to specify voltage-sag immunity requirements to their subsystem and component suppliers.

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