ELECTRIC POWER RESEARCH INSTITUTE

Equipment Immunity Performance Guidelines:
2008 Activities

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Technical Update, December 2008

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REPORT SUMMARY

EPRI has been active in developing new Institute of Electrical and Electronic Engineers (IEEE) and International Electrotechnical Commission (IEC) standards that will lead to better system compatibility. This report details the 2008 efforts.

Background

EPRI has an important role to play in making sure that equipment is compatible with the electrical environment in which it must operate. In the 1990s, the System Compatibility Research Project (SCRP) began work to characterize performance of various electrical devices, processes, and machines against power quality phenomena. A pinnacle point of this work was reached in 1999 as EPRI and member utilities helped to establish the SEMI F47 voltage sag standard for the semiconductor industry. Since that time, new related standards have been issued through the IEC; the SEMI F47 standard has been updated as well. There is concern that current versions of these standards may not lead to system compatibility.

Objectives

To help influence change in existing standards leading to creation of new or revised standards that will improve compatibility with the electrical environment.

Approach

To influence future revisions of IEC voltage sag standards, EPRI has played an active role in a working group that is making recommendations to the IEC for modifications to existing and future standards. In 2008, EPRI remained active in work undertaken by the Conference Internationale des Grandes Reseaux Electriques (CIGRE) / Congrès International des Réseaux Electriques de Distribution (CIRED) / Union Internationale pour les applications de l'électricité (UIE) joint working group JWG C4.110, "Voltage Dip Immunity of Equipment Used in Installations." The goal of this effort is to help influence change in future versions of IEC voltage sag standards. This working group is slated to deliver the final report in January 2009. In the arena of IEEE, a new standard is being developed for voltage sag immunity. Entitled "IEEE P1668 Recommended Practice for Voltage Sag and Interruption Ride-through Testing for End-use Electrical Equipment Less than 1,000 Volts," this standard aims to define an IEEE voltage sag standard that will include test criteria.

Results

Continued involvement in the standards arena is expected to lead to more robust voltage sag standards and improved system compatibility between equipment and the actual electrical environment. EPRI and member utilities agreed in 2006 on a 10-year plan that would include success statements, one of which is to achieve cost-effective power quality (PQ) compatibility between the electrical system and loads. As the IEEE P1668 work is now well underway and the CIGRE/CIRED/UIE group is addressing testing methods such as those detailed in this report, that goal is somewhat closer.

EPRI Perspective

EPRI's role is to bring together members, participants, the Institute's scientists and engineers, and other leading experts to work collaboratively on solutions to the challenges of electric

power. In terms of power quality and system compatibility, EPRI is working collaboratively with the standards community to lead the industry towards more robust equipment designs that push further the limits of improved system compatibility. EPRI is accomplishing this goal while balancing these future requirements with what is technically feasible and cost-effective for those who must build equipment to meet power quality standards. EPRI believes that continued involvement in this work is required to help bridge the gap between equipment performance and the electrical environment.

Keywords

Power quality
Voltage sags
SEMI F47
IEC 61000-4-11
IEC 61000-4-34
IEEE P1668

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CONTENTS

1 INTRODUCTION

This year voltage sag standards activities have continued at a steady pace. EPRI remains involved in these activities to ensure that the end result of the emerging standards work is system improved compatibility. Past history shows that when standards are developed without EPRI and member utility involvement, many issues can later arise. Such problems have arisen due, in part, to the current version of the IEC 61000-4-34 standard in which some test methodologies advocated in the standard do not reflect the most common voltage sag characteristics. This issue along with the need for three-phase characterization has pointed out the need for new and revised voltage sag standards.

In 2008, EPRI, member utilities, consultants, and manufacturers continued to develop a new IEEE standard for voltage sag immunity. In addition, EPRI along with a subgroup of U.S. manufacturers and North American utilities have continued participation in a European working group that is developing recommendations for future IEC standardization. By working in both arenas, EPRI seeks to bring about a convergence of technical ideas such that the new IEEE standard will be as harmonious as possible with future revision of IEC related standards. Furthermore, EPRI remained engaged in IEEE activities related to the color book revisions. This technical update explains EPRI's efforts to stay involved in standards efforts in 2008. Activities discussed in this update include:

- Progress made by the CIGRE/CIRED/UIE joint working group entitled JWG C4.110 "Voltage Dip Immunity of Equipment Used in Installations ". This group will be making recommendations for changing the IEC voltage sag standards.
- Continued work with the IEEE working group developing IEEE 1668 "Recommended Practice for Voltage Sag and Interruption Ride-through Testing for End-use Electrical Equipment Less than 1,000 Volts".
- Updates to the IEEE Color Book

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JWG C4.110 UPDATE

This section of the report details the progress of the C4.110 joint working group as of the fourth quarter of 2008. Much of this information in this section is from a recent September 2008 technical paper written by the working group and from excerpts of the draft chapters of the working group report. A joint effort of CIGRE, CIRED, and UIE, the scope of the working group is to gather technical knowledge on the immunity of equipment, installations and processes against voltage dips[1], and to use this knowledge in the further development of methods and standards. The activities of the working group are divided in seven “chapters”. Chapters 1 and 7 are introduction and conclusions, respectively. Chapter 2 gives a general description of voltage dips as they appear at the terminals of sensitive equipment. Chapter 3 describes the performance of equipment and processes during voltage dips. This chapter also includes recommendations on the design of processes. In Chapter 4 the results from Chapter 2 and Chapter 3 are combined to set requirements for the dip characteristics that should be included in immunity testing. Chapter 5 is the data gathering chapter, covering data not only on voltage-dip statistics at different locations, but also data on the economics of equipment immunity and testing. Finally, in Chapter 6, recommendations for immunity objectives will be given.

Some important contributions of the working group include:

1. Development of a check-list of voltage dip characteristics to be used early in the design of equipment.

2. Creation of a methodology to assess the performance of a complete installation and to include voltage-dip performance in the design of the installation.

3. Recommendations for characterization testing of equipment against voltage dips for single-, two- and three-phase voltage sags.

4. Recommendations for voltage-dip immunity of equipment to include the creation of voltage dip immunity labels for classifying the performance of equipment and to provide a common interface between the utility, equipment buyer and original equipment manufacturer/designer.

This working group convened shortly after the revision of the existing IEC 61000-4-11 and the creation of IEC 61000-4-34 standards. The scope of the working group was to gather technical knowledge on the immunity of equipment and processes against voltage dips and to use this knowledge in the further development of methods and standards.

The working group formed during the autumn of 2005 and started its activities early in 2006. Two meetings were held in 2006, three in 2007 and one in 2008. Two further meetings are scheduled for 2008 and one for early 2009. Starting from a core of about 10 people, the group

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[1] Voltage dip is used in the same context as voltage sag in the new IEC standards. This eliminates the confusion that previously existed between standards and terminology.

has been growing steadily and currently consists of 40 persons: 22 regular members and 18 corresponding members. The members have the following background: 13 network operators; 10 academics and consultants; 6 industrial customers; 5 equipment manufacturers; 3 regulators and 3 persons with extensive experience on immunity testing of equipment. This group will soon complete a report that will be delivered in January 2009. The report will provide guidelines for power companies dealing with customers, equipment manufacturers and other interested parties, and give recommendations for future IEC standardization. Since 2005, EPRI's main involvement in this group has been to provide end-use power quality input, perform the working group secretary duties, and maintain the working group web site [1].

Before reviewing the 2008 efforts, a brief review of European organizations that sponsor the working group is in order to be followed by a review of related IEC standards.

Review of Organizations and Reference IEC Standards

CIGRE (International Council on Large Electric Systems) is one of the leading worldwide organizations on electric power systems, covering their technical, economic, environmental, organizational, and regulatory aspects. A permanent, non-governmental, and non-profit international association based in France, CIGRE was founded in 1921 and aims to:

- Facilitate and develop the exchange of engineering knowledge and information between engineering personnel and technical specialists in all countries as regards generation and high-voltage (HV) transmission of electricity.
- Add value to the knowledge and information exchanged by synthesizing state-of-the-art and world practices.
- Raise awareness on the parts of managers, decision-makers, and regulators concerning the synthesis of CIGRE's work in the area of electric power.

More specifically, issues related to planning and operation of power systems, as well as design, construction, maintenance, and disposal of HV equipment and plants, form the core of CIGRE's mission. Problems related to protection of power systems, telecontrol, telecommunication equipment, and information systems also form part of CIGRE's area of concern [2].

CIRED is the Congrès International des Réseaux Electriques de Distribution, or, in English, the International Conference on Electricity Distribution**.** CIRED is set up as an international association. Since October 2004, it has taken the legal form of a *de facto* association (*association de fait*) under Belgian law. CIRED was established in Belgium. It is a non-profit association, with all costs in the operation of CIRED covered by the individuals or companies who accept to undertake the tasks necessary to conduct CIRED's activities [3].

The **UIE**, the International Union for Electricity Applications, is a non-governmental and non-profit organization founded in 1953. The objective of the UIE is to promote and develop the applications of electricity while respecting demands in the fields of protection of the environment, energy efficiency, economic viability and social acceptance. The organization aims at transferring knowledge and expertise in the field of electricity applications through the network of its member organizations across the world. The activities of the UIE focus on the overall chain of generation, transmission, distribution and efficient use of energy [4].

IEC 61000-4-11 and IEC 61000-4-34 Overview

The IEC 61000-4-11 and IEC 61000-4-34 are testing standards for voltage dips (sags) and short interruptions applied to two categories of equipment: equipment rated at less than 16 amps and equipment rated at greater than 16 amps (the 16A rating breakpoint is based on one of the common breaker sizes for a 220Vac circuits in Europe). The requirements of the standard are multifaceted, depending on what type of equipment is to be evaluated. The basic requirements of the standard are shown in Table 2-1.

Table 2-1
Preferred Test Levels and Durations for Voltage Dips [5]
(IEC 61000-4-11, IEC 61000-4-34)

Class[a]	Test Level and Durations For Voltage Dips (50 Hz/60 Hz)				
Class 1	Case-by-Case According to Equipment Requirements				
Class 2	0% during ½ cycle [2]	0% during 1 cycle	70% during 25/30[c] cycles		
Class 3	0% during ½ cycle [1]	0% during 1 cycle	40%[3] 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. (Shown in Annex B of Standard)
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.

The primary concern raised by EPRI and others related to the IEC 61000-4-11 and 61000-4-34 standards is the lack of a three-phase type of voltage sag test requirement[2,3]. Furthermore, EPRI has raised concerns about the voltage sag test vectors and the inability of certain advocated test methods to accurately portray the voltage sag response of motor drives in the actual electrical environment [6].

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[2] The latest draft revisions of the IEC 61000-4-11 and IEC 61000-4-34 have removed the ½ cycle interruption testing requirements.
[3] The latest draft of the IEC 61000-4-34 standard will require only 50% of nominal voltage dips at this test point for 200-208Vac systems. This modification was made because the 40% of nominal 200ms voltage dip requirement is difficult for universal input power supplies to pass when connected phase-to-phase in a machine design.

This report is organized as follows:

1. **Introduction** – This is an overview of what to expect in the report.

2. **A Description of Voltage dips –** This chapter defines a typical voltage dips including pre-, during, and post-event descriptions. The chapter describes phase angle relationships during voltage dips as well.

3. **Equipment and Process Performance.** This chapter addresses how equipment and processes are affected by voltage dips. A unique concept of process immunity is introduced in this chapter.

4. **Voltage Dip Immunity testing.** This chapter defines how voltage dip testing should be accomplished including the various methods of creating a voltage dip for single-, two-, and three-phase events.

5. **Statistics (formerly Economics).** This chapter has been modified to address the economic statistics for voltage dips. These economic aspects will either be addressed in a new chapter or will appear as appendices to the report since concrete economic data has been difficult to obtain.

6. **Immunity objectives.** This chapter defines the objectives for voltage dip immunity including the recommendation for equipment performance "classes" regarding single-, two-, and three-phase voltage sags.

7. **Conclusions.** This will summarize the findings of the group and its recommendations to the IEC and future standardization bodies.

These chapters, with the exception of "Introduction" and "Conclusion" are shown in a systematic and chronological way in Figure 2-1. As the working group addresses each chapter, they are, in effect, laying the groundwork for the later chapters.

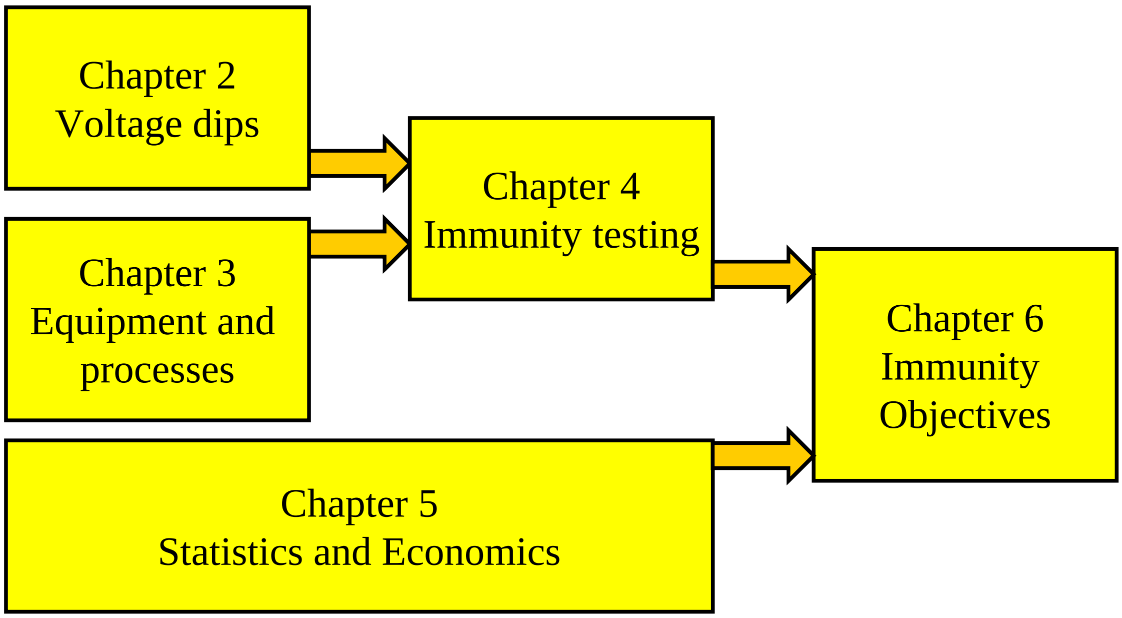


Figure 2-1
Activities Within the Working Group Organized in the Form of Chapters [7]

Chapter 2 – Voltage Dips

The purpose of this chapter is to give a description of individual voltage dip events as they occur in power systems and as they appear at the terminals of end-user equipment. The main aim is to provide a more detailed description of voltage dips than does a description based on the use of a single voltage magnitude value and a single duration value. Such an approach for a more detailed description of voltage dips should allow for better understanding and improved assessment of all relevant factors and parameters that may have an influence on the sensitivities of different types of equipment regarding various voltage dip events. This, in turn, should help the end-users, designers and manufacturers of electrical equipment to quantify, test and compare performance of their equipment in a simple, consistent, transparent and reproducible manner particularly with respect to prescribed tolerance limits and thresholds. Detailed measurement-based dip definitions, like the ones for residual voltage and duration in IEC 61000-4-30, however, will not be discussed here. Although the working group recognizes that there is a general need for detailed measurement-based definitions and does encourage their development, measurement-based definitions are considered to be outside of the scope of this report.

The description of voltage dips based on one voltage magnitude value (residual voltage or depth) and one duration value, as in IEC 61000-4-30, is generally suitable as a first step in quantifying, benchmarking and exchanging information on dip performance of the power supply systems. This simplified description, however, does not allow a clear distinction between a wide variety of voltage dip events that occur in a power system and, more importantly, possible differences in their impact and effects on operation of different types of equipment. The voltage dip description proposed in this chapter of the report is not aimed at replacing existing IEC descriptions but instead at providing a more detailed description of individual dip events based on additional dip characteristics that will be introduced in later sections [8].

Typical Voltage Dip

This chapter of the report presents a typical example of a voltage dip measured in a three-phase system as shown in Figure 2-2. The three recorded waveforms correspond to the three phase-to-phase instantaneous voltages measured at the end-user's 11kV service entrance. In this case, the voltage shows a drop in magnitude in two channels and remains at about the same magnitude in the third channel. As a voltage dip concerns a drop in voltage magnitude, it is more often visualized by plotting the rms voltage as a function of time, which is calculated or derived from the instantaneous voltage data. This rms voltage versus time plot is also shown in Figure 2-2.

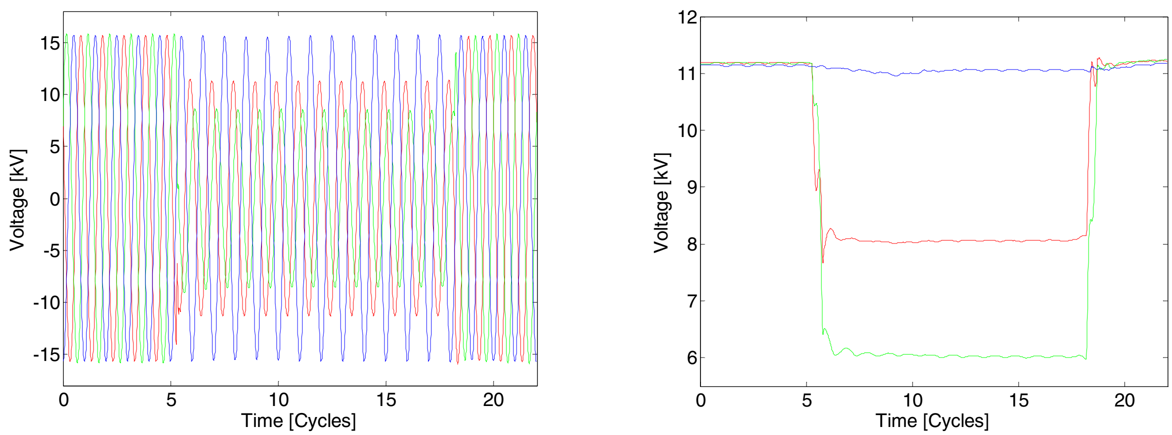


Figure 2-2
Example of a Voltage Dip Recorded in an 11kV Network: Instantaneous Voltage Waveform (left) and rms Voltage Magnitude (right)

The voltage dip event can be quantified by the rms voltage magnitude in each of the three channels as a function of time. This relationship is already shown in the right-hand side of the Figure 2-2, where the one-cycle rms voltage values are used to quantify the reduction in voltage magnitude. This graph is referred to by CIGRE C4.07 working group on Power Quality Indices and Objectives as "characteristic versus time" [9]. From the voltage magnitude versus time characteristic, so-called "single-event indices" or "single-event characteristics" can be calculated. The two most commonly used single-event indices are the voltage magnitude during the dip and the duration of the dip.

Existing Voltage Dip Description

The IEC power quality measurement standard IEC 61000-4-30 gives strict measurement-based definitions of the two main characteristics of voltage dips: the "residual voltage" and the "duration". Both are calculated from one-cycle rms voltage updated every half cycle. The residual voltage is the lowest rms voltage experienced during the event, whereas the duration is the total time during which the rms voltage is below the dip magnitude threshold. The dip magnitude threshold is usually set by the user of the monitoring instrument.

For multi-channel measurements, where more than one phase-to-neutral or phase-to-phase voltage is recorded, the residual voltage is the lowest rms voltage in any of the channels, and the duration is the total time during which the rms voltage in at least one of the channels is below the dip magnitude threshold.

This standard method of characterizing voltage dips is introduced to obtain a reproducible way of quantifying the performance of the supply at a specific location. However, reducing voltage recordings in several channels to just two single-value numbers will result in a substantial loss of information when it comes to the description of individual dip events. Two dips with the same residual voltage and duration may have completely different impacts on end-user equipment [8].

An Alternate Description of Voltage Dips – Dip Segmentation Method

An appropriate description of voltage dips should provide more information about the dip events than a simplified description based on the use of only one voltage magnitude value and one duration value. An example of such a simplified dip description is the one based on residual voltage and duration in IEC 61000-4-30, which is generally suitable as a first step in quantifying, benchmarking and exchanging information on dip performance of power supply systems, but does not allow a clear distinction between a wide variety of voltage dip events and, more importantly, possible differences in their effects on operation of different types of equipment. It is, therefore, concluded within the working group that a more detailed description of voltage dips is necessary for a better understanding and improved assessment of all relevant factors and parameters (i.e. dip characteristics) that may have an influence on the dip sensitivity of different types of equipment.

The standard method of describing voltage dips (with one voltage magnitude value and one duration value) leads to a significant loss of information. The main limitation is that the difference between voltage magnitudes in three channels for measurements in three-phase systems is not considered. Additionally, voltage dips do not always fit the pattern “voltage drop – constant voltage – voltage rise” (shown in Figure 2-2), i.e., voltage dips are not always rectangular in shape. Finally, phase shift and point-on-wave dip characteristics are not considered in the standard description of dip events.

In order to resolve this and some other practical problems encountered during the dip analysis, “dip segmentation method” is introduced in this section of the report***. Voltage Dip Segmentation is a new concept, an outcome of this working group, that may be useful in future voltage dip/sag standardization efforts.*** It extends the description of dip events beyond the standard “one constant magnitude and one total duration” approach, and also incorporates into the analysis several characteristics, aspects and features of dip events nearly always neglected.

The description of the voltage dip in this chapter introduces a number of “segments”, i.e. periods of time during which the voltage magnitudes (and possibly other characteristics of the voltage waveforms) are more or less constant:

a) One pre-event segment.

b) Zero, one or more during-event segments.

c) One voltage recovery segment.

It is further emphasized in the proposed dip description that the transition between two segments does not occur instantaneously. Therefore, so-called “transition segments” are introduced next to the above mentioned “event segments”. For example, in case of dips caused by switching events, usually there will be no during-event segments. The corresponding dip description will consist of a pre-event segment, a voltage recovery segment and one transition segment between them. An example of this type of event is a dip due to motor starting in Figure 2-3.

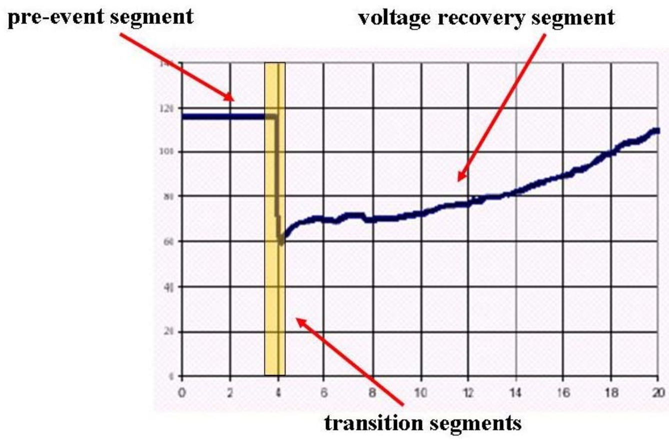


Figure 2-3
Example of a voltage dip with one transition segment [7].

A voltage dip with two transition segments, due to a fault, is shown in **Error! Reference source not found.**4. The transition segments correspond to fault initiation and fault clearing.

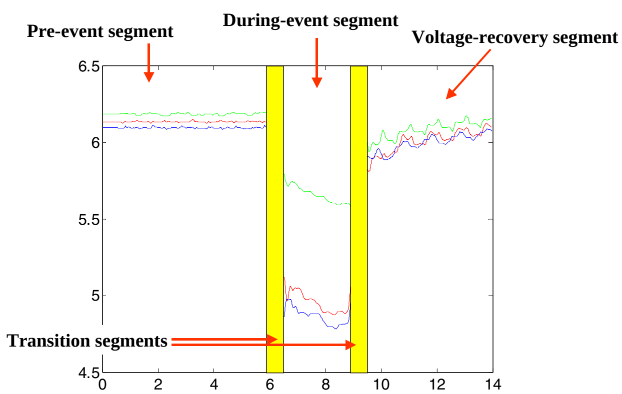


Figure 2-4
Example of a Voltage Dip With Two Transition Segments [7]

Besides the characteristics of pre-event and voltage-recovery segments, the proposed dip description consists of:

- Number of transition segments
- Duration of event segments.
- Characteristics of the transition segments.
- Characteristics of the event segments.

As the voltage magnitude (and other voltage waveform characteristics) do not show large or fast changes during an event segment, practically all of the commonly used analytical tools and calculation methods such as root-mean-square, rms, discrete Fourier transform (DFT), symmetrical components, etc. may be used for the analysis of during-event dip characteristics and will provide a trustworthy dip description.

Characteristics of the during-event segments have been extensively discussed in existing literature and include:

- Voltage magnitude;
- Voltage phase angle;
- Duration of the segment;
- Waveform distortion;
- Unbalance.

During a transition segment, however, the voltage magnitudes and other voltage waveform characteristics exhibit fast changes. The standard methods for the analysis of power systems can no longer be used. Possible characteristics of transition segments include:

- Points on wave, e.g. of dip initiation and ending;
- Rate of change of voltage;
- Oscillation frequency and damping;
- Differences in switching or in fault initiation instants in different phases.

The characteristics of the pre-event segment are related to the voltage magnitude, voltage waveform distortion and three-phase unbalance present immediately before the occurrence of a voltage dip. In most of the practical cases, the voltage before the dip event is in a steady state, so that characteristics over relatively long periods may be used.

Characteristics of the voltage recovery segment are strongly influenced by the system's ability to recover from the event(s) that originally caused the voltage dip and by the actual amount and type of load that is still connected to the system after the cause of the dip is cleared. Examples of relevant phenomena that may occur during the voltage recovery segment at different time scales include: high current taken by induction-motors due to re-acceleration, high in-rush current for power electronic load, recharging of capacitor banks and transformer saturation.

Besides the simple dip events (with one or two transition segments), this chapter also discusses more complex dip events: dips with three or more transition segments, multi-stage dips caused by developing faults, dip sequences due to automatic reclosing operations, and simultaneous occurrence of combinations of dips, interruptions and swells [7].

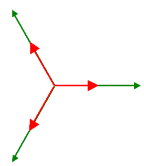
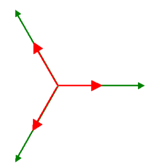
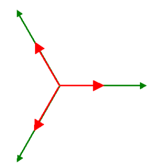
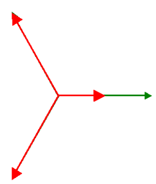
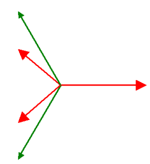
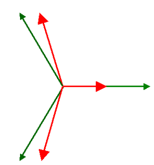
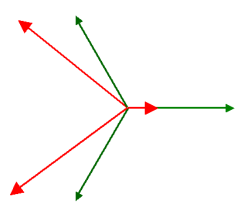
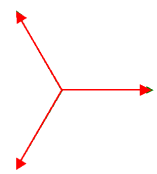
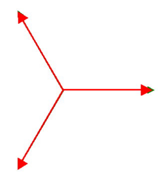
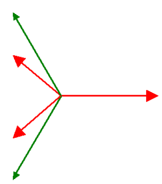
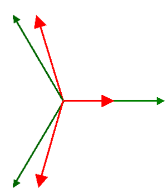
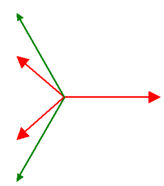
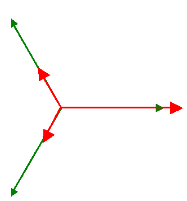
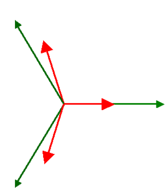
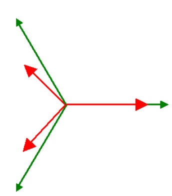
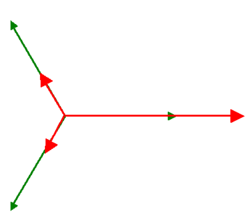
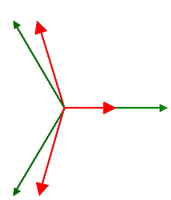
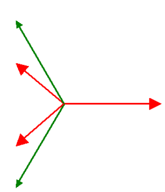
Changes in Dip Characteristics during the Propagation through the Network

One important section included in chapter 2 addresses the changes in the dip characteristics as the event propagates through the power system network. When a short circuit fault occurs at a certain system location, different voltage dips (i.e. dip events with different characteristics) will be measured and experienced at different locations within the system. This phenomenon is commonly known as *"dip propagation"*. A general rule is that the experienced/measured voltage dips will become less severe at the locations further away from the fault position. The term "less severe" implies here that the drop in voltage magnitude in all affected phases/channels is smaller, and that the corresponding change in phase angles is less pronounced.

Table 2-2 illustrates the changes in voltage magnitudes and phase angles of the three phase-to-neutral voltages resulting from dips due to different fault types after propagating through one and two Dy (delta-wye) transformers. The following comments should be made for interpreting the table.

- The green phasors (with smaller arrowheads) indicate the pre-fault phase-to-ground voltages; the red phasors (with bigger arrowheads) indicate the during-fault phase-to-ground voltages.
- For all diagrams, the phasor in one of the phases is given in the horizontal direction. Any phase shift between primary and secondary side of a transformer, is not considered here.
- Any transformer that changes phase-to-phase voltages into phase-to-neutral voltages (i.e. the third type in the above list) will change the dip type in the same way was a Dy-transformer.
- The impact of removing the zero-sequence voltage is the same as the impact of two Dy transformers.
- The impact of changing from phase-to-ground connected measurements to phase-to-phase connected measurements is the same as the impact of a Dy transformer.

Table 2-2
Propagation of Voltage Dip Through Multiple Transformations [8]

Type of fault	Dip at faulted voltage level	Dip after one Dy transformer	Dip after two Dy transformers
Three-phase			
Single-phase in a solidly-grounded network			
Single-phase in a non-solidly-grounded network			
Two-phase			
Two-phase-to-ground in a solidly-grounded network			
Two-phase-to-ground in a non-solidly grounded network			

A dip due to a three-phase fault does not change at all due to the transformers: a voltage drop in three phases remains a voltage drop in three phases. However, a voltage drop in one or two phases, due to such as an asymmetrical fault, changes characteristics (or Types) when transferring through a Dy transformer.

A single-phase fault in a non-solidly grounded system will not cause any significant drop in voltage behind a Dy transformer. The impact of a two-phase-to-ground fault in a non-solidly-grounded system is the same as that of a two-phase fault behind a Dy transformer.

Classification of Voltage Dips into Types

One simplified method of classifying voltage dips, introduced by the working group, is to utilize Dip Types. In its basic form, the classification distinguishes between the three general types of voltage dips that may occur at the terminals of sensitive equipment. The three basic types are as follows:

- Dip Type III is a drop in voltage magnitude that is equal for the three voltages.
- Dip Type II is a drop in voltage magnitude that takes place mainly in one of the phase-to-phase voltages.
- Dip Type I is a drop in voltage that takes place mainly in one of the phase-to-ground voltages.

The definition of these three dip types is given, in mathematical terms, in Figure 2-5, where it should be noted that all quantities are complex voltages. The characteristic voltage has a magnitude and phase angle which are typically different from those of the pre-event voltage. The difference in magnitude depends on the fault location; the difference in phase angle depends on the difference in X/R ratio between the source and the faulted feeder. When the X/R ratios are similar, a small phase-angle difference will result. On the other hand, a large difference in X/R ratio results in a large difference in phase angle. The difference in phase angle between the pre-event voltage and the (during-event) characteristic voltage is referred to as the “characteristic phase angle jump”.

$\overline{U}_a = \overline{V}$	$\overline{U}_a = \overline{E}$	$\overline{U}_a = \overline{E}$
$\overline{U}_b = -\frac{1}{2}\overline{V} - \frac{1}{2}j\overline{V}\sqrt{3}$	$\overline{U}_b = -\frac{1}{2}\overline{E} - \frac{1}{2}j\overline{V}\sqrt{3}$	$\overline{U}_b = -\frac{1}{2}\overline{V} - \frac{1}{2}j\overline{E}\sqrt{3}$
$\overline{U}_c = -\frac{1}{2}\overline{V} + \frac{1}{2}j\overline{V}\sqrt{3}$	$\overline{U}_c = -\frac{1}{2}\overline{E} + \frac{1}{2}j\overline{V}\sqrt{3}$	$\overline{U}_c = -\frac{1}{2}\overline{V} + \frac{1}{2}j\overline{E}\sqrt{3}$
Type III	Type II	Type I

Figure 2-5
Mathematical Expressions for Different Types of Voltage Dips Due to Faults That May Occur in a Three-Phase System[4]

In Figure 2-6, the resulting voltage dips are shown as phasor diagrams for zero-characteristic phase-angle jump and for a characteristic phase-angle jump of 30 degrees. The magnitude of the

[4] $\overline{E}$ is the pre-fault voltage; $\overline{V}$ is the so-called “characteristic voltage” of the dip.

characteristic voltage is in all cases equal to 50%. The illustrative instantaneous voltage waveforms and the rms voltage versus time for the different dip types are shown in Figure 2-7 and Figure 2-8, respectively.

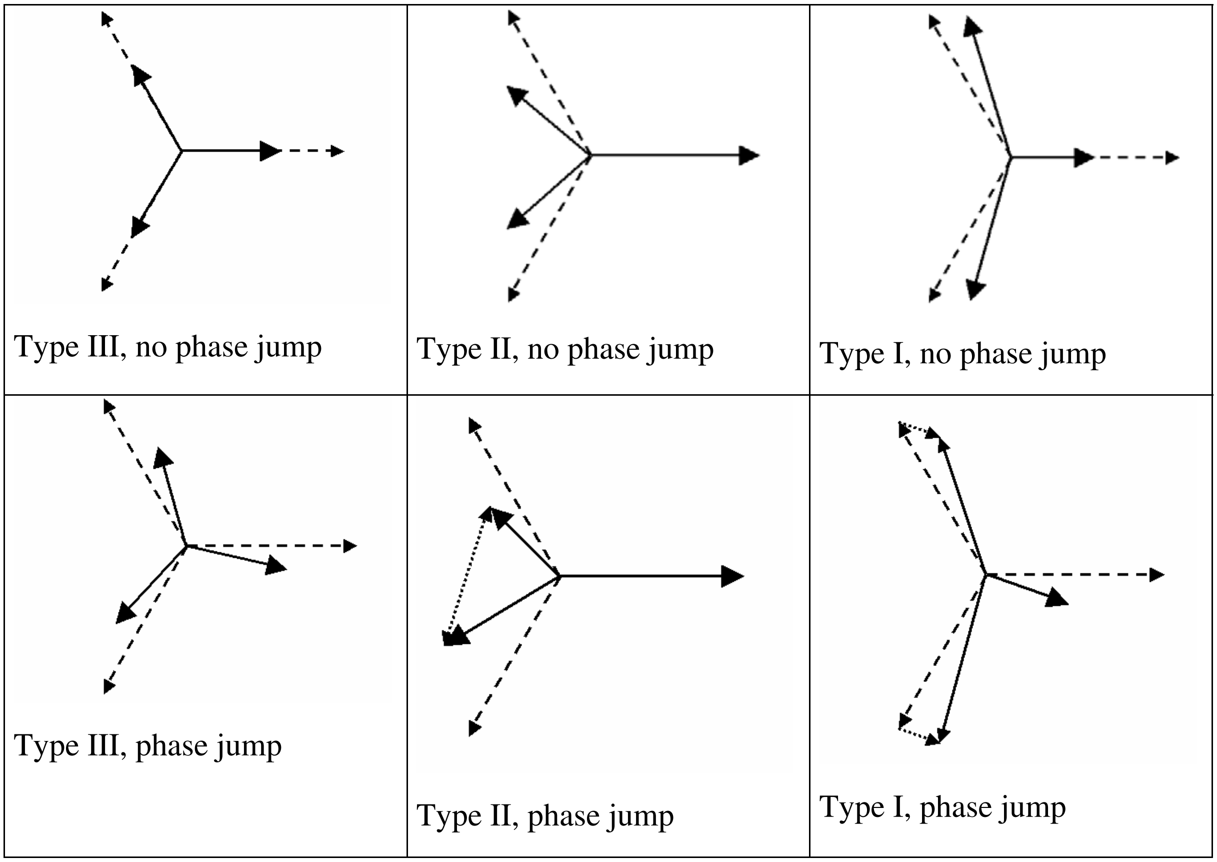


Figure 2-6
Phasor Diagrams for Different Types of Voltage Dips Due to Faults That May Occur in a Three-Phase System [8]

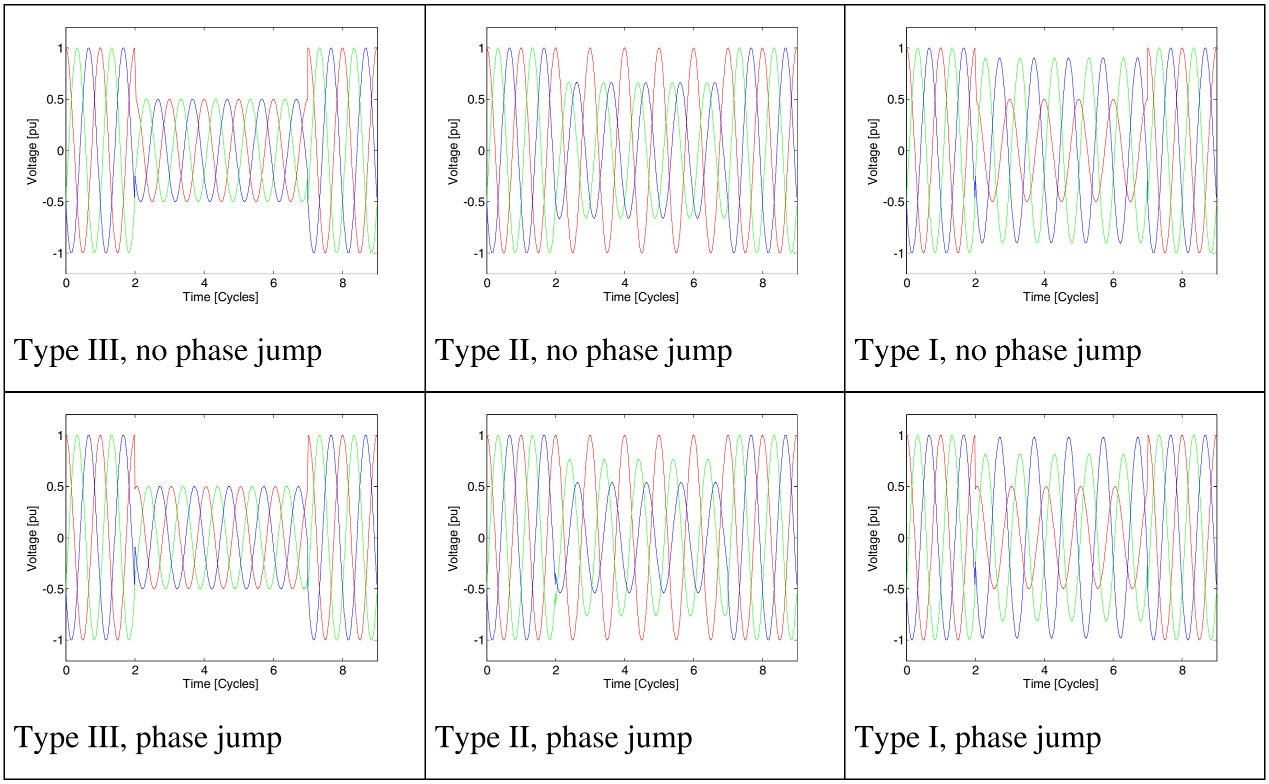


Figure 2-7
The Instantaneous Voltage Waveforms for Different Types of Voltage Dips Due to Faults That May Occur in a Three-Phase System [8]

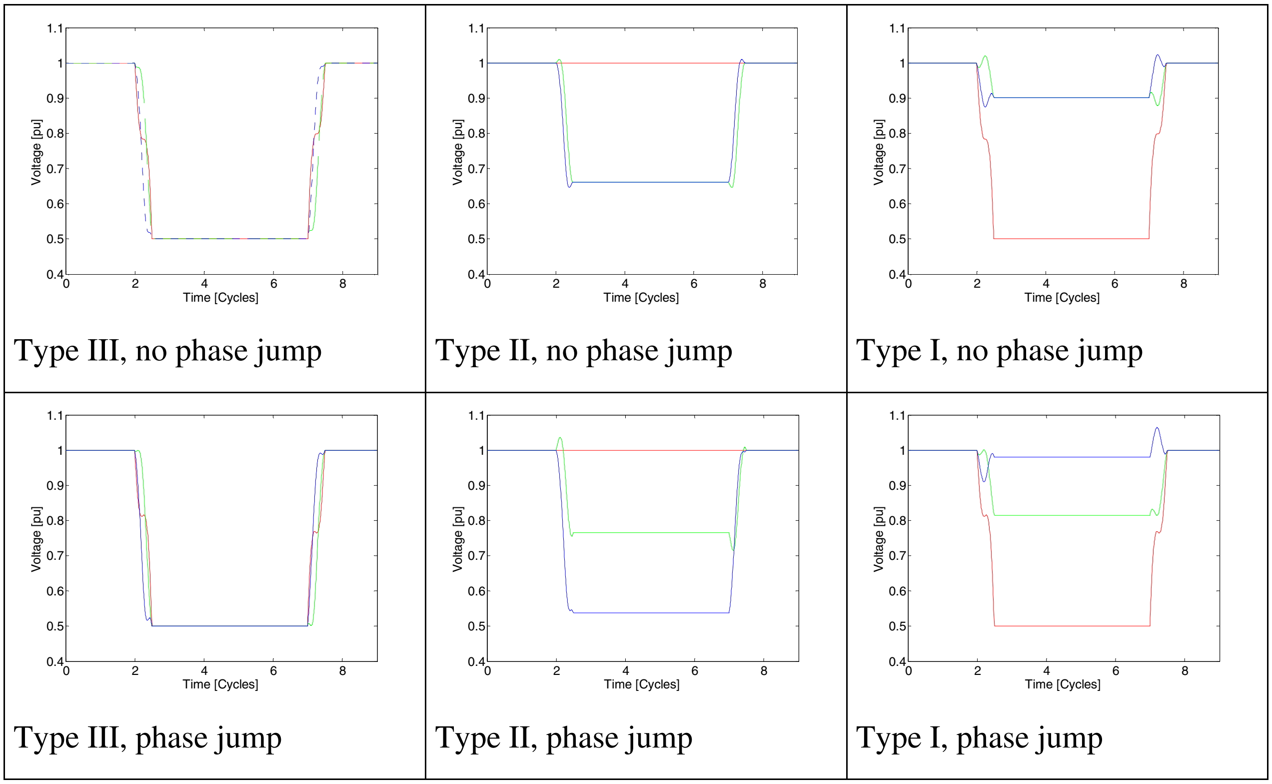


Figure 2-8
The rms Voltage vs. Time Plots for Different Types of Voltage Dips Due to Faults That May Occur in a Three-Phase System [8]

Summary of Voltage Dip Characteristics

Chapter 2 of the report ends with a section that summarizes the relevant dip characteristics. This is a check-list that equipment manufacturers and developers should consider during the equipment design stage. It is hoped that, should this checklist be used earlier in the design process, the cost of power quality-related problems will be lower in the long run. The aim of the list is not to impose additional tests, but to prevent unexpected equipment malfunctions due to the dips at a later stage. The current version of the check-list contains descriptions of each of the following characteristics:

- Dip magnitude
- Dip duration
- Dip shape
- During-dip voltage magnitude unbalance
- During-dip voltage phase angle unbalance
- During-dip phase shift (phase-angle jump)
- During-dip voltage waveform distortion
- During-dip transients
- Dip initiation (transition from pre-dip to during-dip voltages)
- Point-on-wave of dip initiation
- Phase shift at the dip initiation
- Multi-stage dip initiation
- Dip ending (transition from during-dip to post-dip voltages)
- Point-on-wave of dip ending
- Phase shift at the dip ending
- Multi-stage dip ending
- High inrush current at the dip ending
- Post-fault dip (prolonged voltage recovery)
- Post-dip phase shift
- Dip sequences (multiple dip events)
- Composite dip events (combination of dips, swells and interruptions in different phases)

Chapter 3 – Equipment and Processes

The chapter of the working group report is designed to inform the reader about the typical equipment susceptibilities. Furthermore, a concept of evaluating power quality issues in context of the process time constants is introduced and expanded through examples. This chapter discusses the impact of a voltage dip on direct on-line induction motors, synchronous generators, transformers, adjustable-speed drives, contactors, ice-cube relays, PLC’s, PC’s, large rectifier units and lighting systems is discussed.

For each type of equipment, different hardware components, different topologies and control algorithms are implemented by different manufacturers. The discussion of equipment performance is therefore kept rather generic. For direct on-line induction motors and synchronous generators, their behaviour and impact on the supply system during and after a dip is discussed. For contactors and equipment containing power electronics, best-case and worst-case rectangular voltage tolerance curves are presented, based on the current technology of tested pieces of equipment.

The equipment parameters and tripping mechanisms responsible for the high sensitivity of the equipment are also discussed. Knowledge of these parameters often indicates what type of mitigation technique is best suited to immunize the equipment. Finally, the checklist of voltage dip characteristics introduced in Chapter 2 is further discussed in Chapter 3 for the various equipment types as shown in Table 2-3 below. In the example checklist table below, the AC contactor is expected to be influenced by Dip Magnitude, Duration, and point-on-wave of the sag initiation. Furthermore, personal computers are only expected to be influenced by the magnitude and duration characteristics of the voltage dip.

Table 2-3
Checklist of Voltage Dip Characteristics Related to Impact on Equipment Performance [7]

Dip Characteristics	Dip magnitude	Dip duration	point-on-wave	Phase angle jump	Balanced dips	Unbalanced dips	. . .
Contactors (AC)	✔	✔	✔				
Contactors (DC)	✔	✔					
DOL IM	✔	✔		✔	✔	✔	
AC ASD	✔	✔			✔	✔	
DC ASD	✔	✔		✔	✔	✔	
SCR rectifiers	✔	✔		✔	✔	✔	
PC's	✔	✔					
PLC's	✔	✔					
...							

Process Behaviour

The ultimate goal of this section is to keep the industrial processes up and running during a voltage dip event or at least to know what voltage dips will cause a process trip so that measures can be taken for quick recovery. An industrial process can be thought of a combination of many separate pieces of equipment working in harmony to accomplish the overall process goal. As a common practice, engineers try to identify the most critical pieces of equipment. In some large industrial companies, electrical reliability engineers are appointed to identify critical equipment and to increase the immunity against voltage dips. As there are many different pieces of equipment and interactions, this is not always a simple task. It is not uncommon that the interaction between different pieces of equipment and their impact on the process often exceeds the knowledge of the electrical engineer and is not always well known. As the number of pieces of equipment can be very high in complex processes, a natural reflect of engineers is to take into account only the power processing equipment or that equipment that is known to be vulnerable towards the impact of a voltage dip such as adjustable speed drives or contactors. To often, it has been found that processes trip because sensing equipment, controllers or protective equipment was initially not considered. Chapter 3 of the C4.110 report begins with a description of some typical general process example indicating typical equipment used. This analysis indicates that processes can roughly be spit up in two groups – the slow acting and the fast acting. The first group of processes is characterized by slowly varying process parameters such as pressure, temperature, tank levels. In the second group, process parameter change quickly when equipment fails. Examples here are tight torque, speed or position control and synchronisation between movements in machinery.

After this classification, the proposed general framework is introduced. The Process Immunity Time (PIT) concept is defined, linking each process parameter in the process with one or more pieces of equipment. By means of a simplified process model, the usefulness of the framework to analyse process sensitivity is illustrated in a step by step procedure. The chapter concludes with two worked out examples were the PIT concept was used and validated.

In order to evaluate or improve process performance during a voltage dip, good understanding of the process itself is essential. Due to the high variety of processes and production facilities, the working group has decided to set up a general framework to analyze processes.

The process is broken down into subprocesses or functions that allow further scrutiny of the priority and PIT of each subcomponent. The number of levels required depends on the complexity of the process. The lowest level contains all pieces of equipment within the process. Table 2-4 gives an example of the top down approach for a simplified chemical reactor process (level 1). Level 2 describes the different functions within the reactor process such as reactor cooling, reactor flow and the control. Level 3 lists up the pieces of equipment for each function. Finally for the pieces of equipment, the affected function parameter involved is mentioned.

Table 2-4
Analysis of a Process to Determine the Essential Functions and Equipment [7]

LEVEL 1	LEVEL 2	LEVEL 3	Function parameter involved	PIT	Priority	Action
Reactor						
	Cooling					
		DOL IM 1 (water)	Reactor cooling water temp	5s	4	Restart 1
		Oil pump	Oil pressure	1,5s	2	Crucial
		DOL IM 2 – fan	Cooling of the water circuit	3min	7	Restart 3
	Reaction					
		DOL IM 3 (feed)	Flow rate	30s	6	Restart 2
		ASD 1 (mixer)	Reaction time	6s	5	Restart
		ASD 2 (air)	O2	2s	3	Mitigate
	Control					
		Oxigen measurement	% O2	1s	1	Mitigate
		PLC with UPS		1 h	8	

In the second part of the methodology, the impact of a voltage dip on each piece of equipment is analyzed by means of the Process Immunity Time. The Process Immunity Time (PIT) is defined as the time that a process function or single piece of equipment can be subjected to a voltage dip without causing the process or process function to which it belongs to operate out of specification, including the restart time of the function or equipment as shown in Figure 2-9.

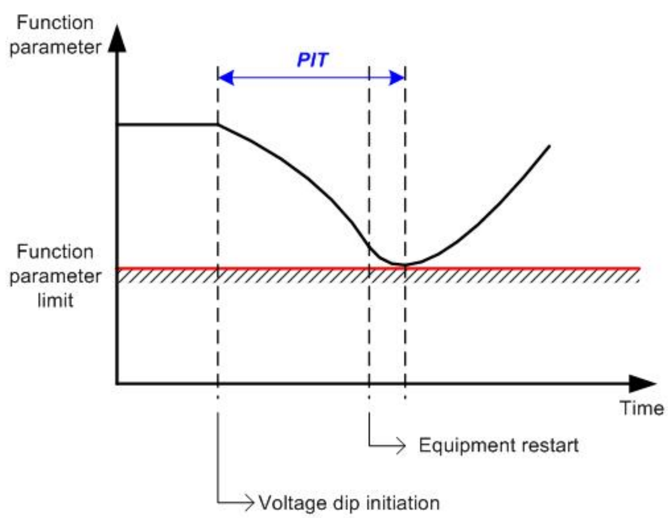


Figure 2-9
Process Immunity Time (PIT) for a Function Parameter Affected by a Piece of Equipment [7]

The definition of PIT does not specify the remaining voltage of the dip considered in the process analysis. If voltage dip information is missing, a voltage interruption can be selected as a worst-case scenario. If a desired immunity level is decided on within the company or statistical information of dip characteristics at the point of common coupling is available, a more realistic voltage dip level can be selected.

The PIT also includes the restart time of the equipment. For long PIT, voltage dip sensitive equipment may be stopped in a controlled manner at voltage dip detection and restarted as soon as the voltage has recovered without noticeable impact on the process. Another example is the coordinated restart of direct on-line induction motors after a voltage dip in order to avoid a voltage collapse due to the high currents during reacceleration. If the impact of each motor on the process is known, the most critical ones can be started first.

Finding correct values for PIT requires good understanding of both the equipment and the process. Therefore, it is suggested to bring electrical engineers, instrumentation engineers and process engineers together when setting up the top down approach.

From the analysis, processes and functions can be divided into two groups. Some processes are perfectly capable to operate without supply voltage for a small period of time (e.g. chemical plants). They have high PIT values. Good coordination of restart mechanisms can increase the process reliability. The second group contains processes with very small PIT. They are interrupted quickly after the occurrence of a voltage interruption or a voltage dip (e.g. extrusion, steel and paper mills). For these processes, the knowledge of the individual equipment behaviour under dip conditions is required to take the correct measures to harden the process [7].

Chapter 4 – Immunity Testing

This is very important chapter in the report and the final version of this section is still being written at the time of this update. This section will give recommendations to standard-setting organizations on the dip characteristics to be included in compliance testing. Recommendations and guidelines will be given to equipment manufacturers and users of sensitive equipment concerning characterization testing. Specifically, the testing will be characterized into two types;

- Compliance Testing
- Characterization Testing

Chapter 4 of the report will give recommendation on the immunity testing of equipment. A distinction will be made between “characterization testing” and “compliance testing”.

Characterization Testing

Characterization tests are usually performed by manufacturers as part of the design and manufacturing of equipment. These tests are aimed among others at providing customers with information on the performance of the equipment during dips. Such tests may be performed by the equipment manufacturer or by the customer under any circumstances deemed appropriate. The test results may for example be part of the technical specification of the equipment.

This chapter will give recommendations to equipment manufacturers on how to provide information to customers concerning the voltage-dip immunity of the equipment. Only results from compliance tests are not sufficient for the customer to determine the compatibility between the supply and the equipment or process. A method for determining this compatibility is described in detail in IEEE Std.1346 and in IEEE Std.493. This method uses the contour chart to quantify the supply performance and the voltage-tolerance curve to quantify the equipment or process performance.

The working group report is expected to recommend the "voltage tolerance curve" for quantifying the performance of equipment. Determining the process performance is based on the voltage-tolerance curve of equipment and on the process immunity time as discussed in Chapter 2 of the working-group report.

The voltage-tolerance curve is a continuous curve of voltage magnitude (or, residual voltage) against dip duration. The curve separates the plane into dips for which the equipment will operate as intended and dips for which the equipment will not operate as intended. An example of a voltage-tolerance curve is shown in Fig. 2-10. Giving the complete curve could be very expensive and time consuming in case physical tests are performed. Therefore it is recommended that the manufacturer provides at least a minimum set of points:

- The longest zero-voltage that the equipment can tolerate.
- The lowest voltage magnitude the equipment can tolerate for dip durations of 1 cycle, 100 ms, 200 ms, 500 ms, 1 second and 5 seconds.

Note that obtaining these 7 points will typically require significantly more than 7 tests.

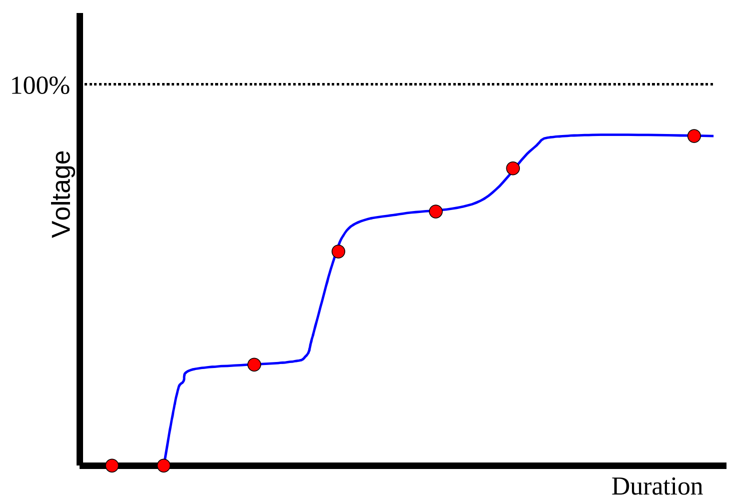


Figure 2-10
Example of a Voltage Tolerance Curve With the Minimum Set of Points to be Provided by the Manufacturer [7]

When it is possible, without excessive costs, to provide more than the minimum seven points, this is strongly recommended. In that way not only the 7 red points in Figure 2-10 will be known but more points of the blue curve. In some cases, performing many tests is easy, for instance with low-power equipment having a short restart time and not prone to damaging. In other cases, simulations will give an accurate estimation of the immunity; also in those cases more than 7 points should be given.

When presenting the voltage-tolerance curve it is very important that the performance criterion is clearly defined and explained. For example “restart by operator intervention” will usually result in a different curve as “motor speed does not deviate from its intended value”.

For single-phase equipment two curves should be presented, one for dips starting at voltage zero and one for dips starting at voltage maximum. When only one curve is provided, the corresponding point-on-wave value should be indicated.

For three-phase equipment it is recommended that three curves are presented, one for each of the types I, II and III. When only one or two curves are presented these should be for Type I and/or Type II.

No recommendations are given by the working group for other characteristics, beyond voltage magnitude, dip duration, point-on-wave and three-phase type, to be included in the information provided to the customer. When the manufacturer is aware of a specific dip characteristic strongly impacting the equipment performance, voltage-tolerance curves for different values of that characteristics should be provided [7].

Compliance Testing

Compliance testing is based on international standards or local regulations and is to be performed by an accredited test lab. Such tests are by nature expensive as the results shall be trustworthy and reproducible. The definition of such tests is the realm of IEC 61000-4-11, IEC 61000-4-34, and the various product standards. The number of tests and the complexity of the tests should not be more than absolutely necessary; however the results of the tests should give a reasonable prediction of the performance of the equipment in reality.

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Chapter 5 – Statistics and Economics

While Chapters 2 and 3 address individual dips and individual installations; chapter 5 takes a more global look at dips and installations. A number of issues are addressed to support the setting of immunity requirements in standards such as IEC 61000-4-11 and IEC 61000-4-34.

Economics of Immunity Requirements

If constraints on cost did not exist, all products could be made completely immune to voltage dips. So selecting voltage dip immunity levels is mostly an economic decision, being a trade-off between how much more should purchasers pay against how much more immune the equipment should be. To make this trade-off successful, one needs to know accurate statistics about voltage dips at the equipment terminals, and one needs to know precise economic data about the costs caused by voltage dips and the costs incurred to increase voltage dip immunity.

The working group has noted a lack of good data about all three above-mentioned aspects: we lack data about dips at the equipment terminals. We lack data about the economic costs of those dips. We lack data about the economic costs of increasing equipment immunity to dips. However, as a practical matter, voltage dip immunity standards are being written and enforced. The writers of these standards are implicitly making estimates about the missing data; so it is concluded that the working group should help them make better estimates.

The costs associated with voltage dips are large, but difficult to quantify. These costs include direct costs, re-start costs, and indirect costs such as effects on downstream processes. The reader may wish to turn to the valuable work being performed in JWG C4.107 for more information. Information about equipment susceptibility to voltage dips is discussed in Chapter 3. Information on the number of dips at the equipment terminals is being collected in this chapter.

Voltage Dip Statistics

The working group has collected measurement data on the number of voltage dips occurring in the power system. Data has been received from over 1000 sites in Canada, Scotland, Portugal, South Africa, Spain, USA, New Zealand, Australia and Japan, with voltage levels from 120 V to 230 kV. The results will be presented in a number of ways to allow the user to draw conclusions on different issues. Some examples are presented in Figure 2-11, Figure 2-12, and Figure 2-13. The three figures apply to the same data set: all dip types at all measurement sites at all voltage levels. The difference between the curves is in the percentile value, ranging from 50% through 95%.

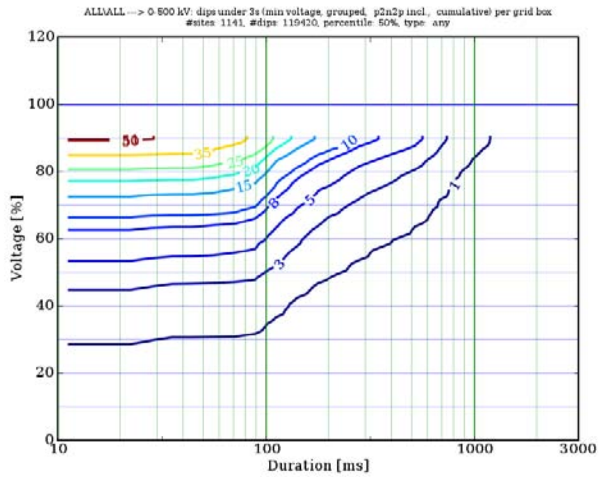

Figure 2-11
Voltage-Dip Contour Chart for 50% of the Sites [7]

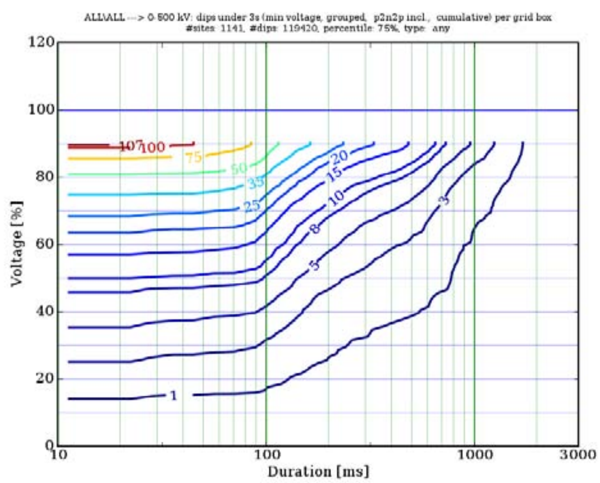

Figure 2-12
Voltage-Dip Contour Chart for 75% of the Sites [7]

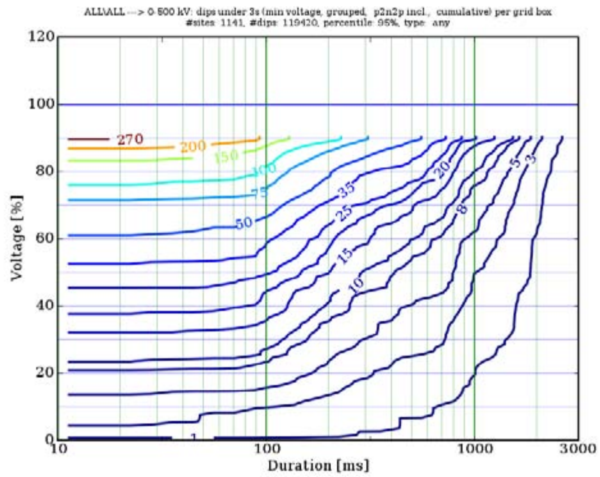

Figure 2-13
Voltage-Dip Contour Chart for 95% of the Sites [7]

The contour chart gives the number of dips per year more severe than a given voltage magnitude and duration. For example in Figure 2-11, there are 8 dips per year with residual voltage below 70% and duration longer than 100 ms. As the contour chart in this figure corresponds to the median value (50-percentile) the conclusion can be drawn that half of the sites have more than 8 dips per year with residual voltage below 70% and duration longer than 100 ms. Including information from the next two figures: 25% of the sites has more than 20 such dips; and 5% of the sites more than 60.

Chapter 6 - Immunity Objectives

Chapter 6 will be the pinnacle chapter of the report as it will set a class of immunity objectives for equipment. This section will give recommendations on immunity of equipment and installations against voltage dips. The contour charts for different percentiles of sites have been used to calculate the expected number of equipment trips to illustrate an example of classes of equipment performance. The three example classes are shown in Figure 2-14. Class A corresponds to a one second interruption test that Samsung has as a regional company standard in Korea. Class B corresponds to the environment “class 3” in IEC 61000-4-11 and 4-34. Class C corresponds to environment “Class 2” in IEC 61000-4-11 and 4-34 and is similar to the ITIC curve voltage dip levels. ***These three classes are shown for illustrative purposes as the working group has not finalized the class levels for equipment performance.***

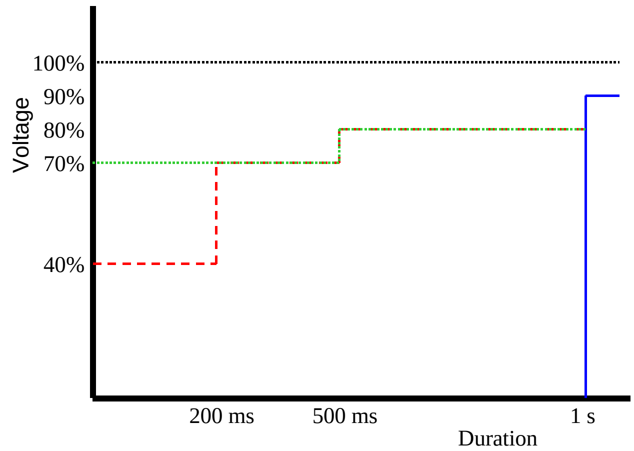

Figure 2-14
Three Example Classes of Performance: Class A (blue solid curve); Class B (red dashed) and Class C (green dotted)

The number of equipment mal-functions per year can next be calculated from the contour chart for the different classes of performance. The results are shown in Table 2-5. There are significant differences between Class B and Class C equipment, but even more severe between a 75-percentile and a 95-percentile site.

Table 2-5
Expected Number of Trips Per Year Based on Example Equipment Performance Class

Percentile	Class A	Class B	Class C
50	2	7.5	14
75	5	16	31
95	20	61	78

C4.110 Working Group Information on the Web

The working group web site is located at www.jwgc4-110.org. The web site provides general information to non-members, however detailed working group documentation and relevant papers and publications are available to the regular or corresponding members in the members area of the web site. Members are defined as those who plan to attend meetings whenever possible and corresponding members are those who want to review working group information and correspond without committing to attending working group meetings.

3

IEEE 1668 STANDARDS ACTIVITIES

Background

The IEEE 1668 Working Group got underway in 2007 and continued on in 2008. This is a working group under the Power System Engineering Subcommittee of the IEEE Industrial Applications Society. Meetings are formally held at the IEEE Industrial and Commercial Power Systems annual meeting and at the Industrial Applications Society annual meeting (when in the U.S.). This working group is expected to form the basis for new testing standards for commercial and industrial equipment in a similar manner to those efforts that produced the SEMI F47 and the IEC 61000-4-11 and 34 standards.

The plan of the working group is to gain consensus on a two-year guide for trial use that will serve as the testing standard for performing system compatibility assessment of industrial and commercial equipment. Should the two-year trial guide be accepted by consensus, the next step will be an approved guide that will serve for five years. There is a possibility after this five-year period of developing either a test standard or a recommended practice document, depending upon the interest.

It is anticipated that this document could form the basis of the proof or certification that the equipment so tested meet various curves or tolerance envelopes. The intended result will be that equipment manufacturers would likely provide a line on their data sheet indicating that the equipment meets IEEE 1668. As EPRI is participating in both the IEEE P1668 work as well as the JWG C4.110 activities described in the previous section of this report, efforts will be made to try and converge the activities and outcomes of these two efforts where possible. If this can be done in a successful manner, the IEEE P1668 recommended practice and the future IEC and SEMI voltage sag standards would be harmonious.

It is also envisioned that this document could feed additional voltage-tolerance profiles for various equipment categories into two existing IEEE documents that are preparing for the revision process: IEEE Std. 1346 and IEEE Std. 1000.

P1668 Working Group on the Web

The P1668 standard working group includes ten manufacturer participants, seven utility participants, and four participants from EPRI. The membership as well as working group information can be found at http://grouper.ieee.org/groups/ias/1668/index.html.

Summary of P1668 Working Group Meetings

The working group held eleven meetings in 2008. One of these meetings occurred at IEEE I&CPS 2008 in Clearwater, Florida while the remaining were conducted via the web. A summary of the 2008 meetings is given in Table 3-1.

Table 3-1
IEEE P1668 2008 Meeting Summary (Meeting #8 through #18)

1668 Sequential Meeting Number[5]	Meeting Date	Location	Significant Highlights
8	January 15, 2008	Web	Section 5: Electrical Environment sub team meeting
9	January 24, 2008	Web	Section 5: Electrical Environment sub team meeting
10	May 5, 2008	IEEE I&CPS 2008 in Clearwater, Florida	Review Chapter 5 Electrical Environment Section, discuss overall effort with attendees.
11	June 6, 2008	Web	Section 5: Electrical Environment sub team meeting
12	June 18, 2008	Web	Overall Review Progress to Date, Action Items, and Subgroup Assignments
13	June 23, 2008	Web	Section 5: Electrical Environment sub team meeting
14	August 11, 2008	Web	Section 5: Electrical Environment sub team meeting
15	September 15, 2008	Web	Section 5: Electrical Environment sub team meeting
16	October 14, 2008	Web	Section 5: Electrical Environment sub team meeting
17	November 5, 2008	Web	Section 5: Electrical Environment sub team meeting
18	December 3, 2008	Web	Section 5: Electrical Environment sub team meeting

Overview of Scope

The scope of the IEEE P1668 is to provide a non-industry specific, recommended practice for voltage sag ride-through performance and compliance testing regarding 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 will include the definition of minimum voltage sag immunity requirements based on actual voltage sag data rather than the capabilities of a given test fixture or platform. An included section, dedicated to the detailed analysis of voltage sags experienced by end users, provides insight into real-world voltage sags. The goal of this document is to clearly define the required testing procedures and test equipment requirements 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.

The working group has also determined that the purpose of the recommended practice is to clearly define test methods and ride-through performance for determining electrical and electronics equipment sensitivity to voltage sags. Analysis of real world sags provides the foundation for both the test methods and the criteria, aligning themselves as closely as possible to the end user's electrical environment. The standard will define the characteristics of the

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[5] This is a sequential listing of the meetings from the start of the effort. For a list of 2007 meetings, see *Equipment Immunity Performance Guidelines: 2007 Activities,* 1013877.

voltage sags depths, durations, phase angle, and vectors required to relate to real world-based voltage sag events. The recommended practice will show how different voltage sag testing methods can be used to simulate real world sags. End users will be able to use the standard in their purchase specifications to ensure the required level of performance. In addition, end users can use the voltage sag criteria as a performance benchmark for existing equipment [10].

Summary of Each Section of IEEE 1668

The IEEE P1668 draft recommended standard is divided into nine main sections and an Annex as shown below.

Section 1 – Overview. This section will define the scope and purpose of the recommended practice.

Section 2 – Limitations. This, basically, will outline that IEEE P1668 is a voltage sag standard as well as what items that the standard does not address.

Section 3 – Normative references. This section will outline the ANSI and IEEE standards that are referenced and related to this recommended practice.

Section 4 – Definitions. The terms that are included in the standard are clearly defined including items such as Ride-Through Capability, Voltage Sag, etc.

Section 5 – Electrical Environment. This section will define the causes of voltage sags, their typical characteristics, the effects of faults on the electric system,how voltage sags occur, how sags propegate throughout the system, how common sags are in the electrical system, and how voltage sags and phase currents are related. Particular focus is placed on how voltage sags appear at the point of connection (PCC) of the customer's equipment.

Section 6 – Test Levels. This section will define the voltage sag test levels that should be used when evaluating equipment.

Section 7 –Test Procedure. This section will define the test proceedures to ensure repeatable and meaningful test results

Section 8 –Testing Equipment Requirements. The basic requirements of the voltage sag generator will be defined in this section.

Section 9 – Certification and Test Reports. The format of certification and test reports will be detailed in this section.

Annex A: Analysis of PQ Data at the End-Use Level. This section will summarize typical low voltage PQ data from an industrial manufacturer's plant bus voltage.

2008 Efforts in P1668 Section 5 – Electrical Environment

The majority of efforts in 2008 have focused on refining the electrical environment chapter of the recommended practice. For this reason, a review of the content of this chapter will be presented. For a review of previous chapters, see the summary of EPRI's 2007 efforts [11]. Section 5 seeks to define the electrical environment including the characteristics of voltage sags, how faults and voltage sags propagate, and how often voltage sags occur. Section 5 begins by summarizing that in today's industrialized and digital economies there is a much higher expectation and process requirement for power quality. Basically, these requirements mean that customers expect a higher quality of electrical power. Nonetheless, even the most highly-developed power systems cannot eliminate variations in voltage that will occur from time to time and that will affect customers.

Voltage Sag Characteristics

Next, the basic definition of voltage sag is presented in terms of magnitude (depth) and duration of the voltage deviation as shown in Figure 3-1.

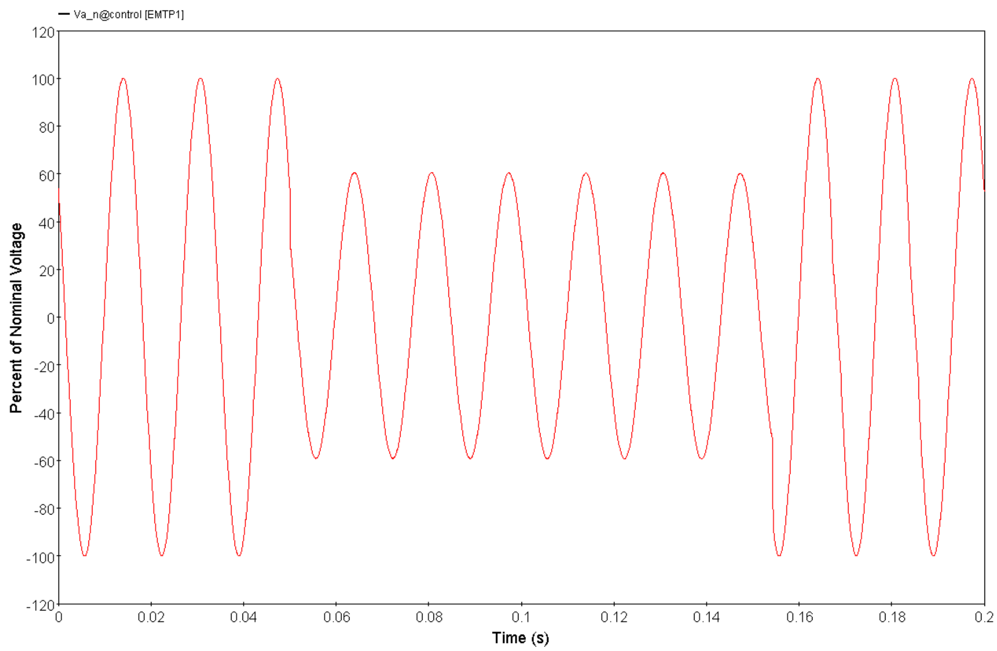

Figure 3-1
60%, 100ms (60 Hz) Single Phase Voltage Sag [10]

Other voltage sag characteristics are then discussed such as point-on-wave and phase shifts. A typical voltage sag that has an initiation at 90 degrees point-on-wave is shown in Figure 3-2.

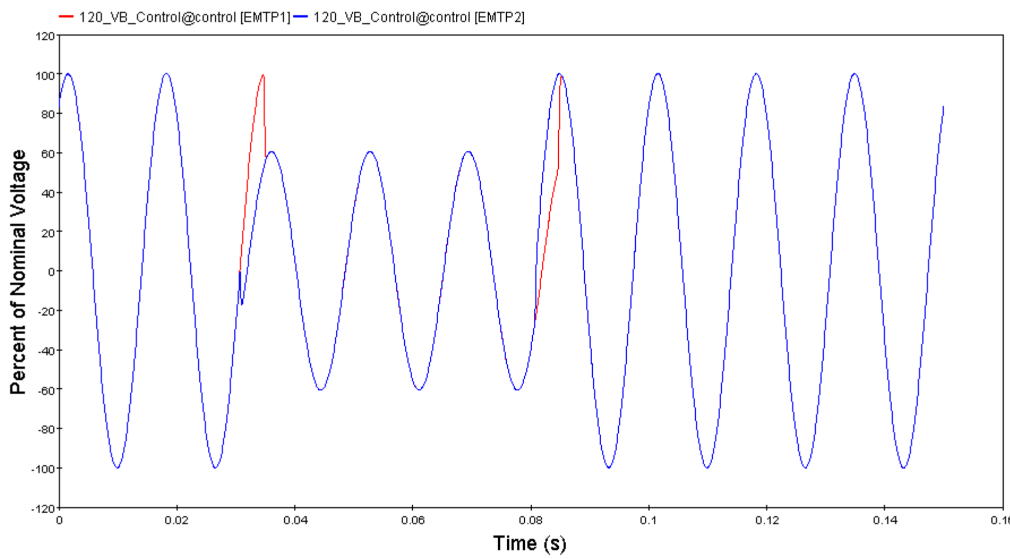

Figure 3-2
Example Voltage Sag Initiated at 90 degrees Point-on-Wave [11]

The section discusses how equipment and devices in many industrial processes may malfunction when subjected to very shallow sags while remaining unaffected during deeper sags. This phenomenon can be related to the point-on-wave at which the voltage sag initiates as shown in Figure 3-3 and will be explained in the draft recommended practice. The figure shows the voltage required to keep the contactor operational in reference to the point-on-wave at which the voltage sag is initiated. Voltage levels experienced during the sag below the curve will cause the contactor to malfunction. Note how more voltage is required to keep the contactor operational at what are basically the zero cross points of the waveform occurring at roughly 0ms and 8ms for a 60Hz contactor. Conversely, less voltage is required at the peak of the sine-wave (4ms), which corresponds to the 90-degree point on the voltage waveform.

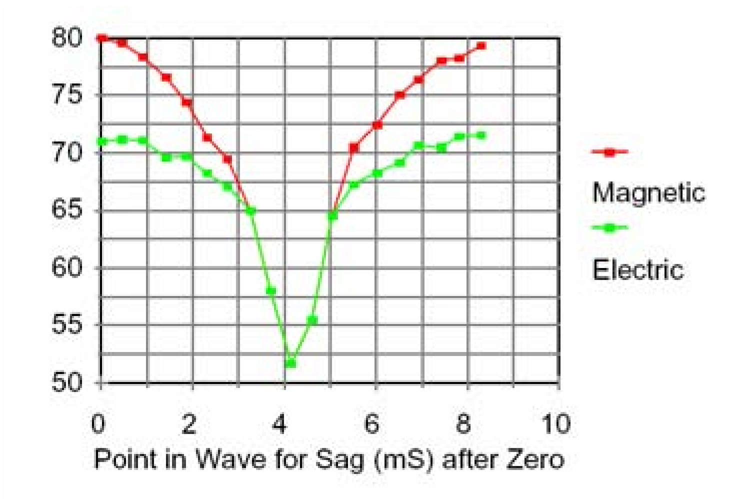

Figure 3-3
Point-on-Wave Effect on 60Hz Contactors After Zero Crossing [11]

This section also discusses the phenomenon of phase angle change, or phase shift that can occur during a voltage sag. An example of an EMPT modeled voltage sag with shifts of phase is shown and discussed to help the reader understand the phenomenon, shown in Figure 3-4, as currently presented in the draft standard. The graphic shows both the waveform as well as the phasor relationship. It is important to note how voltage sags can contain both phase shift and magnitude change.

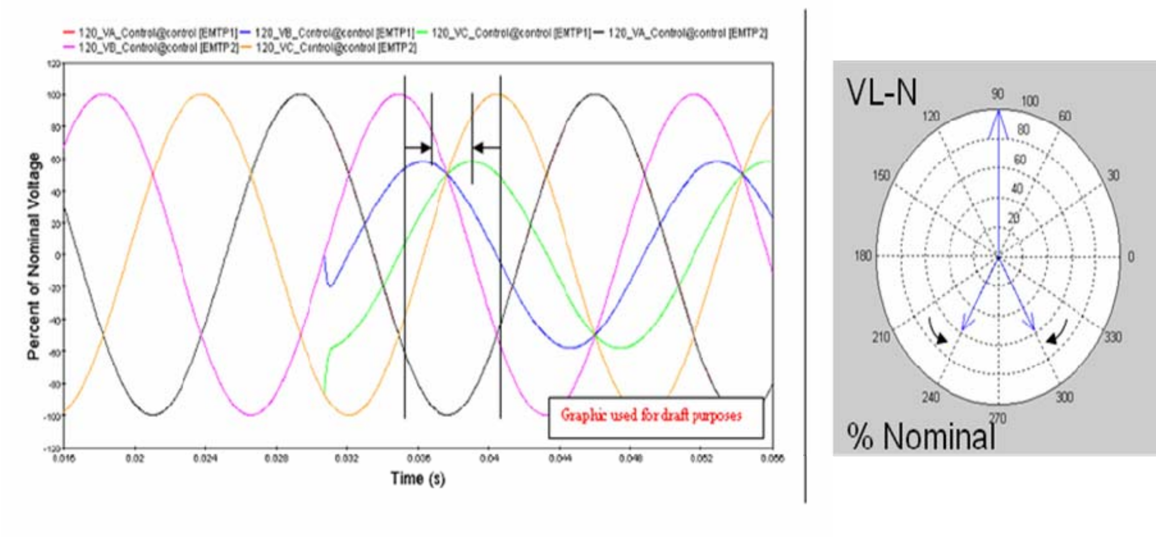

Figure 3-4
Voltage Sags With Positive and Negative Phase Shift [10]

Further examples are presented to show the concept of balanced and unbalanced voltage sags. While balanced voltage sags affect all three phases equally with the normal phase shift between the phase voltages remaining at 120 degrees, unbalanced voltage sags differ in both voltage magnitude and phase shift. The document notes that unbalanced voltage sags occur much more frequently in the real world electrical environment. Examples of balanced and unbalanced sags are shown in Figures 3-5 and 3-6 as they are presented in the draft.

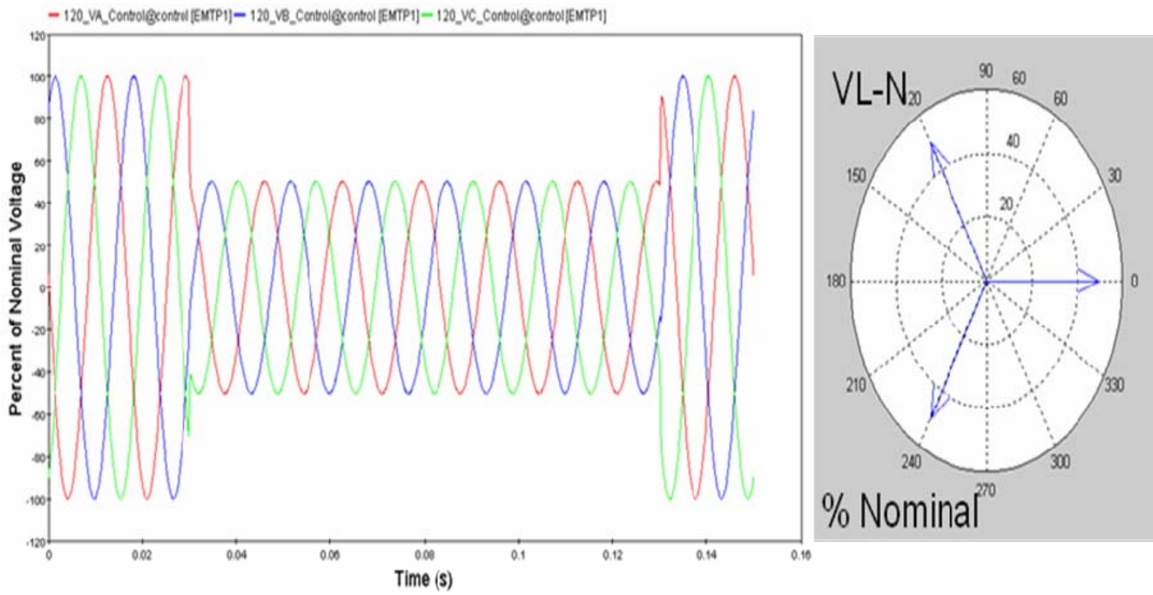

Figure 3-5
Balanced Voltage Sag [10]

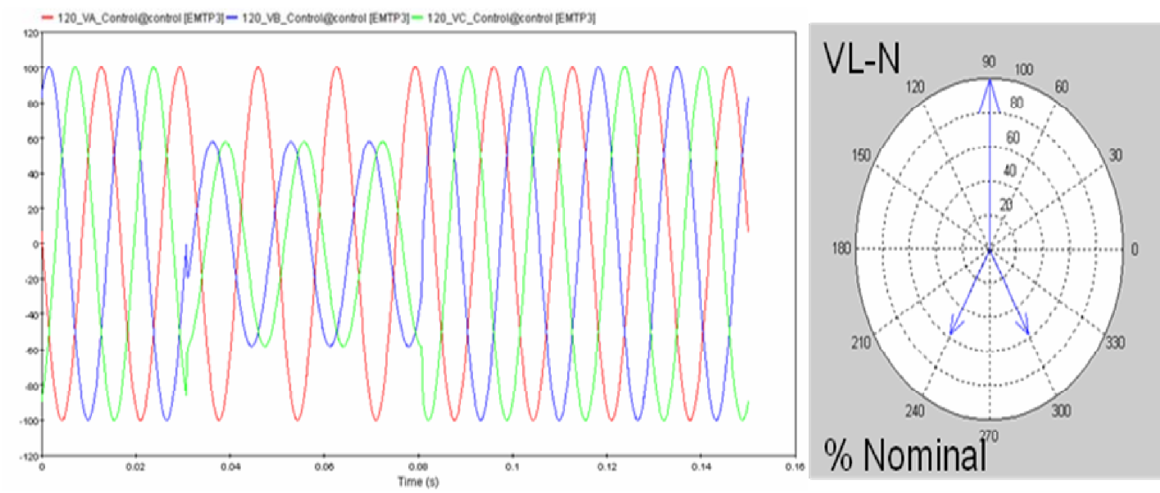

Figure 3-6
Unbalanced Voltage Sag [10]

Faults and Voltage Sags

This section addresses the causes of voltage sags that may occur as a result of initial starting of large motor loads or due to faults on the electrical network. The section discusses the factors affecting the voltage sag characteristics including: electrical distance to the fault, system impedance, radial versus loop fed circuits, numbers of transformations between the measurement point and the fault location and transformer types, type of fault, pre-sag voltage level and the clearing time of the protective equipment. Distinction is made between the typical durations of sags on the transmission, subtransmission and distribution systems. Examples are given for quick voltage recovery after a fault and slow voltage recovery after a fault (Figure 3-7 and Figure 3-8).

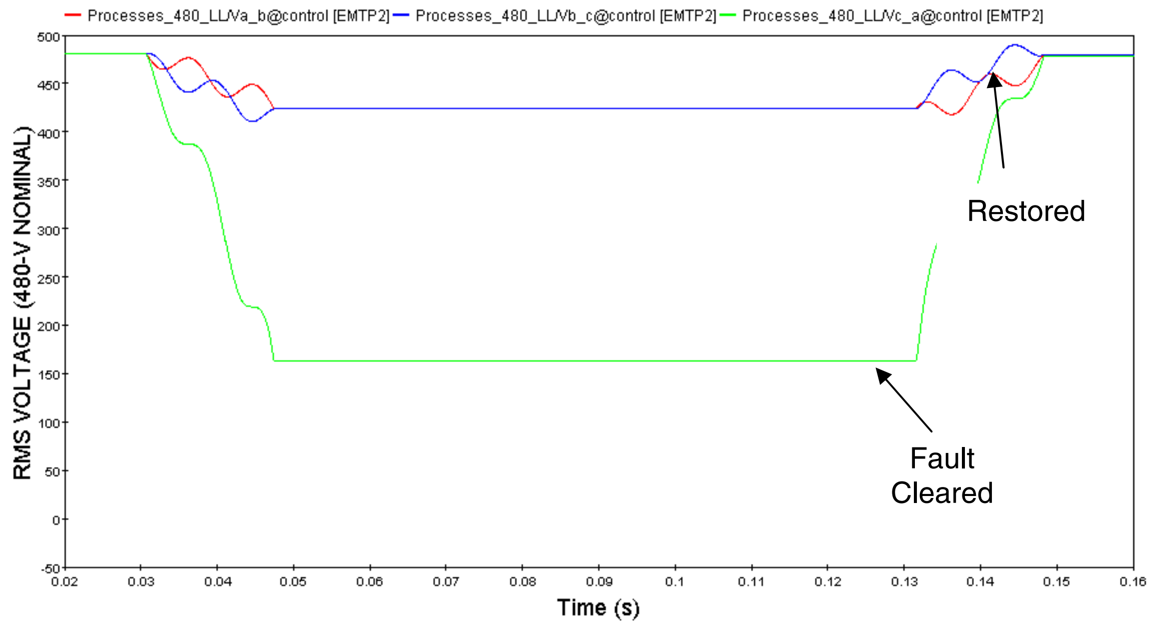

Figure 3-7
Example Voltage Recovery After Fault is Cleared [10]

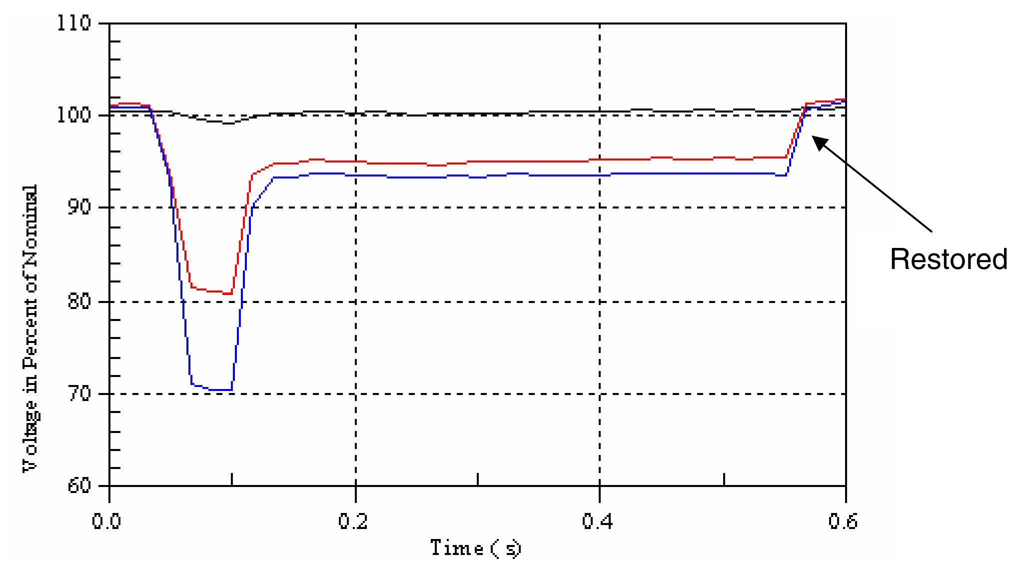

Figure 3-8
Example Slow Voltage Recovery After Fault is Cleared [10]

A unique approach is used in this section to model actual transmission, distribution, and even at the customer's own 480Vac bus. In each case, example rms voltage sag levels resulting from events are shown at the customer 480Vac bus. Figure 3-9 shows a single A phase fault to ground on a 161kV transmission line and the resulting voltage sag at a customer's 480V bus. The utilization voltage, 480V in this case, is transformed via two delta-wye transformers, the first transformer with a secondary voltage of 13.8kV and the second transformer with a secondary voltage of 480V. The transformer connections have a significant impact on how the voltage sag propagates to the utilization level. At the location of the fault, the voltage from A phase to ground will be zero volts. Note how the line-to-line voltages, BC and CA, and line-to-neutral voltages AN, BN, and CN are affected from the single-phase fault due to the two delta-wye transformations.

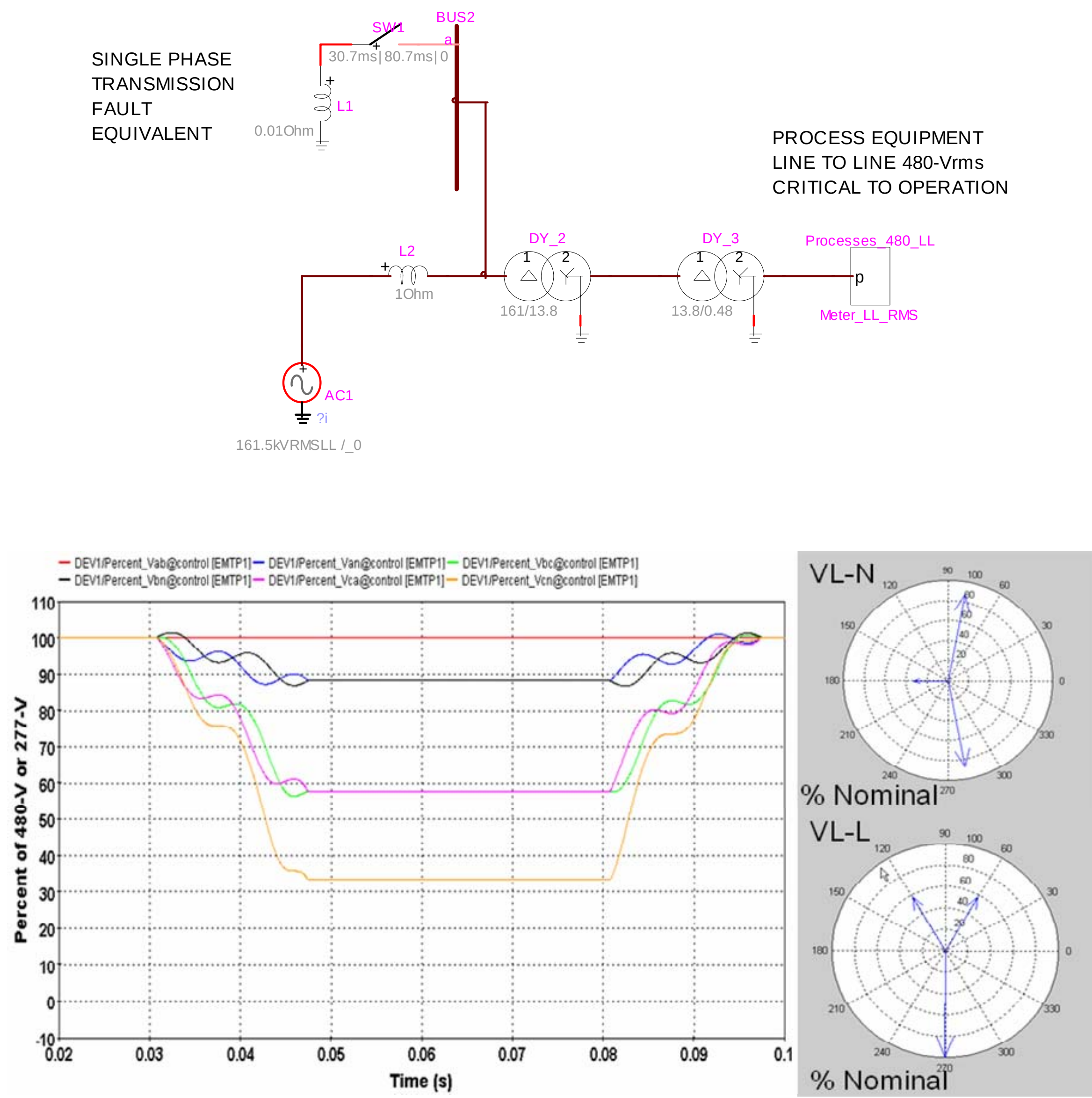

Figure 3-9
Voltage Sag at Utilization Voltage from Transmission System Fault (Phase A-G) [10]

The latest draft of IEEE P1668 contains a very useful table developed by the team members through simulations and collaboration. As shown in Table 3-2, this chart details the first and second transformation vector magnitudes that will occur from a single-phase line-ground fault (Phase A-G) on the transmission system. The table details what will be expected based on the various transformer configurations. It is important to note that some transformer combinations produce a higher secondary voltage after the second transformation than others.

Table 3-2
Approximate Secondary Transformer Voltages (pu) and Phase Angle from 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

Faults and Voltage Sags

The document addresses the relationship between voltage and current during voltage sag events. Distinction between the current relationship when there is a resistive load, a reactive load, and a non-linear load is discussed with example waveforms.

How Common are Voltage Sags?

An important aspect of the electrical environment section is to explain how frequent are voltage sags. The working group has included voltage sag statistics from EPRI DPQ II studies and information from the C4.110 working group on voltage sags.

This part of the electrical environment section begins with the discussion of how a fault at a particular location on an electrical system will cause voltage sag at a wide variety of locations. The discussion notes that the propagation of voltage sags is generally correlated to the topology or characteristics of the electrical system and the type of fault. It is noted that available capacity, configuration of transformer connections as well as line impedance are some of the characteristics that can vary substantially over the electrical system. An example of a bulk transmission loop fault and the voltage sags that would be measured at various locations on the transmission and distribution system is discussed through an example.

The discussion notes that the magnitude of a voltage sag is generally a function of the impedance between the monitoring point and the fault. The impedance is typically related to the length of the conductor or distance. Voltage division calculations based on conductor impedance are commonly used to assess voltage sags on radial systems. The propagation of voltage sags can be substantially affected by the system capacity or stiffness of the electrical system. An example is given of how an electrical system that includes multiple generators or includes a substantial transformer source can lessen the pervasiveness of voltage sags on the electrical system.

The text then discusses how the number of voltage sags can be affected by many causes, referencing EPRI Distribution Power Quality II (DPQII) report. DPQII indicates the relative order of importance of the causes of voltage sags that may include at least equipment failures, lightning flash density, tree limbs near power lines, animals, vehicles contacting power poles and inadequate ground resistance [12]. The cause of faults or voltage sags, though predominately weather, can be affected by maintenance of equipment by the utility, tree trimming and reducing access to animals and vehicles. Further, the extent a power system is underground can influence the rate of voltage sag occurrence. The section references the Annual Average Rate of Voltage Sags noted in DPQ II and the SARFI Voltage sag Indices from the 500 site database as shown in Table 3-3 and Table 3-4.

Table 3-3
Summary of Sags and Interruptions Per Site Per 365 Days [12]

Average Yearly Rate	All Sites
Interruptions (V<10%)	0.83
Sags (10%<V<85%)	26.83
Sags and Interruptions	27.66

Table 3-4
Yearly SARFI Rates per Site (Various Aggregation Periods, All Sites, All Days) [12]

Aggregation Period	SARFI-70	SARFI-50	SARFI-10	SARFI-ITIC	SARFI-SEMI
60 Seconds	13.69	5.74	0.91	13.91	8.29
5 Minutes	13.02	5.49	0.83	13.17	7.81
1 day	9.84	4.49	0.62	9.84	5.95

Figure 3-10 is a graph from the C4.110 working group discussed in Chapter 2 of this report. The IEEE 1668 group is working with the C4.110 group to collaborate where possible and make the best use of common data. The C4.110 group has collected a large amount of voltage sag data in order to determine the voltage sag and interruption environment (See discussion on Voltage Dip Statistics in Chapter 2 of this report). The graph from the C4.110 group illustrates a plurality of contours for Type I (single-phase) voltage sags which are plotted in reference to percent residual voltage and duration in milliseconds on the vertical and horizontal axes, respectively. Each numbered contour indicates the number of voltage sags per year that will occur in a particular region. For instance, in the example below, only one sag per site per year is expected to fall in the region below or to the right of the contour chart line labeled “1”. Likewise, up to 15 events per site per year is possible during which the voltage sag depth and duration falls below or to the right of the line labeled “15”. The contour chart is derived from a database that includes voltage sags from 647 sites and 16013 events.

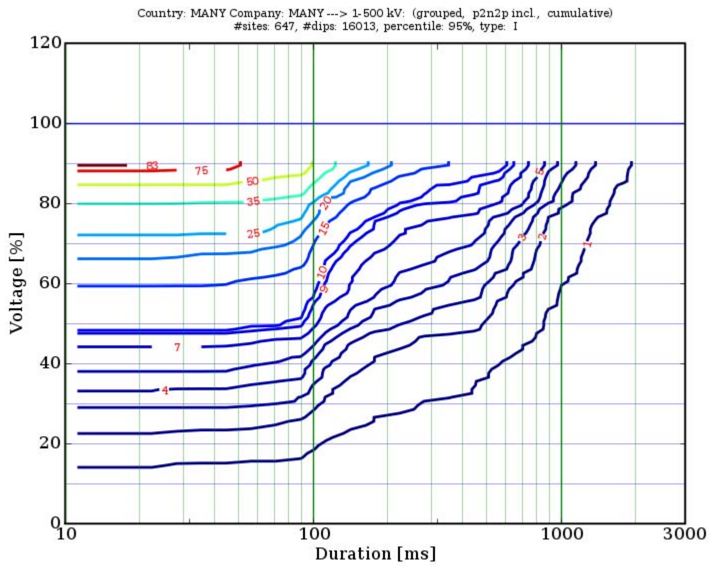

Figure 3-10
Example Voltage Sag Contour Chart 1-500KV Networks from CIGRE [13]

The final portion in Section 5 of the IEEE 1668 draft document continues with further illustrations from DPQ II including the histograms of voltage sag magnitudes, the breakout of single-, two-, and three-phase events from the DPQII data, and the percent of residual voltage remaining by the type of fault (single-, two-, and three-phase) as shown in Figure 3-11. In the figure below, single-phase sags dominate over a range of residual voltages from about 85 percent to about 20 percent. Therefore, single-phase voltage sags are more common and generally not deep. The IEEE 1668 draft notes that the impact of voltage sags originating from a single-phase fault upon a customer’s equipment can depend on the particular phase or line exposed to the fault and which line or lines are connected to the equipment. It is discussed that this can explain why only a portion of the customer’s equipment may be affected, while other equipment may not be impacted by a voltage sag of the same magnitude and duration. The discussion also notes that three-phase voltage sags are less common but deeper and dominate over a residual voltage of about 20 percent down to about 5 percent and that two-phase voltage sags are generally the least common and do not dominate over any particular range of residual voltage.

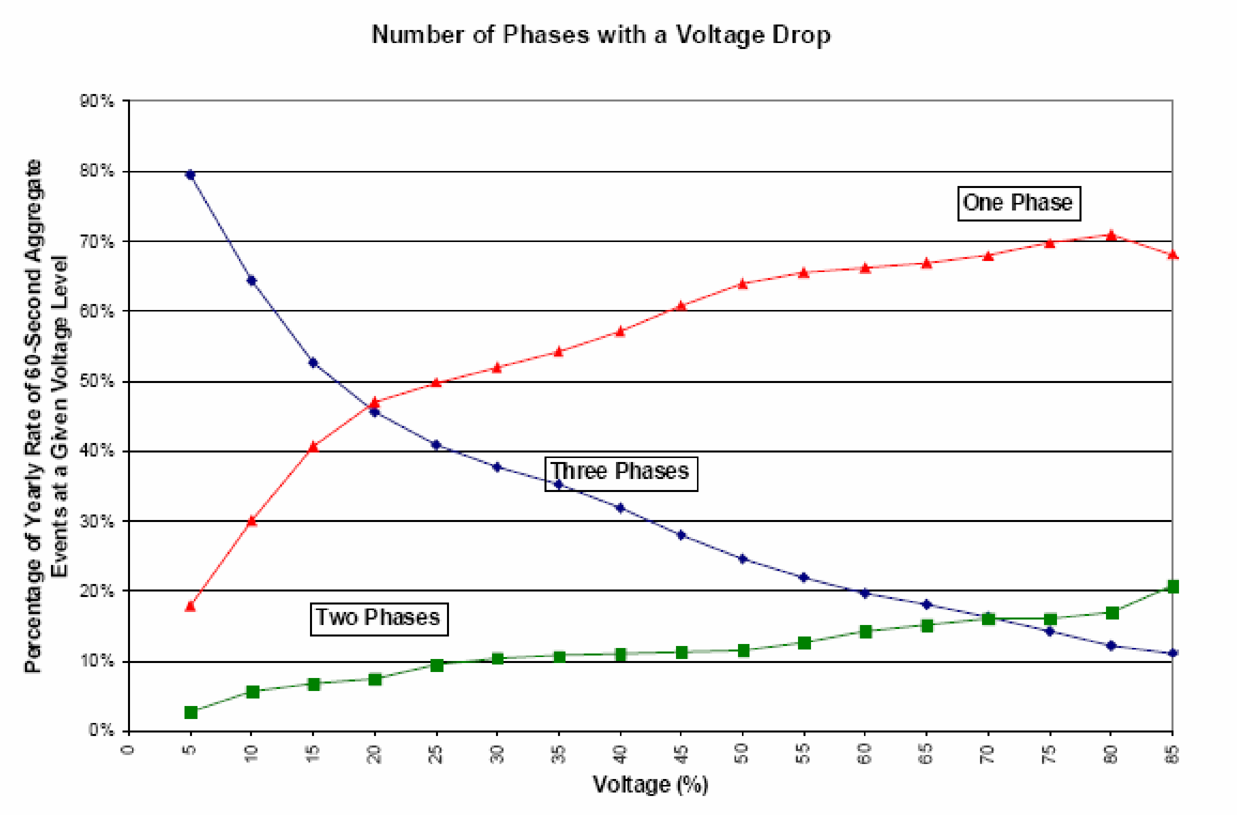

Figure 3-11
Percent Residual Voltage by Type of Fault [10,12]

4

IEEE COLOR BOOKS MEETINGS UPDATE

During the year 2008 the IEEE Colors Books revision activities have begun to move forward with the effort to revise new content by subject matter as opposed to book by book. The IEEE's Industrial Applications Society has determined a need for reorganizing the IEEE's Color Books Series, 13 books that currently cover various topics that fall under the purview of the Industrial and Commercial Power Industry. This comprehensive initiative, driven by the volunteer leadership of I&CPS, acknowledges that the continued and long-term maintenance of IEEE's Color Books has been affected by significant attrition due to declining volunteer resources, the complexity involved in updating each book, and content duplication among the books. The existing content will be integrated into a newly proposed structure by technical topics that will allow for easy updating, more streamlined content, and elimination of duplicative material.

The overarching objective of this work is to create 'virtual' electronic content that can be turned around in a matter of months and delivered in electronic format, thereby eliminating the challenges with the normal seven plus year iteration between book updates and the discrepancies in content that sometimes exists between the various books.

Breakdown of the Revision Effort

To accomplish the broad yet achievable goals of consolidation and update of the color book content, the work has been split up amongst seven different groups of technical experts and each of these groups has been designated as an official working group under the IEEE Technical Books Coordinating Committee.

The seven working groups are as follows:

- Power Systems Design WG – Chair: Peter Sutherland – E-Mail: peter.sutherland@ge.com
- Power Systems Analysis WG – Chair: Farrokh Shokooh – E-Mail: farrokh@etap.com
- Power Systems Grounding WG – Chair: Doug Dorr – E-Mail: d.dorr@ieee.org
- Protection and Coordination WG – Chair: Rasheek Rifaat – E-Mail: Rasheek.Rifaat@jacobs.com
- Emergency and Stand-By Power Systems WG – Chair: Joe Weber – E-Mail: Joe.Weber@emerson.com
- Power Systems Reliability WG – Chair: Robert Arno – E-Mail: rarno@eypmcf.com
- Maintenance, Operations, and Safety WG – Chair: Dennis Neitzel – E-Mail: Dennis.Neitzel@avotraining.com

Each working group has been assigned five to ten specific subjects where that group is responsible for the material and content update. The breakdown of the subject matter and responsibility is shown in the following seven tables:

Table 4-1
Power Systems Design Editorial Working Group Subject Matter Responsibility

Index	Title	Scope Statement
1	Recommended Practice for the Planning of Industrial and Commercial Power Systems (3001.1)	This recommended practice covers the planning of electrical systems in industrial and commercial facilities. It is likely to be of greatest value to the power-oriented engineer with limited experience with such systems. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
2	Recommended Practice for Evaluating the Electrical Service Requirements of Industrial and Commercial Power Systems (3001.2)	This recommended practice covers the evaluation of electrical service requirements of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience with such requirements. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
3	Recommended Practice for the Design of Industrial and Commercial Power Systems (3001.3)	This recommended practice covers the design of electrical systems in industrial and commercial facilities. It is likely to be of greatest value to the power-oriented engineer with limited experience with such systems. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
4	Recommended Practice for Estimating the Costs of Industrial and Commercial Power Systems (3001.4)	This recommended practice describes how to estimate the costs of industrial and commercial power systems, both new and those undergoing expansion or modernization. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
5	Recommended Practice for the Application of Power Distribution Apparatus in Industrial and Commercial Power Systems (3001.5)	This recommended practice covers the selection and application of power distribution apparatus used in industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience with this equipment. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
6	Recommended Practice for the Expansion, Modernization, and Rehabilitation of Industrial and Commercial Power Systems (3001.6)	This recommended practice covers the expansion, modernization, and rehabilitation of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.

Index	Title	Scope Statement
7	Recommended Practice for the Application of Communication and Signaling Systems used in Industrial and Commercial Power Systems (3001.7)	This recommended practice covers the selection and application of communications and signaling systems used in industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience with this equipment. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
8	Recommended Practice for the Instrumentation and Metering of Industrial and Commercial Power Systems (3001.8)	This recommended practice covers the instrumentation and metering of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience with this equipment. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
9	Recommended Practice for the Lighting of Industrial and Commercial Facilities (3001.9)	This recommended practice covers the lighting of industrial and commercial facilities. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
10	Recommended Practice for Electric Space Conditioning of Industrial and Commercial Facilities (3001.10)	This recommended practice covers the electric space conditioning of industrial and commercial facilities. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
11	Recommended Practice for the Application of Controllers and Automation to Industrial and Commercial Power Systems (3001.11)	This recommended practice covers the selection and application of controllers and automation to industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience with this equipment. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.

Table 4-2
Power Systems Analysis Editorial Working Group Subject Matter Responsibility

Index	Title	Scope Statement
12	Recommended Practice for the Modeling and Simulation of Industrial and Commercial Power Systems as a Precursor to Conducting System Studies (3002.1)	This recommended practice describes how to create and maintain simulation models of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
13	Recommended Practice for Conducting Load-Flow Studies of Industrial and Commercial Power Systems (3002.2)	This recommended practice describes how to conduct load-flow studies of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
14	Recommended Practice for Conducting Short-Circuit Studies of Industrial and Commercial Power Systems (3002.3)	This recommended practice describes how to conduct short-circuit studies of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
15	Recommended Practice for Conducting Device Short-Circuit Duty Calculations in Industrial and Commercial Power Systems (3002.4)	This recommended practice describes how to conduct device short-circuit duty calculations in industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
16	Recommended Practice for Conducting Arc-Flash Analyses on Industrial and Commercial Power Systems (3002.5)	This recommended practice describes how to conduct arc-flash analyses of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
17	Recommended Practice for Conducting Transient Stability Studies of Industrial and Commercial Power Systems (3002.6)	This recommended practice describes how to conduct transient stability studies of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.

Index	Title	Scope Statement
18	Recommended Practice for Conducting Motor-Starting Studies in Industrial and Commercial Power Systems (3002.7)	This recommended practice describes how to conduct motor-starting studies of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
19	Recommended Practice for Conducting Harmonic-Analysis Studies of Industrial and Commercial Power Systems (3002.8)	This recommended practice describes how to conduct harmonic analysis studies of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
20	Recommended Practice for Conducting Switching-Transient Studies of Industrial and Commercial Power Systems (3002.9)	This recommended practice describes how to conduct switching-transient studies of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
21	Recommended Practice for Conducting Cable-Ampacity and Sizing Studies of Industrial and Commercial Power Systems (3002.10)	This recommended practice describes how to conduct cable ampacity and sizing studies of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
22	Recommended Practice for Analyzing Voltage Sags in Industrial and Commercial Power Systems (3002.11)	This recommended practice describes how to analyze voltage sags in industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
23	Recommended Practice for Analyzing DC Auxiliary and Battery Systems for Industrial and Commercial Power Systems (3002.12)	This recommended practice describes how to analyze DC auxiliary and battery systems for industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.

Table 4-3
Power Systems Grounding Editorial Working Group Subject Matter Responsibility

Index	Title	Scope Statement
24	Recommended Practice for the System Grounding of Industrial and Commercial Power Systems (3003.1)	This recommended practice covers the system grounding of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
25	Recommended Practice for Equipment Grounding and Bonding in Industrial and Commercial Power Systems (3003.2)	This recommended practice covers the grounding and bonding of equipment in industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
26	Recommended Practice for Static-Discharge Protection Grounding of Industrial and Commercial Power Systems (3003.3)	This recommended practice covers the grounding of industrial and commercial power systems to achieve protection from static discharges. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
27	Recommended Practice for Lightning Protection Grounding of Industrial and Commercial Power Systems (3003.4)	This recommended practice covers the grounding of industrial and commercial power systems to achieve protection from lightning. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
28	Recommended Practice for the Powering and Grounding of Electronic Equipment in Industrial and Commercial Power Systems (3003.5)	This recommended practice covers the powering and grounding of electronic equipment used in industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.

Table 4-4
Power Systems Protection and Coordination Editorial Working Group Subject Matter Responsibility

Index	Title	Scope Statement
29	Recommended Practice for the Application of Instrument Transformers in Industrial and Commercial Power Systems (3004.1)	This recommended practice covers the selection and application of instrument transformers used in industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience with this equipment. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
30	Recommended Practice for the Application of Protective Relays in Industrial and Commercial Power Systems (3004.2)	This recommended practice covers the selection and application of protective relays used in industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience with this equipment. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
31	Recommended Practice for the Application of Low-Voltage Fuses in Industrial and Commercial Power Systems (3004.3)	This recommended practice covers the selection and application of low-voltage fuses used in industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience with this equipment. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
32	Recommended Practice for the Application of Medium- and High-Voltage Fuses in Industrial and Commercial Power Systems (3004.4)	This recommended practice covers the selection and application of medium- and high-voltage fuses used in industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience with this equipment. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
33	Recommended Practice for the Application of Low-Voltage Circuit Breakers in Industrial and Commercial Power Systems (3004.5)	This recommended practice covers the selection and application of low-voltage circuit breakers used in industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience with this equipment. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
34	Recommended Practice for Ground-Fault Protection of Industrial and Commercial Power Systems (3004.6)	This recommended practice covers the protection of industrial and commercial power systems from ground faults. It is likely to be of greatest value to the power-oriented engineer with limited experience in the area of protection and control. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.

Index	Title	Scope Statement
35	Recommended Practice for Conductor Protection in Industrial and Commercial Power Systems (3004.7)	This recommended practice covers the protection of conductors and cables used in industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in the area of protection and control. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
36	Recommended Practice for Motor Protection in Industrial and Commercial Power Systems (3004.8)	This recommended practice covers the protection of motors used in industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in the area of protection and control. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
37	Recommended Practice for Transformer Protection in Industrial and Commercial Power Systems (3004.9)	This recommended practice covers the protection of transformers used in industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in the area of protection and control. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
38	Recommended Practice for Generator Protection in Industrial and Commercial Power Systems (3004.10)	This recommended practice covers the protection of generators used in industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in the area of protection and control. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
39	Recommended Practice for Bus and Switchgear Protection in Industrial and Commercial Power Systems (3004.11)	This recommended practice covers the protection of bus and switchgear used in industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in the area of protection and control. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
40	Recommended Practice for Service Supply Line Protection in Industrial and Commercial Power Systems (3004.12)	This recommended practice covers the protection of the service supply line or lines feeding industrial and commercial facilities (i.e., the utility / power-user interface). It is likely to be of greatest value to the power-oriented engineer with limited experience in the area of protection and control. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
41	Recommended Practice for Overcurrent Coordination of Industrial and Commercial Power Systems (3004.13)	This recommended practice covers how to selectively coordinate overcurrent protective devices used in industrial and commercial facilities. It is likely to be of greatest value to the power-oriented engineer with limited experience in the area of protection and control. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.

Table 4-5
Power Systems Emergency and Standby Power Systems Editorial Working Group Subject Matter Responsibility

Index	Title	Scope Statement
42	Recommended Practice for Determining the Need for Emergency and Stand-By Power Systems in Industrial and Commercial Facilities (3005.1)	This recommended practice describes how to determine the need for emergency and stand-by power systems in industrial and commercial facilities. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
43	Recommended Practice for the Application of Generator Systems for use in Emergency and Stand-By Power Systems (3005.2)	This recommended practice covers the selection and application of emergency and stand-by generator systems for industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience with this equipment. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
44	Recommended Practice for the Application of Stored-Energy Systems for use in Emergency and Stand-By Power Systems (3005.3)	This recommended practice covers the selection and application of stored-energy systems for industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience with this equipment. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
45	Recommended Practice for Improving the Reliability of Emergency and Stand-By Power Systems (3005.4)	This recommended practice describes how to improve the reliability of emergency and stand-by power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
46	Recommended Practice for the Energy Management of Industrial and Commercial Power Systems (3005.5)	This recommended practice covers the selection and application of energy-management tools, techniques, and equipment to industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
47	Recommended Practice for the Energy Management of Motors, Electrical Equipment, and Lighting Systems in Industrial and Commercial Power Systems (3005.6)	This recommended practice covers the selection and application of energy-management tools, techniques, and equipment to motors, electrical equipment and lighting systems found in industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.

Index	Title	Scope Statement
48	Recommended Practice for the Application of Metering for Energy Management of Industrial and Commercial Power Systems (3005.7)	This recommended practice covers the application of metering for the energy-management of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
49	Recommended Practice for the Application of Distributed Generation to Industrial and Commercial Power Systems (3005.8)	This recommended practice covers the application of distributed generation to industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.

Table 4-6
Power Systems Reliability Editorial Working Group Subject Matter Responsibility

Index	Title	Scope Statement
50	Recommended Practice for Reliability Planning and Design of Industrial and Commercial Power Systems (3006.1)	This recommended practice covers reliability planning and design of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in the area of reliability. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
51	Recommended Practice for Evaluating the Reliability of Existing Industrial and Commercial Power Systems (3006.2)	This recommended practice describes how to evaluate the reliability of existing industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in the area of reliability. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
52	Recommended Practice for Determining the Impact of Preventive Maintenance on the Reliability of Industrial and Commercial Power Systems (3006.3)	This recommended practice describes how to determine the impact of preventive maintenance on the reliability of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in the area of reliability. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
53	Recommended Practice for Determining the Impact of Emergency and Standby Power Systems on the Reliability of Industrial and Commercial Power Systems (3006.4)	This recommended practice describes how to determine the impact of emergency and standby power systems on the reliability of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in the area of reliability. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
54	Recommended Practice for the Use of Probability Methods for Conducting a Reliability Analysis of Industrial and Commercial Power Systems (3006.5)	This recommended practice describes how to use probability methods for conducting a reliability analysis of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in the area of reliability. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
55	Recommended Practice for Reliability Compliance Testing of Emergency and Standby Power Systems (3006.6)	This recommended practice covers compliance testing of emergency and standby power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in the area of reliability. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.

Index	Title	Scope Statement
56	Recommended Practice for Determining the Reliability of "7 x 24" Continuous Power Systems in Industrial and Commercial Facilities (3006.7)	This recommended practice describes how to determine the reliability of “7 x 24” continuous power systems in industrial and commercial facilities. It is likely to be of greatest value to the power-oriented engineer with limited experience in the area of reliability. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
57	Recommended Practice for Analyzing Reliability Data for Equipment Used in Industrial and Commercial Power Systems (3006.8)	This recommended describes how to analyze reliability data for equipment used in industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in the area of reliability. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.
58	Recommended Practice for Collecting Data for Use in Reliability, Availability, and Maintainability Assessments of Industrial and Commercial Power Systems (3006.9)	This recommended practice describes how to collect data for use in reliability, availability, and maintainability assessments of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in the area of reliability. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.

Table 4-7
Power Systems Maintenance, Operations and Safety Editorial Working Group Subject Matter Responsibility

Index	Title	Scope Statement
59	Recommended Practice for the Operation and Management of Industrial and Commercial Power Systems (3007.1)	This recommended practice covers the operation and management of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the operation and maintenance of industrial and commercial power systems.
60	Recommended Practice for the Maintenance of Industrial and Commercial Power Systems (3007.2)	This recommended practice covers the maintenance of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the maintenance of industrial and commercial power systems.
61	Recommended Practice for Electrical Safety in Industrial and Commercial Power Systems (3007.3)	This recommended practice covers all aspects of electrical safety in industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the development of electrical safety operating practices and procedures for use in industrial and commercial power systems.

Power Quality Specific Related Content

This section provides more extensive detail on the power quality related efforts as that is of high interested to the EPRI program sponsors.

Regarding the PQ materials, there was a substantial discussion on the overall IEEE technical books revision plan as well as the many-many possible ways to proceed with updating the power quality materials in the existing color books – (primarily the Emerald Book, but some Red, Green and Orange Book overlap). The salient points of the working group discussions on this effort are captured in the following summary along with future action items:

1. Instead of a single PAR covering all PQ topics (more than 800 pages of content) the WG will ultimately include at least 4 PARs to break the material up and make it easier to get the work accomplished in a timely manner.
2. Each PAR submitted will be tied the creation of a task force (TF) that reports to the Grounding Editorial Working Group. The TF will be responsible for identifying materials to update and for the revision of those materials in a timely manner. Each TF will have a TF Chair responsible for meeting the development timelines.
3. First two PARs (for starters) to be submitted will be:
   - General Needs/Guidelines – TF chair TBD
   - Power Conditioning Equipment and Specifications – TF Chair Tom Gruzs

4. Third and fourth PARs that will be submitted once the first two sections are done will most likely be:
    - Site Surveys-Equipment-Case Studies – TF chair TBD
    - Recommended Design/Installation/Application Practices – TF chair TBD
5. It is anticipated that the existing color books will be orderable for the foreseeable future, but the grounding working group update effort will not impact the actual book as published – but will instead create revised/updated content and subject matter that is independent of the media (book, web content, CD, or other)
6. IEEE has not yet supplied guidance on how the new content will need to be indexed (keywords, metatags, wikipedia style, etc.) so the preliminary objective is to create content that flows in a systematic and logical progression. For example the General Needs/Guidelines material that is developed will likely be created similar to a web report, where the table of contents or headings and subheadings are clickable links and each topic that is discussed at a high level (such as Sags, Transients, Ground Loops etc..) would be clickable to provide the more detailed descriptions and support material/references. One could envision that the existing Emerald Book could practically be converted to this format.
7. Overall summary…….the revision objective is to:
    - Update Existing Content to the state of the art for 2010 era
    - Consolidate where multiple color books discuss similar or identical subject matter
    - Break up the efforts so subject matter can be revised and balloted much more quickly and efficiently than in the past.

5
FUTURE WORK

In 2008, EPRI participated in both the CIGRE C4.110 and IEEE P1668 efforts and worked on the IEEE color book revision efforts. As the CIGRE C4.110 work is in the final stages in January 2009, there is a significant opportunity to make future IEC and IEEE standards converge. The IEEE group has begun direct collaboration with the CIGRE group this year offering cross-input to one another. As the end goal of EPRI's work is to promote system compatibility, the output of the IEEE P1668 and C4.110 groups will ultimately lead to the creation of an IEEE Recommended Practice that will be in line with the recommended changes in the IEC 61000-4-34 and SEMI F47 standards. The inclusion of three-phase sags and realistic test vectors will promote further compatibility with the electrical environment. EPRI and member utilities should continue to strive towards the development of the IEEE P1668 in 2009 to develop the draft standard for balloting. The development of a strong IEEE standard is likely to have far-reaching effects throughout all manufacturing industries as it would be a generic standard rather than having an industry specific focus.

6
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