

IEEE Recommended Practice for Evaluating Electric Power System Compatibility With Electronic Process Equipment

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Abstract: A standard methodology for the technical and financial analysis of voltage sag compatibility between process equipment and electric power systems is recommended. The methodology presented is intended to be used as a planning tool to quantify the voltage sag environment and process sensitivity. It shows how technical and financial alternatives can be evaluated. Performance limits for utility systems, power distribution systems, or electronic process equipment are not included.

Keywords: power quality, power quality monitoring, sensitive equipment, voltage loss, voltage sags

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Introduction

(This introduction is not part of IEEE Std 1346-1998, IEEE Recommended Practice for Evaluating Electric Power System Compatibility With Electronic Process Equipment.)

The proliferation of microprocessors and power electronics in commercial and industrial facilities has greatly increased the financial losses of power quality to business. There are no large-scale studies on the cost of power quality to business. However, estimates of the cost range up to tens of billions of dollars (U.S.) each year in the U.S. alone due to inattention to compatibility. Before electronics invaded lighting, machine tools, and heating and cooling equipment, power compatibility meant verifying that the equipment nameplate voltage and frequency were consistent with the supply. Unfortunately, the electronics in today's equipment that provide expanded features and flexibility demand more careful attention to their application with the power system.

Traditionally, power quality has focused on the technical issues associated with the electric supply. The emphasis has been on fixing existing problems rather than preventing future problems. This document recommends a method to evaluate the power quality environment and process sensitivity. First, a method to determine the financial loss due to the disruption is presented. Then a method for determining the annual number of power quality related disruptions is provided. From that information, the financial cost of compatibility can be found and alternatives to reduce the loss can be evaluated.

The Working Group on Evaluating Electric Power System Compatibility with Electronic Process Equipment, which undertook the development of this recommended practice, had the following membership:

Van Wagner, *Chair and Technical Editor*

Larry Morgan, *Secretary*

Industry Applications Society Working Group Members

Robert Beaker
Math Bollen
William Bush
Edward Cantwell
Randy Collins
Douglas Dorr
Bruce Douglas
Dennis Emerson
Richard Epperly
Norman Fowler
Dave Gulachenski
Erling Hesla
Tim Hostetler

Robert J. Kretschmann
Blane Leuschner
Philip Lim
J. Michael Liptak
Jim Lousier
Daniel Love
Steve McCluer
Reginald Mendis
Ken Michaels
Steve Miller
Robert Morgan
Bill Moylan
John Mungenast
Jun Qui

Steven Rossiter
Donald Ruthman
Hector Sarmiento
Lynn Saunders
David Shipp
Mike Simon
Ronald Smith
John Sullivan
Stephanie Takai
Annette Van Jouanne
Marek Waclawiak
Al Warner
Donald W. Zipse

Power Engineering Society Working Group Members

Reuben F. Burch, IV
Larry Conrad
John Csomay
Robert Gilleskie
Joe Groesch
Gil Hensley
John A. Kennedy
David Kreiss

Paul Krischiunas
Mike Lowenstein
Chris Melhorn
Bill Moncrief
Allen Morinec
Ram Mukherji
Ed Owen

Brian Prokuda
Melissa Reading
D. Daniel Sabin
Murray Slater
Rao Thallam
Tim Unruh
David Vannoy
Cheri Warren

The following individuals provided substantial contributions to the development of this recommended practice:

<i>Overview</i> Van Wagner	<i>Annex A, Financial evaluation</i> Stephanie Takai Van Wagner Ronald Smith	<i>Annex D, Constructing coordination charts</i> Larry Conrad Math Bollen
<i>Definitions</i> Van Wagner		
<i>Compatibility evaluation</i> Larry Conrad Larry Morgan	<i>Annex B, Power system performance</i> Joseph Groesch Larry Conrad	<i>Annex E, Example</i> Van Wagner Larry Morgan
	<i>Annex C, Equipment performance</i> Robert Kretschmann Douglas Dorr	

The following persons were on the balloting committee:

Reuben F. Burch, IV Larry Conrad Joe M. Craven Paul T. Finlayson Ronald E. Ghizzoni Gilbert C. Hensley John A. Kennedy	Robert J. Kretschmann Cory Lemerande J. Michael Liptak Walter A. Maslowski Brian Prokuda D. Daniel Sabin Philip C. Sarikas	Lynn F. Saunders Michael E. Simon Anthony N. St. John W. L. Stebbins Richard H. Temple David Vannoy Thomas J. Woginrich
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The final conditions for approval of this standard were met on 5 May 1998. This standard was conditionally approved by the IEEE Standards Board on 19 March 1998, with the following membership:

Richard J. Holleman, <i>Chair</i>	Donald N. Heirman, <i>Vice Chair</i>	
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*Member Emeritus

Kristin M. Dittmann
IEEE Standards Project Editor

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IEEE Recommended Practice for Evaluating Electric Power System Compatibility With Electronic Process Equipment

1. Overview

1.1 Purpose

The purpose of this document is to recommend a standard methodology for the technical and financial analysis of compatibility of process equipment with an electric power system.

This recommended practice does not intend to set performance limits for utility systems, power distribution systems, or electronic process equipment. Rather, it shows how the performance data for each of these entities can be analyzed to evaluate their compatibility as a system in financial terms. The recommended methodology also provides standardization of methods, data, and analysis of power systems and equipment in evaluating compatibility so that compatibility can be discussed from a common frame of reference.

1.2 Scope

This recommended practice is intended to be applied at the planning or design stage of a system where power supply and equipment choices are still flexible and incompatibilities can be resolved. The cost of trying to fix an incompatible system after installation is hundreds to thousands of times more than addressing it in the planning stage. Consequently, this document does not discuss troubleshooting or correcting existing power quality problems.

Since voltage sags present the greatest financial loss due to compatibility, this first edition of the recommended practice develops a compatibility methodology specifically for voltage sags. However, compatibility encompasses many other issues such as harmonics, surges, radiated interference, etc. As better information is available on the environment/equipment response and experience is gained with this approach, compatibility methodologies will be developed for other issues. To aid the evaluation of the non-sag compatibility issues, a guideline list is included in 4.3.

This recommended practice does not discuss technical options to improve compatibility. The alternatives are so numerous and evolving so quickly that such a listing would detract from the basic purpose of the document, which is to plan for compatibility.

Clause 4 is the heart of the document and contains the worksheets used for evaluating compatibility. Completed worksheets provide an estimate of the number of disruptions, the financial loss, and financial analysis of alternatives associated with the compatibility of a system. The annexes provide the background and techniques necessary to apply the worksheets. They are financial analyses, power system performance, equipment performance, and constructing the compatibility charts. An example analysis is provided in Annex E.

2. References

This recommended practice shall be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply:

IEC 61000-4-11 (1994), Electromagnetic compatibility (EMC)—Part 4: Testing and measuring techniques—Section 11: Voltage dips, short interruptions and voltage variations.¹

IEEE Std 100-1996, IEEE Standard Dictionary of Electrical and Electronics Terms, 6th Edition.²

IEEE Std 1159-1995, IEEE Recommended Practice for Monitoring Electric Power Quality.

IEEE Std 1250-1995, IEEE Guide for Service to Equipment Sensitive to Momentary Voltage Disturbances.

3. Definitions

3.1 Technical terms used in this recommended practice

3.1.1 dip: *See sag.*

3.1.2 dropout voltage: The voltage at which a device will release to its de-energized position (for this document, the voltage at which a device fails to operate).

3.1.3 interruption, momentary (power quality monitoring): A type of short duration variation. The complete loss of voltage (<0.1 pu) on one or more phase conductors for a time period between 0.5 cycles and 3 s.

3.1.4 interruption, sustained (power quality monitoring): A type of long duration variation. The complete loss of voltage (<0.1 pu) on one or more phase conductors for a time greater than 1 min.

3.1.5 interruption, temporary (power quality monitoring): A type of short duration variation. The complete loss of voltage (<0.1 pu) on one or more phase conductors for a time period between 3 s and 1 min.

3.1.6 momentary (power quality monitoring): When used as a modifier to quantify the duration of a short duration variation, refers to a time range at the power frequency from 30 cycles to 3 s.

¹IEC publications are available from IEC Sales Department, Case Postale 131, 3, rue de Varembe, CH-1211, Genève 20, Switzerland/Suisse. IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

²IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

3.1.7 noise: Unwanted electrical signals in the circuits of the control systems in which they occur. (For this document, “control systems” is intended to include sensitive electronic equipment in total or in part.)

3.1.8 nominal voltage (V_n): A nominal value assigned to a circuit or system for the purpose of conveniently designating its voltage class (as 208/120, 480/277, 600).

3.1.9 notch: A switching (or other) disturbance of the normal power voltage waveform, lasting less than 0.5 cycles, which is initially of opposite polarity than the waveform and is thus subtracted from the normal waveform in terms of the peak value of the disturbance voltage. This includes complete loss of voltage for up to 0.5 cycles.

3.1.10 oscillatory transient: A sudden, nonpower frequency change in the steady-state condition of voltage or current that includes both positive or negative polarity value.

3.1.11 overvoltage: When used to describe a specific type of long duration variation, refers to a measured voltage having a value greater than the nominal voltage for a period of time greater than 1 min. Typical values are 1.1 to 1.2 pu.

3.1.12 phase shift: The displacement in time of one waveform relative to another of the same frequency and harmonic content.

3.1.13 sag: A decrease in rms voltage or current at the power frequency for durations of 0.5 cycle to 1 min. Typical values are 0.1 to 0.9 pu. *Note:* To give a numerical value to a sag, the recommended usage is “a sag to 20%,” which means that the line voltage is reduced down to 20% of the normal value, not reduced by 20%. Using the preposition “of” (as in “a sag of 20%,” or “a 20% sag”) is deprecated.

3.1.14 sustained: When used to quantify the duration of a voltage interruption, refers to the time frame associated with a long duration variation (i.e., greater than 1 min).

3.1.15 swell: An increase in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 min. Typical values are 1.1 to 1.8 pu.

3.1.16 transient: Pertaining to or designating a phenomenon or a quantity which varies between two consecutive steady states during a time interval that is short compared to the time scale of interest. A transient can be a unidirectional impulse of either polarity or a damped oscillatory wave with the first peak occurring in either polarity.

3.1.17 undervoltage: When used to describe a specific type of long duration variation, refers to a measured voltage having a value less than the nominal voltage for a period of time greater than 1 min. Typical values are 0.8–0.9 pu.

3.1.18 voltage dip: *See sag.*

3.1.19 voltage imbalance (unbalance), polyphase systems: The ratio of the negative or zero sequence component to the positive sequence component, usually expressed as a percentage.

3.2 Financial terms used in this recommended practice

3.2.1 bill of materials: A report showing the material costs of a single unit of product; listing of all unit components with part numbers, quantities, and supplier prices.

3.2.2 payback: A financial analysis technique where the cost to implement a project is compared to the annual savings due from the project.

3.2.3 unloaded labor rate: Variable costs of labor per hour, excluding all forms of benefits such as vacations, medical insurance, retirement, etc.

3.2.4 weighted average cost of capital: The average interest rate used in financial analysis by business for capital projects.

3.2.5 work in progress: Production units in a semifinished state, either being processed or waiting in buffer inventories between processing steps.

3.3 Abbreviations used in this recommended practice

ASD	adjustable speed drive
BIL	basic impulse level
BOM	bill of materials
EUT	equipment under test
MOV	metal oxide varistor
PLC	programmable logic controller
PWM	pulse-width modulation
WACC	weighted average cost of capital
WIP	work in progress

4. Compatibility evaluation

4.1 Introduction

This clause provides the charts that should be used for evaluating voltage sag compatibility. Instructions on how to gather the necessary data and apply the format are contained in the annexes. The content of the annexes is as follows:

- *Annex A, Financial evaluation*—A normative annex that discusses how to determine the cost of a process disruption and how to evaluate payback.
- *Annex B, Power system performance*—An informative annex that explains how to evaluate the voltage sag environment of the power supply system.
- *Annex C, Equipment performance*—An informative annex that describes how to evaluate the voltage sag susceptibility of process equipment.
- *Annex D, Constructing coordination charts*—A normative annex that shows how to apply the graphical procedure to determine the annual compatibility disruption rate.
- *Annex E, Example*—An informative annex that provides an example of the compatibility methodology applied to a fictitious system.

Equipment sensitivity guidelines are listed in 4.3 for discussion of a broader range of compatibility issues.

4.2 Compatibility templates

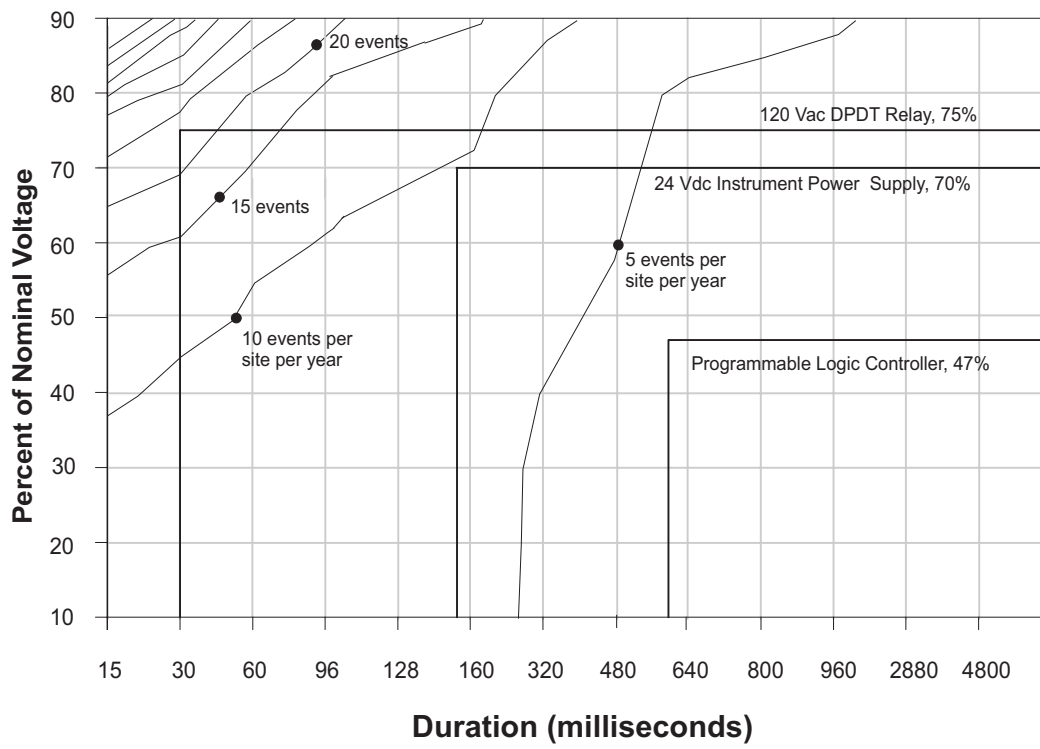


Figure 1—Sample overlay of sag environment and equipment susceptibilities

Investment	Return
One-time capital outlay	Annual benefit
+ Installation	– Ongoing annual expense
Net investment	Net annual return
Payback (months) = (net investment/net annual return) · 12	

Figure 2—Sample compatibility impact financial analysis form

4.3 Compatibility guidelines

This subclause provides a list of selected questions that may be posed to the equipment supplier during the review of equipment specifications. These guidelines are optional and are not part of this recommended practice.

- a) *How much can the supply voltage sag, and for how long, before equipment malfunctions?*
Inadequate: A fixed value of some magnitude (i.e., 20%–30%) with no mention of duration or unbalance.
Preferred: A valid example would be a graph showing both magnitude (from nominal to zero) and duration (from zero to seconds), voltage imbalance tolerance and point on wave tolerance. Onsite testing as a part of the acceptance testing of the installed complete machine can be part of the purchase contract.
- b) *What are the steady-state voltage tolerances?*
Inadequate: $\pm 5\%$. Typically tight tolerances of this nature are trying to improve ride-through characteristics using unrealistic criteria.
Preferred: Values can be a minimum of $\pm 10\%$ of the equipment rating. All machine components can be rated to the same value.
- c) *How long can zero voltage be tolerated?*
Inadequate: A time value without load or process dependency.
Preferred: Test results of the composite machine can be provided. Onsite tests as a part of the acceptance testing of the installed complete machine can be part of the purchase contract. Orderly shutdown is able to be maintained.
- d) *What is the machine's transient voltage withstand capability?*
Inadequate: The equipment is protected by MOV arresters with ____ joule of protection.
Preferred: The equipment has a fully coordinated transient suppression scheme as demonstrated by curves of let-through voltage per amp of transient energy vs. the withstand curves of electronic components and basic impulse level (BIL) of internal circuitry. This scheme is adequate in a Class B environment with grounding sufficient for a frequency range of 3 kHz to 1 GHz.
- e) *How much voltage distortion can the equipment tolerate?*
Inadequate: It meets all standards, such as IEEE Std 519-1992 [B22]³.
Preferred: Voltage distortion tolerance of $<10\%$, crest factor of <2.5 , and notching of $< __ \text{ V} \cdot \mu\text{s}$ can be tolerated without affecting the equipment.

³The numbers in brackets preceded by the letter B correspond to those of the bibliography in Annex F.

Annex A

(normative)

Financial evaluation

A.1 Introduction

This annex explains a method to evaluate and analyze the financial impact of compatibility. It is intended to be generic in coverage and does not necessarily represent any particular type of business. Although generic guidance is provided, the user should very carefully ensure that all applicable costs particular to the user's specific operation are identified if the analysis is to provide meaningful results. The method presented is intended to identify general costs associated with power quality disruptions and is not intended to function as an accounting system. In other words, for compatibility evaluation, it is only necessary to identify approximate losses. Determining accurate losses would be more appropriate after the magnitude of the problem is known and resources are available for further investigation.

A method to analyze the overall cost of compatibility is also presented based on simple payback. Individual businesses may have different methods or criteria than those presented here. However, it is intended to provide a technique that can quickly identify cost saving potentials associated with compatibility.

A.2 Cost of disruption

There are several suggestions to help assure a successful cost of disruption evaluation. First, involve everyone who is impacted by the disruption in estimating the loss. The most obvious are those familiar with the operational impact of equipment disruption such as front-line workers, supervisors, and maintenance technicians. The list should also include finance and accounting personnel who may have established methods of estimating financial losses associated with downtime. Sales and marketing personnel can represent the impact on customers and management can provide the longer-term, strategic consequences of disruptions. The evaluation requires a balance of both high-level and detailed perspectives. Data from the information tracking system of the business should be used wherever possible.

Second, if for some aspects of the analysis it is not possible to obtain documented costs, use the best estimate of someone experienced with the process. Their estimates are often later shown to be surprisingly accurate.

Finally, where the personnel involved are not sufficiently knowledgeable or objective to offer good estimates, observational sampling may be applied. Keep in mind this guideline is only intended to expose approximate costs.

The costs discussed here are listed in the cost of disruption evaluation form shown in Figure A.1. A separate tabulation should be generated for each compatibility evaluation.

A.2.1 Downtime related

A.2.1.1 Lost work

The product or service is not generated for a period of time until recovery is complete. A process flow of the product or service should be developed for the other supplied processes (either inside or outside the facility) or customers to determine when and how they are affected.