P1409 CUSTOM POWER TASK FORCE

TF 15.06.05.01

Meeting Minutes

IEEE PES 1997 Winter Meeting, New York, New York
Tuesday, February 4, 1997, 1:00 - 3:00 PM
Hilton Petit Trianon Conference Room

A meeting of the Custom Power Task Force was held prior to the Distribution Voltage Quality Working Group meeting at the 1997 Winter Power Meeting in New York. The meeting was chaired by Dan Sabin. The previous chair was Harshad Mehta, who stepped down as chairman of the task force prior to the February meeting. Dan Sabin previously had performed the role of task force secretary.

Welcome and PAR Update

As a first order of business, the chairman gave a short presentation to orient the new members of the group to the efforts of the task force during the past few years. His presentation stated that the task force focuses on custom power, which is the application of power electronic-based equipment on utility distribution systems to improve power quality and control. The technology is unique in its use of new high-powered semiconductors. The chairman stated that the primary purpose of P1409 is to develop an IEEE guide for the emerging technology of custom power which would provide guidelines and performance expectations, offer a resource to utilities in entering the competitive marketplace, and furnish detailed information about custom power devices as options to solving power quality problems. P1409 can also offer a forum for utilities to exchange information. Since the application of custom power devices is relatively new phenomena, P1409 can provide a clearing house of information related to research, installation and testing.

The chairman stated that the mission of P1409 is to ensure that the resulting guide is a benefit to utilities. The task force must balance the discussion to include all derivatives of the technologies being designed and implemented, encourage more constructive participation, and to coordinate with CIGRE’s new custom power working group (CIGRE WG 14.31).

At this point, Dan Ward of Virginia Power pointed out that the task force has discussed in the past the possibility of writing an IEEE special publication rather than an IEEE guide. He felt that opting for the special publication was a good idea because it would be easier than trying to have the guide published. If the task force worked to create a special publication, then a Project Authorization Request (PAR) form would not need to be submitted to the IEEE Standards Board New Standards Committee (NesCom). Jim

Burke of Power Technologies, the chairman of the IEEE Voltage Quality Working Group (WG 15.06.05) was in agreement with Dan Ward. However, Marek Waclawiak of United Illuminating felt that the original goal of the custom power task force – to write an IEEE guide – should still be pursued in order to make it easier to specify the requirements of custom power devices. A discussion ensued in which it became apparent that the group was divided between those in favor of producing an IEEE special publication and those in favor of a guide. No official vote was taken, but an informal show of hands make it clear that about one-third of the room wanted a guide, one-third wanted a special publication, and one-third was undecided. The chairman decided that it was best to leave this discussion open, to be resolved at a future meeting. This decision seemed to be reasonable because at this stage the work to produce a guide and the work to produce a special publication are the same.

Introductions

Introductions were made and a total of 64 people signed the attendance list, a summary of which is attached. Attendees were asked to update their addresses, phone numbers, etc., on the membership list passed around. The updated membership list is also attached. No members were downgraded from membership status to guest status at this time.

Minutes from Denver

The minutes prepared by Dan Sabin for the meeting of the P1409 task force at the 1996 IEEE PES Summer Meeting in Denver were reviewed. They were unanimously approved, though Marek Waclawiak noticed an error in the minutes regarding the installation of 50 Hz custom power devices at PSE&G. No such devices are, or course, being installed. The typographical error was noted and has been corrected in the on-line version of the minutes.

One of the action items from the last meeting was to establish an Internet homepage for the group. The page was placed on-line just prior to the meeting. Currently, the following information is available at the site:

- General information about P1409
- Archive of drafts of the P1409 Guide in Adobe Acrobat PDF format
- Announcements of meetings
- Latest version of the custom power technology development list
- Minutes and agendas from prior meetings in PDF format

An action item for the current meeting was to transfer the Internet site to the SPAsystem on the IEEE Standards Home Page. When that it done, it is expected that the homepage will be found at http://stdsbbs.ieee.org/groups/1409/index.html.

Custom Power Technology Development List

The list of utilities and organization who are currently testing, installing, or applying custom power devices was briefly reviewed. After the meeting, the chairman solicited updates to the list; the latest version is attached to these minutes.

Liaison Relationships

Mark McGranaghan pointed out that liaisons with no working groups had been established. He suggested that future agendas provide some time for liaison reports. During the course of the meeting, liaisons were requested with P1433*, A Standard Glossary of Power Quality Terminology*; CIGRE WG 14.31, *Custom Power Working Group*; and P1159.2, *Power Quality Event Characterization*. Identifying candidates for these liaisons will be the work of the task force chairman; final approval will occur at the next full meeting of the task force.

Draft of P1409 Guide

The first draft of the P1409 Guide was distributed at the meeting. It is also available from the site's Internet homepage. It represents a first attempt at collating and editing the input from the task force chapter chairmen from the last few meetings. Although not particularly succinct nor completely thorough, the document does represent a good beginning. The task force members were asked by the chairman to review the draft and return comments by March 4 to be included in draft 1.1 of the guide. They were asked to try to address comments on content, focus, concerns about proprietary technology, overlooked devices, topologies, etc. Task force members wishing to contribute suggested revisions and/or additions to individual chapters can do so by phone, fax, postal mail, or email. Contributions can be sent either to the chairmen responsible for individual chapters or to the task force chairman.

Chapter Chair Reports

The chapter chairman were asked to make short presentations on the work which they contributed to the first draft of P1409. These minutes focus on the discussion surrounding each chapter rather than on the presentations themselves, which are sufficiently summarized in the attached draft 1.0 of the document.

Definitions and Configurations/Objectives Chapters

Neil Woodley, Westinghouse Corporation

Specific editing requests we made for the definitions chapter. These changes made sense and will be incorporated for version 1.1 of the document.

General Needs

Dan Sabin, Electrotek Concepts, Inc.

Dan was asked to review the text in section 4.5 of draft 1.0. Larry Morgan felt that a revision in the logic of the section was in order. Dan was also asked to expand the table in section 4.4 of the guide to include more standard power quality solutions such as voltage regulators.

Input/Output

Stephen Middlekauff, Duke Power Company

Jim Crane of Commonwealth Edison offered to provide information for this chapter on his experience with static switches. A concern was raised concerning Figure 6.2.3 and 6.2.4, which shows per unitized voltage measurements. Two of the plots were expressed in instantaneous voltage, while two others were expressed in rms voltage. It was requested to make the distinction between the two types of plots clearer.

Performance Measurements

Mark McGranaghan, Electrotek Concepts, Inc.

In addition to performance results, Mark was requested by Larry Morgan to include both predicted and actual infant mortality rates for custom power devices.

Case Studies

Ashok Sundaram, Electric Power Research Institute

Ashok stated that he would focus on several case studies with custom power technology with which he has experience. He also solicited input from other members of the task force. Vladi Basch volunteered case studies performed by Baltimore Gas and Electric for this chapter.

Engineering Issues

Paul Stecuik, Power Technologies, Inc.

Paul was not present at the meeting. Jim Burke agreed that he would check into whether Paul could continue his role as the lead author of this chapter.

Bibliography

Vladi Basch, Baltimore Gas & Electric

Vladi asked that the task force members assist him in this section of the guide by ensuring that he not miss any important references.

Economic Assessment

Ram Mukherji, Consultant

Ram asked that the chairman provide him with some work performed by Electrotek Concepts on the economic assessment of an end-use device used to provide active line conditioning. Jim Burke volunteered a cost benefits analysis paper that he has written recently which should provide some good guidelines in writing this chapter of the guide. Some discussion at this time focused on whether or not this chapter should answer the question of who pays for this technology, perhaps by providing a business case example. Not all of the task force members embraced this suggestion. Some advice was given to look to market studies of the UPS market in writing this chapter.

New Business

Larry Morgan asked that the task force look into making a presentation at the October 1997 IEEE IAS meeting considering that the society has many members which could offer valuable input to this guide. He identified the Power Quality Working Group chaired by Reg Mendis of Cooper Power Systems as a possible audience. Based upon the approval of this action by the task force, the chairman agreed to look into it.

At the Voltage Quality Working Group Meeting following the task force meeting, Jim Burke asked if the P1409 wanted to participate in a panel discussion at the 1998 IEEE PES Winter Meeting in Tampa, Florida. Dan Sabin agreed to organize the panel discussion.

Action Items

ACTION	ASSIGNED TO:	TARGET COMPLETION DATE:
1. Comments by task force members	All Task Force Members	March 4, 1997
2. Revise and/or add to individual chapters	Guidebook Chapter Chairmen*	April 7, 1997
3. Complete draft 1.1 incorporating comments	TF Chairman	April 24, 1997
4. Move Internet homepage to IEEE SPAsystem™	TF Chairman	March 1, 1997
5. Organize a panel discussion for the 1998 IEEE PES Winter Meeting	TF Chairman	April 1, 1997
6. Investigate a presentation at the IEEE IAS Meeting	TF Chairman	April 1, 1997

Next Meeting

The next meeting of the Custom Power Task Force will be at the 1997 IEEE PES Summer Meeting in Berlin, Germany, which is from July 20 to 25. Because of the expected low attendance by task force members, this will not be working meeting involving action items but rather an informational meeting for the European community. Presentations on the work of the task force will be made.

The next full meeting of the task force will be at the IEEE PES Winter Meeting in Tampa, Florida, which meets from January 31 to February 5, 1998.

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* The Guidebook Chapter Chairmen are Neil Woodley, Dan Sabin, Larry Morgan, Stephen Middlekauff, Mark McGranaghan, Ashok Sundaram, Paul Stecuik, Vladi Basch, and Ram Mukherji.

Attachments

1. Meeting Agenda, Custom Power Task Force Winter 1997 Meeting
2. Meeting Attendance, Custom Power Task Force Winter 1997 Meeting
3. Most recent membership list for the Custom Power Task Force
4. P1409 Guide, Draft 1.0
5. Most recent copy of the Custom Power Technology Development List

Minutes Submitted by

D. Daniel Sabin
Task Force Chairman

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Meeting Agenda

IEEE PES 1997 Winter Meeting, New York, New York
Tuesday, February 4, 1997, 1:00 - 3:00 PM
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The Custom Power Task Force will meet next during the IEEE Power Engineering Society 1997 Winter Meeting in New York, New York. We will meet on Tuesday, February 4, 1997 1:00 to 3:00 PM in the Petit Trianon Conference Room of the Hilton Hotel. The meeting will review developments on the custom power task force guide book over the last six months.

1. Welcome .... Harshad Mehta

2. Introductions

3. Review minutes from Denver and agenda for present meeting .... Dan Sabin

4. Chairman's Report .... Dan Sabin

5. Guidebook Chair Reports
   Definitions .... Neil Woodley
   General Needs .... Dan Sabin
   Configurations and Objectives .... Neil Woodley
   Input/Output .... Stephen Middlekauff
   .... *Performance*
   Measurements .... Mark McGranaghan
   .... *Case Studies*
   Ashok Sundaram .... *Engineering*
   Issues Paul Stecuik .... *Bibliography*
   Vladi Basch .... *Economics*
   Larry Morgan,
   Ram Mukherji

6. Round-Table Discussion to Review Task Force Guidebook Draft and Objectives

7. New Business

8. Next Meeting: Summer IEEE PES Meeting in Berlin in July 1997

9. Adjourn

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Meeting Attendance

IEEE PES 1997 Winter Meeting, New York, New York
Tuesday, February 4, 1997, 1:00 - 3:00 PM
Hilton Petit Trianon Conference Room

Name	Company
Rajaie Abu-Hashim	Commonwealth Edison
Charlie Antonopulos	ABB Power Systems
Gene Baker	Florida Power Corporation
Philip Barker	Power Technologies, Inc.
Vladi Basch	Baltimore Gas and Electric
Roger Bergeron	Hydro Québec
Richard Bingham	Dranetz Technologies
James J. Burke	Power Technologies, Inc.
Randy Collins	Clemson University
Larry Conrad	Cinergy Corporation
James Crane	Commonwealth Edison
John Csomay	Virginia Power
Fouad Dagher	New England Power Service Company
Mike Ennis	S&C Electric
Betty M. Fritz	Tampa Electric
Erik Hanson	General Electric
Gil Hensley	Pacific Gas & Electric Company
Reza Iravani	University of Toronto
Sasan Jalali	Siemens
Jon Jipping	Detroit Edison
John Kennedy	Georgia Power Company
Thomas S. Key	TCRD/PEAC
Ljubomir Kojovic	Cooper Power Systems
David Kreiss	Kreiss Johnson Technologies
Frank Lambert	NEETRAC
Jeff Lamoree	Electrotek Concepts, Inc.
Jim Lemke	Cinergy
Yiqiao Liang	Cegelec Automation
Mark F. McGranaghan	Electrotek Concepts, Inc.
Mark McVey	Virginia Power
Stephen Middlekauff	Duke Power Company
William A. Moncrief	Jacobs Sirrine Engineers, Inc.
Larry Morgan	Duke Power
Allen Morinec	Cleveland Electric Illuminating Company
David Mueller	Electrotek Concepts, Inc.
Ram Mukherji	Consultant
Helyne S. Noyes	LADWP

Name	**Company**
Chikaodinaka O. Nwankpa	Drexel University
Gregory L Olson	Public Service Electric & Gas Company
Jim Osborne	Osborne Transformer Corporation
Tamara A. Otterstetter	Detroit Edison Company
Dan Pearson	Pacific Gas & Electric
Scott Peele	Carolina Power & Light Company
Brian Prokuda	Keweenaw Power Systems
Paulo F. Ribeiro	Babcock & Wilcox
Dave Richardson	Electric Power Research Institute
Jacob Roiz	Canadian Electricity Association
D. Daniel Sabin	Electrotek Concepts, Inc.
John Schwartzenberg	Silicon Power Corporation
Tom Short	Power Technologies, Inc.
H. Jin Sim	CHEDF - Cornell University
Tejindar Singh	PQES, Inc.
Ashok Sundaram	EPRI
Betty Tobin	Seattle City & Light
Linh Tu	Pacific Gas & Electric
David Vannoy	Delmarva Power and Light
Marek Waclawiak	United Illuminating Company
Van Wagner	Detroit Edison Company
Dan Ward	Virginia Power
Michael Weinold	Siemens AG
Steve Whisenant	Duke Power Company
Neil H. Woodley	Westinghouse Electric Corporation
Peter Yan	Commonwealth Edison

Total in Attendance: 63

IEEE Custom Power Task Force Membership List

Tuesday, February 18, 1997

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Status Key: M = Member, CM = Correspondence Member, G = Guest

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Guide for Application of Power Electronics for Power Quality Improvement on Distribution Systems Rated 1 kV through 38 kV

P1409
February 4, 1997

Developed under the Working Group on Voltage Quality Working

IEEE Standards Department
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Contents

CLAUSE PAGE

IEEE Guide for Application of Power Electronics for Power Quality Improvement on Distribution Systems Rated 1 kV through 38 kV

1. Overview

1.1 Scope

This guide introduces and defines the emerging technology of custom power. This technology involves devices and circuit configurations of power electronic equipment used in utility power distribution systems rated 1 kV through 38 kV for the purposes of mitigating problems associated with power quality. This guide will include definitions, general need guidelines, performance objectives, electrical environments, input/output criteria, performance measurements, case studies, bibliography, and engineering tradeoffs.

1.2 Purpose of Guide

This guide's purpose is to provide guidelines and performance expectations for the application of power electronic-based equipment on utility distribution systems to improve power quality and control in these distribution systems. It will be a resource to utilities as they enter into the competitive marketplace, providing detailed information about custom power devices as options to solving power quality problems.

2. References

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

[1] ANSI C84.1-1989, American National Standard Voltage Ratings (60 Hz) for Electric Power Systems and Equipment.[1]

[2] IEEE Std. 100-1992, The New IEEE Standard Dictionary of Electrical and Electronic Terms (ANSI).[2]

[3] IEEE Std. 1100-1992, IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment (Emerald Book).

[4] IEEE Std. 1250-1994, IEEE Guide for Service to Equipment Sensitive to Momentary Voltage. Disturbances

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[1] ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[2] IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, Post Office Box 1331, Piscataway, NJ 08855-1331, USA.

[5] IEEE Std. 1159-1995, IEEE Recommended Practices on Monitoring Electric Power Quality.

3. Terminology

3.1 Definitions

The primary source of information for this section is the IEEE Std. 100-1992. The second choice was to use other appropriate sources such as IEEE 1100-1992, and the final choice was to introduce a new definition that conveys a common understanding for the word, as used in the context of this Guide. A number given in brackets after a definition correspond to those references listed in clause 2.

3.1.1. custom power: the concept of employing static controllers in the distribution system by electric utilities for the purposes of supplying the level of reliability and **power quality** necessary by the end-user.

3.1.2. dip: see **sag** [5].

3.1.3. insulated gate bipolar transistor (IGBT): a solid-state usually used for pulse-width modulation (PWM) waveform synthesis function.

3.1.4. IGBT: See **insulated gate bipolar transistor**.

3.1.5. gate turn-off (GTO) thyristor. A solid-state device capable of turning off current conduction at any instant on the current waveform. The device is typically more expensive than the **SCR thyristor**. Typical current interruption speeds are less than 50 microseconds.

3.1.6. GTO: see **gate turn-off thyristor**.

3.1.7. power quality. The concept of powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment [3].

3.1.8. sag: see **dip**. A decrease to between 0.1 and 0.9 pu in rms voltage or current at the power frequency for durations of 0.5 cycles to 1 minute. Typical values are 0.1 to 0.9 pu. [5].

3.1.9. silicon controlled rectifier (SCR) (thyristor): A solid-state device able to conduct higher currents and which must be gated at a current zero to turn off the ac current flow.

3.1.10. static circuit breaker: a device usually based on GTO and SCR thyristors capable of providing sub-cycle interruption on faulty feeders.

3.1.11. static series compensator: a power electronics-based waveform synthesis device that is series connected directly into the utility primary distribution circuit by means of a set of series-connected single- phase insertion transformers. The principle function of the solid-state series compensator is to inject or absorb real power during a short-duration change in the primary feeder voltage. These devices may be coupled with energy storage capability.

3.1.12. static shunt compensator: a power electronics-based waveform synthesis device that is shunt connected through a standard (or specially designed) two- (or more) winding transformer to the utility transmission or distribution circuit for the purpose of instantaneous voltage regulation, power factor correction, and reactive power control.

3.1.13. static transfer switch: a device which can supply a critical load with either one of two independent primary feeds and which may switch the load from one feed to the other during power quality disturbance conditions. The solid-state device may be assembled with either **GTO** or **SCR** thyristor devices depending upon the continuous current-carrying requirement and required transfer speed.

3.1.14. voltage distortion: Any deviation from the nominal sine wave form of the ac line voltage [5].

4. General Needs

4.1 Overview

The term power quality is often used in conjunction with problems arising from malfunctioning power electronic equipment which is supplied with a voltage that is somehow less than perfect. The most important cause for the increasing concern about power quality problems is the dramatic increase in sensitive microprocessor and power electronic equipment being used to control assembly line production, to automate office work, and to enhance the home. Important compatibility gaps have developed between power electronics manufacturers, power producers, and power users, in that many of these systems are too sensitive for the electrical environment in which they are being placed.

4.2 Typical Disturbances and Impacts on Customer Equipment Operation

4.2.1. Sustained Interruptions: Up to eighty percent of faults on the overhead distribution system are temporary in nature, often caused by two conductors being blown together, a tree branch being brushed against one or more lines, lightning strikes, or by a small animal which creates an arc between part of the system and a grounded object [reference]. If these faults do not clear themselves within a few milliseconds, a circuit breaker or recloser may automatically interrupt current to the affected system area. During this interruption, the distribution system is given a chance to restore its insulation strength before current is restored, usually after a brief period ranging from about twenty cycles to a few seconds. If the fault persists after current restoration, the breaker or recloser may repeat this interrupt/reclose cycle two or three times, sometimes with a longer duration between interruptions. By lengthening the time that the circuit is exposed to a high current condition, downline fuses are given a chance to operate if the problem section of the system is located on a fused branch off the main distribution circuit. If this protection scheme does not clear the fault, then the condition is considered permanent and the breaker or recloser will interrupt the current once more, this time remaining in the open circuit, or “lock-out,” position. At this point, a utility line crew must be dispatched to effect repairs to the distribution system before the protective device can be reset or replaced in order to re-energize the line.

4.2.2. Momentary Interruptions: However, sustained interruptions which require distribution circuit repair are not the only events which cause problems for electric power customers. The momentary breaker and recloser operations before lock-out can be just as detrimental to a piece of sensitive end-use equipment as the actual lock-out itself. For example, a plastics molding plant may require up to six hours to restore full production due to an interruption as short as 0.5 seconds. The same short duration interruption can cause office computer networks without a backup system such as an uninterruptible power supply (UPS) to shut down, losing the information in memory and possibly causing problems due to unwritten file allocation tables. In the home, where it is not unusual to find up to five or six digital clocks, momentary interruptions can be blamed for countless blinking displays on clock radios, microwaves, and video cassette recorders.

4.2.3. Voltage Sags: In addition to problems due to momentary interruptions, sensitive loads may trip off-line even when the voltage is not completely zero. Short duration reductions in voltage, known as sags, are defined in IEEE Std. 1159-1995 as a decrease in rms voltage for durations from a half cycle up to one minute. They are usually associated with the voltage depression caused by fault current, but can also be caused by the starting of large equipment or motors. Sags may cause shutdowns in electronic process controllers which are equipped with fault-detection circuitry. Sags also are behind many unexpected computer system crashes. Where momentary interruptions affect only the customers downline from a protective device, sags are felt by every customer on the distribution circuit which experiences a fault, as well as many customers on parallel circuits, as demonstrated in Figure 4.1.

4.2.4. Voltage Swells: Voltage sags are sometimes accompanied by voltage swells, which are short duration increases in rms voltage, appearing on the unfaulted phases of a three-phase circuit experiencing a single-phase short circuit. Swells can cause misoperation of electric controls and electric motor drives, including commonly used adjustable speed drives, which trip due to the protective circuitry built in the drive’s controls. Swells may also stress delicate computer components sometimes leading to premature failure. Surge arresters, which are pole-mounted protective devices that absorb the energy associated with high voltage transient disturbances like lightning strikes, are at long term risk when exposed to frequent high-magnitude voltage swells.

4.2.5. Over- and Undervoltages: Sags and swells are not the only problems that face sensitive electronics. Longer duration increases and decreases of voltage, defined as overvoltages and undervoltages by IEEE Std. 1159-1995, are known to occasionally occur. Undervoltages are sometimes attributed to a purposeful reduction of voltage by the utility to decrease load during peak demand periods. These planned undervoltages, often called "brownouts," are sometimes implemented during hot summer days when air conditioning load is heavy and utilities do not have enough generation to meet the demand. The conditions can also occur due to incorrect settings on a transformer which is used to reduce voltage from the higher transmission and distribution levels to the level at which end-use equipment can utilize it. The magnitude of the voltage rise or fall with an over- and undervoltage is generally not as large as compared with a swell or a sag, but since the duration of these events can be many minutes long, they may still adversely affect computers and electronic controllers. In addition, an undervoltage may decrease output from capacitor banks. Capacitor banks are often installed by the utility or by a customer to help maintain voltage and to minimize losses due to inductive nature of conductors and many loads. The effect of overvoltages is not as immediate as a swell, but may serve to shorten the life span of power system equipment and motors which draw larger currents in order to maintain output in a lower voltage situation.

4.2.6. Transients: Voltage disturbances which are shorter in duration than sags and swells are classified as transients and include two basic classes: (1) impulsive transients, often attributable to lightning and load switching, and (2) oscillatory transients, usually caused by capacitor bank switching. Utility capacitor banks are often switched into service early in the morning in anticipation of a higher power demand period. Transients with a high magnitude and fast rise time can lead to insulation breakdown in motors, transformers, capacitors, and switchgear. Lower magnitude transients can also become a problem depending upon how frequently they occur.

4.2.7. Harmonic Distortion: The quality of the voltage and current waveforms during steady-state conditions can also be important. Variations in the quality of these waveforms are referred to as harmonic distortion. Harmonic distortion on the utility system is the result of connecting nonlinear customer loads such as adjustable speed drives, arc furnaces, compact fluorescent lights, and rectifiers. Rectifier power supplies are found in nearly every modern computer, ubiquitous in offices today. The problem arises because these loads do not draw current for the entire power cycle, and can be modeled as actually “injecting” current of frequencies that are integer multiples (harmonics) of the fundamental power frequency (50 Hz or 60 Hz). When the current injected is relatively large to the amount that the power system can absorb, the level of voltage distortion local to the area of the nonlinear load is increased. Large levels of harmonic distortion result in overheating of motors, generators, and transformers, premature operation of protective devices including fuses, and metering inaccuracies. IEEE 519-1992 provides guidelines and limits for current and voltage distortion levels on transmission and distribution circuits.

4.2.8. Other Steady-State Problems: Other steady-state power quality problems include waveform notching, unbalance, and flicker. Notching is related to normal operation of power electronics devices which provide continuous DC current from a three-phase supply. One of the more interesting side-effects of notching is that the voltage waveform may cross the zero potential line more than twice per power cycle, which is what electronics designers expect. Thus it is not uncommon to hear stories of clocks running fast around a large load which is causing notching. Thus it is not unusual for a power quality trouble-shooter to ask utility customers if their digital clocks are running fast due to the extra zero-crossings in an effort to discover a notching problem. Unbalance affects motors and other devices which depend upon a three-phase voltage source, with the magnitude of each phase equal and phased by 180 electrical degrees. Flicker is a phenomenon often associated with steel mills which contain arc furnaces, devices which draw a different amount of current each power cycle, thus causing low-frequency changes (less than 20 Hz) in system voltage in the mill’s general vicinity. The voltage variations actually affect the luminous output of lighting near the plant, causing a “flicker” perceptible to the human eye.

Sags, swells, momentary interruptions, and other power quality phenomena are not new; they have been characteristics of electric power systems for a hundred years. Power quality was not considered a significant problem decades ago because the loads connected to electric distribution systems were generally immune to their effect. For example, when the traditional industrial workhorse -- the induction motor -- experienced a sag, it would not shut itself off. Rather, the motor’s output would merely decrease until the sag was ended. Probably the most noticeable impact of the voltage reduction would be the dimmed lights around an industrial plant. For this reason, electric utilities did not need to maintain statistics which described power quality levels which could be used to determine what would be considered normal or abnormal. However, with the world-wide proliferation of advanced power electronic equipment and the increasing integration of microcomputers in process control and automation, we are seeing that these same power system characteristics considered relatively harmless before can now be very expensive in terms of process shut-downs and equipment malfunctions.

4.3 Power Quality Disturbance Incidence Rates

Insert data from the EPRI DPQ Project with respect to rms voltage variations and voltage harmonic distortion.

4.4 Range of Available Solutions

Disturbance Type	Utility-Side Solutions	Customer-Side Solutions
Voltage Sags and Swells	• static series compensator • static shunt compensator • static transfer switch • line reactor	• line conditioner • uninterruptible power supply (UPS) system • voltage regulator
Voltage Interruptions	• static circuit breaker • static transfer switch • combination of static shunt compensator and energy storage • superconducting magnetic energy storage (SMES)	• UPS system • motor-generator set
Impulsive and Oscillatory Transients	• high energy surge arrester • static series compensator • static shunt compensator • static transfer switch • pre-insertion resistors and inductors and synchronous closing	• line conditioner • surge arrester
Harmonic Distortion	• filter • static shunt compensator • static series compensator	• line conditioner • filter
Noise		• grounding and shielding • line conditioner • filter

4.5 Role of Custom Power Solutions

For customers with sensitive loads, achieving the level of power quality necessary to ensure trouble free operation can prove to be very expensive. It is often possible to improve quality through a systematic program which may include:

- improvements in line insulation and insulation coordination
- rerouting of service to selected critical loads on the customer site

- improvements to grounding arrangements
- installation of passive filters

However, these measures may still not achieve the desired level of power quality. To gain further improvement a significant capital investment is required. For the customer this is likely to be UPS or local generation, both of which incur high running costs. The burden on a utility would be to install a second feeder to the customers site from an alternate source.

Custom power devices provide a third option, which allow the utility to provide a power quality solution on its side of the distribution network at a level which is deemed satisfactory to the customer. In many cases this can provide the most economic solution to establishing the required level power quality.

4.6 Technical Requirements of Custom Power Technologies

5. Configurations and Performance Objectives

5.1 Introduction

This section provides basic configurations for the electrical and mechanical arrangements of the components making up the custom power systems that are employed for power quality improvement at the primary distribution feeder level. These systems include:

- static series compensator
- static shunt compensator
- static circuit breaker
- static transfer switch

5.3 Custom Power Technology

Custom power devices should be able to react in real time to the state of the distribution system and rapidly adjust to maintain the required level of power quality. The key technology which has made custom power devices possible is the turn-on/turn-off solid state switch. Developments in gate turn-off thyristors (GTOs) and insulated gate bipolar transistors (IGBTs) mean that devices with operational capabilities suitable for high power applications are now available at a cost which makes them economically possible for distribution power levels. Also important to realizing this technology have been the advances made in micro-controllers, signal processors, fiber optic communications and techniques to series connect the solid state switches.

At the heart of the many custom power devices is a three-phase voltage source inverter, based on the IGBT switch. This type of device often chosen because it offers low loss switching at fairly high frequencies (> 1kHz) which allows relatively clean waveforms to be generated using pulse width modulation (PWM) techniques. Inverters using IGBTs have seen widespread and reliable use for traction and drive applications for many years, although generally not at the same voltages or power levels. The inverter is controlled by a control system which constantly monitors the distribution line and compares the data with a reference signal. Connection of the inverter to the distribution line is via a distribution transformer. To reduce unwanted harmonics generated by the inverter, pulse forming magnetics are used to smooth the output waveform.

The inverter itself consists of individual circuit blocks which incorporate the IGBT, firing circuit, snubber network, anti-parallel diode and heat sinks. These blocks are connected in series to create poles, which are in turn configured in anti-parallel pairs to create a single-phase module, of which three are required for three-phase applications. Modules are common connected at the DC side of the inverter to facilitate energy transfer between phases.

To fully realize some of the functions of the shunt or series compensators, some form of energy storage device is necessary. A number of technologies are now at sufficient stage of maturity to be considered as viable alternatives for custom power applications. These include:

- Ultra-high energy density capacitors (e.g. capacitor double layer technology)
- Advanced batteries
- Flywheel energy storage
- superconducting magnetic energy storage (SMES)

All of the above can provide DC output and are hence capable of deriving their energy from the DC terminal of the inverter. However to control the flow of energy between the energy storage and the inverter a DC - DC power flow controller is required. This manages both the rate of charging and discharging of energy from the storage medium.

5.4 Static Shunt Compensator

A typical static shunt compensator consists of three single-phase voltage source inverters with a common DC bus. Connection to the distribution network is via a standard distribution shunt transformer, hence simply by altering the turns ratio the static shunt compensator can be made suitable for all classes of distribution voltages. In its basic form, the static shunt compensator injects a voltage in phase with the system voltage, thus providing voltage support and regulation of var flow. Because the device generates a synchronous waveform, it is capable of generating continuously variable reactive or capacitive shunt compensation at a level up to the maximum MVA rating of the static shunt compensator. An advantage of the inverter method is that the amount of compensation the device can provide varies linearly with the line voltage. For instance, at 70% voltage the static shunt compensator can provide 0.7 p.u. compensation, whereas a switched component bank is only capable of providing ~0.5 p.u. support.

The static shunt compensator can also be used to reduce the level of harmonics on the distribution system. The use of high frequency inverters to synthesize the necessary signal means that the device can inject complex waveforms to cancel out voltage harmonics generated by non-linear loads. Because the static shunt compensator continuously checks the line waveform with respect to a reference AC signal, it always provides the correct amount of harmonic compensation. By a similar argument the static shunt compensator is also suitable for reducing the impact of voltage transients.

When coupled with the solid-state breaker (mounted upstream of the static shunt compensator) and energy storage, the static shunt compensator can be used to provide full voltage support to a critical load. In the event of supply disturbance the solid-state breaker isolates the line and the static shunt compensator supports the entire load from its own energy storage. The time interval that support to the critical load can be maintained is determined by the amount of energy storage provided while the load power level that can be carried is limited by the MVA rating of the static shunt compensator inverters.

5.5 Static Series Compensator

The static series compensator employs a similar technology to the static shunt compensator. The principle difference is that the static series compensator is connected in series with the distribution line through a set of series-connected injection transformers. This allows the static series compensator to inject synchronous voltages in quadrature with the line current, allowing it to provide a complimentary set of control functions to the static shunt compensator.

The static series compensator in its most basic form is capable of supplying continuously variable capacitive or reactive series compensation to a distribution feeder. One control function achievable with the static series compensator is that it can inject a lagging voltage in quadrature with the system voltage, making it suitable for fault current limitation applications. Because the static series compensator generates the injection voltage from a PWM waveform, it is also capable of reducing the level of harmonic voltages present on the distribution system.

In the event of a (short duration) change in system voltage the static series compensator can inject or absorb real power, given sufficient energy storage capability. During this time the static series compensator uses the energy storage interface to provide real power at the DC terminals of the inverter, which is in turn injected as a voltage across the series winding of the injection transformer at a magnitude sufficient to restore the load side voltage to the reference value. It does not require isolation from the system to achieve this, in contrast to the static shunt compensator. Further, because the static series compensator only needs to supply the missing portion of the supply voltage, for protection against sags and swells the static series compensator is a far more effective device than the static shunt compensator for applications where the critical load must be protected from such system disturbances.

5.7 Static Circuit Breaker

Unlike the other two custom power devices, the static circuit breaker are usually based on GTO and SCR thyristors, although they employs many of the same techniques to achieve operation at distribution voltage levels. The static circuit breaker is connected directly in series with the line and is capable of providing subcycle interruption on faulty feeders.

The GTO components of the breaker provide the rapid interruption capability. For protection coordination it is sometimes necessary to allow conduction of the fault current for a short duration. However, GTOs are not capable of conducting high surge currents. To facilitate the coordination, a parallel SCR switch with an optional current limiting reactor may also be employed to conduct the fault. In this way, the GTO breaker element provides rapid subcycle switching for the clearing of upstream and downstream faults and the SCR breaker element supports limited fault current for the clearing of downstream faults by slower conventional downstream protective devices.

The solid state breaker is typically constructed from a number of anti-parallel, air-cooled GTO modules. In normal operation the GTO element is closed, providing uninhibited flow of current. Under a fault or abnormal condition the static circuit breaker detects the rise in both steady state current and the rate of current change (dI/dt) and therefore opens rapidly to interrupt the current flow. For highly reactive loads such as transformers, the breaker should be programmed to modulate (or “soft start”) current flow to limit the inrush current.

5.8 Static Transfer Switch

6. Device Input and Output Requirements

6.1. Overview

6.2 Requirements of Static Series Compensator

The static series compensator is an active device, designed to provide a pure sinusoidal load voltage at all times, correcting for sags, swells, and harmonics up to its bandwidth capability. A static series compensator compensates for voltage anomalies by inserting the ‘missing’ voltage onto the line, typically through an insertion transformer, as shown in Fig. 6.2.1. Typical designs for static series compensators may utilize some source of energy to insert this voltage; this storage energy may be capacitors or batteries.

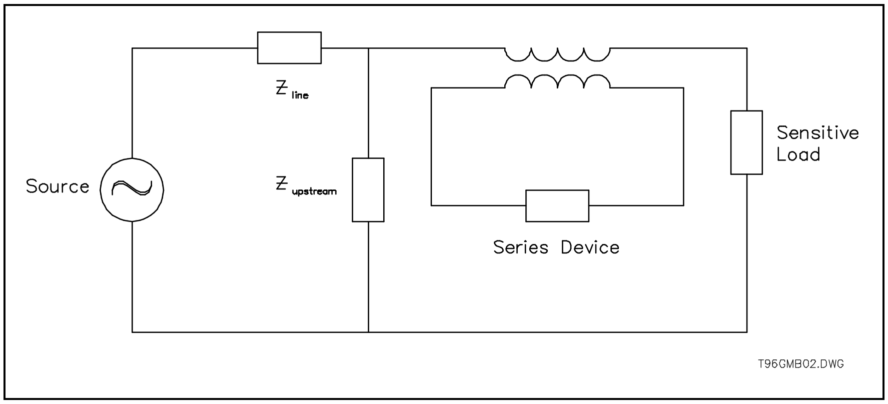


Fig. 6.2.1 ¾ Diagram of a static series compensator in a circuit

6.2.1 Importance of Waveshape. The primary purpose of a static series compensator is to mitigate the effect voltage sags have on a sensitive customer's load. Typically, voltage sags are characterized by magnitude and duration. Sag profiles for a feeder or a customer can be generated using a combination of circuit modeling and recorded data. These profiles are often presented using 'sag matrices' or graphically with a two-dimensional rms magnitude versus duration curve. Additionally, the frequency of the sags can be included on a three-dimensional presentation. A representative three-dimensional plot is shown in Fig. 2.2.2.

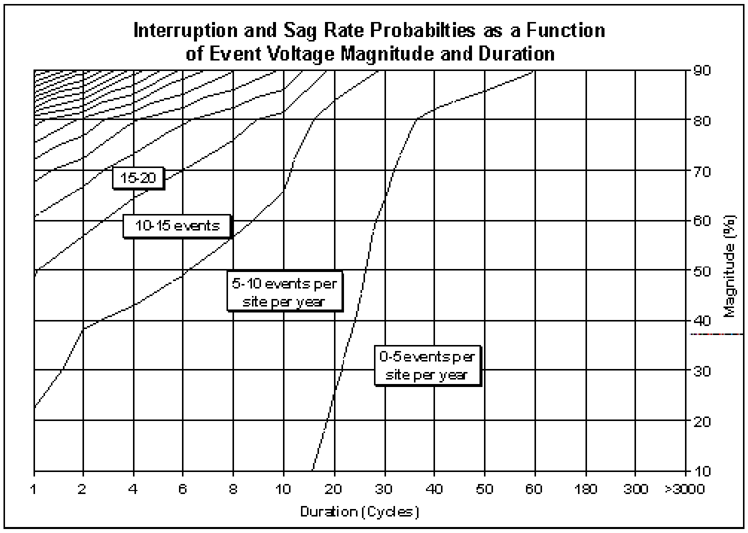


Fig. 6.2.2 - An example magnitude-duration curve

Unfortunately, the rms representation does not describe the waveshape of the disturbance. The rms calculation is based on a periodic signal and assumes steady-state conditions. To calculate an rms magnitude during a transient event, a one-cycle moving window is often used. The lowest rms value obtained during the event is used as the sag "depth." The sag waveshape is normally not sinusoidal, and may contain a phase shift. Due to the complexities of sag waveshapes, the rms calculations do not adequately characterize many sags.

Typically a static series compensator is designed to provide a certain percent voltage injection capability. For example, a static series compensator with 50% injection capability could compensate for all sags to 50% rms magnitude. Since the static series compensator is an injection device and adds voltage to make up for the loss, the percent capability is only accurate if the sag is smooth with no phase shift. In reality, the static series compensator compensates on an instantaneous basis, and must be sized accordingly. The inherent one-cycle averaging effect of the rms calculation will mask high speed transients and the true instantaneous correction required.

6.2.2 Unpredictable Waveshape. There are many factors influencing the waveshape of a sag. Sags are typically due to faults caused by lightning, trees, animals, and even humans. Many factors influence the shape and duration of the sag, such as the type, impedance, and location of the fault, the load and transformer connections, mutual coupling, and protective devices in the circuit. The location of faults is essentially random, and may involve any combination of the three phases. They may be on an adjacent feeder or the same feeder as the customer. If the fault is on the same feeder, its location relative to the customer and the type of fault (e.g., arcing) also influences the waveshape.

A large majority of voltage sags seen on utility systems are single-phase events, and another portion are two-phase sags. A static series compensator must treat each phase independently, and be prepared to compensate for disturbances on any phase, or any combination of phases. A sag on one phase may result in a swell on another phase, and the static series compensator must be capable of handling both sags and swells simultaneously.

6.2.3 Phase Shift Considerations. Many disturbances have phase shift associated with them, especially in the case of line-to-line faults. This can make it difficult to ‘size’ a static series compensator for an application. Fig. 6.2.3 shows a generic 50% sag with no phase shift, and its rms calculation using a common method. Fig. 6.2.4 shows another generic 50% sag, this time with a -60° phase shift during the sag, and its corresponding rms calculation. Notice that the rms calculations shown for both sags in Figs. 6.2.3 and 6.2.4 are nearly identical since the maximum depth computed by the rms calculation will not be influenced by the phase shift of sags lasting more than one cycle.

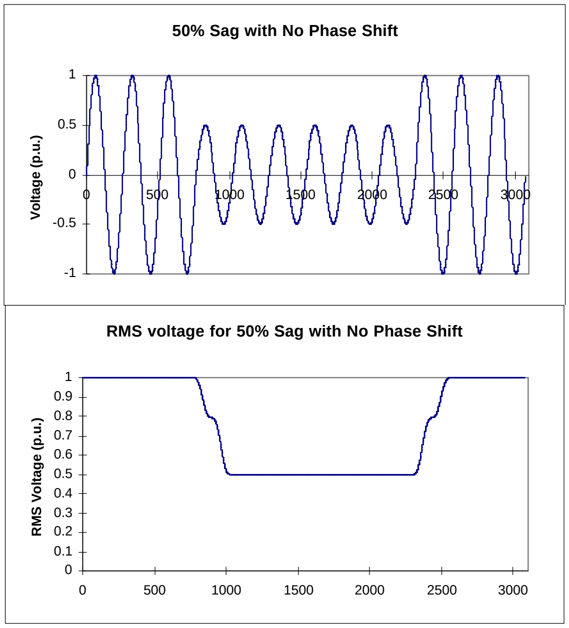


Fig. 6.2.3 - Generic sag of 50% and rms calculation

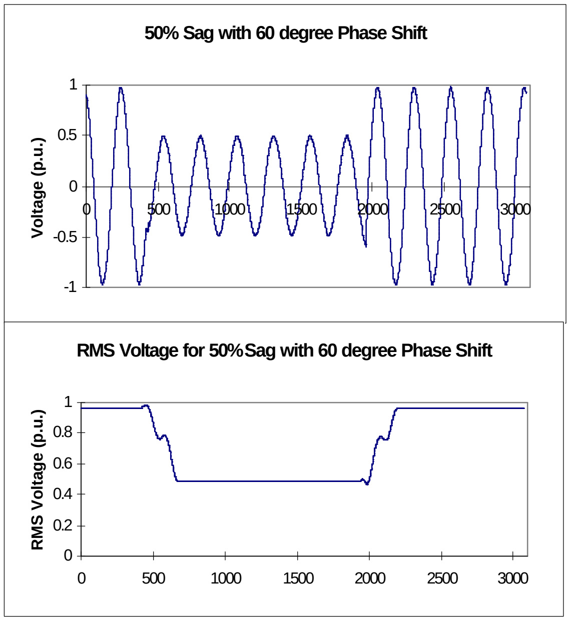


Fig. 6.2.4 - 50% sag with 60° phase shift and rms calculation

A static series compensator with a 0.5 p.u. injection capability will not be able to compensate the sag shown in Fig. 4 back to 1.0 p.u., even though it would be described as a sag to 50%. Analyzing the 'missing voltage' for this sag as shown in Fig. 6.2.5, the required rms voltage to restore the load to 1.0 p.u. is 0.86 p.u. This voltage would have to be injected at an angle of +30°. The static series compensator actually injects voltage on an instantaneous basis, and the peak voltage required to perfectly correct a 50% sag is $0.866\sqrt{2} = 1.22$ p.u. of the nominal rms value. This is the actual sizing requirement for the static series compensator's voltage injection capability for this particular sag.

When the static series compensator has a voltage injection limitation, the control algorithm and headroom will determine the resulting output waveform. For example, a static series compensator with 50% injection capability can correct this sag by injecting at most 0.5 p.u. rms voltage (or an instantaneous maximum of 0.707 times the nominal rms voltage). The static series compensator's controls now have several options for handling this sag. One possibility is to maximize the rms output voltage. In this case, the voltage injection would be at -60° and would yield 1.0 p.u. rms output voltage, albeit with a 60° phase error. A second possibility is to inject voltage in phase with the pre-sag voltage; this yields an output voltage of 0.866 p.u. with a -30° phase error. If the controls attempt to insert the required voltage ($0.866\angle 30^\circ$) with the correct phase angle, the static series compensator will run out of headroom at 0.5 p.u. As a result the output waveform will be clipped, and will not be sinusoidal. The controls could inject a voltage waveform which yields an output waveform that is not clipped and contains the correct phase trajectory, but this will result in an output waveform of $0.707\angle -15^\circ$ p.u. However, this would require a priori that the sag's waveshape is purely sinusoidal; this is clearly unrealistic. Deeper sags, and/or larger phase shifts exacerbate this problem.

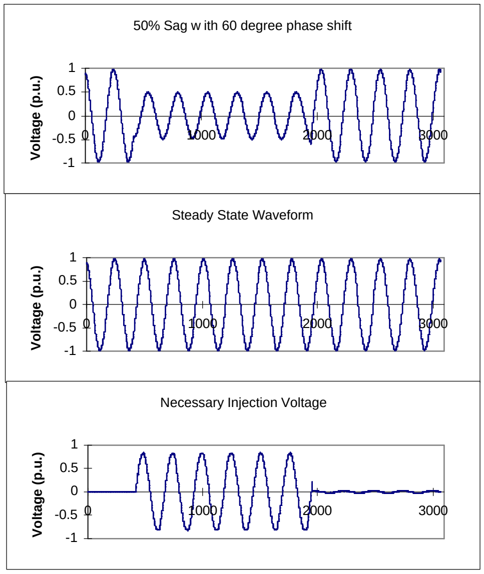


Fig. 6.2.5 - Required injection voltage for -60° phase shifted 50% sag.

Which is more important: phase shift, magnitude, or waveshape? The answer is load-dependent. Three-phase AC motor drives with front-end rectifiers are very sensitive to voltage magnitude and phase unbalance. Thyristor-based power supplies (such as in DC drives) need accurate zero-crossing information, so phase shift and waveshape are important. AC motor contactors are not as sensitive to phase shift and waveshape, however voltage magnitude and point-in-wave of the initiation of the event plays a key role in tripping the contactor. For optimal performance, the static series compensator must be sized to inject the voltage required for any expected disturbance. This may require as much as 2.0 p.u. headroom. Otherwise, the control algorithm must be tailored to the load to minimize equipment misoperation when the static series compensator cannot fully compensate for all likely disturbances.

6.2.4 Static Series Compensator Response Time. The static series compensator's controls will have a finite response time, typically on the order of milliseconds. Due to these speed limitations, as well as bandwidth limitations and slow transient response of the magnetics, very fast transients will be difficult to identify and correct. High order harmonics and high frequency or fast transients (e.g., capacitor switching) will most likely pass through the static series compensator with no correction. Likewise, an additional problem is created upon sag recovery. Once the line voltage has recovered, the static series compensator's controls will not react infinitely fast, so there will be a brief overvoltage seen by the load, as the static series compensator will continue to inject voltage onto the restored line voltage. Depending on the capability of the static series compensator, this may result in a line voltage as much as 3.0 p.u.

6.3 Recovery of Sag Problems

Most loads such as large AC motors and transformers will draw a large inrush current upon recovery of a sag. This inrush current can create problems such as blowing of fuses, or tripping of breakers. With optimal operation of a static series compensator, the load voltage will not see a disturbance and thus will not cause an inrush current. If the static series compensator cannot fully correct the sag, the load will see a sag and an inrush may occur to re-magnetize transformer windings, accelerate motors, and recharge capacitors. This may cause the static series compensator to go into current limit to prevent damage to its power semiconductors and other relatively fragile devices. As a result, the output (load) voltage may be reduced by the static series compensator, prolonging the sag at the load even though the power line has recovered completely.

6.3.1 Preventing Damage from Inrush Current. If the sag is not fully compensated, these same inrush current effects will be seen on both sides of the static series compensator's series transformer. This current must pass through the primary side (line side) and will thus be seen on the secondary side of the static series compensator transformer. If the load current is sufficiently high, the power electronics in the secondary circuit within the static series compensator may be damaged. The static series compensator's controls must have a protective scheme to prevent damage to itself, and therefore will try to remove itself from the line if other current limiting techniques (output voltage reduction) do not work, i.e. it will go into a bypass mode. If the line voltage has recovered from the sag, there would not be a problem with temporarily removing the static series compensator from the system provided another disturbance does not occur. The static series compensator must have a clever bypass scheme so as not to create additional disturbances onto the system which affect the load.

6.3.2 Transformer Saturation. If the transformer is not properly sized, saturation can occur. Upon detecting a sag, the static series compensator will apply voltage on its secondary which in-turn injects voltage onto the line via the primary. The point-in-wave upon which correction begins will determine the flux state of the transformer. If the transformer saturates due to a lack of flux "headroom," the magnetizing currents will become very large. Without protection, the power electronics can be exposed to damaging over-currents. The static series compensator protection scheme will likely remove itself from this situation, and thus will not be on-line to correct the sag. To avoid saturation under all conditions, the transformer must be sized to handle two times the normal steady-state flux requirement at maximum rms injection voltage without saturating.

6.4 Upstream Recloser Operation

A static series compensator cannot be integrated into a system without carefully considering the consequence utility circuit configuration and protective devices in the circuit. The static series compensator is an additional energy source to the system and is a series device. Therefore, it is capable of delivering energy to the system at any time (e.g. during faults) and it must have a continuous current path. The static series compensator cannot operate if the source circuit is broken immediately upstream or downstream of the static series compensator.

6.4.1 Effect on Upstream Loads. An open circuit upstream of the static series compensator is a particularly interesting situation. To illustrate the problem, a simple, single-phase equivalent circuit with a static series compensator, an upstream recloser, and another load between the static series compensator and the recloser representing the combined parallel upstream load is shown in Fig. 6.4.1. Fig. 6.4.1a shows the normal steady-state operation and the direction of current flow through the system. Fig. 6.4.1b shows the new current path after a recloser operation. The static series compensator is now the only energy source on the load-side of that phase. It will try to maintain V_2 at its pre-event magnitude, frequency, and phase. The input voltage to the static series compensator, V_1, is related to the static series compensator output by a voltage divider, shown in the equation below the figure. The direction of current is now reversed (i.e., a large phase shift in voltage V_1 and current I_1) through the upstream load, which could create a damaging situation. This simple diagram depicts passive loads with no coupling from the other phases, which is not representative of many applications. Active upstream loads could cause additional unknown effects.

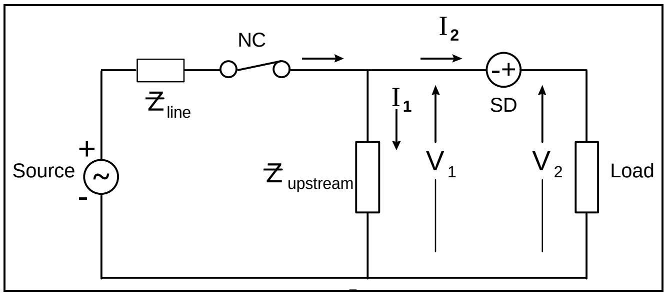
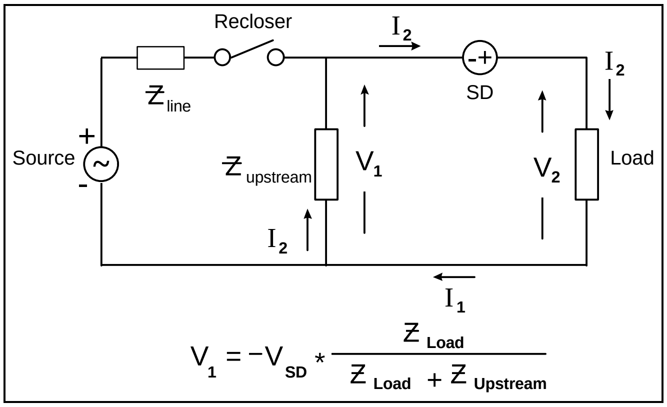


Fig. 6.4.1a. Circuit with static series compensator and closed upstream recloser. (V_1=V_2)



$$V_1 = -V_{SD} * \frac{Z_{Load}}{Z_{Load} + Z_{Upstream}}$$

Fig. 6.4.1b. Circuit with static series compensator and open upstream recloser

6.4.2 Possible solutions. There are a number of possibilities for mitigating this problem. In each case, unfortunately, the static series compensator cannot protect the load and the customer will experience a disturbance. However, the opportunity for a damaging problem is eliminated and the system protection will operate normally.

Communication could be used to send a signal to the static series compensator that the recloser is going to operate and the static series compensator would be removed from the line (i.e., bypass). This may not be feasible since a communications wire must be run from the recloser to the static series compensator along the utility lines and would have to operate relatively quickly. Another possibility would be for the static series compensator to have some method of power flow direction sensing capability, possibly sensing when there is a change in current direction at an upstream branch. A seemingly simple solution would be for the static series compensator to detect when it sees zero volts for a specified time and remove itself from the line under the assumption that there has been a recloser lockout. This will not work under most situations, however, since a single-phase recloser will not normally cause the voltage on that phase downstream of the recloser to go to zero, due to coupling to the other phases through transformers, loads, etc. This solution is a bit precarious since it may result in many unnecessary bypasses, however making the specified time too long could result in damage to upstream loads.

7. Performance Measurements

7.1. Characterizing Power Quality Variations to Define Power Quality Requirements

7.1.1 Voltage Regulation
7.1.2 Energy Storage and Ride-Through
7.1.3 Harmonic Control
7.1.4 Transient Control
7.1.5 Steady-State Variations
7.1.6 Voltage Fluctuations / Flicker
7.1.7 Harmonic Distortion
7.1.8 Sags/Swells
7.1.9 Interruptions
7.1.10 Transients

7.2 Summarizing Power Quality Levels - Performance

7.3 Monitoring to Evaluate Equipment Performance

7.3.1 Location
7.3.2 Response to Individual Events
7.3.3 Efficiency
7.3.4 Summary Statistics

8. Case Studies

9. Engineering Issues

9.1 Distribution Design and Implementation Issues

9.1.1 Fault Levels/Overcurrent Protection

- Radial and Unidirectional power flow

- Fault detection with overcurrent protective devices

9.1.2 Location
- Substation
- Primary distribution feeder
- Secondary

9.1.3 Reliability
- Overvoltage Concerns
- Protective Coordinate

9.1.4 Fault Current Levels
- Effects on Relay/Fuse Coordination
- Sectionalizing/Reclosing Concerns

9.1.5 Voltage Control/Regulation Concerns
- Maintenance/Utility Work Practices/Safety Issues
- Capacity
- Grounding/Island Issues

9.1.6 Interfacing transformer connection

9.1.7 Island operation

9.2 Technical feasibility and Effectiveness

9.2.1 Fault Clearing

9.2.2 Harmonic Distortion

9.2.3 Voltage Sags/Swells

9.2.4 Flicker
- Undervoltage/Overvoltage
- Transients
- Interruptions

9.3 Comparison to Other Technologies

9.3.1 Relative Cost/Performance

9.3.2 Standards/Simulation

9.3.3 Lack of testing standards

9.3.4 Lack of simulation tool and models

10. Economics

11. Bibliography

P1409 CUSTOM POWER TASK FORCE

TF 15.06.05.01

Custom Power Technology Development List

IEEE PES 1997 Winter Meeting, New York, New York
Tuesday, February 4, 1997, 1:00 - 3:00 PM
Hilton Petit Trianon Conference Room

A continuing goal of the Custom Power Task Force will be to centralize information concerning the development of custom power technology and the installation of devices which utilize this technology. This list presents the most current information available regarding custom power technology as of February 18, 1997.

Note that this is an "application-oriented" listing of projects. With these new technologies, companies are very reluctant to apply them until there is some field experience. Sharing of information about applications helps to generate acceptance for the technologies in the marketplace, identifies benefits and potential problems with the technologies in specific applications, and helps identify areas for future technology improvements. All of these are important overall benefits that can be achieved without the sharing of proprietary information about particular products and technologies.

A similar approach has been used for years in the HVDC Subcommittee and its associated working groups (more recently expanded to include FACTS technologies). The HVDC groups published a number of papers and bibliographies that documented HVDC installations around the world, helped develop guidelines for equipment specifications, and significantly enhanced the visibility of these new technologies in the marketplace. These are the kind of objectives that we would like to accomplish with the activities of the Custom Power Task Force.

Custom Power Technology Development

Baltimore Gas & Electric

Testing a medium voltage subcycle transfer switch at downtown office

Cinergy Corporation

Testing a 15 kV, 600 A solid state fast transfer switch. The switch is self-contained on a pad with an outdoor enclosure, removing the need for special rooms or trailers. *(Last Update: February 1997)*

Clemson University

Development of input/output objectives for series compensation devices

Commonwealth Edison

Testing a transfer switch

Detroit Edison Company

Detroit Edison Company installed a static transfer switch at the Ford Motor Company Sheldon Road Plant. It was placed in service on November 10, 1996. This plant is fed from a 40-kV subtransmission system and has a load has a load of 9 MVA. The switch is installed on the 13.8 kV side of the transformers. It has operated about 13 times including testing since installation. The most recent was during a sag to 83% of nominal. There have been no disruptions reported at the plant during any of these switching operations. *(Last Update: February 1997)*

Duke Power Company

A series compensation device was placed on-line carrying critical customer plant load in late August 1996 on the Duke Power Company system in Anderson, South Carolina. The device is going through commissioning is now in service at Orian Rug Company where the unit is to protecting the automated yarn manufacturing and weaving plant from voltage sags and disturbances coming from the Duke Power distribution system that serves the plant. The unit carries approximately 120 amps at 7.62kV line to neutral voltage. *(Last Update: January 1997)*

Florida Power Corporation

A series compensation device is installed at the FPC 230/12.5 kV, 100 MVA Econ substation in Orlando where it protects one of the six 12.5-kV feeders. The project is designed to demonstrate of the ability of the DVR to provide improved feeder power quality in a high isokeraunic environment. Power quality measurements of the Econ feeder data will be compared with the unprotected feeders. *(Last Update: January 1997)*

Hydro-Québec

Hydro-Québec is currently doing simulation on the application of Custom Power Devices on its network. Also, a feasibility study on solid state tap-changer is being done. In 1997, they will study custom power parks. Hydro-Québec is not planning to install custom power devices until 1998. *(Last Update: September 1996)*

Pacific Gas & Electric

PG&E installed a first static transfer switch which became operational in September 1996 and a second installed in October. Both are rated at 25 kV, 300 A, are on-line and functioning. They have yet to protect either customer from sag events because all sags have been communicated through the transmission system, so far. PG&E is progressing with development of a fast voltage regulator rated at the same voltage and current. This will protect the customer from sags even on radial taps. The first full-size prototype unit is expected to be operational by the summer of 1997. *(Last Update: February 1997)*

Powercor Australia, Ltd.

A 50 Hz series compensation device is being commissioned at the Bonlac Foods plant at Stanhope, Victoria, in Australia where it will protect the sensitive dairy food process plant load from disturbances originating on the Powercor Australia 22-kV overhead rural distribution system. The Bonlac plant produces powdered milk and other related dairy products from milk supplied by nearly 800 dairy farms in the area. *(Last Update: January 1997)*

Public Service Electric & Gas

PSE&G has been involved in a number of custom power projects, including:

- 150 kVA advanced power line conditioner
- solid state breaker
- series compensation device
- pole-mounted advanced static var compensator

PSE&G also has each of the devices, except the last, in place and operational. *(Last Update: August 1996)*