Power Quality Standards

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Why have PQ Standards?

- The engineer's reason:
  - Compatibility between grid and loads
- The business reason:
  - Shifting the cost/blame to someone else
- The electric power company reason:
  - To demonstrate that the product being delivered meets specifications
- The military reason:
  - To make sure everything works

Who writes PQ Standards?

- They all start with a blank piece of paper (or blank screen!)
- All are "written" by groups, but skilled typists, wordsmiths, politicians, compromisers have the advantage
- Most participants represent some interest group: national utility, business, country, etc. Some academic and pure technical participants, but (in my experience) they can get overwhelmed.

continued...

Who writes PQ Standards?

continued...

- Group interests conflict. What's good for electric companies, for example, may be bad for computer manufacturers.
- Some PQ Standards have been paralyzed by this conflict.
- Where there is no conflict, bad standards result because some group's interests have been overlooked.

Sources of PQ Standards

- International technical standards (e.g. IEC)
- International tech standards, without enforcement (e.g. IEEE)
- Industry (e.g. SEMI, CBEMA, ITIC)
- Power companies, and organizations
- National standards (e.g. JP, ZA)
- Military

Partial summary of PQ Standards

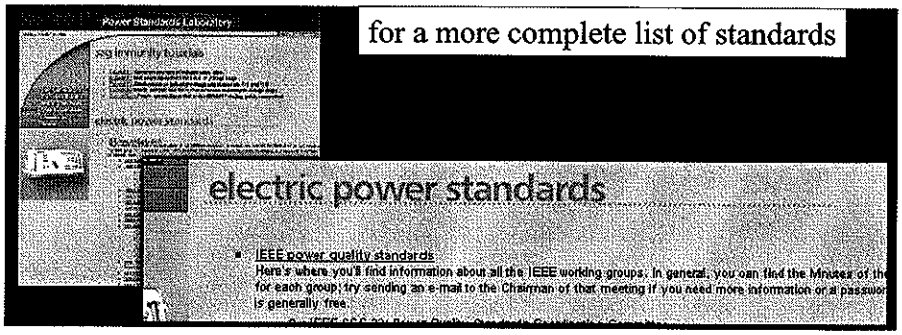
- IEC 61000-x-x series: environment, load, measurement
- EN series (Euro Norm) – e.g. EN50160
- IEEE standards e.g. IEEE 1159, IEEE 519
- National standards e.g. ZA NRS048
- Industry standards, e.g. SEMI F47, ITIC, CBEMA
- Military e.g. MIL STD 704E (aircraft)

continued...

Partial summary of PQ Standards

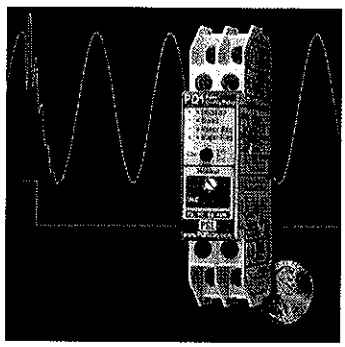
continued…

www.PowerStandards.com/tutor.htm



Too many PQ standards?

16 different standards built into a simple low-cost power quality relay… (*www.PQRelay.com*)



2002 Problems with PQ Standards

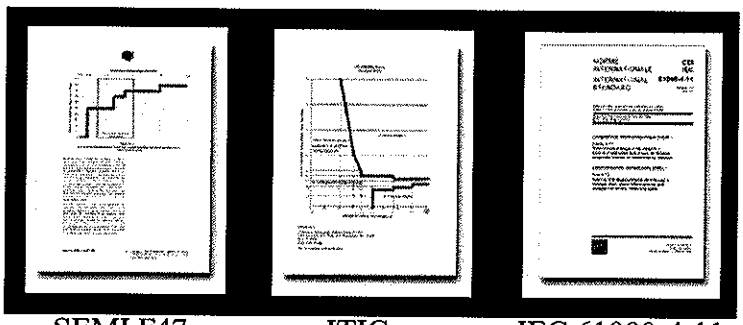
- Sometimes mis-applied by well-meaning engineers, purchasers
  - IEEE 1159, for example
- Some fail to balance technical, economic needs
  - Discuss proposed harmonics standards
- Some are so one-sided that they aren't useful
  - EN50160, for example

continued...

2002 Problems with PQ Standards

continued...

- And some conflict with each other



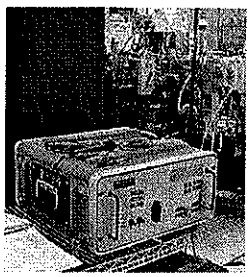
SEMI F47 ITIC IEC 61000-4-11

But there is hope!

- Many conflicts are inadvertent
  - International communication about PQ standards is very, very helpful – and here we are!
- PQ measurement standard is about to be released – IEC 61000-4-30
- Greater cooperation between conflicting groups – electric companies, their customers
- World-wide recognition of the problem will lead to solutions

SEMI F47 – A standard that actually solves problems

- SEMI F47 – one of the best PQ standards
- Practical, easy to implement
- Makes loads tougher with very little cost



SEMI F47 testing in Singapore by
Power Standards Lab and Precicon Ltd.
www.Precicon.com.sg

SEMI F47

A standard that actually solves problems

- Educates engineers to design for PQ disturbances
- Rarely requires power conditioning – mostly solved with software changes, component value changes

- An excellent model for future Power Quality Standards!

Power Quality Standards

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Power Quality Standards: The Need for Continual Efforts

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October 24th , 2002

IPQC 2002

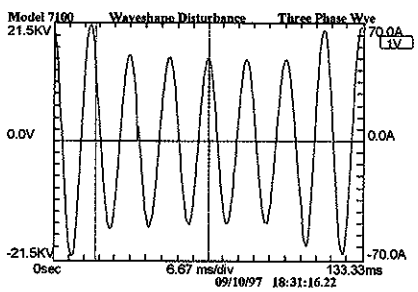
Increased Power Quality Requirement Because of.....

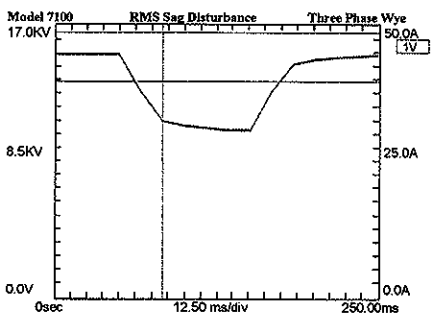
- Advances in microelectronic.
- Increase in automation.
- Change in process from batch to continuous flow.
- Replacement of electromechanical controls to electronic controls.
- Computers moving from the computer room to office and production floors.
- Continuous around-the-clock 24/7 operation.

Quality versus Reliability

- Reliability
  - Power "On" or "Off."
  - Outages.
  - Customer's understand outages and can live with them if the frequency and duration are minimized.
- Power Quality
  - Temporary deviation from normal (milliseconds to seconds).
  - Disrupts process operation for no apparent reason.
  - Customers have difficulty understanding why the "Blink" happened on a clear day!!

Quality versus Reliability





Large Industrial Customer: Perfect Power from Reliability Perspective (0 outages)

On average, customer experiences 10 voltage "Blinks" per year that cause process disruptions.

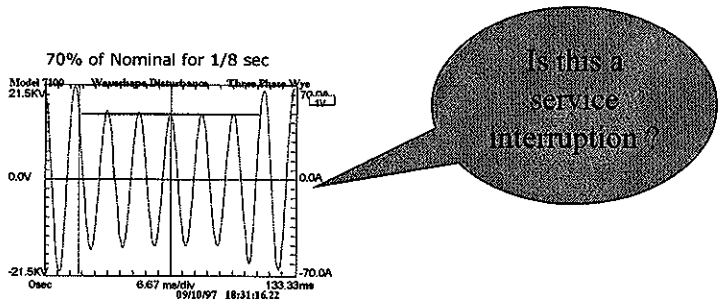
Is the reliability of power adequate?

Is the quality of power adequate?

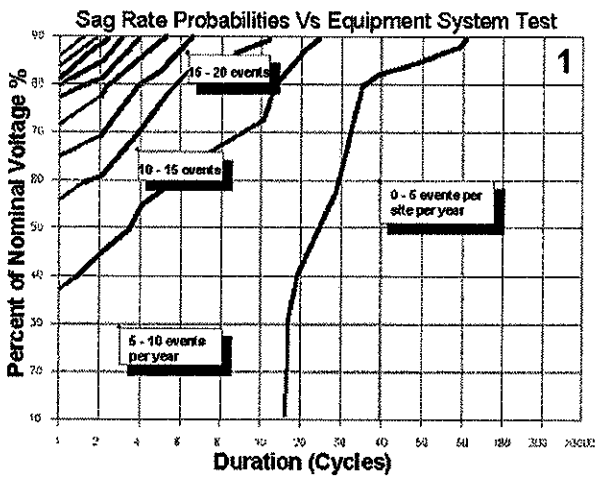
Does Reliability = Quality?

Quality of Power – Perception & Reality

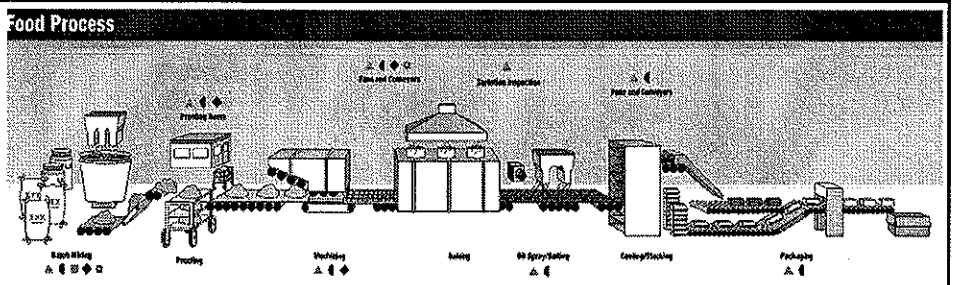
Electric utility definition of *service interruption* will differ from customer perception of *service interruption* as load sensitivity increases.



From EPRI DPQ Study



The Ultimate Goal: Eliminating... The Weakest Link!



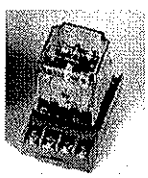
- The process is as robust as its "weakest link."



- Process controls are in most cases are the weakest link.
- Managing PQ disturbances are often managing the weakest links in a process.

Weak Links - AC Relays and Motor Starters

"ice cube" relays



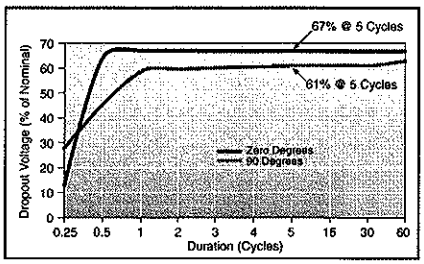


Figure 5. Composite Low-Voltage Tolerance of Relays

Motor Starters



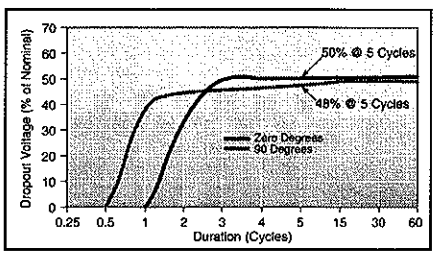
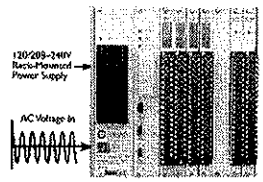
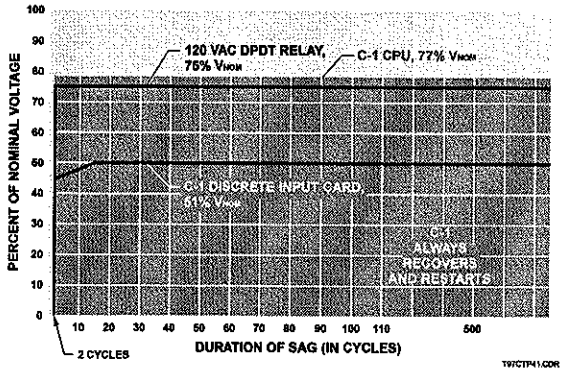


Figure 6. Composite Low-Voltage Tolerance of Motor Starters

Weak Links - PLCs

PLC Shuts down based on incoming AC Voltage before Control System is affected.

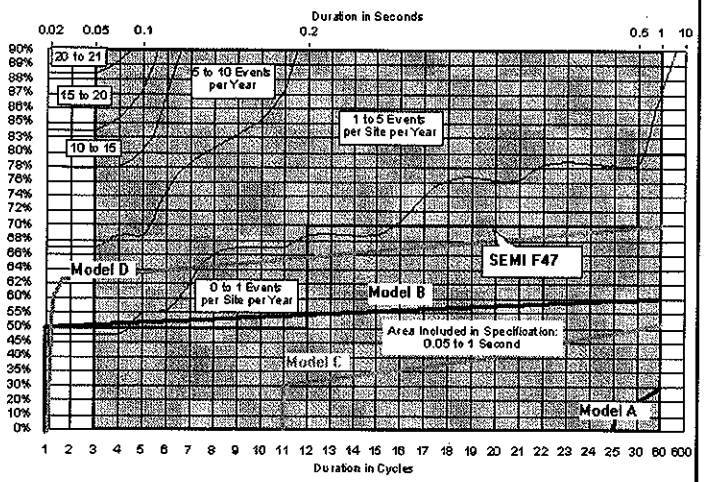




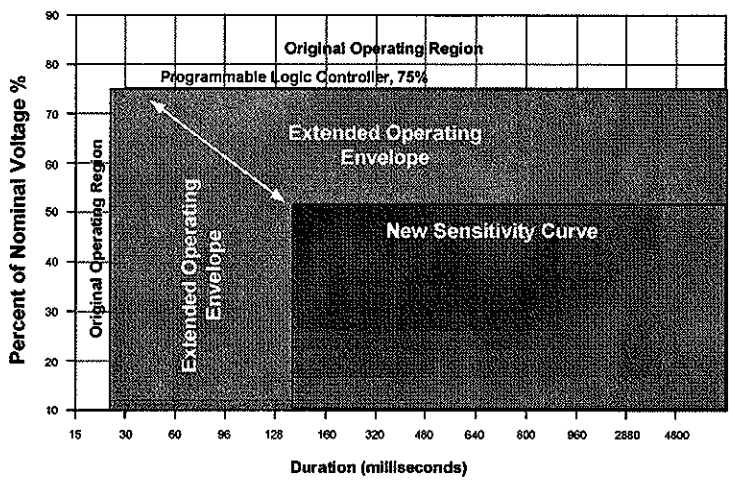
Weak Links- ASDs (Phase-to-Phase Sag Susceptibility)



- DC bus under voltage trip
- Interfacing Relay sensitivity



The End Goal of Standards – To Extend The Operating Envelope



EPRI Power Quality Standards Efforts and Initiatives

- Semiconductor Industry :
  - SEMI F47 – Completed 2000
  - See www.f47testing.com for more information
- Machine Tool Standards
  - Ongoing Efforts
  - See www.f47testing.com/cncpq for more information
- Robotics
  - Ongoing EPRI Characterization Projects
- Automotive
  - Ongoing Utility Sponsored Regional Efforts
- Food and Beverage
  - Ongoing Utility Sponsored Regional Efforts

Standard in Action - SEMI F47

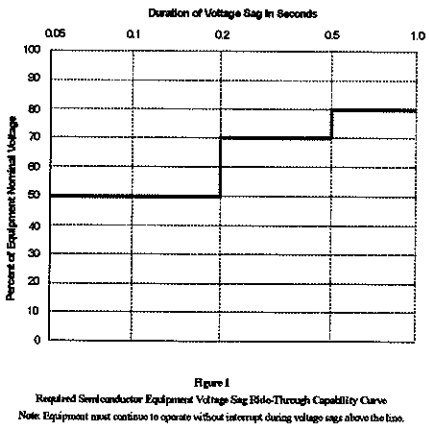


Figure 1
Required Semiconductor Equipment Voltage Sag Ride-Through Capability Curve
Note: Equipment must continue to operate without interrupt during voltage sags above the line.

- Semiconductor equipment is meeting new PQ standard
- Serves as proof to other industries that improved equipment level compatibility is possible
- See www.f47testing.com for more information

EPRI Machine Tool Power Quality Efforts

Background Review

In the past two years, EPRI PEAC has worked with NIST on Advanced Machine Tool Power Quality Problems and Solutions.

This project is focusing on standards development and an ultracapacitor demonstration project for machine tools





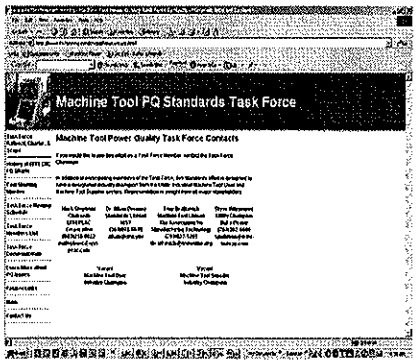
Machine Tool Standards Effort

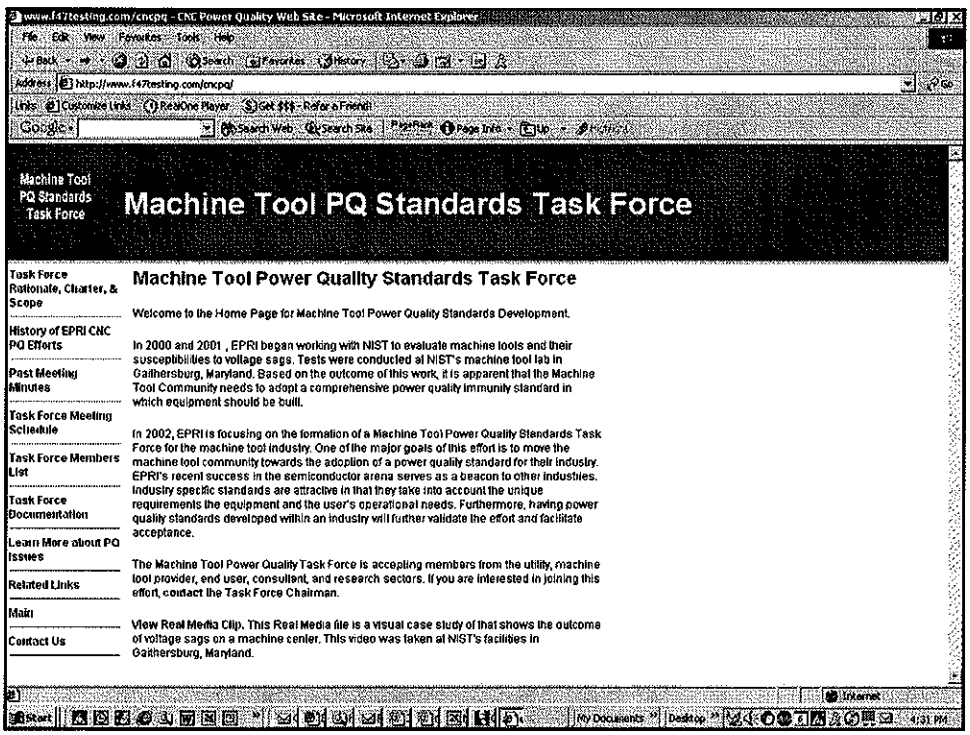
- EPRI PEAC has launched
  www.f47testing.com/cncpq
  Standards web site
- Active Machine Tool Standards Task Force effort is now underway!
- 4 Webex Meetings through end of August
- Representative Also attended NEMA standards meeting
- Effort being publicized through www.f47testing.com newsletter and will be in November issue of test and measurement
- Make a note to visit site to see what is happening!

Get to the website by:

1. www.epri-peac.com, jump to Machine Tool PQ

2. www.f47testing.com, select Machine Tool Task Force Icon





Machine Tool Demonstration Project Activities.









We tested two Tools...

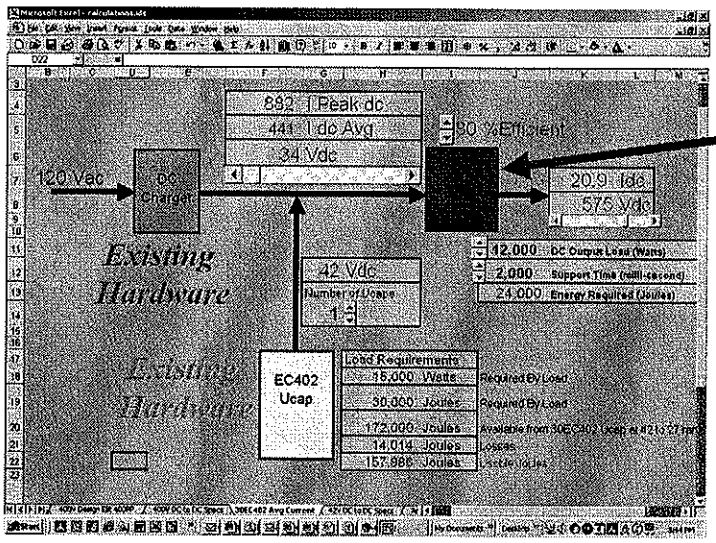
Using Duke's Sag Gen...

Sags damaged Parts !

Sags broke Cutting tools!

- On July 30th and 31st Duke and EPRI PEAC conducted tests on two CNC machines at a customer site
- Purpose of the test was to determine voltage sag susceptibility and gain understanding of energy requirements for demonstration project
- Used information gained to determine design specs for ultracap ride-through device
- Currently in design and prototype stage for ultracap ride-through device

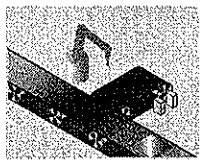
Demonstration Project Ucap Ride-Through Device Design Modeling



*DC-to-DC Converter is Not off the Shelf due to power and input/ output specs.

Conclusions

- Through the SEMI F47 effort and numerous other EPRI PEAC experiences, Low-Cost Solutions have been proven to work.
- The same type of outcome for the Semiconductor Industry should be pursued for other industries and equipment.
- Building on the success of the SEMI F47 efforts, EPRI is leading the way to develop standards in other industries.





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Conducting SEMI F47 Evaluations: Importance of Waveform Precision and Avoiding Extreme Phase-Shifts

October 14th, 2002

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Abstract

In 1996, EPRI PEAC began evaluating the power quality immunity of semiconductor tools as a part of an EPRI initiative. To date EPRI PEAC has conducted SEMI F47 testing on nearly 60 different semiconductor tools, hundreds of components, and dozens of subsystems. Pioneering the method in which to test semiconductor tools and supplying critical test data in the effort, EPRI PEAC's work was instrumental in the development of the SEMI F42 and SEMI F47 standards. Since SEMI F42 and SEMI F47 have been released, some of test companies are conducting SEMI F47 compliance tests in a manner that is different from the method used by EPRI PEAC to determine the base-line tool ride-through knowledgebase used to set the SEMI F47 requirements. Problems with waveform controllability and extreme phase-shift are leading to false negative SEMI F47 test results on some semiconductor tools. This paper clarifies the differences in the test methods, examines how the EPRI DPQ study data supports each test method, and discusses how testing equipment and methods may influence your ability to design systems that can cost effectively achieve compliance.

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Introduction

In order to conduct voltage sag testing against a power quality standard, the test methods and test equipment must perform in a precise and repeatable manner. Variations induced by the test equipment and test method can lead to invalid test results. Such results can be costly in that equipment suppliers may be forced to employ voltage conditioning in order to comply with requirements not provided for within the SEMI F47 standard. Therefore, the test equipment and test methods must be precise and repeatable to correctly characterize the equipment or device under test.

Importance of Waveform Precision and Controllability

SEMI F42 sets the minimum requirements for the voltage sag generator performance requirements as shown in the table below. One of the most important parameters to consider is dynamic load regulation, listed here as requirement number five.

Table 1, Voltage Sag Generator Performance Requirements from SEMI F42-0600

Requirement	*Parameter*	*Requirement*
1	Insertion loss (the difference between sag generator input and output voltages when set to 100% of nominal)	Less than 1.5%.
2	Change in output voltage as load is varied from 0–100% (steady state load regulation)	+/- 5%
3	Output current capability	As required by the DUT.
4	Capability to supply in rush current	Not to be limited by the sag generator.
5	**Under all conditions, the maximum deviation from required voltage (dynamic load regulation)***	**Less than ? 10% for not more than 1 cycle (20/17 ms).**

*Note: This refers to deviation within the sine wave of the voltage sag.

Defined as the maximum deviation from the required voltage, the sag generator output must generate a waveform that is less than +/- 10 percent of the required range. For example, for a 12 cycle, 50 percent of nominal voltage sag the generator should be able to produce the output voltage within 10 percent of the required voltage. If the voltage desired Pre-sag voltage is 120Vac, then the output should be within +/-10 percent of 60Vac rms (66Vac to 54Vac) and that deviation must not be more than 1 cycle in duration. This parameter is very critical when determining if the Device Under Test (DUT) passes SEMI F47. In Figure 1, the output waveform of a voltage sag generator is shown where the dynamic load regulation requirements are not met in the last ½ cycle of the waveform. The error of the last cycle is nearly 90 percent. Such a deviation invalidates the test since a false-negative result will be obtained.

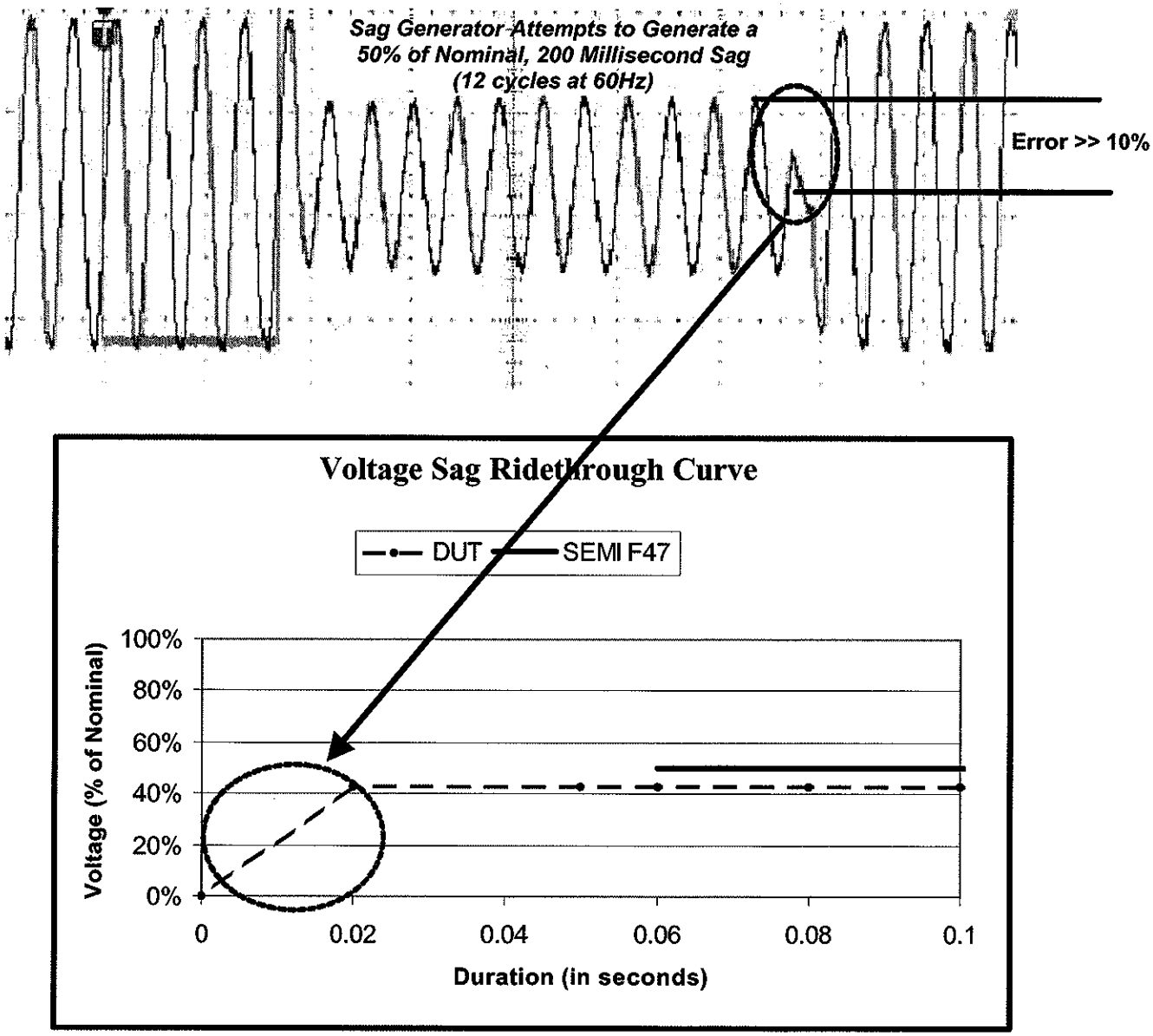

Figure 1, SEMI F47 Compliant Contactor will fail SEMI F47 test due to Dynamic Load Regulation Error created by the Voltage Sag Generator

In contrast to the output waveform shown in Figure 1, Figure 2 shows an example portable sag generator output that exceeds the SEMI F42 standard for sag generator performance requirements. As shown in the figure, the error in the Dynamic Load Regulation is much less than 1 percent during a 200 millisecond (12 cycle), 50 percent of nominal voltage sag. Such precision on the sag generator output will not lead to false negative test results.

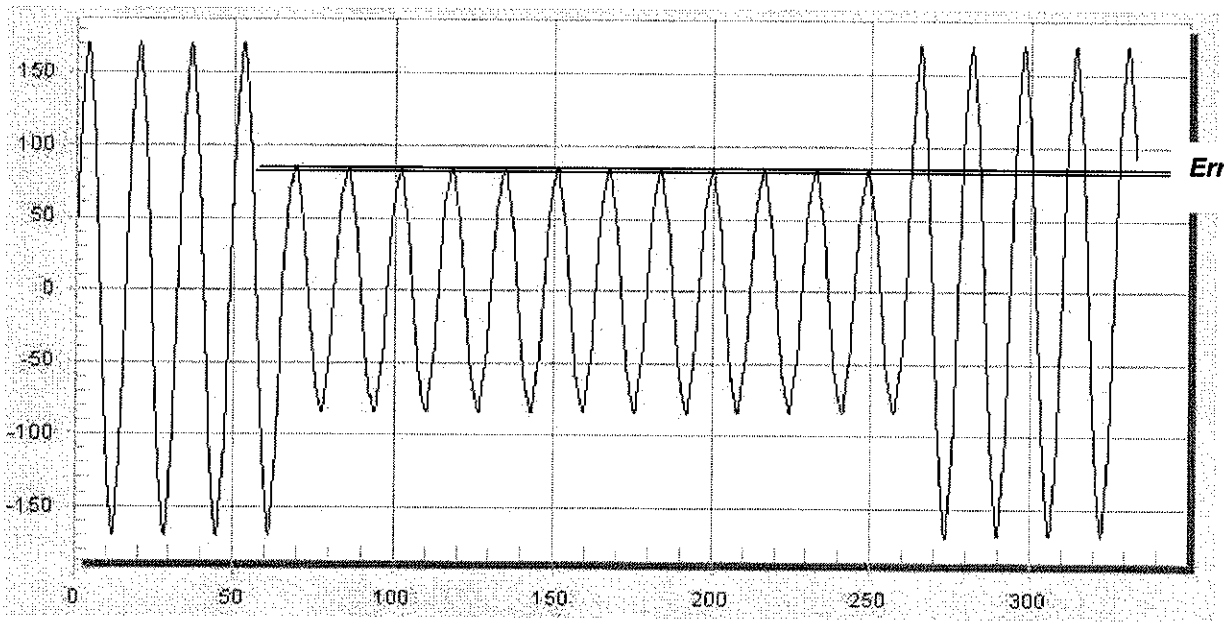

Figure 2, 12cycle, 50 Percent of Nominal Voltage Sag Waveform that Exceeds SEMI F42 Dynamic Load Regulation Requirements
(Source: Actual EPRI PEAC Sag Generator Output Test Data, Porto-Sag Software, version 4.4)

Importance of not Inducing Extreme Phase-Shift

The characteristics of the voltage sags generated for test purposes must be representative of events observed in the real electrical environment. When conducting phase-to-phase voltage sag tests, it is important not to artificially induce too much phase-shift. Extreme phase-shifts can make subcomponents drop out as a result of the voltage sag.

Phase-to-Phase Voltage Sag Testing Method A

EPRI PEAC creates voltage sags by referencing a neutral connection as shown in Figure 3 below and as shown in the SEMI F42 standard, Related Information Section, Figure R1-1. As an example, to generate a 50 percent of nominal voltage sag phase-to-phase, two phase-to-neutral voltages are reduced to 50 percent of nominal. As shown in Figure 4, conducting tests in this manner induces no phase shift between each phase-to-neutral voltage. It is important to note that the nominal value for each vector is defined as 1.0 per unit for the purposes of the illustration.

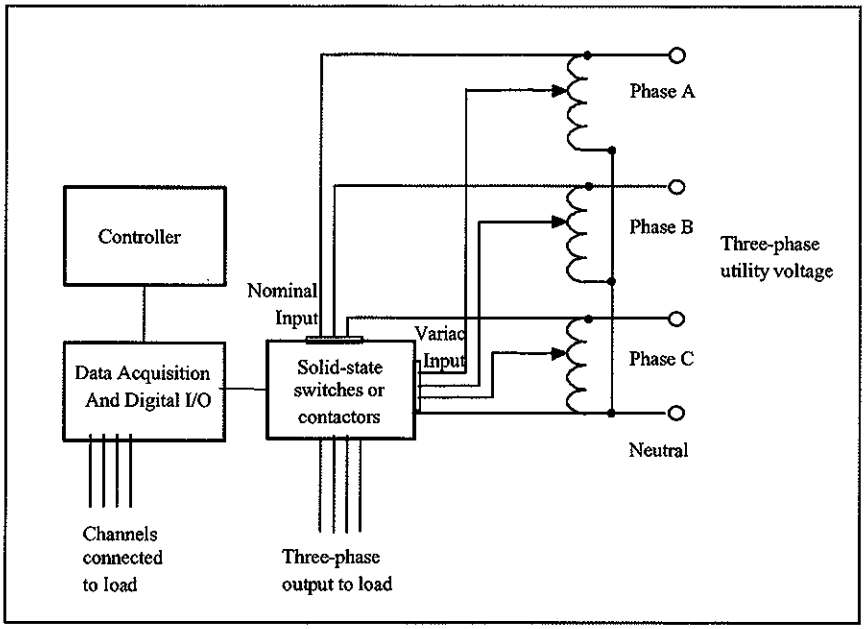

Figure 3, Voltage Sag Generator Configuration Used by EPRI PEAC References a Neutral Conductor to Minimize Phase Shifting
(Source: SEMI F42-0600, Related Information Section)

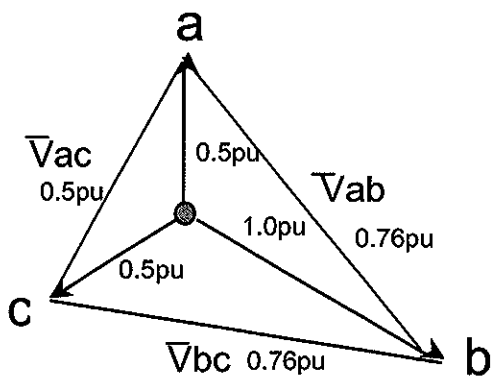

Figure 4, Setting Van=50% and Vcn=50% Results in Vac vector of 50% of Nominal with no Phase-Shift with Respect to Neutral

This method requires that EPRI PEAC utilize a neutral conductor even if one is not present at the tool. This method can also allow a single hook-up between the tool and the electrical power source. There is no need to reconnect the sag generator to test all phase combinations. Although in some cases this method may require extra test hardware to create a neutral, the resultant test is much closer to the nature of a real voltage sag event than Method B as described below.

Phase-to-Phase Voltage Sag Testing Method B

Some test companies are conducting three-phase voltage sag testing by inducing voltage sags phase-to-phase as described herein as Method B. In this method, the voltage sag generator is connected across a phase combination (i.e. across Vac). The tests are conducted on this phase by referencing one phase against the other. Next, the sag generator is connected across the other phase combination (i.e. Vab) and the test is repeated. Finally, tests are concluded by connecting the sag generator across the final phase combination (Vbc) and the tests are performed again. Figure 5 shows the basic electrical connection used in this method. The sag test can be done with or without a neutral connection since it is not referenced.

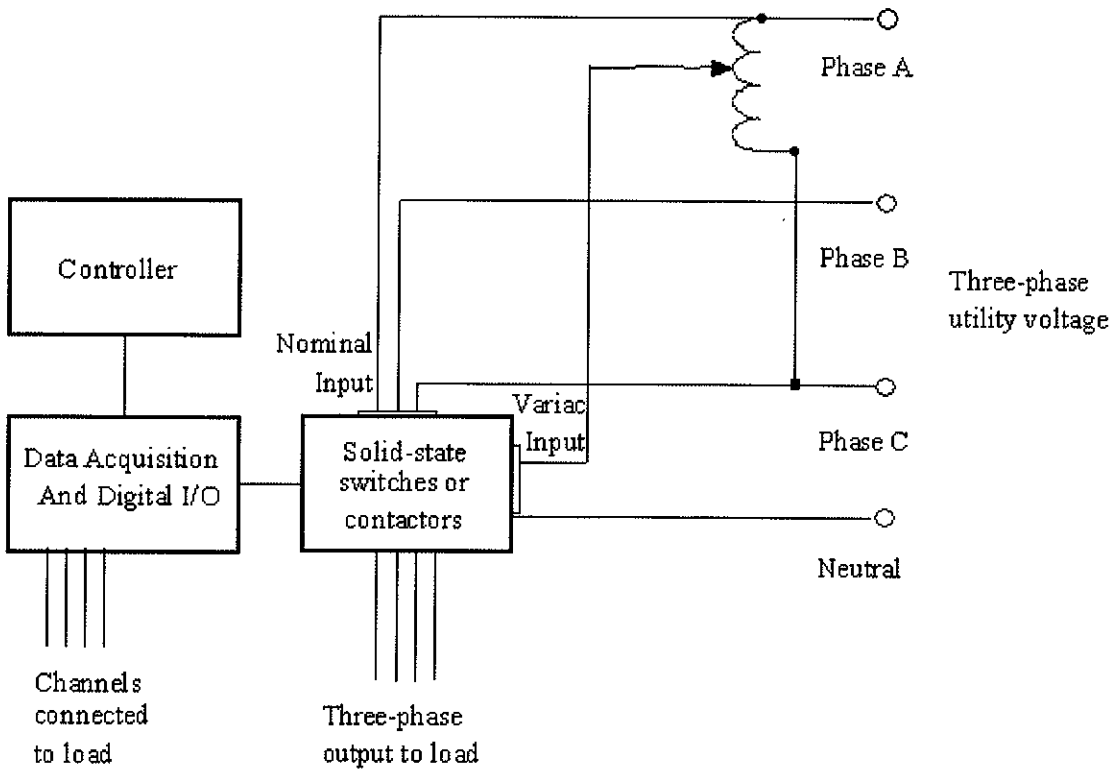

Figure 5, Basic Concept of Test Method B Involves Injecting Phase-to-Phase Voltage Sags by referencing One Phase against the Other.

For phase-to-neutral connected loads, such as in five-wire, wye-type connected equipment, phase-shifts as large as 60 degrees can be induced using Method B. Figure 6 shows the phase shift in vector Vcn using this method to create a 50 percent of nominal voltage sag for vector Vac. Furthermore, Figure 7 shows that when using Method B, the phase-to-neutral vector will be shorter than the phase-to-phase vector over much of the SEMI F47 test range. This effect has been shown to cause "over testing" of the phase-neutral vector by as much as 8 percent over the SEMI F47 test range when compared to the magnitude of the phase-to-phase vector. Because Method A adjusts the magnitude of two phase-to-neutral vectors to create a phase-to-phase

voltage sag, the magnitudes correspond linearly. Again, it is important to note that the nominal value for each vector is defined as 1.0 per unit for the purposes of the illustrations.

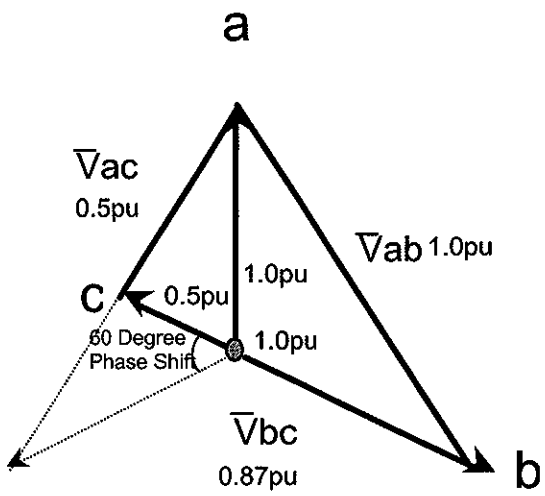

Figure 6, Phase-to-Phase Voltage Sag Method 2 Results in Abnormally Large Phase Shift Not Characteristic of Actual Voltage Sag Events

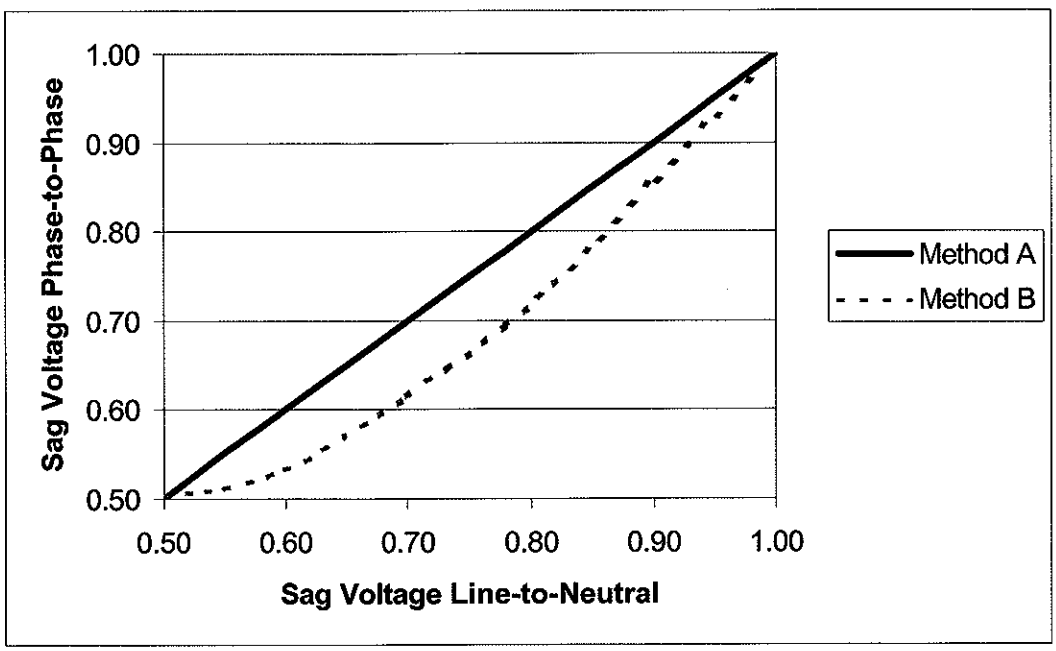

Figure 7, Comparison of Line-to-Neutral Vector Shortening Effect of Method B Versus Method A over the SEMI F47 Test Range

Effect of Extreme Phase-Shift on Component Voltage Sag Susceptibility

Such extreme phase shifts can make components be more susceptible to voltage sags at a given magnitude. This susceptibility to extreme phase shifts can make a tool fail the SEMI F47 test

due to component sensitivity. As a part of the original EPRI semiconductor initiative, exhaustive tests were conducted on a load bank containing 21 different control loads such as control relays, motor starters, contactors, and power supplies. The results of the phase-shift tests indicated that a change as much as 60 degrees could result in a susceptibility variability range of as much as 35 percent of nominal. Therefore, components that would pass SEMI F47 with no phase-shift induced on the phase-to-neutral load may not pass the standard when subjected to extreme phase shifts. Table 2 illustrates several examples in which the load device is more sensitive when phase shifts are induced. The data also illustrates that small control relays are the most susceptible while DC power supplies are not susceptible to phase-shifting. Other devices that can be affected by this type of phase shifting include those that utilize phase locked loop circuits that utilize the zero crossing of the voltage waveform.

Table 2, Magnitude (Percent of Nominal Voltage) in Which Component Dropped Out During 6 Cycle Voltage Sags (7 Different Phase-Shifts)
(Source: EPRI Test Brief 45: The Effects of Phase Shift on the Low Voltage Tolerance of Industrial Devices, June 1998)

Phase Shift	Device																				
	CR1	CR2	CR3	CR4	MS1	MS2	MS3	MS4	MS5	MC1	MC2	MC3	MC4	MC5	MC6	MC7	PS1	PS2	PS3	PS4	PS5
-60	90%	70%	55%	55%	55%	45%	35%	50%	55%	35%	40%	50%	55%	55%	60%	55%	75%	65%	50%	60%	90%
-40	70%	70%	55%	55%	55%	50%	35%	50%	55%	35%	40%	50%	55%	55%	60%	50%	75%	65%	50%	60%	90%
-20	70%	70%	55%	55%	55%	45%	35%	50%	55%	35%	40%	50%	50%	55%	55%	55%	75%	65%	50%	60%	90%
0	70%	70%	55%	55%	55%	45%	30%	50%	55%	35%	40%	50%	50%	55%	55%	55%	75%	65%	50%	60%	90%
20	70%	75%	60%	60%	55%	40%	30%	50%	55%	35%	45%	50%	55%	55%	55%	55%	76%	65%	50%	60%	90%
40	80%	80%	70%	70%	60%	45%	35%	50%	55%	35%	45%	50%	55%	55%	50%	50%	75%	65%	50%	60%	90%
60	90%	95%	90%	75%	55%	45%	30%	50%	60%	35%	40%	50%	50%	60%	55%	60%	75%	65%	50%	60%	90%
Range	20%	25%	35%	20%	5%	10%	5%	0%	5%	0%	5%	0%	5%	5%	10%	10%	0%	0%	0%	0%	0%

Relevance of EPRI DPQ Data in Phase-Shift Analysis

In the mid 1990s, EPRI conducted a study on distribution power quality. The DPQ study measured power quality at nearly 300 sites across the US. This benchmark study represents the most extensive power quality database of disturbance data available for the United States electrical distribution system. Follow on work ensued in the late 1990s to understand waveform characteristics of voltage sags such as where the voltage sag begins in a waveform (known as point of initiation) and phase-shifting. The EPRI report entitled "Waveform Characteristics of Voltage Sags" (TR-112692), shows that voltage sags do not typically contain extreme phase-shifts. Single, two, and three phase voltage sags were recorded in this study with respect to neutral. Therefore, this data is an outstanding reference in understanding how much phase-shift occurs with respect the neutral conductor. The phase-shift data for over 101,835 voltage sag events recorded by DPQ study is shown in Figure 8.

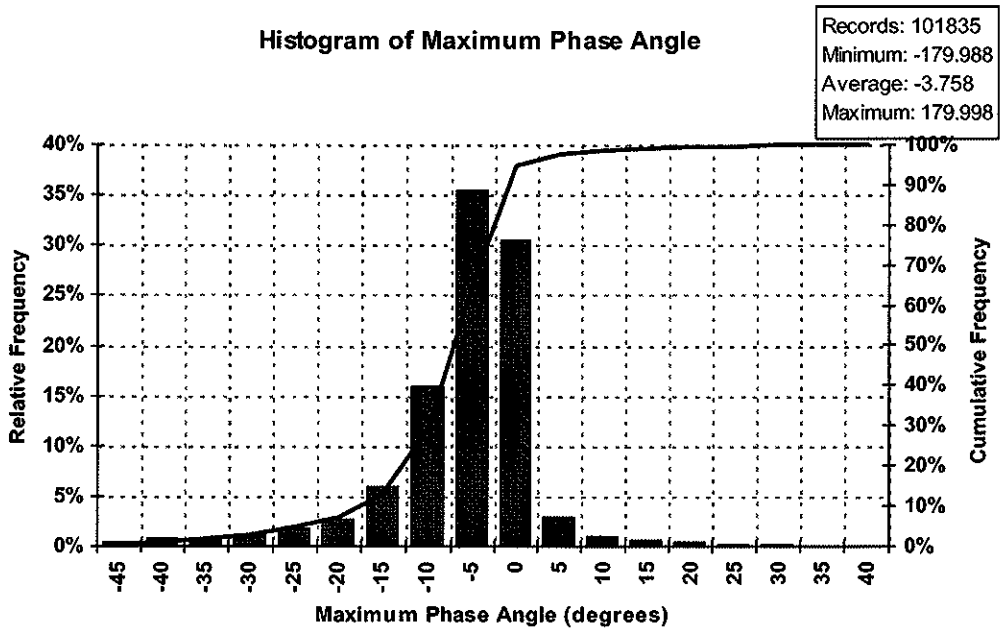

Figure 8, Histogram of Maximum Transition Angle During Event for RMS Variations 6/1/93 to 6/1/95, Treated by Sampling Weights, All Sites
(Source: Waveform Characteristics of Voltage Sags, EPRI TR Report TR-112692, April 1999.)

From Figure 8, it is shown that average phase-shift with respect to neutral is –3.758 degrees. Furthermore, over 92 percent of the voltage sags indicate a phase-shift between –20 and +5 degrees. Furthermore, the Histogram shows that phase-shifts as extreme as +/- 60 degrees on the phase-to-neutral conductors are just not realistic in the electrical environment. ***This data further validates Method A of voltage sag testing for five-wire, wye-type systems and shows that Method B does not simulate the real electrical environment.***

Conclusions

When conducting SEMI F47 testing, it is important to use a voltage sag generator that meets the SEMI F42 requirements. If the output waveform on the voltage sag generator is not precise, the tests results can yield false negative results – leading to unnecessary design changes or unwarranted application of power conditioners when none may be needed to pass the SEMI F47 standard. Furthermore, the manner in which phase-to-phase testing is conducted must reflect conditions that can normally occur in the electrical environment. The best and most accurate way to conduct phase-to-phase testing on a five-wire (L1, L2, L3, N, G), wye-type system is to reference a neutral conductor as denoted in Method A. However, if the system utilizes only a four-wire delta type hook up (L1, L2, L3, G) either Method should yield acceptable results. Future revisions of the SEMI F42 and SEMI F47 standards should further specify the acceptable test equipment performance and phase-to-phase test methods for semiconductor tool loads.

References

SEMI F47-0200 "Specification for Semiconductor Processing Equipment Voltage Sag Immunity", SEMI, February 2000

SEMI F42-0600 "Test Method for Semiconductor Processing Equipment Voltage Sag Immunity", SEMI, June 2000

EPRI Test Brief 45 " The Effects of Phase Shift on the Low Voltage Tolerance of Industrial Devices", June 1998

Waveform Characteristics of Voltage Sags, EPRI TR Report TR-112692, April 1999.

Other Relevant Documents

M. Stephens, D. Johnson, J. Soward, J. Ammenheuser, "Guide for the Design of Semiconductor Equipment to Meet Voltage Sag Immunity Standards", International SEMATECH Technology Transfer document 99063760B-TR, 1999.

EPRI Task 24 Final Report: Power Quality in the Semiconductor Industry, February 1999.

Acknowledgements

The authors would like to thank Dennis Johnson of TI for his review and comments on this technical paper. The authors would also like to thank Daniel Brooks of Electrotek Concepts, Inc. for providing clarification related to the phase-shifting data.

International Power Quality Conference

IPQC 2002

If Power Quality is a Global Problem – Where is the Data?

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SoftSwitching TECHNOLOGIES
Revolutionizing Power Protection

Important Questions & Issues in Power Quality

- Power quality is a financial problem – not a technical problem!
- For the past 100 years, the utility's job has been to keep the 'lights on'. For today's high-tech factories and processes, that is no longer sufficient.
- As the reliability of utility service is increased, the number of PQ events increases!
- When the cost of PQ monitoring exceeds the cost of the solution, and often the cost of the problem – we have a problem!
- If a customer experiences a voltage sag, does it make him feel better if no one has a record of it?
- If a ¼ second voltage sag takes down a customer's process for 1 hour, did the customer experience a ¼ second or 1 hour power event?
- Without adequate data, the PQ market is based on fear!
- First step is knowledge of the problem, then comes the solution!

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PQ & PR Monitoring: Existing Solutions

Typically provide multi-function monitoring
- Voltage, current, power, VAR, energy, harmonics

Low-End Monitors		
Providers	**Cost**	**Trade-offs**
• Fluke • Dranetz/BMI • PML • RPM	• ~$1,000 to $2,500	• Stand alone 'instruments', no networking or data aggregation • Labor intensive use, especially with multiple monitors
High-End Monitoring Systems		
Providers	**Cost**	**Trade-offs**
• Dranetz/BMI • PML • RPM	• $10,000-$25,000 (system) • $800-$4,000 (monitor) • $400-$3000/yr (operating)	• Multiple monitor internal network (Internet/Ethernet for external communications) • Require significant hardware, software, infrastructure
Automatic Metering Systems		
Providers	**Cost**	**Trade-offs**
• ION • GE • SmartSynch	• System cost borne by utility • $800/monitor + monthly charge	• Primarily revenue grade meters, limited PQ/PR capability • Require expensive infrastructure, including full back-end integration with utility billing system

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Ideal PQ & PR Monitor

- Low cost, simple to use (plug & play), minimal infrastructure & low operating cost
- Provides real-time 24x7 access to grid-wide data anytime & anywhere
- Provides relevant & timely data - easy to interpret, analyze, & report
- Allows drill-down for detailed information & analysis
- Cost-effective at single user level, & scales to meet needs of larger & more sophisticated users
- Provides user with valuable resource, but frees them from burden of data storage & system administration
- Needs to work globally

- We need a new paradigm in power monitoring

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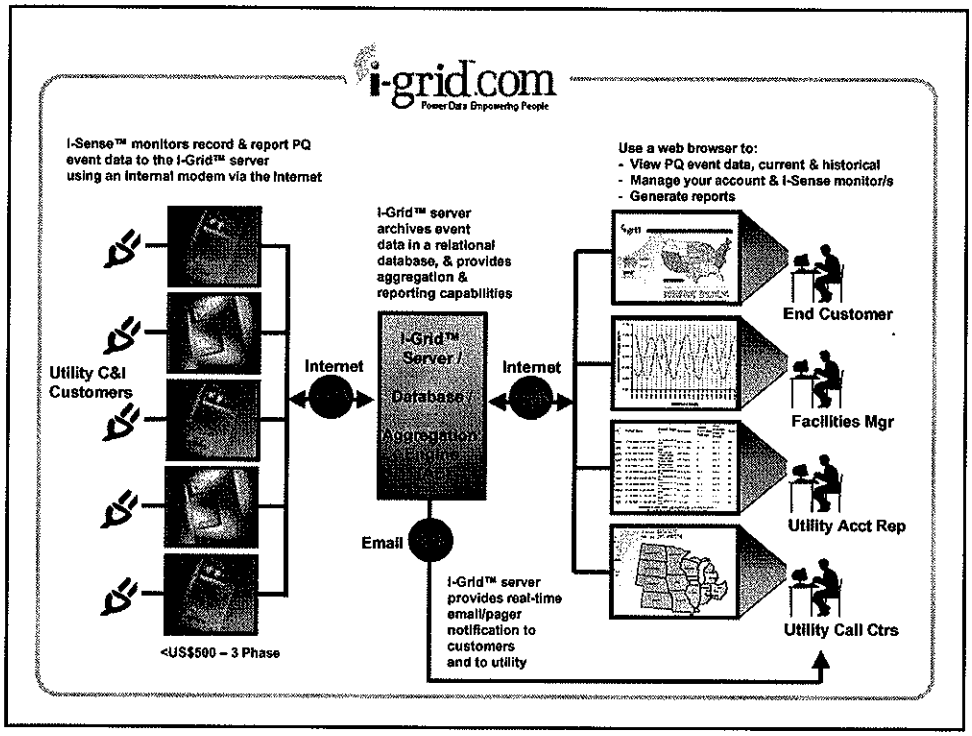
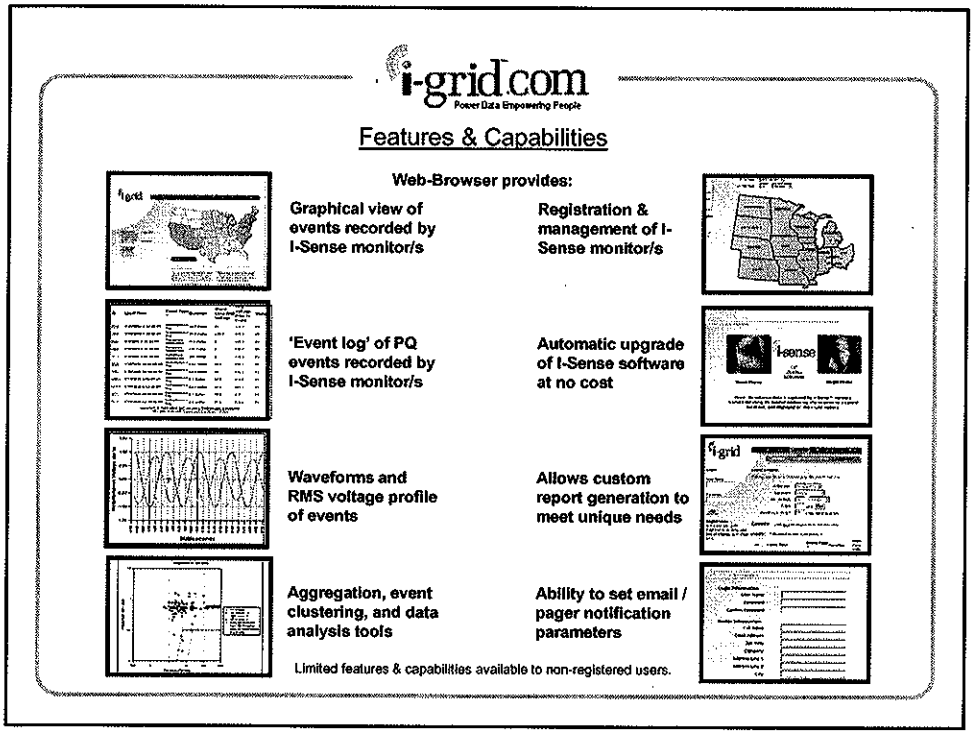
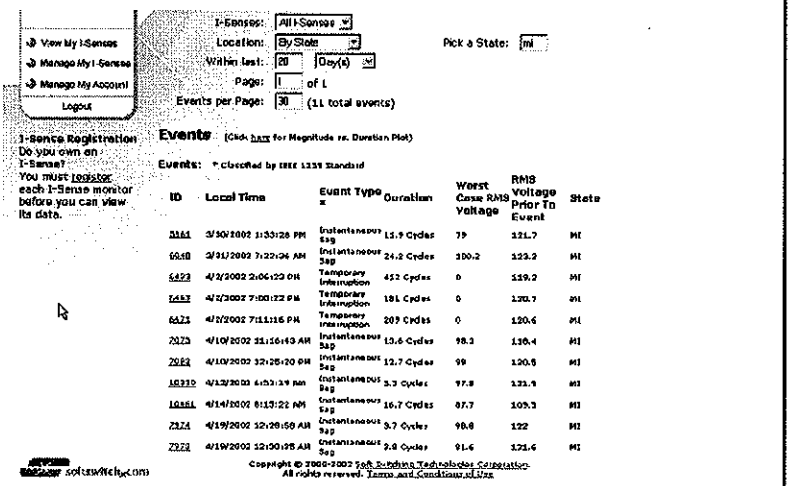

i-grid.com
Power Data Empowering People
I-Sense™ monitors record & report PQ event data to the I-Grid™ server using an internal modem via the Internet
Use a web browser to:
- View PQ event data, current & historical
- Manage your account & I-Sense monitor/s
- Generate reports
I-Grid™ server archives event data in a relational database, & provides aggregation & reporting capabilities
Utility C&I Customers
Internet
I-Grid™ Server / Database / Aggregation
Internet
End Customer
Facilities Mgr
Utility Acct Rep
Utility Call Ctrs
Email
I-Grid™ server provides real-time email/pager notification to customers and to utility
<US$500 – 3 Phase


i-grid.com
Power Data Empowering People
Features & Capabilities
Web-Browser provides:
Graphical view of events recorded by I-Sense monitor/s
Registration & management of I-Sense monitor/s
'Event log' of PQ events recorded by I-Sense monitor/s
Automatic upgrade of I-Sense software at no cost
Waveforms and RMS voltage profile of events
Allows custom report generation to meet unique needs
Aggregation, event clustering, and data analysis tools
Ability to set email / pager notification parameters
Limited features & capabilities available to non-registered users.

Event Log



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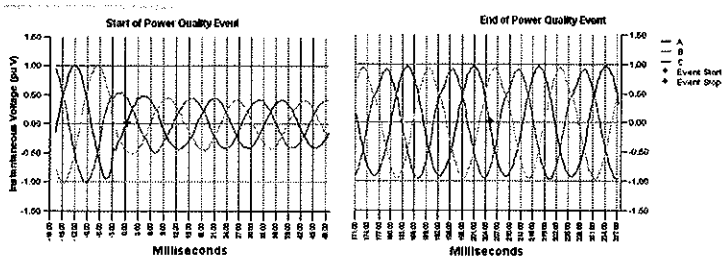
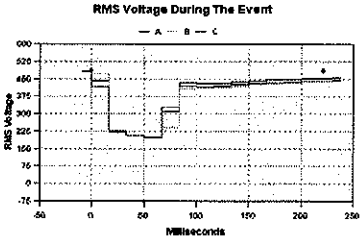
Event Waveforms & RMS Voltage Profile



Date:	7/14/2002
Time:	8:20:49 PM
Location:	Southwest Region



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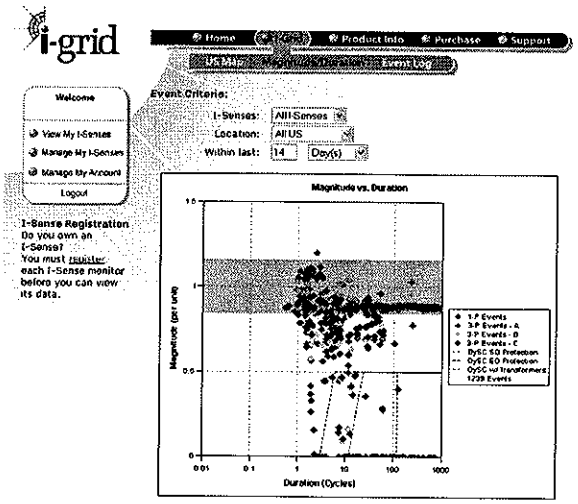
Event Mag-Dur Plots



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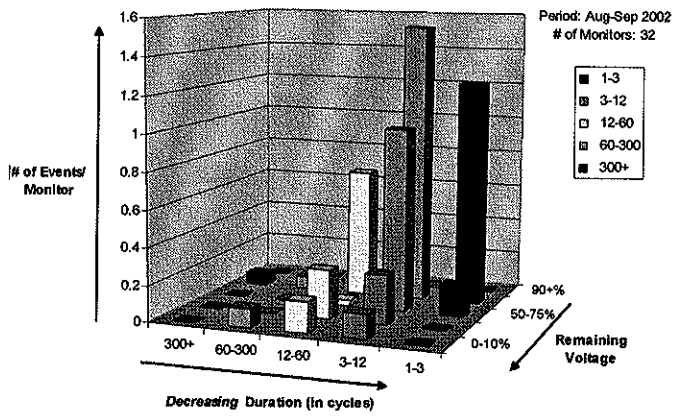
Event 3D Mag-Dur Event Density Plots

Mag-Dur Event Density Map for Multiple Facility Industrial Customer



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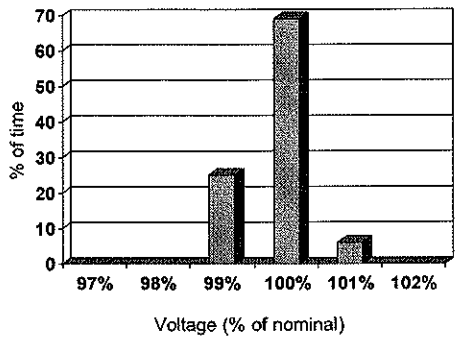
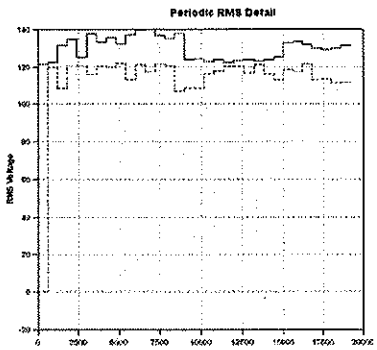
RMS Voltage Distribution Profile

- Eastern Utility Substation, one week voltage profile for one site



- West Coast end-of feeder apartment building RMS voltage profile (5.3 h)



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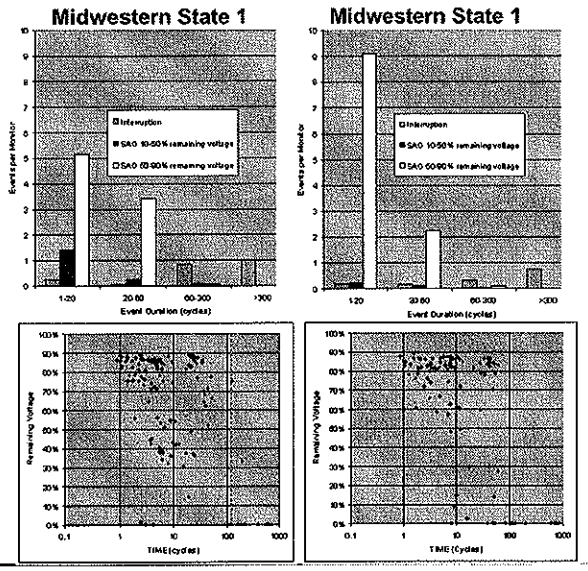
State-Level Event Statistics (2 months)



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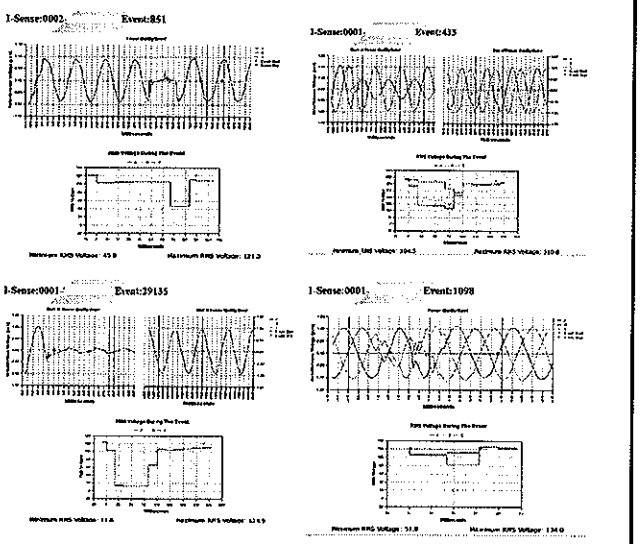
Event Analysis

Four sensors around Madison picked up a disturbance at 7:12pm on April 30, 2002:

- Time stamp allows easy identification of clustered events
- MG&E, local Utility company, confirmed 'crow' event
- Event caused several unprotected loads to trip, shows correlation



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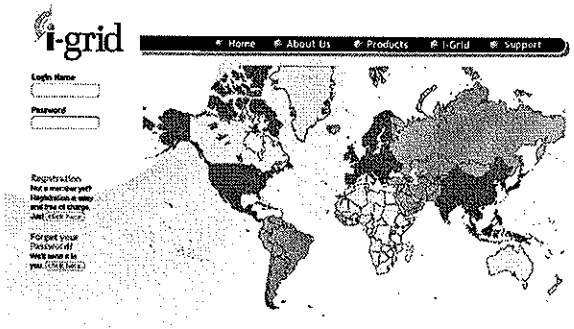
I-Grid™ - Current Status

- Commercially available since May 2002, prototype pilot system since early 2001
- Over 650 units shipped; extensively being used by utilities, industrial manufacturing plants, commercial facilities
- Independent testing by EPRI-PEAC, utilities, and industrial users
- Over 19,000 events have been recorded all over the US
- Operation demonstrated in Singapore, Mexico, and Canada



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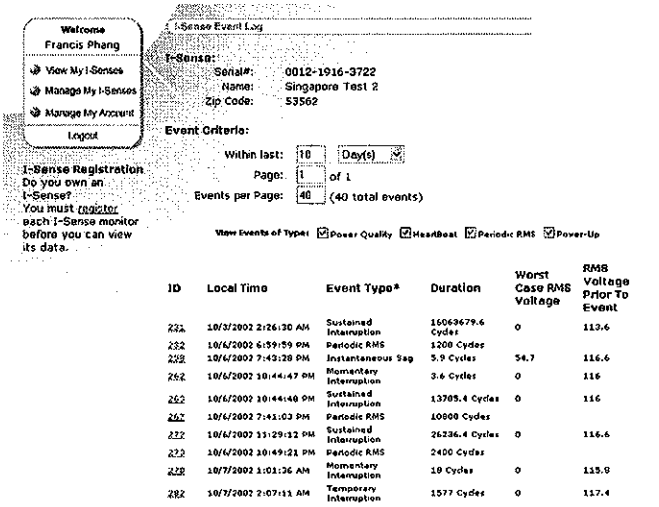
Singapore Event Log



ID	Local Time	Event Type*	Duration	Worst Case RMS Voltage	RMS Voltage Prior To Event
231	10/3/2002 2:26:30 AM	Sustained Interruption	16063679.6 Cycles	0	113.6
232	10/6/2002 6:59:59 PM	Periodic RMS	1200 Cycles		
259	10/6/2002 7:43:28 PM	Instantaneous Sag	5.9 Cycles	54.7	116.6
262	10/6/2002 10:44:47 PM	Momentary Interruption	3.6 Cycles	0	116
263	10/6/2002 10:44:49 PM	Sustained Interruption	13705.4 Cycles	0	116
267	10/6/2002 7:41:03 PM	Periodic RMS	10800 Cycles		
272	10/6/2002 11:29:12 PM	Sustained Interruption	26236.4 Cycles	0	116.6
273	10/6/2002 10:49:21 PM	Periodic RMS	2400 Cycles		
278	10/7/2002 1:01:36 AM	Momentary Interruption	19 Cycles	0	115.9
282	10/7/2002 2:07:11 AM	Temporary Interruption	1577 Cycles	0	117.4

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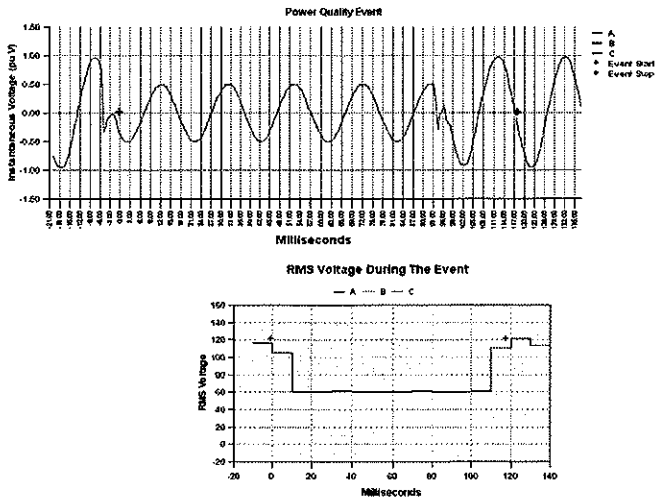
Singapore Waveforms



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Conclusions

- For the past 100 years, the utility's job has been to keep the 'lights on'. For today's high-tech factories and processes, that is no longer sufficient.
- Power quality is a global problem, but we need the data to implement effective solutions
- Existing monitoring solutions are too expensive for wide-spread deployment
- A new paradigm, enabled by the Internet, promises grid-wide real-time power quality and reliability data in near real-time.

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TECHNOLOGIES
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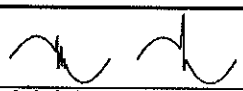
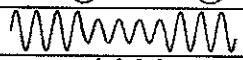
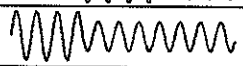
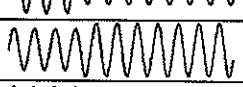
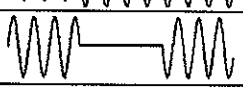
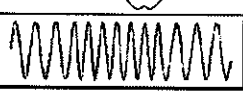
Power Quality

Power Quality Issues and Mitigations



Dr. Li Hongqun
SP Systems Pte Ltd
International Power Quality Conference 2002, Singapore
25 October 2002

Power Quality Problems

Transients		Less than 0.5 cycles
Voltage Sag		0.5-180 cycles
Voltage Swell		0.5-180 cycles
Undervoltage		**Greater than 180 cycles**
Overvoltage		**Greater than 180 cycles**
Voltage Interruption		**Greater than 0.5 cycles**
Noise		Steady-state
Harmonics		Steady-state
Frequency Variation		Less than 600 cycles

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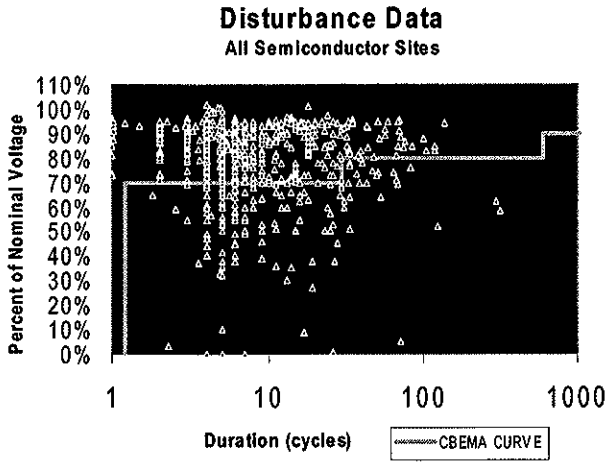
Disturbances Recorded By SEMI Power Quality and Equipment Ride-Through Task Force



- Task Force that created SEMI F47 Studied 16 Plants, 14 in US
- 30.5 Monitor years
- Total events = 1064
- Average number of Events below SEMI F47 per site per year is 3.1

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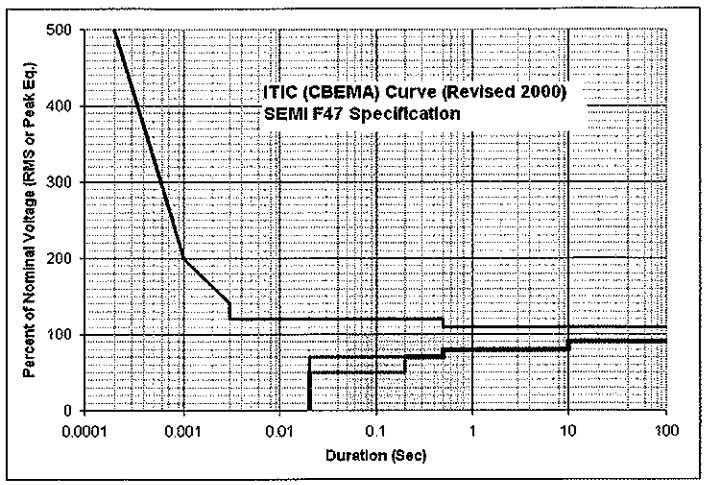
ICTC (CBEMA) & SEMI F47



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Voltage Sag Causes Problems Due To

- Voltage drops to less than the minimum holding voltage of electromagnetic components
- Insufficient power supplied to equipment
- Over transient of equipment during voltage sag
- Lock of motor of compressor

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Electromagnetic Components

COMPONENT	DROPOUT CONDITION
Relay	>30% rated voltage, <10-15 ms
Contactor*	>50% rated voltage, <10-15 ms
Electromagnetic valve	>50% rated voltage, <10-15 ms
Under-voltage relay	Dependant on setting
EMO circuit	>50% rated voltage, <10-15 ms

* IEC947 specifies that the dropout voltage should be less than 70% and greater than 20% of rated voltage

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Insufficient Power

DEVICE	SPECS	STOPS OPERATION
Industry computer	Input voltage: 90-264V	When connected to 120V supply, reboots while a sag of 67% and 40 ms is applied.
SMPS	Input voltage: 100-240V	When connected to 120V supply, stops operation while a sag of 50% and 200 ms is applied.

Linear DC supply is more sensitive

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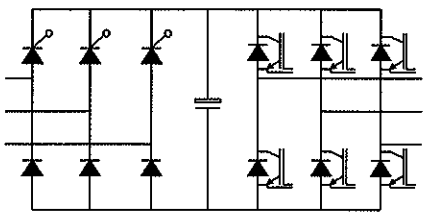
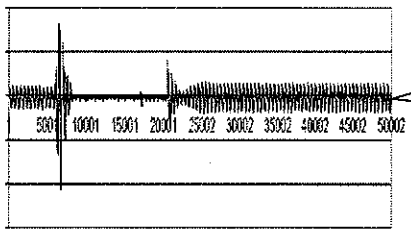
Transient



VSD
Some UPS
DC supply
Induction motor



Input current of a 10 kVA UPS during a voltage sag

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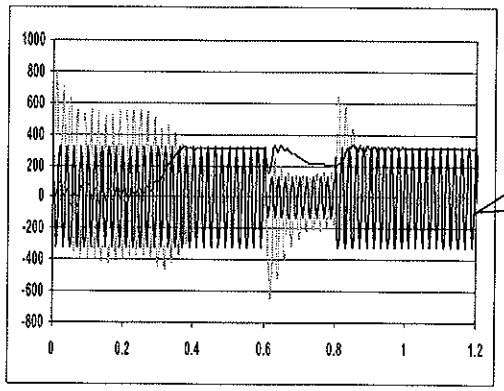
Response of Induction Motor to Voltage Sag



Response of a 15 kVA induction motor to a 60% voltage sag (simulation)

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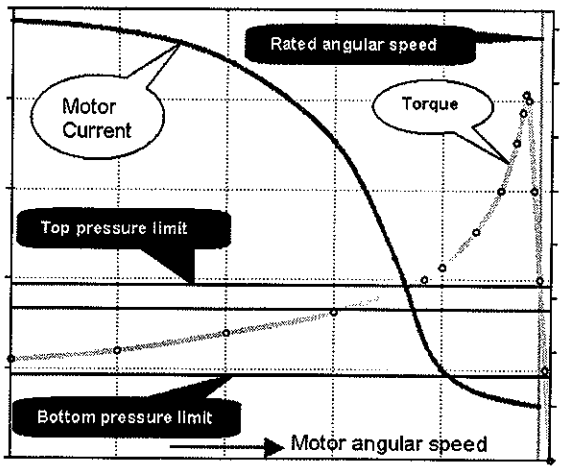
Compressor



During compression, a voltage sag can cause the lock of the compressor motor.

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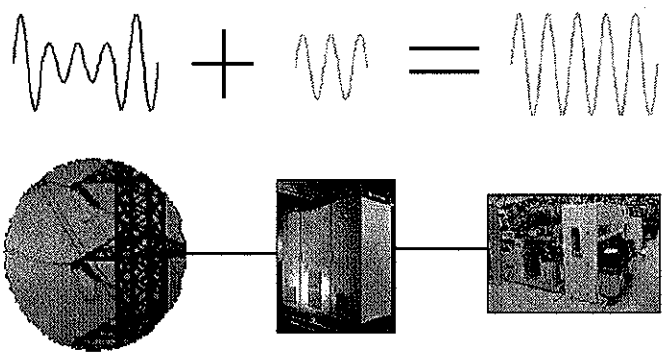
Mitigation Of Voltage Sag



Power from sagged supply + Power from energy storage = Power to load

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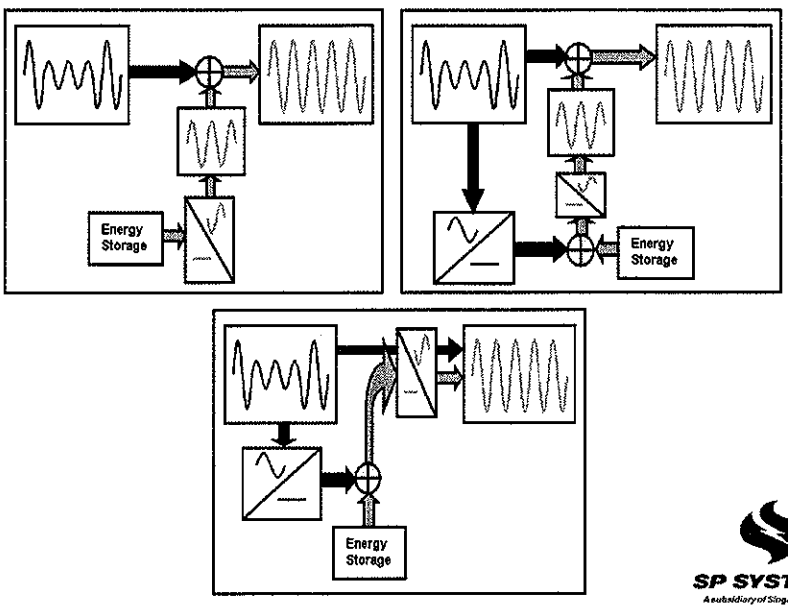
Implementation Of Dynamic Voltage Compensator



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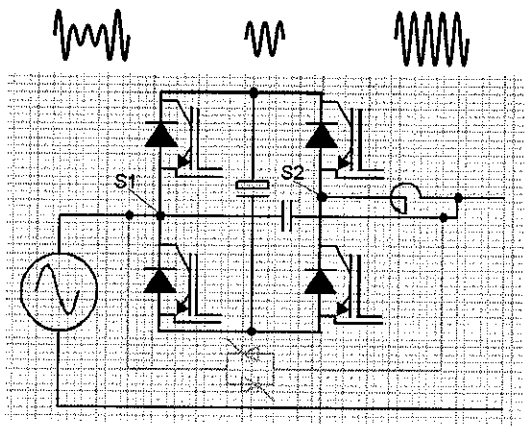
Scheme of DynaCom™



In DynaCom™, direct injection scheme is used. This means that the injection transformer is saved.

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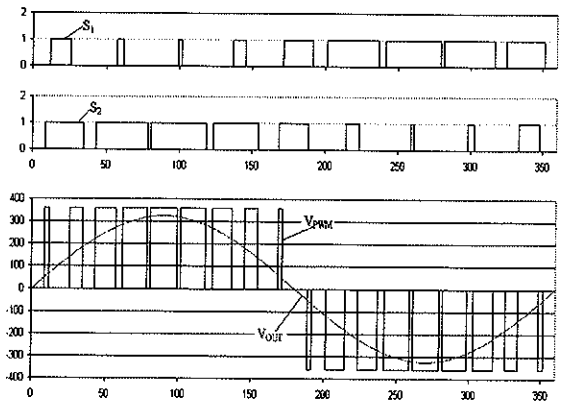
Switching Scheme of DynaCom™



In DynaCom™, double switching frequency scheme is implemented by full bridge single phase inverter.

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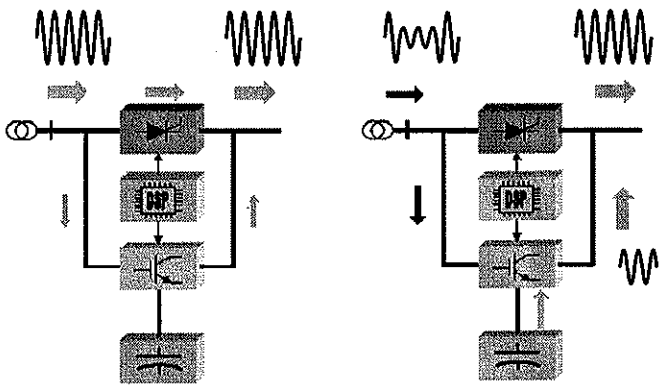
Operation of DynaCom™



During normal operation, customer enjoy very high efficiency

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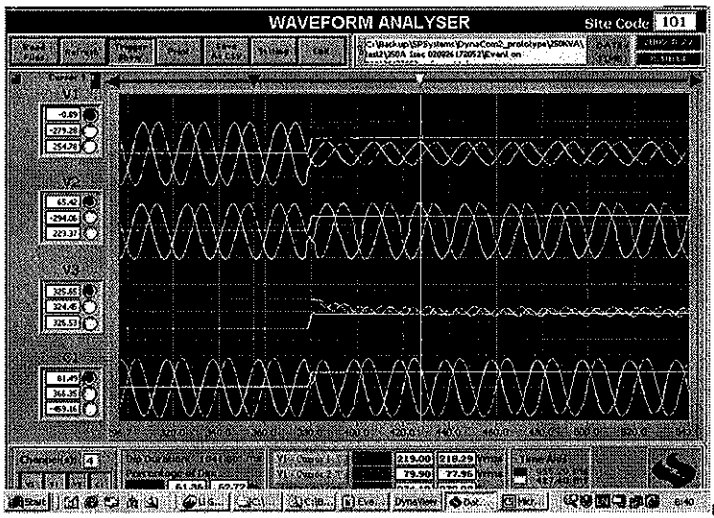
Force Commutation Of Thyristor Bypass switch



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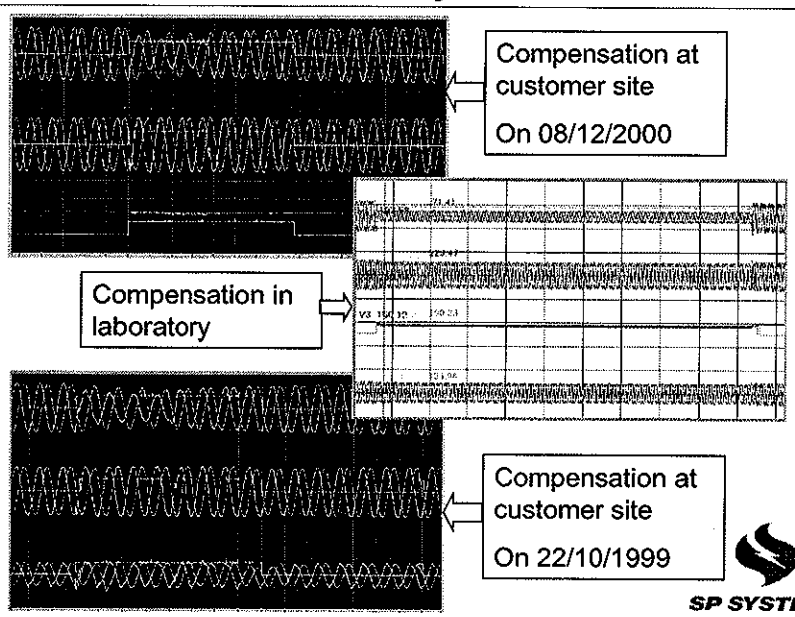
Compensation in Laboratory And At Customer Site



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Features Of DynaCom™

Direct injection	**■Inverter is floating to line voltage.** **■Insulation depends mainly on traditional insulation means.** **■Junction of transistor is not stressed by system overvoltage.** **■Injection transformer is removed so footprint and transient can be smaller.**
Stored energy for compensation	**■Required energy could be guaranteed.** **■Compensation would not cause impact to other circuit.**
Thyristor bypass switch for no sag operation	**■High operation efficiency (voltage drop across bypass switch is less than 1V dc).** **■High capability to provide starting current to load.**

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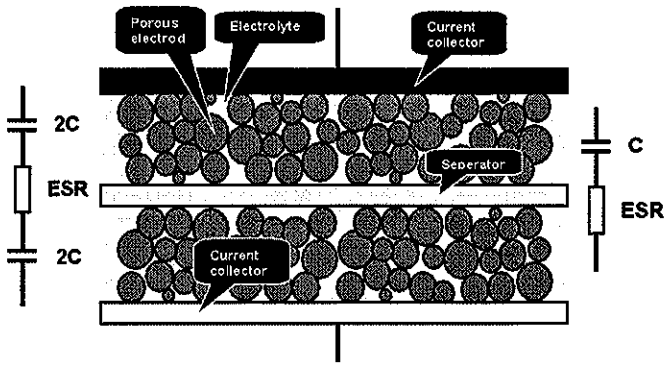
Ultra-Capacitor

- Large contact area of porous electrode makes very big capacitance
- Can be charged and discharged almost indefinitely
- Made of non-toxic and relatively inexpensive material



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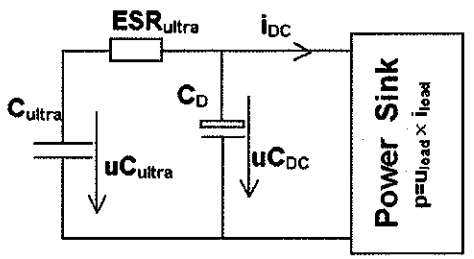
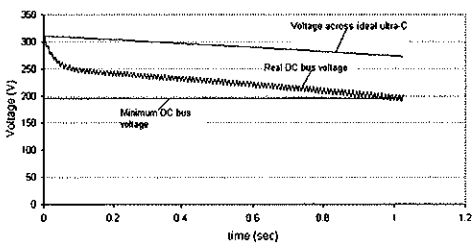
Determination Of The Size Of Ultra-Capacitor





- Power sink concept is used in calculating the size of ultra-capacitor
- This method can also be used in the estimation of the size of battery bank

The result of size estimation of ultra-capacitor for a 12 kVA DynaCom™

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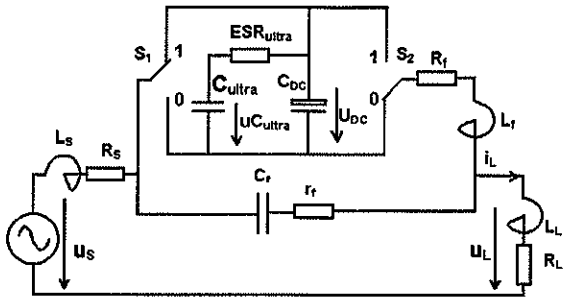
Simulation Model And Parameters (12kVA)



Component	Value	Component	Value
C_{ultra}	100/124=0.806 F	ESR_{ultra}	124x 0.018=2.232 Ω
C_{DC}	0.01 F	L_f	600 uH
R_f	0.05 Ω	C_f	60 uF
r_f	0.001 Ω	L_L	2915 uH
R_L	4.508 Ω	L_s	29.15 uH
R_s	0.04508 Ω	$UC_{ultra}(0)$	310 V
$UC_{DC}(0)$	310 V	$f_{switching}$	5 kHz

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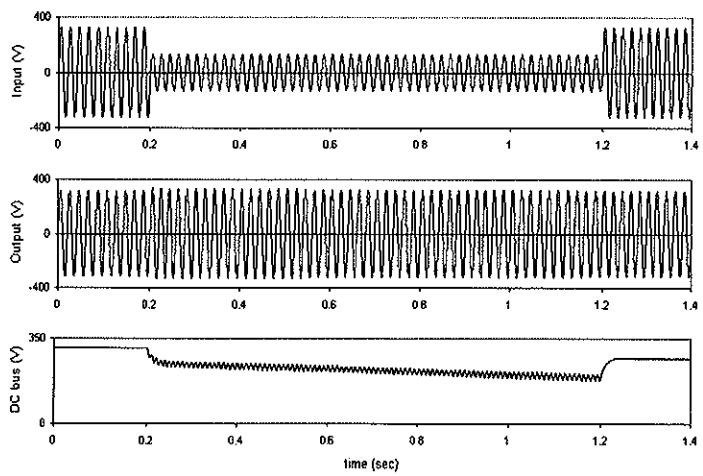
Simulation Result Of Compensation



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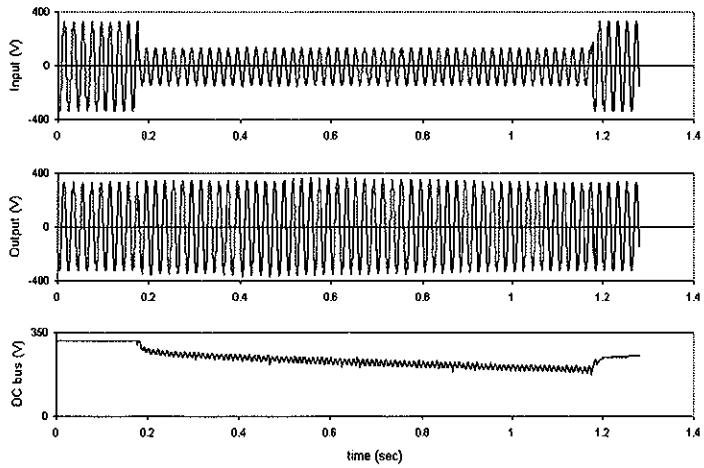
Experimental Result of Compensation



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Summary Of The Presentation

- Voltage sag is one of the dominant power quality problems.
- Voltage sag causes problems because of
  - voltage drops to below holding voltage of electromagnetic components
  - Insufficient power to equipment
  - Transient in AC/DC convert circuit and in induction motor
  - Lock of motor of compressor
- Dynamic voltage compensator could be used to solve voltage sag problem.
- The main concept of dynamic voltage compensator is to make use of the remaining power of the sagged supply and the power derived from stored energy.
- DynaCom™ make use of direct injection scheme and stored energy for compensation.
- Ultra-capacitor can be used as an energy storage means for dynamic voltage compensator.
- The calculation and simulation method proposed could be used for general development of dynamic voltage compensator

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Power Quality

Power Quality is our Business!



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International Power Quality Conference

IPQC 2002

Power Quality & Critical Manufacturing

Deepak Divan, PhD, Fellow IEEE

President & CEO
SoftSwitching Technologies
8155 Forsythia St, Middleton, WI 53562 USA
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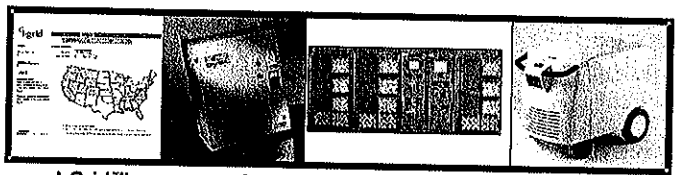
www.softswitch.com
ddivan@softswitch.com

SoftSwitching TECHNOLOGIES
Revolutionizing Power Protection

Company Profile

- Leaders in the power technology market
- Founded in 1995
- Technology roots from University of Wisconsin
- Headquartered in Middleton, WI (suburb of Madison)
- 54 Employees
- Products



I-Grid™	DySC®	Dual Source DySC™	Fuel Cells
PM	PQ	PQ + PR	DR

- Investors: GE Capital, JP Morgan, Beacon Group, Perseus, DTE Energy, Exelon, OPG, and Venture Investors
- Singapore Distributor – Precicon Automation

BusinessWeek

DySC

"...the hottest new technology comes from startup SoftSwitching Technologies"

R&D 2001 Winner

SoftSwitching

Power Quality & Critical Manufacturing

- Power quality is a financial problem – not technical
- For the past 100 years, the utility's job has been to keep the 'lights on'. For today's high-tech factories and processes, that is no longer sufficient
- As utility improves system reliability and availability, a natural consequence is reduced power quality
- In the ideal world, a standard such as SEMI F47 would provide the line of utility/customer responsibility
- Without power quality data, it is difficult to specify cost-effective solutions
- The most cost-effective solutions are applied at point-of-pain, not for the entire facility



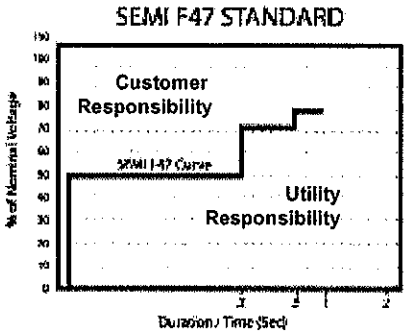
Availability vs. Process Uptime

NORMAL GRID				PREMIUM GRID			
Normal Utility Events	Utility Reliability Level	Process Uptime 1 Hr Downtime per Event	Typical Applications	Premium Utility Events	Utility Reliability Level	Process Uptime 1 Hr Downtime per Event	Typical Applications
25 events/yr: 22 at ¼ s, 1 at 2 s, 1 at 5 min, 1 at ½ hour	2107 seconds total/yr, 99.99%, 4-nines	25 Hrs total downtime/yr, 99%, 2-nines No protection	Plastics, PCs, Machinery, Textiles, Cell towers, Residential	10 events/ yr, 0.25 s each	2.5 seconds total/yr, 99.99999%, 7-nines	10 Hrs total downtime/yr, 99%, 2-nines No protection	Semi mfr, Auto mfr, Fiber optic cables, Web farms, Continuous processes
92% Events Protected with a DySC 2 events/yr, 2 hours total downtime/yr, 99.9% Process Uptime 3-nines				100% Events Protected with a DySC 100% Process Uptime 9-nines			



SEMI F47: Line of Responsibility?

- F47 allows semiconductor fabs to have a common platform for OEM tool design
- Specifies ride-through requirements with 'a reduction or elimination in the use of battery storage devices'



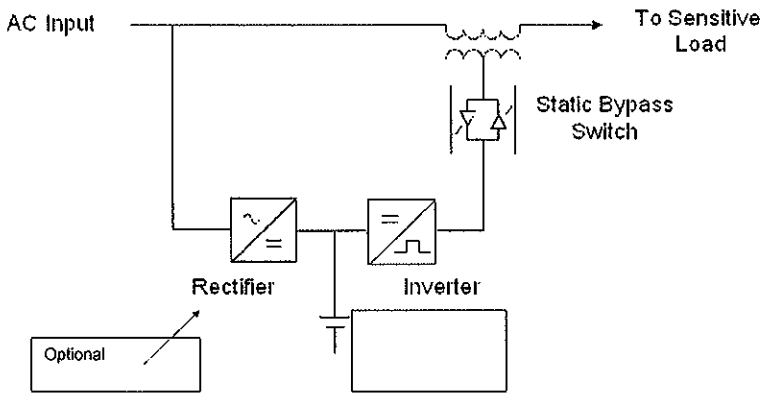
- For premium grid customers, SEMI F47 may provide a line of utility/customer responsibility

Key Decision: Point of Pain vs. Facility Wide

	Point of Pain Protection	Facility Wide Protection
Positives	Cost-effective, protects sensitive loads only Can be staged, highest impact loads first – budget friendly Standard product based, rugged and reliable	Protects all loads (but more expensive $/kVA of protected loads) Installation may be simpler, (but may require outside trailer/facility)
Negatives	Installation may be more complex	Requires major budget commitment and engineering effort, also higher $kVA of protected load Custom product, difficult to protect at MV level

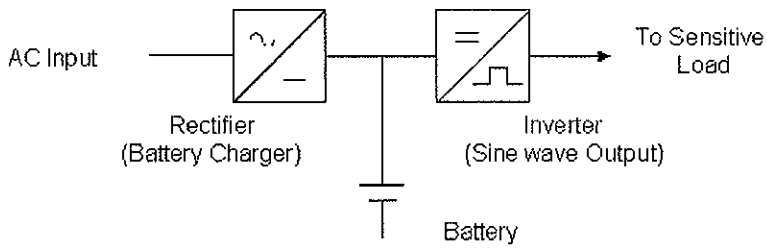
Circuit Schematic for Various PQ Solutions

Series Transformer-Based PQ Solution (DVR)



Circuit Schematic for Various PQ Solutions

On-Line UPS

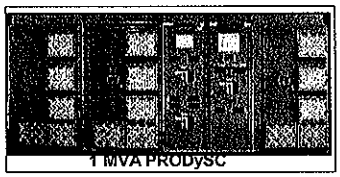


Dynamic Sag Corrector® (DySC®)

DySC Product Family
0.25 kW to >3000 kW







1 MVA PRODySC

- Effective protection against short duration power disturbances
- Meets or exceeds SEMI F47
- Cost effective solution
  - Pays for itself with first event in high-impact applications
- Proven product
  - Over 500 units installed in critical manufacturing applications (~20,000 kVA installed base)
- No batteries, no flywheels, low maintenance, long-life, high efficiency, compact size, silicon intensive
- Wide power range gives application flexibility
- Provides 100% protection for premium grid customers

DySC

Applications

Premium Grid–
- Semiconductor Mfg
- Automotive Mfg
- Fiber Optic Cable Mfg

Normal Grid–
- Plastics
- Steel
- Food Processing
- Paper
- Glass
- All Continuous Processes

R&D 2001 Winner!

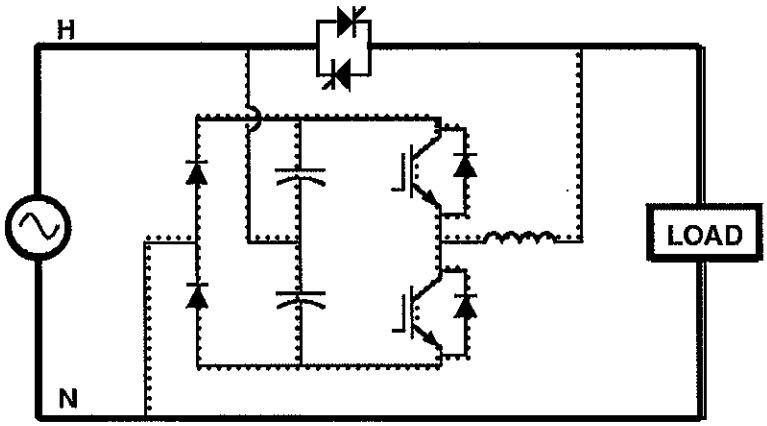
DySC® Design Objectives

- Correction for deep sags (50%) for 2 seconds cumulative every 60 seconds
- Ride-thru on momentary interruption for 3 cycles standard, 12 cycles optional
- Exceeds SEMI F47 standard
- Cuts –in at 87% nominal and maintains output at +5% to –10% nominal
- Fast sub-cycle response (1-2 msecs)
- Overload capabilities to handle load in-rush requirements
- High efficiency (>99%)
- Minimal maintenance
- Optional electro-mechanical bypass (manual or automatic)
- Single phase and three phase configurations

The DySC™ Circuit – Single Phase

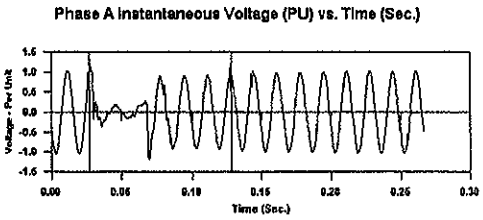
Normal Operation
- Power Electronics Off Line
- No Thermal Cycling
- Capacitors Stay Charged
- Very Long Life Design
- Low maintenance
- Highly efficient (>99%)

Voltage Sag Correction
- 1-2 ms sag detection
- Static switch force commuted off, Power electronics 'on'
- Additional Current drawn from line for sags down to 50%
- Energy from capacitors for total power loss (3-12 cycles)



Protected by Issued and Pending Patents

Event at Semiconductor Plant



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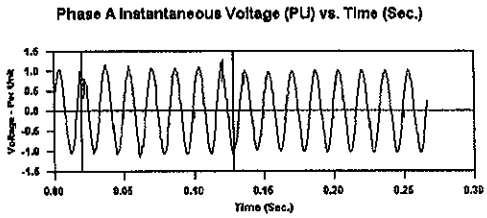

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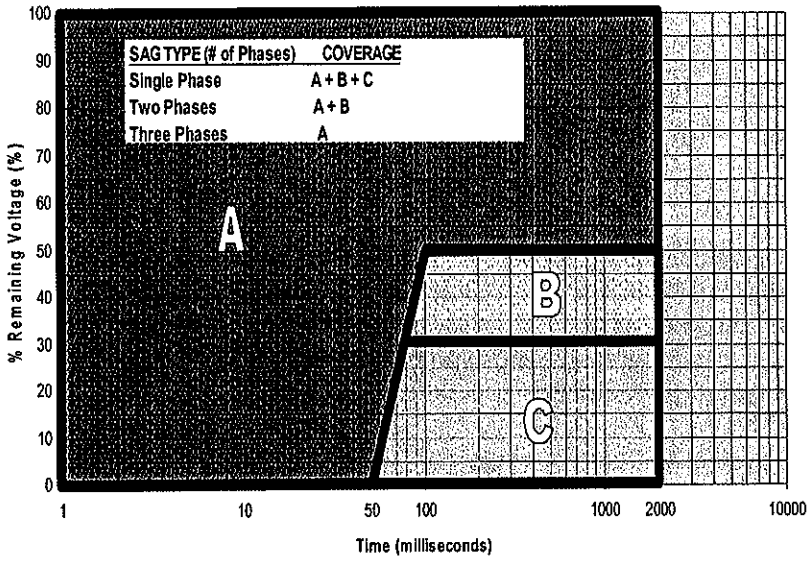
DySC Protection: PRODySC with Deep Sag Option

Standard PRODySC Coverage (w/Deep Sag Option)



DySC® Solution Customers

Semi Customers / Installations:

Applied Materials · Intel · Air Liquide · KLA-Tencor · Hitachi (Inspire the Next) · ST · Motorola · IBM · Lam Research · Microchip · AMD · TI · TECH · Sony · NEC

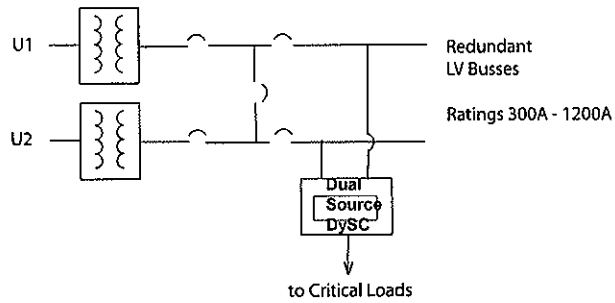
Other Manufacturing Customers:

BMW (The Ultimate Driving Machine) · GM · Lucent Technologies · Procter&Gamble · Anheuser Busch · John Deere · Fort James · Ford Motor Company · Kodak · Kimberly-Clark · ExxonMobil

Independent Testing and Validation:

EPRI-PEAC	Salt River Project	Duke Energy
Power Standards Lab	American Electric Power	TVA
Electrotek	Reliant Energy	

Dual Source DySC™



- Provides continuous uninterrupted power for sags, swells, brownouts, over-voltages, or outages on any one bus
- Can handle simultaneous voltage sags on both busses (transmission level events)
- 3-12 cycle ride-through for full outage on both feeds
- Integrated maintenance / emergency automatic bypass switch with bump-less transfer
- Full protection from any single fault upstream or internal to Dual Source DySC™ device
- Uses existing power system architecture
- Can team with utilities to provide 100% solution for premium power

CNC Machining Application

- Application: CNC machining of large steel axles and rotors (15' Lg., 4' Diam.)
- Events: 10 to 15 per year
- Losses: Up to 24 hours of production loss, expensive rotors scrapped, delayed shipments
- Collaboration: AEP and EPRI collaborated with the customer to deploy solution
- Solution: 300 kVA PRODySC for main CNC Machines, HID lighting, and Office load
- Results Down time and scrap material has been virtually eliminated

  Office computer re-boot and data re-storage problems eliminated

  Customer not considering re-locating business

Fiber Optic Cable Manufacturing

- Application: Fibre Optic Cable Sheathing extrusion lines
  Integrated DC & AC drives, and PLC extruder controls
  2 mile long cables, over 500 individual fibres per cable
- Events: 6 to 10 voltage sags per year
- Losses: $150,000 to $500,000 per event!
- Collaboration: Over five years of PQ data recorded indicating only sags events.
  Utility feed from transmission grid
- Solution: Over 3500 kVA of PRODySC units installed on part of cable lines
  - Ratings include 166 kVA, 330 kVA & 500 kVA
  - Capability to add capacitive energy storage for additional ride through
- Results In the first three months two definite saves recorded on two lines
  - The investment on each line paid for itself in first event

Plastics Extrusion Manufacturing

- Application: Manufacturer of large die plastics extrusion products
- Events: Multiple sag and momentary loss of power due to being in lightning belt
  - At time of installation, only computer on shop floor monitored weather
  - During storms within 50 mile radius, all off-site staff on standby for clean-up and re-starting lines
- Losses: Major production losses
  Up to 8 hours of clean up and restart time after event
  Significant scrap material
  Delayed shipments
- Collaboration: TVA and EPRI-PEAC collaborated with the customer to deploy solution
- Solution: 300 kVA PRODySC to protect 5 of eight lines
  - Unit equipped with 15 cycle extended outage option for momentary loss of power
- Results Many recorded saves of connected lines
  Lines not protected shut down

Automotive Application

- Application: Body Shop robot welding systems, PLC controls, material handling
- Events: 8 to 12 major events per year
- Losses: $11,000 per min; 2 to 4 hrs of production loss
- Collaboration: Major East Coast Utility collaborated with the customer to evaluate (test) different solutions & recommended the PRODySC
- Solution: 1 MW PRODySC for Body Shop power distribution panel
  - Expandable to 1.3 MW
  - Capability to add capacitive energy storage for additional ride-through
  - Installed I-Sense™ Power Monitors at input & output
- Results: Several saves recorded where body shop kept running when other parts of plant shut down. I-Sense e-mail reports verified protection by the PRODySC. Customer preparing to install a larger unit for plant expansion

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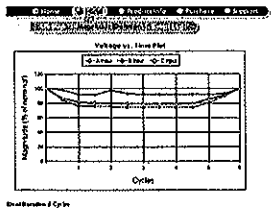
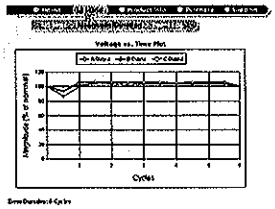


INPUT



OUTPUT

Singapore Applications – Chemical Plant

- Application: Chemical plant based on Jurong Island
- Events: Process interruptions due to voltage sag events
- Losses: The sag typically caused the contactor circuit in the Motor Control Centre to drop-off, resulting in interruption of operation.
- Limitations: Battery storage devices were not ideal because 1) Singapore's premium grid minimizes outages, and 2) prolonged ride-through by a battery storage device during an extended power outage event would in any case require a shut down of the entire process.
- Solution: To save the contactor from tripping, a single phase DySC (MINIDySC) was applied.
- Results: The DySC has since saved the company from several voltage dip events and prevented tripping of the motors.

Singapore Applications – Disk Drive Manufacturer

- Application: Major disk drive manufacturer
- Events: Sputter machine would trip during a voltage sag or dip.
- Losses: Unscheduled downtime costing about S$40,000 per machine per event
- Limitations: The clean-room had very limited space to install a battery storage system.
- Collaboration: A study was conducted identifying the EMO circuit, PLC, and the servo drives to be the weak link.
- Solution: A specially design DySC, which incorporated a single phase and three system, was supplied to mitigate the voltage sag problem.
- Results: The system is now installed and running.

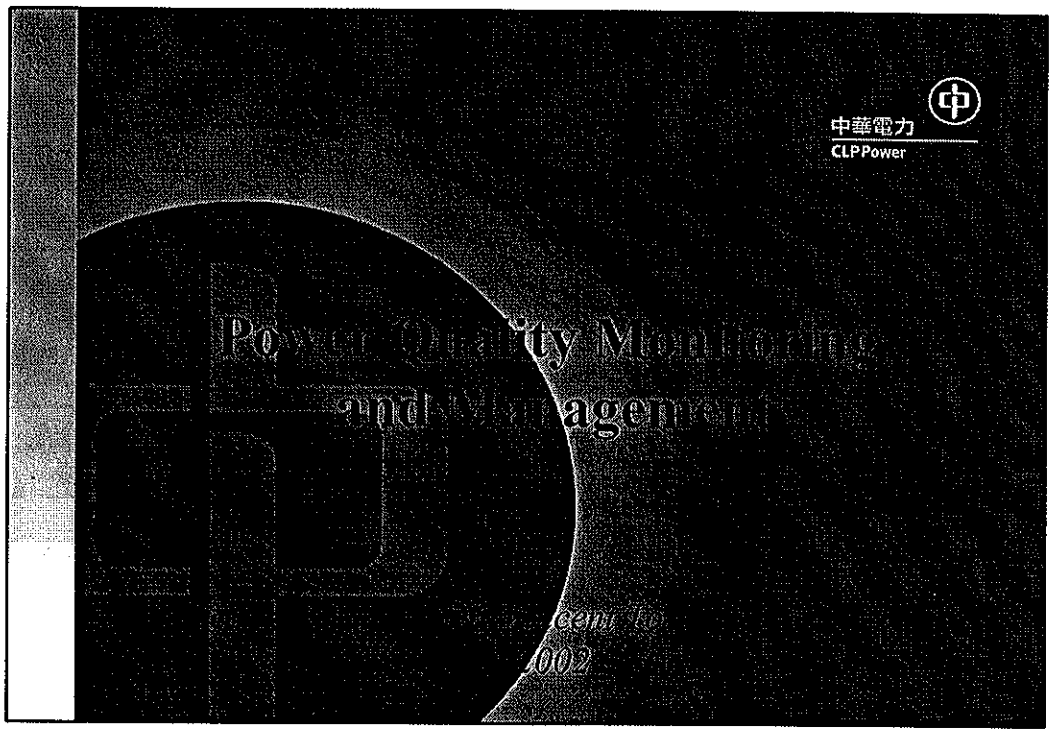
Singapore Applications – Wafer Fab Plant

- Application: Wafer fabrication plant
- Events: Facility chiller system often tripped during a voltage sag event.
- Limitations: Protecting the entire chiller system was not economically viable.
- Collaboration: EPRI-PEAC conducted a study and recommended that the control circuit of the chiller be protected using a single phase MINIDySC.
- Solution: The MINIDySC advantages included a small footprint, low cost and minimum maintenance.
- Results: The DySC is presently in the final stage of discussion on the implementation.

Conclusions

- Power Quality is a dominant cause of unscheduled downtime in critical high-tech manufacturing applications
- Point-of-use solutions within customer facility provide targeted cost-effective PQ solutions
- The DySC is a cost-effective battery-less solution that is proven in high cost of downtime applications
- There are over 20,000 kVA of installed base of DySC units around the world, including Singapore

SoftSwitching
TECHNOLOGIES
Revolutionizing Power Protection



Presentation Outline

中華電力
CLP Power

- Introduction
- Quality of Power
- Measurement Methodology
- Considerations in PQ Measurement
- PQ Standard
- PQ Monitoring and Management

Introduction

中華電力 CLP Power

- To define a PQ baseline and get ready for providing Premium Power Service









- Benchmarking and better customer service through long-term PQ monitoring



- PQ measurement/monitoring plays an important role to meet the above needs



Importance of Power Quality

中華電力 CLP Power

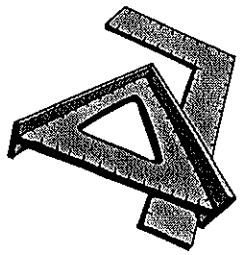
- Electricity is a raw material/product: customers expect better quality and lower price

- Deregulation creates a need for identifying baseline power quality levels and opportunities for differentiated services.

Measurement Parameters

中華電力 CLP Power

- Basic power data
  - V, I, frequency
  - kW, kVAr, power factor
  - kWh
- Power quality data
  - Voltage dip, Transient
  - Harmonics (voltage and current)
  - Voltage Imbalance, Voltage Flicker
- No commonly adopted standards



Measurement Methodology

中華電力 CLP Power

Importance to establish a common Standard and Measurement Methodology

- Avoid comparing an apple with an orange
  - e.g. rms vs. instantaneous





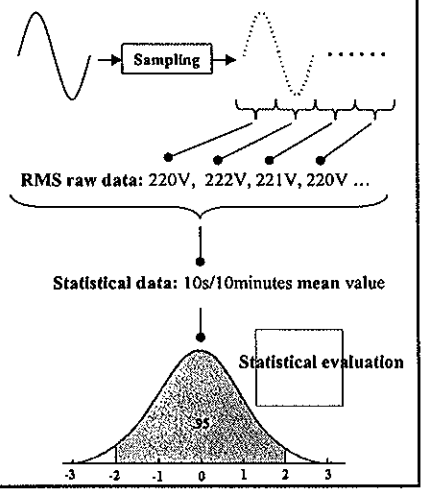
- A common platform for data comparison
  - International Standard as a reference
  - Measurement methodology
  - Other standards/practices

Measurement Methodology

中華電力 CLP Power

Measurement Methodology

- **Sampling:** 128 sample per cycle
- **RMS value:** produced in every 10ms
- **Statistical data:**
  10-second mean value for frequency
  10-minute mean value for all other parameters
- **Statistical evaluation:**
  95% percentile over a week



Considerations in PQ Measurement

中華電力 CLP Power

- **Waveform capture:** at least 2 cycles before the event (pre-trigger) and at least 12 cycles for post-trigger



- **Current transducer (CT):**
  Minimum accuracy: Class 1 (± 1%)
  Bandwidth: 50Hz to 3kHz

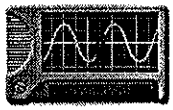


Considerations in PQ Measurement

中華電力 CLP Power



- **Operation under fault conditions:**
  Able to withstand thermally and dynamically under fault condition



- **Voltage surge:**
  Able to withstand a surge and fast transient test such as ANSI/IEEE C37.90-1989



- **Data Storage:**
  Portable recorder: At least 500M byte
  On-line monitoring (with communication): At least 8M byte

Considerations in PQ Measurement

中華電力 CLP Power

- **Communication:**
  Ethernet connection with TCP/IP protocol is more reliable and is highly recommended



PQ Standard

中華電力 CLP Power

PQ Standard - EN50160

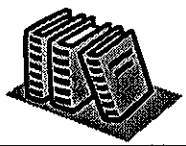


Parameters	Statistical Data	Limits	Compliance
Frequency	10s mean	50Hz±1%	> 99.5% for a year
		50Hz+4%/-6%	100% of time
Voltage	10 min mean	U_n ±10%	> 95% of one week
Harmonics	10 min mean	VTHD < 8%	> 95% of one week
Voltage Unbalance	10 min mean	< 2%	> 95% of one week

PQ Standard

中華電力 CLP Power

PQ Standard - EN50160



Parameters	Definitions		Guidelines
Voltage Dips	Duration (d)	10ms < d < 60s	Few 10's to 1000 in a year
	Voltage Magnitude (U)	1% U_n < U < 90%U_n	
Transient	Duration	µs to ms	
	Voltage Magnitude	< 6kV peak	
Short Interruption	Duration	< 1s	Few 10's to several 100 in a year
	Voltage Magnitude	U < 1%U_n	
Long Interruption	Duration	> 3 minutes	Less than 10 to 50 in a year
	Voltage magnitude	U < 1%U_n	

PQ Standard

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CLP Power

System Average RMS (Variation) Frequency Index ($SARFI_x$)

$$SARFI_x = \frac{\sum N_i}{N_T}$$

where;

x = RMS voltage threshold; any positive value is possible, however, some of the more common values include 140, 120, 110, 90, 80, 70, 50, and 10

N_i = number of customers experiencing voltage deviations with magnitudes above X % for X >100 or below X % for X <100 due to measurement event i

N_T = total number of customers served from the section of the system to be assessed

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Why is PQ Monitoring so important ?

"You cannot manage what you do not measure" – Jack Welch, CEO of General Electric

PQ Monitoring and Management (Customer)

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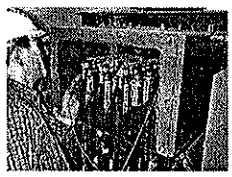
Discrete Measurement – for ad-hoc PQ service

- Short-term PQ measurement
- Equipped with GSM modem
- Mainly for customer services



Case Study

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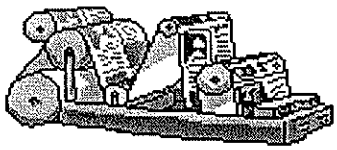
Problem

•Frequent cap. bank failure



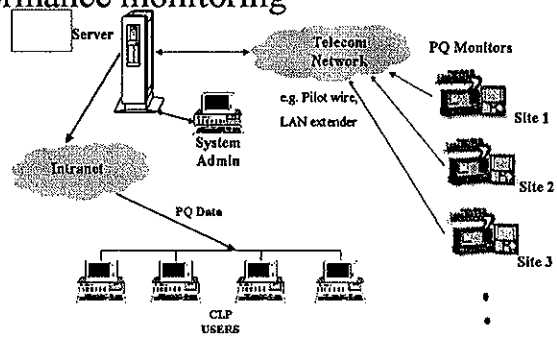
		Without Harmonic Filter			With Harmonic Filter		
Harmonics and Power Factor		Phase A	Phase B	Phase C	Phase A	Phase B	Phase C
Voltage Harmonic	THD	5.96%	6.68%	7.87%	3.60%	3.92%	4.17%
	5th	2.04%	2.65%	2.73%	1.00%	0.98%	1.23%
	7th	1.33%	1.29%	1.57%	0.80%	0.82%	0.94%
Current Harmonic	THD	237 A	241 A	242 A	65 A	65 A	66 A
	5th	208 A	214 A	212 A	21 A	24 A	23 A
	7th	32 A	31 A	35 A	18 A	18 A	20 A
Power Factor		0.66 lag	0.66 lag	0.64 lag	0.90 lag	0.90 lag	0.89 lag

PQ Monitoring and Management (System wide)

中華電力 CLP Power

System-wide PQ monitoring – for PQ benchmarking

- Long-term PQ measurement
- Communicate via fixed telecom network
- Mainly for performance monitoring



Methodology

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- Review of Current PQMS
- Site Selection Process
- Specification of monitoring system for System Wide Power Quality Monitoring system

Review of Current system

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- Current PQMS can help CLP better serve top customers with on-line PQ information.
- The current system requires an enhancement prior to system wide implementation.
- Other deficiencies include:
  - Handling large amounts of data
  - Room for improvement on reporting functions
  - Communication reliability via pilot wires

Site Selection

Sample Design

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- The sample design has three tasks:
  - Identify PQ descriptors with high correlation to dips
  - Choose the sampling method
    - Simple random
    - Stratified random
  - Define the boundaries of the descriptors
    - How many strata?
    - What are the break points?
    - What are the mean and standard deviation values?

Site Selection

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Strong PQ Indicators

- Circuit exposure
- Lightning flash density
- Transformer impedance & number of feeders
- Load density

Specification of PQMS

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- General Technical Specification
- PQ Monitor
- Communication Network
- Information Technology System
- Maintenance Service

Benefits

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- Utilities across the world are installing system wide monitoring to help event investigation and improve system reliability
- High-tech and top customers are requiring that utilities be able to provide information concerning power quality events. System wide monitoring allows utilities to respond to these needs.
- By using system wide monitoring to benchmark power systems, utilities are able to document what "normal power" is and help to develop premium power guidelines and services.

Making Power Quality Part of Your Strategy for Economic Growth

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(865) 470-9222
markm@electrotek.com



Power Quality and Your Strategy for Economic Growth

- Thanks
- What is power quality?
- Power quality and economics
- Developing a strategy
- See what others are doing right
- Find some things you can do better
- Conclusions



Developing a Strategy

The Importance of Customer Focus

"They may not remember what you said but they will always remember how you made them feel."

- Will Rogers

ELECTROTEK CONCEPTS

5

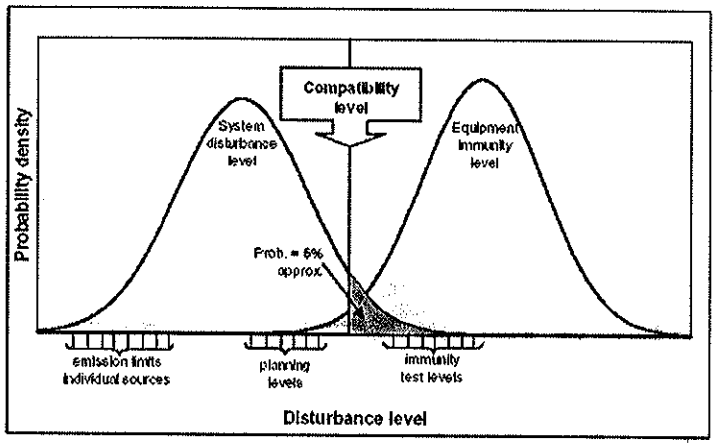
Find out what others are doing right

Then copy it

ELECTROTEK CONCEPTS

6

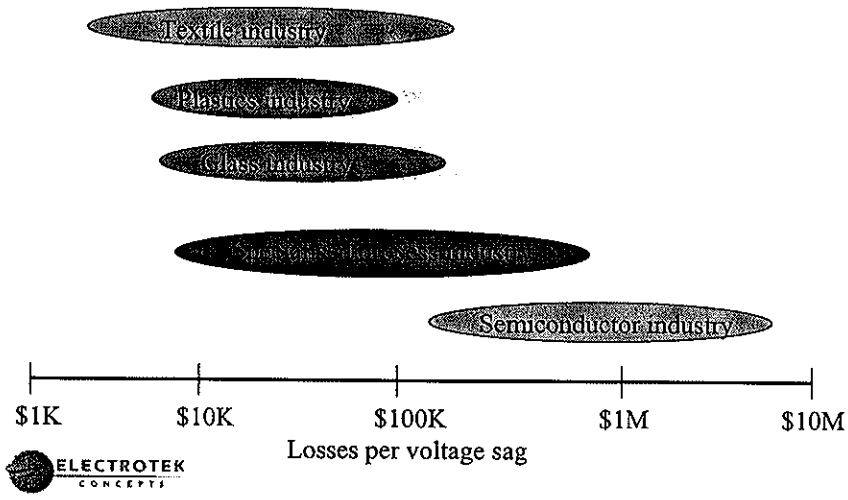
What is Power Quality?



ELECTROTEK CONCEPTS

3

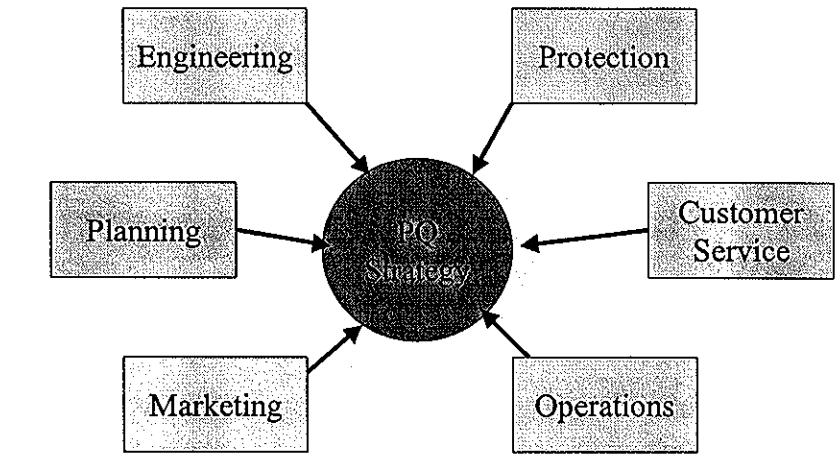
Power Quality is ECONOMICS



ELECTROTEK CONCEPTS

4

Involve the whole company



ELECTROTEK CONCEPTS

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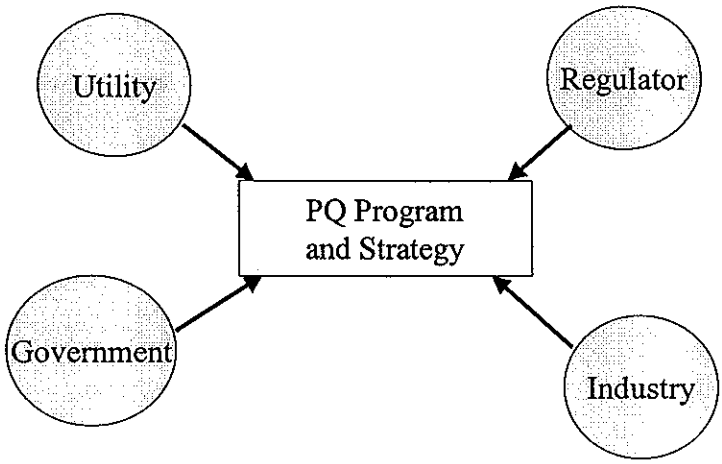
Involve everyone

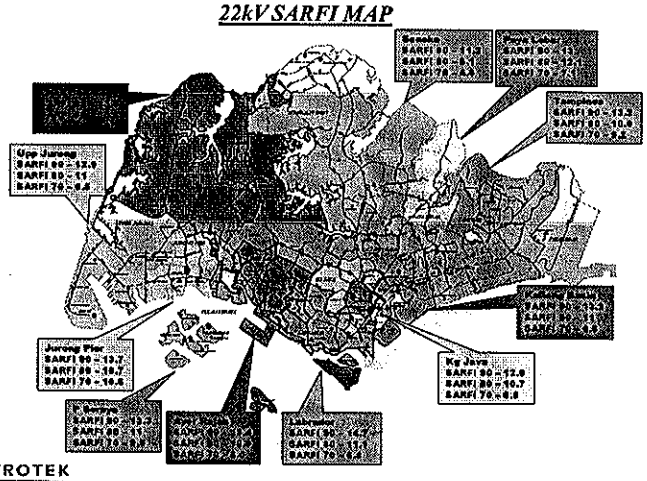


ELECTROTEK CONCEPTS

8

Understand the system performance

22kV SARFI MAP



ELECTROTEK CONCEPTS

9

Get everyone talking



ELECTROTEK CONCEPTS

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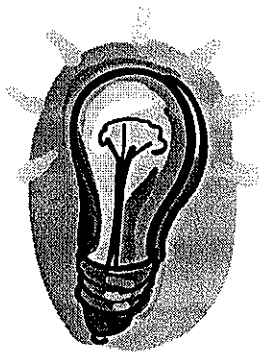
Try something new



ELECTROTEK CONCEPTS

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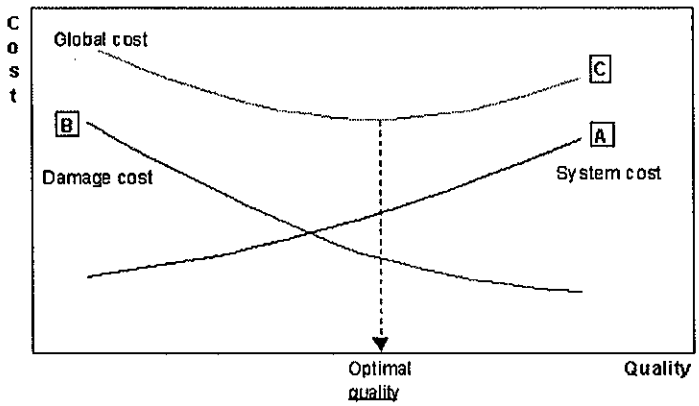
Understand the economics





ELECTROTEK CONCEPTS

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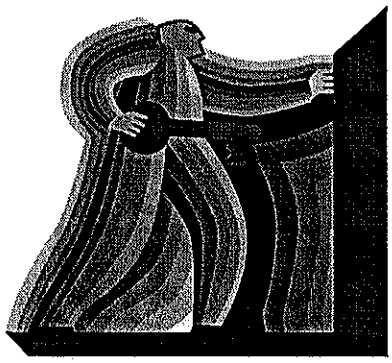
What can you do better?



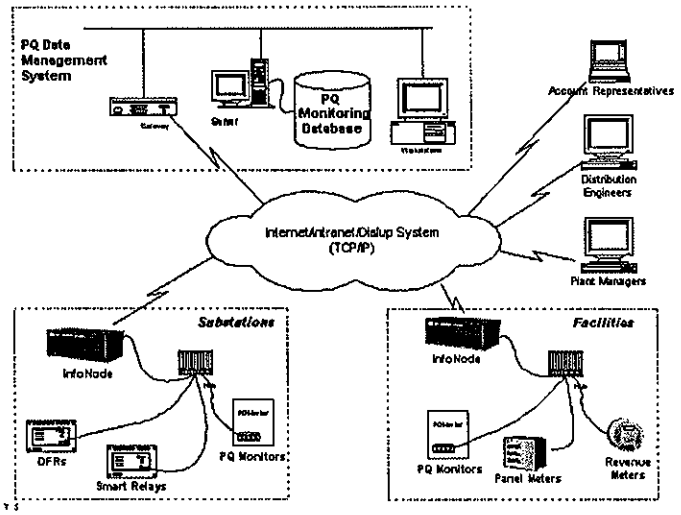
ELECTROTEK CONCEPTS

Share your ideas

International Power Quality Conference

ELECTROTEK CONCEPTS

Monitor, Monitor, Monitor



ELECTRO CONCEPTS

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Conclusions

- You can learn a lot from Singapore
- Understanding power quality is just economics
- Get everyone involved and make power quality part of your strategy for economic growth

ELECTROTEK CONCEPTS

16

On voltage restoration for power quality improvement: the impact of phase shift on loads

SS Choi, JD Li and DM Vilathgamuwa
School of Electrical and Electronic Engineering
Nanyang Technological University
Singapore

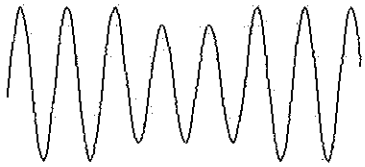
Int. Power Quality Conf., Singapore Oct 2002

Outline

- Series compensation
  - mitigation method
  - phase-angle jump
- DVR-load Dynamics
  - analysis
  - modeling
- Conclusions

School of Electrical and Electronic Engineering
Nanyang Technological University

Voltage Sag

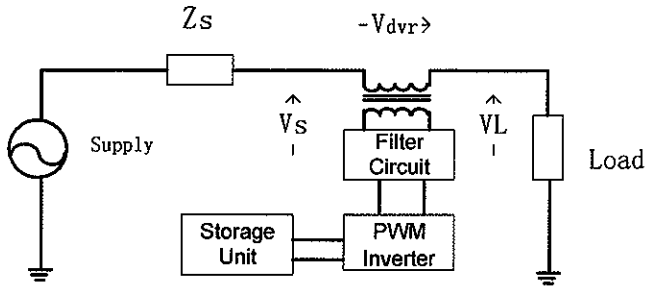


Typical duration: 5-10 cycles

Magnitude: 0.1-0.9 pu

Mitigation method : series compensation

A typical series compensator: the dynamic voltage restorer (DVR)



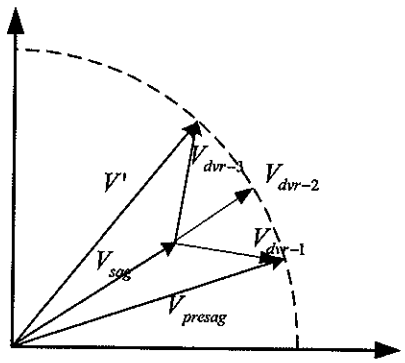
Schematic diagram of a power system with DVR

Control Methods

Pre-sag compensation: V_{dvr-1}

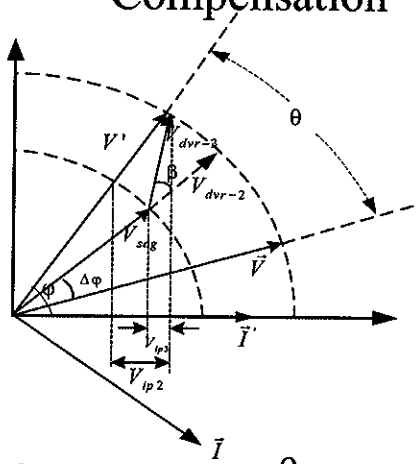
In-phase compensation: V_{dvr-2}

Energy-saving compensation: V_{dvr-3}



Possible Control methods

Phasor Diagram - Energy-saving Compensation



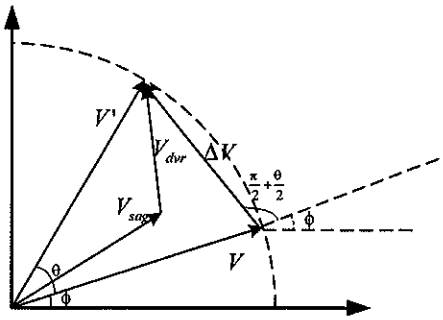
Numerical examples show that θ could exceed $\pm 20^{\circ}$.

Phase-Angle Jump

Load voltage change could be expressed as :

$$\Delta V = V\angle\theta - V$$

$$= |V| \cdot 2\sin(\frac{\theta}{2}) \cdot \angle(\frac{\pi}{2} + \frac{\theta}{2} + \phi)$$



Load Modeling

- Linear Static Load

General three-phase RL circuit:

$$L\frac{di_k}{dt} + Ri_k = v_k(t) \qquad k = a,b,c$$

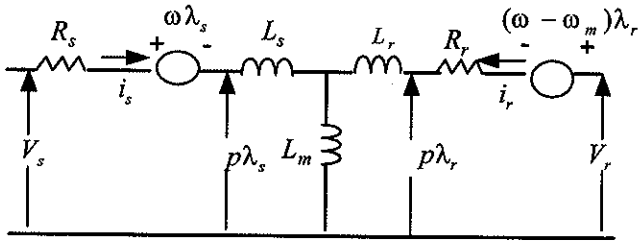
Transform into the dq frame:

$$\begin{bmatrix} R + L\frac{d}{dt} & -\omega_1 L \\ \omega_1 L & R + L\frac{d}{dt} \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} v_d \\ v_q \end{bmatrix}$$

Set: $v = v_d + jv_q \quad i = i_d + ji_q$

$$i = \frac{v}{R + pL + j\omega_1 L}$$

Induction Motor Load



Space phasor equations :

$$V_s = R_s I_s + p\lambda_s + j\omega_x \lambda_s \qquad \lambda_r = L_r I_r + L_m (I_s + I_r)$$

$$V_r = R_r I_r + p\lambda_r + j(\omega_x - \omega_m)\lambda_r \qquad \lambda_s = L_s I_s + L_m (I_s + I_r)$$

Simplified Induction Motor Load

$$I_s = \frac{V_s}{R + pL + j\omega_x L}$$

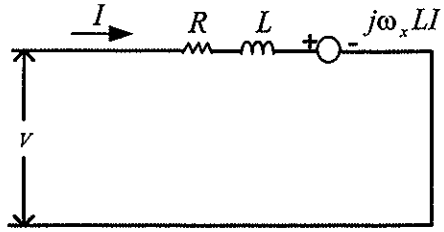
where $R = R_s$ **is the stator resistance and**

$$L = \begin{cases} L_s + L_r, \text{for transient} \\ L_s + L_m \dfrac{(\frac{R_r}{s} + j\omega_1 L_r)}{j\omega_1 L_m + (\frac{R_r}{s} + j\omega_1 L_r)}, \text{for steady-state} \end{cases}$$

Induction Motor Model (continue)

- Simplified fourth-order motor model is similar with the static linear load.

Load modeling is given by:



Single Aggregate Load Response

Load response under step voltage shift in the s-domain:

$$\Delta I(s) = \frac{\Delta V}{s} \cdot \frac{1}{L(R/L + j\omega_x + s)}$$

Single Aggregate Load Response

Phase current in the induction motor:

$$\Delta i_a(t) = 2\sqrt{2}V \sin\frac{\theta}{2}\{\frac{\sin(\omega_1 t + \frac{\theta}{2} + \frac{\pi}{2})}{\sqrt{R^2 + \omega_x^2 L_{steady}^2}}$$

$$-\sin[(\omega_1 - \omega_x)t + \frac{\theta}{2} + \frac{\pi}{2}]\frac{e^{-R/L_{transient}\,t}}{\sqrt{R^2 + \omega_x^2 L_{transient}^2}}\}$$

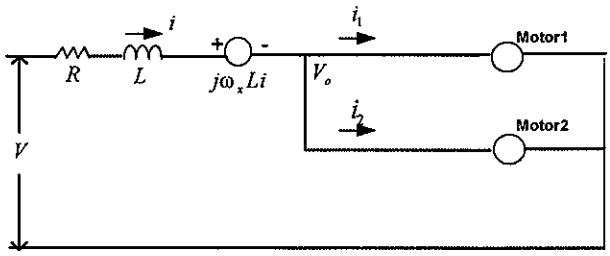
Peak Value of Load Current

$$\left|\Delta i_{a-peak}\right| \approx \left|\frac{K}{\sqrt{R^2 + \omega_x^2 L_{steady}^2}}\right| + \left|\frac{KK_1}{\sqrt{R^2 + \omega_x^2 L_{transient}^2}}\right|$$

Where, $K = 2\sqrt{2}V \sin(\frac{\theta}{2})$

$$K_1 \approx \sin(\frac{\theta}{2} + \frac{\pi}{2}) = \cos(\frac{\theta}{2}) \qquad (\omega_1 - \omega_x)t \approx 0$$

Parallel Loads



$$\Delta i_1 = \Delta V \frac{Z_2}{(Z+\Delta Z)(Z_1+Z_2)}$$

$$\Delta i_2 = \Delta V \frac{Z_1}{(Z+\Delta Z)(Z_1+Z_2)}$$

$$\Delta i = \Delta i_1 + \Delta i_2 = \frac{\Delta V}{Z+\Delta Z}$$

Where,

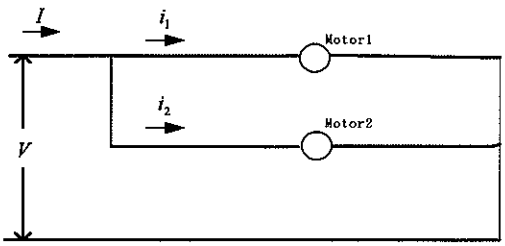
$$\Delta Z = Z_1 // Z_2 = \frac{Z_1 Z_2}{Z_1+Z_2}$$

$$Z_1 = R_1 + L_1 p + j\omega_x L_1$$

$$Z_2 = R_2 + L_2 p + j\omega_x L_2$$

$$Z = R + Lp + j\omega_x L$$

Special Case For Parallel Loads



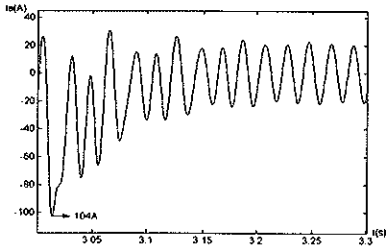
$$\Delta i = \Delta i_1 + \Delta i_2 = \frac{\Delta V}{R_1 + L_1 p + j\omega_{m1} L_1} + \frac{\Delta V}{R_2 + L_2 p + j\omega_{m2} L_2}$$

$$I_a(t) = \sum_{i=1}^{n} I_{a(i)}(t, \omega_{m(i)}, R_i, L_i, \theta)$$

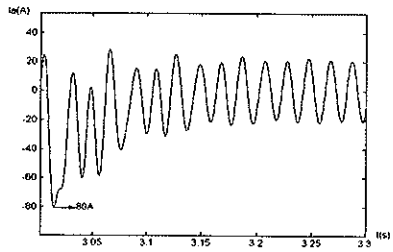
$$I_{a_peak}(t) \approx \sum_{i=1}^{n} I_{a_peak(i)}$$

Illustrative Examples (1)

Motor current (Phase-A) under different voltage phase shifts



$\theta = 30^{\circ}$



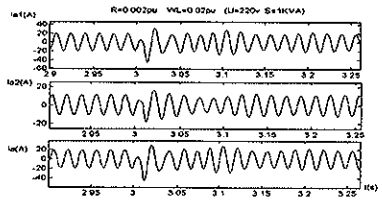
$\theta = 20^{\circ}$

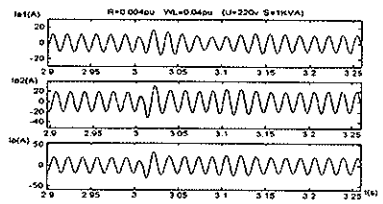
Given, $\dfrac{L_s + L_r}{R_s} = 0.044\ s$

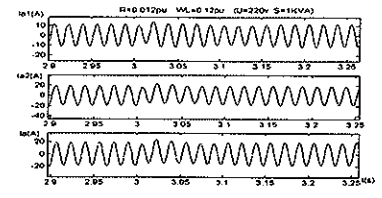
Estimated peak values: 127A , 90A

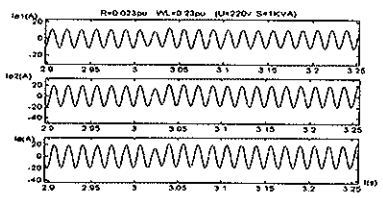
Illustrative Examples (2)

Response of Parallel Loads With Different Impedances Between the Loads and the DVR: $\theta = 30^{\circ}$









Conclusions

- **Linear static load and induction motor both exhibit similar dynamic response under the step voltage phase shift.**
- **For a single motor, the decay time of the dynamic response will be decided by $\frac{L_s + L_r}{R_s}$. Peak value of transient current could be several times that of its rated value.**
- **For parallel loads, the impedance between the DVR and loads could help mitigate the effect of the step voltage shift.**

Further Work

- Thermal effect in the DVR inverter caused by voltage phase shift.
- Estimation of safe operation regime of DVR switching devices.

End

Thank you



School of Electrical and Electronic Engineering
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Malaysia's experiences with Power Quality Standards

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- Overview of the Malaysia PQ Problems
- Implications of PQ problems
- PQ problem management
- Power Quality Standardisation

Power Quality

- Electrical Power quality may be defined as :
  - the degree of any deviation from the nominal values of the voltage magnitude and frequency
  - the degree to which both the utilisation and delivery of electric power affects the performance of electrical equipment.

Study on Malaysia PQ Status

- The Malaysian Electricity Supply Industry Trust Account (MESITA) has funded a two-year study that monitors PQ events at 52 sites in the peninsular for more than a year.
- Preliminary results of the study gave statistics of voltage sags, harmonics and flicker in the peninsular Malaysia.

Preliminary results of Malaysian PQ monitoring study

- The MESITA study found that the THD of monitored sites are below 0,5%.
- Harmonics are from the customer side of the point-of-common-coupling.
- The national annual cost of losses due to harmonics has not been estimated in any countries.
- The estimation is the rather difficult, since the damage is mostly in individual equipment or component.

Voltage sags

- Statistics from the peninsular Malaysia utility, TNB, shows that in 1999 and 2000, at least 50% of the annual interruptions are beyond its control.
- Those interruptions are caused by natural disasters, such as storms and floods.

Voltage sags (cont)

- Only momentary voltage drop which deops to lower than 0.9 pu as a result of the network interruptions are voltage sags
- Not all voltage sags disrupt sensitive loads.
- It was found that the Malaysian severe voltage sags frequency are comparable or better than the estimated USA average. (data from a study carried by the National Power Laboratories (NPL) on 130 user sites all over)

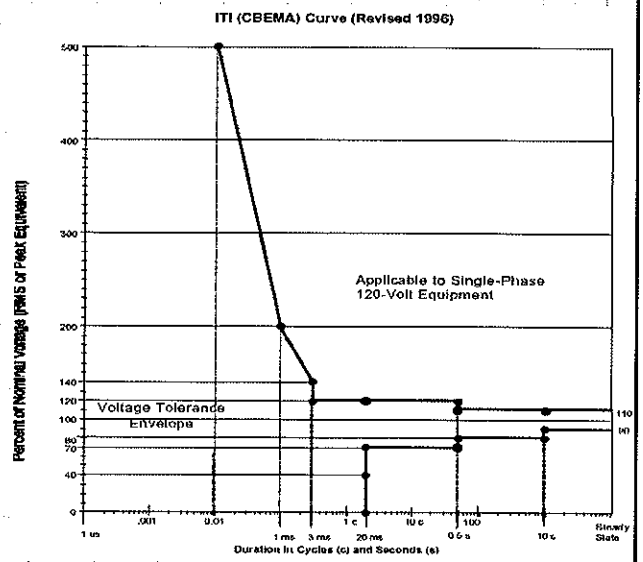
Compatibility between supply and equipment

- Department of Commerce published a document known as Federal Information Processing Standards (FIPS) Publication 94.
- CBEMA provided a sag tolerance curve to be included in the FIPS publication. The Curve, is actually a susceptibility profile meant only for mainframe computers

a guideline to summarize the issues pertaining to the fundamental of powering, grounding and protecting sensitive (solid-state) electronic devices..

Equipment Sucsceptibility

- Since then the CBEMA curve has been frequently used as equipment compatibility level. In 1996 it has been updated to be the ITI curve.



Susceptibility Curve

- The effectiveness of ITI curve as compatibility level for all equipment is questionable.
- In 1990 a group Semi conductor manufacturer industry (SEMI) led a development of another compatibility curve named SEMI F47.
- In its latest draft the IEC SC77A has proposed an amendment to IEC61000-4-11 where the sensitivity is measured according the following table and curve.

Suceptibility

- Equipment compatibility is an issue between consumers (equipment supplier) and utility.
- The new IEC draft on voltage sag characterisation emphasised the fact that different equipment has different tolerance level.
- The draft standard accommodated the differences by having three different classes of testing. Class 1 is a case-by-case characteristic to be defined by the relevant product committee. Class 1 allows for the incorporation of SEMI F47 standard into the IEC PQ testing and measurement standard.

Susceptibility

- The proposed changes in 61000-4-11 documents is to clarify different sensitivity curve.
- It is a result of requirements by different industries. Thus voltage sag tolerance characteristics have evolved a long way from the CBEMA curve.

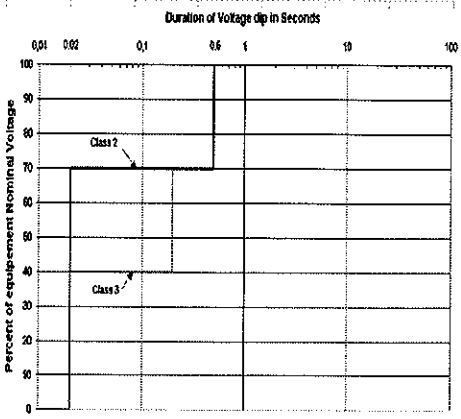


Figure 2 Graph of the test levels and durations for voltage dips in a new committee draft of IEC 61000-4-11

Harmonics

- Most of the transient voltages in a facility are caused by switching operations within the facility. Wiring and grounding problems increase susceptibility to problems.
- Power electronics equipment, such as adjustable speed drives, result in a continuous string of transients (notching) as well as steady state harmonic distortion.

Harmonics

- Harmonics cause increase loading of neutral conductor due to zero sequence harmonics (triplen harmonics).
- Harmonics increase thermal losses and thermal stress on equipments and insulators. They cause metal fatigue due to mechanical oscillations and increase eddy current losses in transformers.
- Harmonics also can cause resonance which may cause capacitor failures and stresses insulators. In a power electronic control that relies on phase angle or phase zero crossing point harmonics may cause malfunction.

Economic impacts on Malaysian Industries

- In the Malaysian scenario, a comprehensive study on the cost of losses due to power quality problem has not been carried out yet.
- A petrochemical based industries customer may lose up to RM164,000 (US$43,000) per incident related to a voltage sag event.
- A MNC semiconductor-based industry estimated the loss of RM5 million for the year 2000.
- A cement plant has reported an average loss of RM300,000 per incident.

Voltage sags

- In year 2000 the Malaysian manufacturing In the peninsular Malaysia, there are about 2500 industrial and commercial customers who used more than 2.5 million kWhr of electricity per year.
- The losses in Malaysia due to voltage sags can be estimated to be in the millions of dollars.

PQ problem management

- Co-ordination strategies among stakeholders
  - Customers.
  - Equipment Manufacturers.
  - Engineering Consultants/Technical Service Providers.
  - Utilities.
  - Research Institutions/universities.
  - Regulators.

Contribution of Standards to PQ problem management

- A standard is a document, established by consensus and approved by a recognized body, that provides for common and repeated use rules, guidelines or characteristics.
- A standard can be used as a reference document in contracts or in international trade.
- In Malaysia standards are voluntary. The energy industry is regulated under an act of Parliament, which set up a regulatory body called the Malaysian Energy Commission.
- The Energy commission can introduce regulation, which requires conformance to a cited standard: in this case, the standard becomes mandatory. The practice of the Energy Commission is to cite Malaysian standards whenever it is available.

Power Quality Standardisation

- Malaysian PQ standards with respect to international standards
- all Malaysian standard are adopted or adapted with a slight modification from International standard such as IEC.
- The Agreement on Technical Barriers to Trade (TBT) is one of the 29 individual legal texts of the WTO Agreement that obliges Members to ensure that technical regulations, voluntary standards and conformity assessment procedures do not create unnecessary obstacles to trade.

Malaysian standard

- Owners know the best equipment to fulfill their requirement and thus should be permitted to choose any equipment as long as they do not pollute the PCC.
- Many owners give highest priority on short-term investment. Import of cheap equipment disadvantage local manufacturers that have to comply with harmonic standard such the requirement under the EU EMC directive.
- Not all users, such as personal computer users, are aware that harmonics are fire hazards.

Technical Barriers to Trade (TBT) Clause in WTO

- The TBT Agreement recognizes the important contribution that international standards and conformity assessment systems can make to improving efficiency of production and facilitating international trade.
- Where international standards exist or their completion is imminent, Standardising bodies should use them, or the relevant parts of them, as a basis for standards they develop.
- It also aims at the harmonisation of standards on as wide a basis as possible, encouraging all standardising bodies to play as full a part as resources allow in the preparation of international standards by the relevant international body.

Technical committee on Malaysian Standard for Power Quality

- In the Malaysia standards development an Industrial Standard Committee (Electro-technical), ISC E, handles standards for Electrical and Electronics industries.
- The ISC E considers the standardst and public comments before recommending for ministerial approval.
- ISC E established the Technical Committee for Power Quality in early 2000.
- The membership of the committee represents stakeholders of Power Quality.
- Malaysian standard will incorporate local conditions, environment as well as national priority, which may not be taken into account by international standard.

Malaysian PQ Standards

- The PQ Technical Committee has produced a standard on Recommended practices for monitoring electric power quality (MS 1533: 2002).
- It is adapted from the IEEE 519 Standard because there was no equivalent IEC standard.
- The IEC has now proposed a new standard IEC 61000- 4-30: Testing and Measurement Techniques - Power Quality Measurement Methods.
- The committee has worked on five standards based on the IEC and are in the processed of putting them up for public comments.

Issues on Harmonics standard

- The IEEE 519-1992 does not suggest any limits on any equipment.
- The IEC 61000-3-2 Emission specifies limits for Harmonic current emissions (equipment input current < 16 A). This document is part of the EMC directive issued by The European Union.
- The IEC 61000-3-2 ed 1995 was much criticized for its severity. There were reports that differences in the calculation of the limits may caused equipment under test would apparently pass in one laboratory and fail in another.

Issues on Harmonics Standard

- Many multinational companies in Malaysia, MNCs, are familiar with IEEE Std 519-1992 which suggests limits on the harmonics current that a user can induce back into the utility power system and also specifies the quality of the voltage that the utility should furnish the user.
- These standards do not explicitly say how to share the harmonics limits of the point of common coupling.
- The need to streamline these three documents is one of the issues need to be addressed in Malaysia and in countries facing the same problem.

Present Malaysian Practice

- Currently TNB is using the Electricity Association Engineering Recommendation G5/4:2001 for planning levels for harmonic voltage distortion and the connection of non-linear equipment to transmission systems and distribution networks.
- A similar standard from the IEC, 61000-3-6 (1996) deals with the assessment of emission limits for distorting loads in MV and HV power systems.

Harmonics Standard

- The amendment since then and the newer version in 2001 have accommodated those concerns.
- The new edition of IEC 61000-3-2, has changed class D equipments to include only television receivers and desktop computers (for now), an acknowledgement in digital society where the usage of this equipment has proliferated and cause harmonic problems to the supply network.

Public Participation in Malaysia PQ Standardisation effort

- Comments received when proposed drafts are offered the public to study was helpful. The comments indicated the level of concerns amongst the public particularly from the industries.
- Recently the Malaysian standard PQ Technical Committee helps the Department of Standard Malaysia and SIRIM organized a one-day seminar on PQ.
- There were more than 150 participants and nearly 100 participants asked to be informed of draft standards in the future when they are offered for the public to comment.

Malaysian PQ Standards

- There are seven Malaysian standards on Power Quality, all of which were adopted from the IEC standards
- The Technical Committee realized that IEC PQ standardization is going at quite a steady pace. SC77A has produced a work plan for all the 26 relevant standards of the PQ.
- In the past many Malaysian standards were developed without the benefit of knowing the development that are taking place in the IEC Technical Committee 77, which is the EMC committee of the IEC.

Malaysia and IEC SC77A

- On the recommendation of the Malaysian PQ Standard Technical Committee Malaysia has become a participating member in SC77A, which is a subcommittee of the TC 77.
- It is intended that, if necessary, as soon as practicable draft IEC Standards will be developed as a proposed Malaysian standards or revised standards and offered for public comments.
- In this manner MS standards will be up to date. By participating in SC77A, technical committee hopes to influence the IEC standards and avoid issues that disadvantaged national industries.

Conclusion

- Power Quality problems pose challenges to any country that rely on advanced manufacturing and digital economy.
- One of the strategies to manage the PQ problem is the development of PQ Standards.
- Malaysia obligation under WTO means that national standards must be based on international standards.
- With the input from all stakeholders of the power quality problems, Malaysia can learn and also hopes to influence international standardization for the benefit of all.

FROM JUNGLE FERN TO JUNGLE FAB

(power quality experience of a small utility)

by

Victor Wong
Manager Energy Services & Marketing

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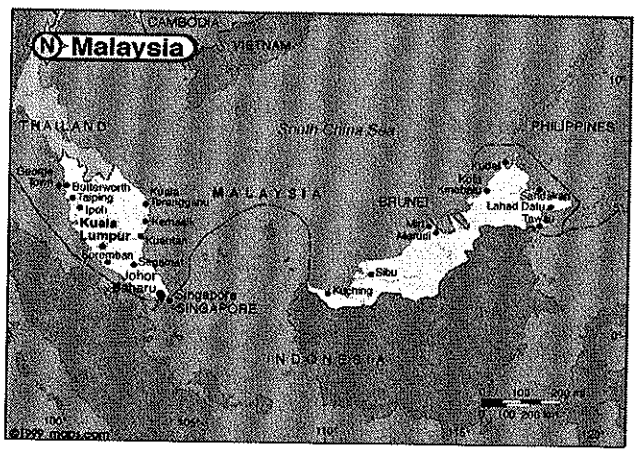
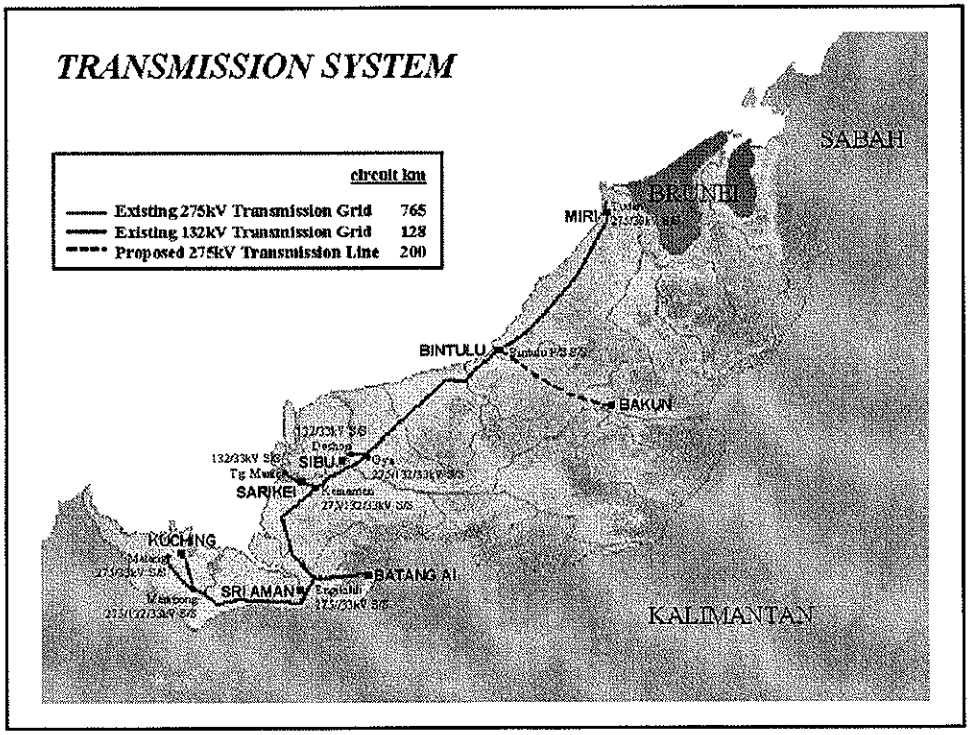
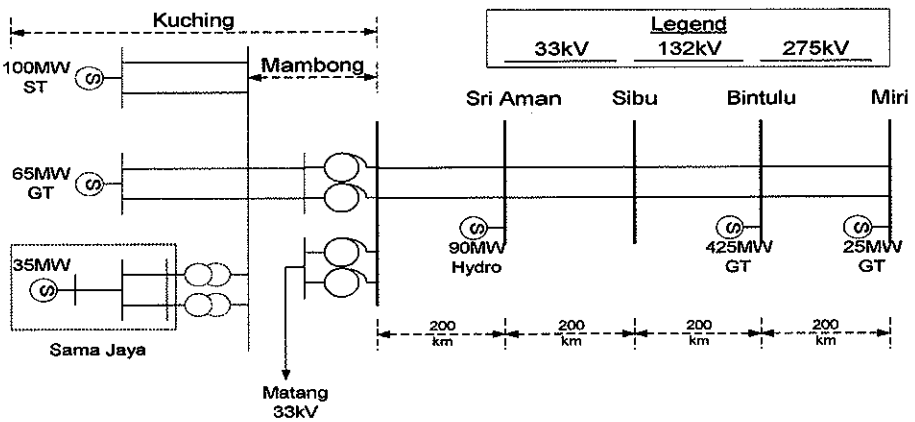
http://www.sesco.com.my email: victorwong@sesco.po.my

Where are we?

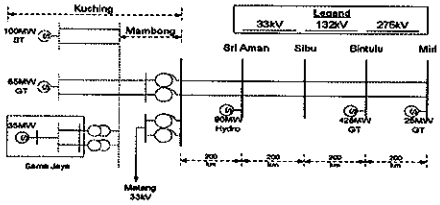




Characteristics of SESCo Network



Characteristics of SESCo Network



- **Small generation capacity** - sensitive to disturbances
- **Long transmission line** - high exposure to natural elements
- **Single 275kV line** - severe consequences for loss of line
- **Polarisation of generation and loads** - easily separated
- **Rapid growth** - pressure on existing equipment
- **High lightning activities**
- **A difficult system to operate**

Power Quality (PQ)
Vs
Power Reliability (PR)

Quality

	Electrical Network	Road System
Causes	Short circuit (lightning, equipment failure)	Pot holes (due to flooding)
Results	**Voltage dips**	**Bumpy rides**
Impacts	Product damage (Semicom industry)	Damage to fragile goods
Solutions	**Network** - reduce dip severity **Customer** - filter out dips, reduce sensitivity	**Road** - better road, raise road level etc. **Vehicle** - better shock absorbers, better car etc.

Reliability

	Electrical Network	Road System
Causes	Severe thunder storm and a tree brings down both 275kV circuits	Severe flooding and a bridge washed away
Results	Supply interrupted	Road cut
Impacts	Production interrupted	Goods not delivered
Solutions	**Network** - alternative 275kV lines, local generaton **Customer** - standby generators	**Road** - flood mitigatiopn, alternative routes, better bridges **Vehicle** - other transportation or other sources of goods.

PQ Vs PR

Causes

- PQ
  - single cause
  - eg lightning or single equipment failure
- PR
  - Multiple causes
  - Usually simultaneous tripping of 2 or more items of equipment or line

Occurrence

PQ - frequent
PR - infrequent

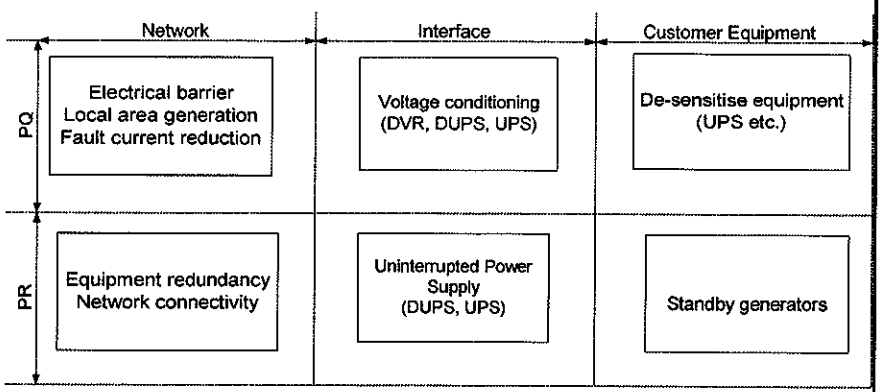
Effects

PQ - widespread
PR - restricted to downstream of fault

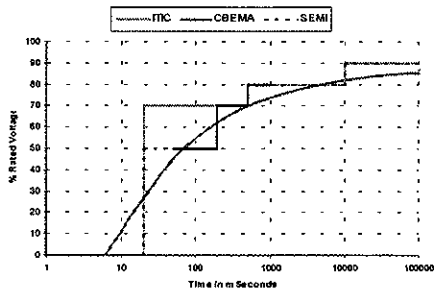
Financial impacts

PQ - low to high
PR - extreme

PQ and PR Solutions



PQ Standards

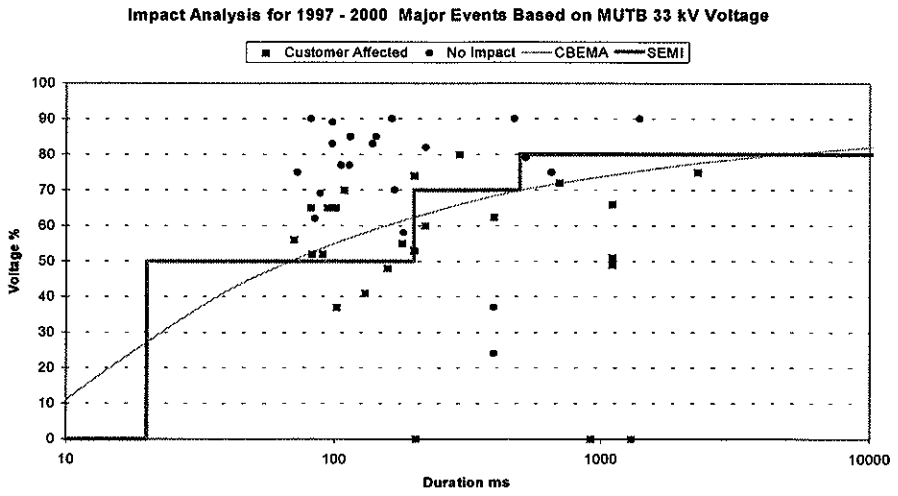


CBEMA & ITIC - non industry specific
SEMI standard
- industry specific but not applicable to existing equipment
- may be too stringent for equipment suppliers
- not applicable to facilities

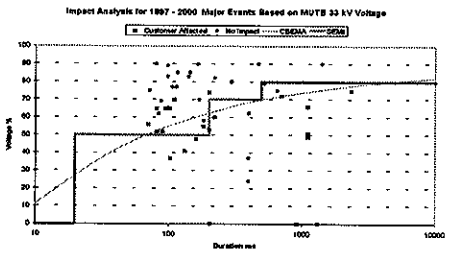
Compliance non-mandatory

- It will take a long time for semiconductor industry to comply fully with SEMI standard
- Semiconductor industry lacks a suitable PQ standard
- Utility's traditional focus - PR & prices
- Incompatibility exists between utility system and equipment designs

PQ Management

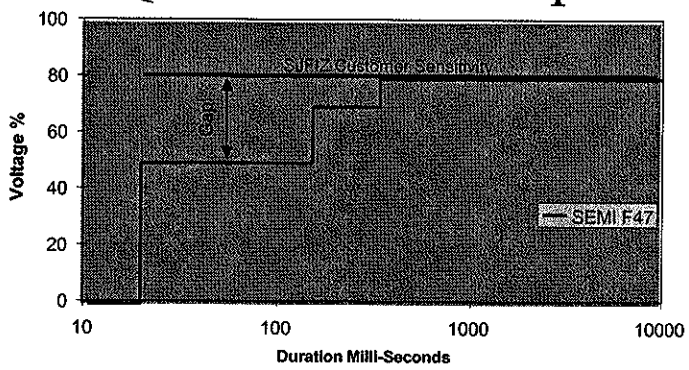


PQ Management



- Monitoring devices limited and different
- PQ measurements at different voltage levels make correlation difficult
- Lack of information on equipment tolerances
- Incomplete and inaccurate information on impact
- Limited rectification possible as design of equipment already fixed
- Responsibility and cost have to be addressed in the proper manner

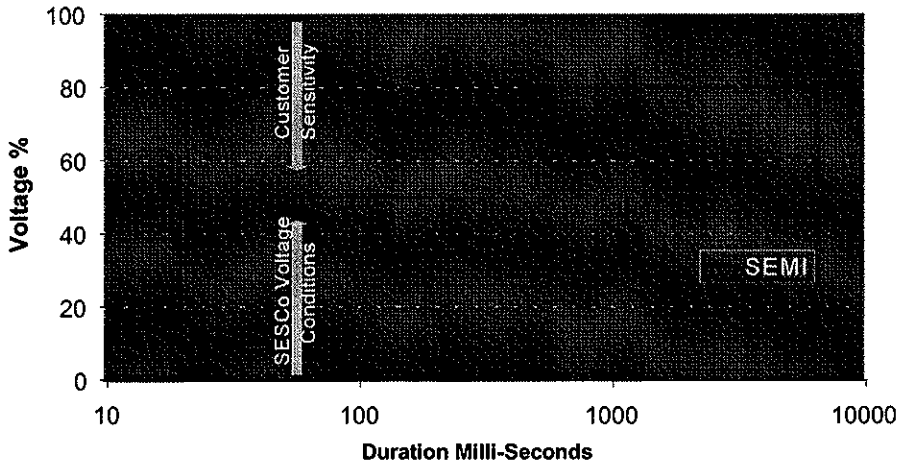
PQ Performance Gaps



Gaps between existing customer equipment and
- SEMI standard
- SESCo electrical environment

Joint effort needed to breach the gaps

Partnership Approach



SESCo's PQ and PR Initiatives

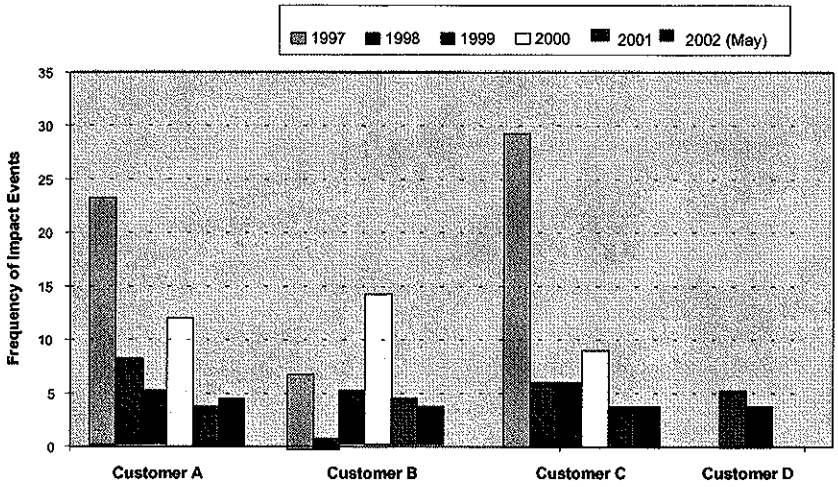
SESCo's PQ and PR Initiatives

- PQ & PR
  - Segregation of SJFIZ supply from rest of 33kV distribution network
  - Kuching generation capacity planting up (another 100MW baseload units by early 2005)
  - Careful coordination in switching and testing works
- PQ
  - Implementation of recommendations of 3 extensive studies (PTI-US, Mott MacDonald and ENERGEX)
  - Extensive and high-quality PQ monitoring system
- PR
  - Higher level of generation at Kuching
  - Automatic underfrequency load shedding scheme to rescue essential loads

Benefits From PQ & PR Initiatives

- Kuching area generation and Kuching outer ring
  - Reduce severity of most voltage dips
  - Reduce probability of total blackouts
- Consequently
  - Over 85% of 275kV faults have no customer impact
  - Ditto for most 33kV faults
- Customers in Sama Jaya FIZ are only affected by:
  - Multi-phase 275 kV faults
  - 275kV single-phase faults close to Kuching
  - Any fault on the Muara Tabuan 132 kV system
  - Multi-phase faults on the Samajaya 33 kV system

Frequency of Customer Impacts



Conclusions - PQ

- An industry-specific PQ standard (SEMI) was developed only in 1999
- Lack of a specific standard contributed to incompatibility between utility supply system and equipment design
- Large gap presently exists between performance of existing equipment and SEMI standard
- Gap also exists between utilities' PQ performance and SEMI standard
- The semiconductor industry most probably is unable to comply with the SEMI standard for some years due to:
  - Stringent nature of the SEMI standard to equipment manufacturers
  - Standard being non-mandatory
  - The appropriateness of the standard being questionable

Conclusions on PQ (Cont'd)

- SESCo's supply network is prone to voltage dips due to inherent weaknesses brought about by:
  - Geographical and climatic conditions of Sarawak
  - Large separation between load and generation centres
- Initiatives by SESCo since 1997, including Kuching outer ring, have effectively reduce the impacts
- Presently over 70% of these voltage dips are within the 20% threshold level and do not affect customer operation.
- PQ performance may be further improved by:
  - Additional Kuching area generation
  - Reducing earth fault current for Muara Tabuan 132 kV system

Conclusions on PR

- SESCo's supply network is also prone to frequent supply failure due to
  - Inherent network weaknesses and vulnerability to nature
  - High growth rate exerting pressure on existing system
- To achieve benchmark levels, SESCo will adopt the following measures:
  - Provide additional generation in the Kuching area.
  - Enhance the UFLS to protect important loads
  - Adopt customer solutions.

ON-GOING/FUTURE PQ ENHANCEMENT PROGRAMS

PQ and PR Enhancement Program

- Joint Technical Working Group by SESCO and customers on specific areas of need

Development of PQ and PR Report Cards

- Summary PQ& PR KPI's, performance compliance and trends + detailed reporting levels to suit different user needs

Total Quality Management Program

- Incorporating PQ focus into Planning, Design, Materials, Construction, Operation and Maintenance processes

KEYNOTE ADDRESS BY MR KHOO CHIN HEAN, CHIEF EXECUTIVE, ENERGY MARKET AUTHORITY AT THE INTERNATIONAL POWER QUALITY CONFERENCE, 21-25 OCTOBER 2002

DELIVERY OF QUALITY POWER TO CUSTOMERS IN A MODERN DIGITAL ECONOMY

Distinguished guests
Ladies and Gentlemen
Good morning.

Introduction

Many of our processes are heavily reliant on IT and precision equipment. This includes not only manufacturing but also commercial processes. Even energy markets can be realised only because of very powerful computing power that has today become economically viable.

2 These mean that the use of voltage sensitive equipment has become pervasive, even common place. This has changed the notion of reliability in the electricity industry. Whereas in the past reliability means no-blackouts or brown-outs, today reliability means the delivery of almost rock steady voltage.

3 A voltage deviation of no less duration than a blink is disastrous to many of the processes supporting manufacturing and commerce today.

4 A recent study by the Electric Power Research Institute (EPRI) estimated that power quality problems account for about US$15-24 billion in annual losses in the United States. Voltage dips, transients, and momentary and complete outages are the major causes of power quality problems. Others include disturbances to the voltage and current harmonics caused by interaction of devices within a power system.

5 We have had our share of power quality problems in Singapore. As we became increasingly aware of the problems power quality can cause, we have had to rethink many of our controls.

6 One source of voltage dips in Singapore had been due to cable damage. Our cables are buried. With so many development projects taking place, digging has for many years been a favorite pastime in Singapore. Put the two together and we have disasters waiting to happen. They did.

7 Today the controls over excavations have been strengthened. Contractors must first engage cable detection workers to detect buried cables before they dig. The penalties are heavy if they cause damage to buried cables. These include fines of up to S$1 million and/or imprisonment of up to 5 years for causing damage to cables. As a result, the number of damages to transmission cables due to excavation had dropped significantly from 4 in 1998 to 1 in 2001. No damage to transmission cables has occurred thus far in 2002.

8 Until recently another cause of voltage dips had been due to cable joints failing. The rogue cables have since been taken out of service so that the joints can be replaced.

9 Failures in electrical installations had also been a major contributor to voltage dips. Though their effects are localised, they are no less disruptive to voltage sensitive processes in the vicinity. To ensure electrical installations are properly maintained, the EMA has also implemented a scheme to tighten maintenance of such installations. This includes providing information on our web-page for licensed electrical workers to share information about installations that had given trouble. Punitive actions against errant licencees include fines and suspension of licences.

10 The combined effects of all these measures had led to a reduction in the occurrences of voltage dips in Singapore. The number of dips had fallen from 36 in 1999 to 24 in 2001 For the first eight months of 2002, there was a total of 12 incidents of voltage dips.

Customers' perspective in the supply of quality power

11 Any electrical network that is extensive will always be vulnerable. Measures can be taken to reduce the occurrences of damage and voltage dips. However such occurrences can never be eliminated.

12 Not all consumers are voltage sensitive. While it may be tempting to suggest the network can be hardened with a view to preventing power quality deviations, it will not offer any protection to voltage sensitive consumers. The outcome of such an approach will be to increase grid costs to all consumers, even for those consumers who are not voltage sensitive.

13 While all measures should be taken to prevent power quality deviations, consumers who are voltage sensitive must also take measures to protect themselves. This means having to invest in equipment that helps to ride through deviations in power quality that may happen from time to time.

14 The level of protection however varies from consumer to consumer. This has to be evaluated and the degree of protection as well as the type of equipment determined on an application by application basis. A surgical approach as this enables the most cost effective solutions to be implemented.

The Singapore Experience

15 Singapore's power infrastructure compares well with any other jurisdiction. The system average interruption time, which measures the availability of electricity supply, has reduced from 1.95 minutes in the year ended Mar 01 to 0.93 minute in the year ended March 2002. The number of supply interruptions per 1,000 customers has also improved from 0.84 to 0.80 over the same period.

16 We have discovered that these are not enough. We need also to deliver quality power. For this, Singapore Power has launched several complementary initiatives to enhance power quality.

Power Quality Initiatives

17 As the network owner, PowerGrid Ltd is required to provide a high quality and reliable electricity supply to the customers.

Earthworks & cable monitoring

18 As part of its remit, PowerGrid monitors all earthwork activities around the island closely and advice is given to contractors on measures to be taken to avoid damaging cables. To make sure that all necessary care and precautionary measures are taken to prevent cable damages, PowerGrid carries out daily patrols along all its transmission cable routes and critical distribution circuits.

Network monitoring

19 PowerGrid has put in place equipment to monitor the condition and performance of its network assets.

20 This includes on-line partial discharge monitoring system for all switchgears in 400kV substations and 230kV substations. The system provides early-warnings of impending failure.

21 PowerGrid has also implemented a Condition Monitoring Programme for its underground transmission cable network. It has a programme to regularly analyse insulating oil used in all 400kV and 230kV oil filled cable joints for dissolved gas. Thermal scanning and SF6 gas quality checks are carried out on the transmission and distribution equipment.

22 With this capability, PowerGrid is today able to implement a proactive condition-based maintenance regime to minimize failures of equipment and cables in its vast network of over 9000 substations and 30,000 km of cables.

Monitoring of power quality

23 PowerGrid has recently completed the installation of its island-wide Power Quality (PQ) Monitoring System to measure the magnitude and duration of voltage dips. The data will be used for network analysis with a view to finding opportunities for power quality improvements.

24 PowerGrid will share the data with consumers who want to do their own voltage dip sensitivity analysis and mitigation. Potential investors and new customers coming into Singapore will also be able to use it to plan and design their plants to incorporate equipment specifications with adequate voltage dip ride-through capability or to adopt power conditioning options.

Network enhancements

25 In planning the transmission network, PowerGrid has enhanced its fault handling capability and also the quality of power with the commissioning of the 400kV transmission system in 1998. They have split the 230kV network in Singapore into the Northern and Southern blocks. The benefit of this is that it has lessened the severity of voltage dips experienced by customers in one block when the fault occurred in the other block.

26 Singapore Power set up a Power Quality Solution Fund of $150 million for two years in July 2000. The scheme provided financial incentives to those industries who need quality power in their installations, to implement user-end solutions.

Conclusion

27 Singapore has made progress in its efforts to minimise voltage dips.

28 The hosting of the International Power Quality Conference, which is held in this region for the first time, demonstrates Singapore's commitment on power quality. I am sure that it would be an opportunity for industry experts,

researchers, players from the power companies, the consumers, equipment manufacturers and the Regulator to share their knowledge and experience in the latest technologies for power quality improvement and management of Power Quality issues.

29 I would like to congratulate the organisers of the conference for the fruition of this conference and wish the conference every success.

Thank you.

Making power quality part of your strategy for economic growth

Mark McGranaghan
Electrotek Concepts

First of all, I want to thank Dr. Lock, Mr. Sim and the other conference organizers for the invitation to this excellent conference and the opportunity to give the keynote speech.

I am very honored by this opportunity and I hope I can provide a few insights that will be beneficial as we share our ideas in the power quality area. It's a critical topic in this region and in the whole world for that matter.

What is power quality?

First, let's ask the question – What is Power Quality?

Is Power Quality about the level of harmonic distortion in the voltage? Is it about the characteristics of a voltage sag?

Of course it is! But power quality means **Compatibility.** It means designing and operating the power system for compatibility with customer equipment and customer processes. And this means we must always be able to take the customer perspective when looking at power quality concerns.

Power quality is economics

Most importantly, Power Quality means **Economics**. This is something I always try to emphasize when teaching power quality workshops around the world. It can't be emphasized enough. Power quality problems cost money. If they didn't, we wouldn't be worried about power quality. Power quality problems make customers less productive, less competitive. Power quality concerns affect where they locate plants and the processes they are willing to locate in those plants. Power quality problems affect employment. They affect the whole economy.

Let's look at a few examples:

- Semiconductor industry (critical in this whole region). This is the industry with probably the highest costs of power quality problems of any industry. Chips that take weeks to produce and are worth millions of dollars in sales can be ruined with one voltage dip lasting 80 msec.

- Plastics and chemicals industry. This industry has very large motors and drives that can be impacted by power quality variations. The processes are continuous

and can take long periods to restart. The costs can easily be in the hundreds of thousands of dollars.

- Commercial and Data Processing concerns. The internet and handling of financial transactions make power quality critical for many commercial applications. Internet centers and corporate data centers go to great lengths to assure the quality of power for critical servers and support equipment.

Basically, any industry with process equipment is going to be concerned about power quality. When any piece of equipment in the process is disrupted, the whole process can be shut down and the consequences very expensive.

As I said, power quality is Economics.

Developing a strategy

So obviously a strategy to deal with power quality issues should be a high priority for all electric utilities. But the strategy should involve more than just the electric utilities. Power quality issues affect the whole economy so all players involved in developing the economy should be involved in the strategy.

Most importantly, though, the strategy should be customer-focused. Remember that power quality problems are customer problems in the end and we must understand them from that point of view and develop our strategy with that in mind.

I have a friend that is also here for this conference and has been one of the most important people in power quality for many years. He started a number of successful companies over the years, including the company that did the most for advancing the state of the art in power quality measurements. He has now started another very successful company that is helping customers to understand how sensitive their equipment is to power quality variations – Power Quality Standards Laboratory. I once asked him what his secret was in starting and growing such successful companies. He told me that the key is to find out what everyone else in the industry is doing well – and copy it – then figure out a few things that could be improved and make them better.

I think this approach can work well for developing your strategy for dealing with power quality.

Find out what others are doing right and copy it

What better place to look for the state of the art and for things that are being done right than right here in Singapore.

Let's take a look at how power quality issues are being handled in Singapore. I'm sure we will learn more from various papers and discussions here at the conference but I have a few opinions of my own about the things they have done right.

I must say that I am very honored to be followed Mr. Chang from PowerGrid in helping to start off this conference. I met Mr. Chang at a power quality conference in South Africa in 1998 as PowerGrid was going around the world to see how other utilities were dealing with power quality issues (just as I am recommending here). It was Mr. Chang's initiative that resulted in us working with PowerGrid to put a new emphasis on power quality. Right off the bat, I was impressed with Mr. Chang and others involved because they understood that power quality was a Singapore issue, not a PowerGrid issue.

Voltage sags were the issue in Singapore. Customers in Singapore don't experience very many voltage sags – there are not very many system faults in Singapore. However, they still wanted to improve the performance. They weren't happy that these few events were a major cost to some of their most important customers. Mr. Chang understood the economics involved. These customers are critical to all of Singapore and, therefore, they are critical to PowerGrid.

Through the last three years of working with PowerGrid, I have become even more impressed with the resolve and commitment to power quality. Not only to improve the power quality that they supply to their customers, but to understand the impacts of the power quality variations and help customers to deal with them.

Here are a few of the things I think they have done right and would be worth copying:

The whole company should be involved

Support for a power quality initiative must start at the top. Then it needs to involve all parts of the company – engineering, planning, operations, protection, marketing, customer service, etc.

This was the case in Singapore from the beginning. In our first presentation about benchmarking power quality levels in Singapore, I was very impressed to be talking directly to the President of Singapore Power and the Managing Director of PowerGrid. You can't get any higher support than that. And they weren't there just as a formality. They wanted to understand the issues and what could be done to improve the situation.

It's bigger than just the utility

And support for a power quality initiative must go beyond just the utility. Remember that power quality issues affect the whole economy – attracting industry, helping industry be as productive and competitive as possible, and maintaining that advantage.

In Singapore, power quality was a major focus for the regulator (PUB), the Ministry of Trade and Industry (MTI), and the Economic Development Board (EDB). Mr. Khoo gave another example of this emphasis in the opening speech. The pressure and interest at all levels of the government helps keep the focus on the most important economic issues and the role of power quality in these issues.

You need to understand the system performance

This is the first step in any power quality program. Power quality is more than reliability and often utilities don't understand what power quality levels are really being provided to customers.

Benchmarking and understanding what the system is capable of supplying is critical. Publishing PQ standards helps everyone understand what can be expected. International standards can provide a good starting point but you will have to look at the unique characteristics of your systems, especially when characterizing voltage sag performance.

PowerGrid understood this and the first effort in their power quality initiative was to benchmark the expected voltage sag performance in Singapore. This helped focus attention on capability of the system rather than just arguing about what the power quality should be. After understanding the existing capability, the focus can move to improving performance.

Get all parties involved and talking

Get the customers directly involved and talking about their power quality problems. Listen to them – don't just argue with them.

In Singapore, a power quality working group was formed with participation from government, regulators, the utility, and industry.

This kind of continuous dialogue has worked well in many places in the US as well to help focus efforts on the most important issues, to understand the economics on both sides (there's that word again), and the realities of the system operation.

This is not a one time meeting and then go off and solve the problems. This should be a continuous dialogue.

Don't be afraid to try something new

Try something. Be innovative. Action shows that you are doing something, trying to improve, trying to solve problems.

Everyone appreciates that.

It may not be the optimum solution or the ultimate solution, but it shows your commitment to attack the problem.

Just starting the entire power quality program is an example of the actions taken by PowerGrid. Initiating a system monitoring program to understand the system performance better and be able to react to disturbances better was another major investment.

I was very impressed one week I was working with PowerGrid. At the beginning of the week, we talked about the effectiveness of building a new substation to supply some of

the critical customers and isolate them from faults that can cause voltage sags. By the end of the week, the decision had been made to go ahead with the idea despite the tremendous cost. This was an example of how fast they could make decisions. I couldn't believe it and eventually we talked them out of that idea (there were much more effective ways to spend that money after looking at the alternatives) but the point was they were ready to act.

In the end, PowerGrid implemented one of the most innovative programs ever to help existing customers improve their productivity. They agreed to pay half the cost of any power quality solution implemented in the facilities to improve immunity and performance during voltage sags. This put the investment where it could do the most good.

Understand the economics

I can't emphasize this enough. Power quality comes down to economics and you need to understand the unique economics of power quality issues for your system and your customers.

I like to use an example of Duke Power in the United States. They supply many textile industry customers and this industry is critical to the region (like the semiconductor and electronics industries are here). These textile industry customers have processes that are very sensitive to voltage sags. They are supplied from a 100 kV transmission system that is a network so they virtually never have interruptions (their reliability is excellent) but they experience sags whenever there is a momentary fault somewhere on the system, usually resulting from a lightning stroke to a transmission line. Duke recognized the economic impact of these events to the whole region and initiated a program to improve the tower grounding on their entire transmission system. This was an investment of millions of dollars but resulted in customer productivity improvements that was worth more to the region than the investment. It meant jobs were retained and continued electricity sales to these important customers and all the supporting industries associated with them.

That's taking the global economic perspective.

Singapore's program to share in the costs of voltage sag immunity investments is another example of understanding the global economic picture.

What can you do better?

Keep all those things in mind and you will should be able to come up with an effective strategy for addressing power quality issues. But what can you do even better. That's the other part of the equation.

Here are two thoughts. I'm sure this conference will help you come up with many more. That's the purpose of it.

Share your ideas and practices

Don't be secretive with what you are doing to deal with power quality issues. Write about it, talk about it, share it with the world. I realize this is a controversial attitude but the advantages of opening up your ideas to comment, review, and criticism more than outweighs the disadvantage of letting your potential competitors know what you are doing. As long as you continue to learn and innovate, you will always stay one step ahead.

The companies with the best power quality programs in the world use this approach – Duke Power and Scottish Power just to name a couple. Go talk to them – they will tell you exactly what they are doing and they will be very interested in your opinions on it.

The fact that you are here is a good sign. Hopefully, you are here to share your experiences as well as learn from the experiences of others.

Monitor, monitor, monitor

You can't go too far with understanding the system. Monitoring is the way to understanding. Start out small with a pilot project if you need to but monitor the system performance continuously.

Eventually, we will be monitoring every substation and every circuit. Carolina Power and Light and United Illuminating already do it. They haven't regretted the investment involved for one moment. The benefits accrued in understanding the causes of disturbances, reacting faster to problems, providing information to customers immediately, relating power quality problems to equipment problems, and sharing the information throughout the company have greatly exceeded the costs.

PowerGrid is embarking on a large monitoring project to better understand the system performance continuously here in Singapore.

This is money and effort well spent.

Conclusions

You can learn a lot here in Singapore. I know I will learn a lot this week.

It starts with understanding that power quality is just economics. Economics in the big picture.

With that understanding you can get everyone involved and help power quality be part of your overall strategy for creating economic growth.