IES-IEE JOINT SEMINAR

Power Quality for Mission Critical Facilities

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By

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POWER QUALITY for MISSION CRITICAL FACILITIES

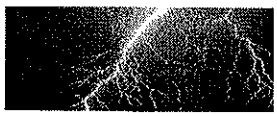
- Various issues of power quality for mission critical facilities
- Nature of voltage dips and impacts on sensitive equipment
- Requirements of SEMI F47
- Solution alternatives: Voltage regulators, static UPS, dynamic UPS, DVR
- Design of reliable electrical distribution system
- PQ references in CD ROM

POWER QUALITY OVERVIEW

- What is PQ?
- Causes of poor PQ
- Effects of poor PQ
- Characteristics of different types of PQ problems
- Voltage dips: causes, effects and mitigations
- General PQ assurance

WHAT IS POWER QUALITY?

- Power Quality is the physical characteristics of the electrical supply provided under normal operating conditions that do not disrupt or disturb the customers' processes- IEC (1000-2-2/4) and CENELEC EN 50160



WHAT IS POWER QUALITY?

IEEE STD 1100-1999 defines:

"Power Quality is the concept of powering and grounding electronic equipment in a manner that is suitable to the operation of that equipment and compatible with the premise wiring system and other connected equipment."

WHAT IS POWER QUALITY?

- Reliability/availability - a measure of whether supply is on or not
- Reliability index, availability index
- Power quality depends on voltage quality
- Voltage dips, voltage sags
- Waveform distortion- harmonics
- Surges, transients, EMC issues
- Earthing problems
- Wiring problems
- ESD problems

POWER QUALITY CONCERNS (1)



- 7 x 24 mission critical facilities
- Large financial losses due to downtime, rejects, rework and overheads
- More sensitive or critical loads -malfunction, nuisance trips
- Increased disturbances & supply pollution
- More demanding & influential customers
- Loss of customer confidence
- Safety

POWER QUALITY CONCERNS (2)

- Degradation or damage of equipment
- Competition from power industry de-regulation
- Concerns of top administrators/politicians
- Regulations/penalty
- More educated, informed customers
- Power quality can be measured.

TRADITIONAL RELIABILITY INDEX

- Counts customers who suffer a power loss, and for how long
- Common international index is ASAI (Average Service Availability Index). Ratio of hours of available service in a year to the hours of service demand in a year
- In developed countries ASAI is usually 0.99989, and so the utility can claim 99.99% reliability.

RELIABILITY INDICES

- SAIFI: System Average Interruption Frequency Index
- SAIDI: System Average Interruption Duration Index
- CAIFI: Customer Average Interruption Frequency Index
- CAIDI: Customer Average Interruption Duration Index

QUALITY INDICES

- System Average RMS (Variation) Frequency Index ($SARFI_x$) represents the average number of specified rms variation measurement events that occurred over the assessment period per customer served, where the specified disturbances are those with a magnitude less than x for sags or a magnitude greater than x for swells.

$SARFI_x$

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

Where

X= rms voltage threshold; possible values – 140, 120, 110, 90, 80, 70, 50, and 10

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

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

OTHER INDICES

- System Instantaneous Average RMS (Variation) Frequency Index (SIARFIx)
- System Momentary Average RMS (Variation) Frequency Index (SMARFIx)
- System Temporary Average RMS (Variation) Frequency Index (STARFIx)

IEEE Std 1159-1995

Category	Duration	Voltage Magnitude
Short Duration Variation		
Instantaneous		
Sag	0.5 to 30 cycles	0.1 to 0.9 pu
Swell	0.5 to 30 cycles	1.1 to 1.8 pu
Momentary		
Interruption	0.5 cycles to3 s	<0.1 pu
Sag	30 cycles to 3 s	0.1 to 0.9 pu
Swell	30 cycles to 3 s	1.1 to 1.8 pu
Temporary		
Interruption	3 s to 1 min	<0.1 pu
Sag	3 s to 1 min	0.1 to 0.9 pu
Swell	3 s to 1 min	1.1 to 1.8 pu
Long Duration Variation		
Sustained Interruption	> 1 min	0.0 pu
Undervoltage	> 1 min	0.8 to 0.9 pu
Overvoltage	> 1 min	1.1 to 1.2 pu

THE "9s" OF RELIABILITY

Reliability/ Availability (%)	Total duration of outage/interruptions	Acceptable for
99.9	8.6 hours/year	Homes
99.99	1 hour	Factories
99.999	5 min	Hospitals, airports
99.9999	30 s	Banks
99.99999	3 s	
99.999999	1/3 s	E-commerce
99.9999999	32 ms	Data Centres

THE REQUIREMENTS

- Utility usually provide about four 9's
- Modern economy requires about five or six 9's
- Semiconductor industry demands eight 9's
- Data centre demands nine 9's

PQ MALAYSIA

1. At transmission level
   - 132 kV 24 to 35 events/year
     - Average 29% sag, worst 86%
     - Average 97 ms, worst 1.3 s
   - At 275 kV, 11 to 19 events/year
     - Average 31% sag, worst 61% sag
     - Average 112 ms worst 485 ms

PQ SINGAPORE 1996 to 1999

Causes of voltage dips	Average number of voltage dips/year
Cable damage	3
PowerGrid's equipment/cable	13
Consumers' equipment/cable	14.75

PQ SINGAPORE SARFI

- SARFI 90 –
- SARFI 80 –
- SARFI 70 –

WHO CAUSES POWER QUALITY PROBLEMS

- The Utility
  - voltage dips, lightning & switching, rain, wind, surges, harmonics
- The Neighbors
  - switching transients, voltage dips, harmonics
- The User (Internal)
  - Harmonics, sags and swells, transients, electrical noises, wiring & grounding problems

USER

- Needs to understand how the power disturbances will affect sensitive loads and therefore develop appropriate specifications, or install appropriate power conditioning
- Develop facility guidelines that address power quality (sensitive load circuits, power factor correction, surge suppression, etc)
- Needs to comply with power quality standards

THE MAJOR CONCERN

Voltage dips is of particular interest and hence we shall examine this issue further .....



VOLTAGE SAGS/ DIPS

- An RMS reduction in the ac voltage, at the power supply frequency, for durations from a half cycle to a few seconds.
- Voltage dips are of major concerns in Singapore
- High-tech industries, e.g semiconductor & electronic manufacturers suffer $ millions of losses for each dip



CHARACTERISTICS OF VOLTAGE DIPS



- Magnitude
- Duration
- Frequency
- Three phase unbalance
  - 1-phase fault, phase-to-phase fault, 2-phase-to-ground fault
- Point-on-wave characteristics

RMS VOLTAGE

A voltage dip/sag is a short-duration reduction in rms voltage

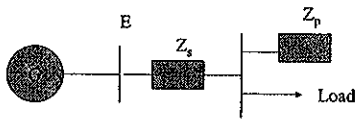
$$V_{rms}(n) = \sqrt{\frac{1}{n}\sum_{k=n-N+1}^{k=n} v(k)^2}$$

where N=multiple of one cycle or one half-cycle

CAUSES OF VOLTAGE DIPS

- Faults on power system, T & D
  - equipment faults, cable faults, transformer failures
- Lightning strikes
  - operation of circuit breaker, recloser
- Faults within facilities
  - equipment faults, capacitor short-circuit, inadequate discrimination of protective relays, etc
- Starting of large motors
- Neighbours/ other users' HT equipment faults

VOLTAGE SAG



$$V_{sag} = \frac{Z_F}{Z_S + Z_F}$$

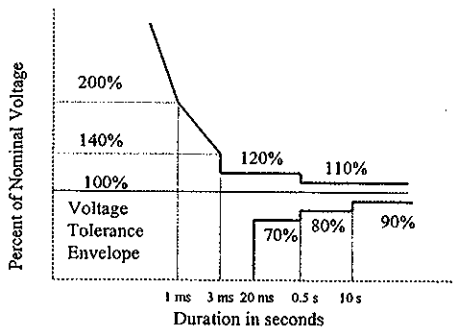
EFFECTS OF VOLTAGE DIPS

- Variable Speed Drives (VSDs)
  - ride through time from 0.05 sec to 0.5 sec
- Computers & Telecom Equipment
  - CBEAM or ITIC curve
- Motor contactors
  - drop out at 50% to 70% voltage range
- Process Controller, PLCs
  - some trip even at 90% voltage
- High-Intensity Discharge (HID) Lamps
  - extinguishes at around 80% normal voltage

THE CBEMA/ ITIC CURVE

- Developed by the Computer Business Equipment Manufacturers Association, the CBEMA Curve is a set of curves representing the withstand capability of computers in terms of the magnitude and duration of the voltage disturbance.
- The CBEMA curve has become the de facto standard reference to define the capability of various loads and devices for protection from power quality variations.

ITI CBEMA CURVE (REVISED 1996)



DATA PROCESSING EQUIPMENT

- Computers use ground as a reference for all operations
- Computer circuits operate at very low voltage level, e.g. ± 5 V, or lower
- Computer data circuits are connected to other data processing equipment or loads.



REQUIREMENTS OF DATA PROCESSING EQUIPMENT

- A disturbance or surge with enough energy can cause component failure
- High frequency impulses can scramble memory or programs
- Voltage fluctuation can activate undervoltage, overvoltage and power fail detection circuit with shut-down action
- Improper ground can result resets/reboots and parity errors.
- EMI can affect the VDU.

PROCESS EQUIPMENT (1)

- The basic microprocessor control is susceptible to voltage variations or transients, causing memory scramble, program loss and semiconductor failure among other problems
- The remote, digital to analog (D/A) controls may be disabled, blocked or forced into false operation
- Voltage sag can cause shutdown of process

PROCESS EQUIPMENT (2)

- Feedback controls (A/D) may be activated by the false operation of a D/A controller
- In-built power supply monitoring circuitry may be confused by harmonic distortion of a voltage waveform forcing false shutdown
- EMI from other facilities equipment may cause false operation.

VSD - VOLTAGE SAG PROBLEMS

- Voltage-source inverters are the most common VSDs in use
- The dc link voltage drops during a voltage sag and not able to maintain inverter output voltage, leading to increased current exceeding permissible value
- In-built sensing circuit stop inverter operation for system protection.

VOTAGE SAG TRIPPING

Equipment fails because there isn't enough voltage

- Most electronic equipment use dc power for internal circuit
- Undervoltage relay trips
- Unbalance relay trips
- A quick-acting relay shuts the system down, typically in the emergency-off circuit
- A reset circuit may incorrectly trip at the end of the voltage sag
- AC contactors can dropout to shutdown power to devices or processed they control

VOLTAGE SAG SENSITIVITY

- Equipment fails because there isn't enough voltage.
- DC power derives from ac supply through converter circuits which incorporate dc link capacitor
- Capacitor voltage drops below designed voltage and not able to deliver the required current/power safely
- The dc link voltage sensor trip the protection circuit.

UNDERVOLTAGE CIRCUIT TRIPS

- Careful system designers may include a circuit that monitors the ac power system for adequate voltage
- The "adequate" voltage may be set without full understanding of the load requirement
- It may trip even for 1 cycle undervoltage

UNBALANCE RELAY TRIPS

- On 3-phase system, voltage sags are often asymmetrical
- 3-phase motors and transformers can be damaged by sustained voltage unbalance due to overheating
- Voltage sag that causes 20-50% unbalance for a second or two does not cause equipment damage, but unbalance relays with inadequate delays can cause the sensitive system to shut down.

EMO CIRCUITS

- The EMO (emergency off) circuit in an industrial load typically consists of a normally-closed switch that can disconnect power to a latched relay coil
- If the relay operates quickly, it may interpret a brief voltage sag as an operator hitting the EMO switch. The whole system will shut down unnecessary.

TRIP BY RESET CIRCUIT

A reset circuit may incorrectly trip at the end of the voltage sag:

- Many electronic reset circuits are designed to operate at "power up" – when first turn on the equipment, the circuit ensures all microprocessors start up properly, the latches are all properly initialized, etc.
- One common design detects a sudden increase in voltage, which also happens at the end of a voltage sag
- Different parts of a system may have different reset circuits which response with varying sensitivity.

AC Contactors During Sags

- Sag magnitude and duration are important factors
- Coil current specifically determines the limits of AC contactor engagement
- Point in wave where a voltage sag occurs has significant impact

MITIGATION OF VOLTAGE SAGS



- Reducing the number of short circuit faults on the T&D networks
- Reducing the fault clearance time
- LIMITING FAULT CURRENT
- Changing the network configurations such that short circuit faults result in less severe events at the equipment terminals or at the customer interface
- Installing mitigation equipment
- Improving equipment immunity

FIXING VOLTAGE DIPS (1)

- Specify and use equipment with a good degree of sag immunity
- Design distribution circuits with PQ in mind
- Find and fix the problem
- Switch power supply setting to a range where the top setting is close to the existing supply voltage
- Connect single-phase power supply phase-to-phase (where applicable)
- Reduce the load on the power supply

FIXING VOLTAGE DIPS (2)

- Use over-size power supply for the same load
- Use 3-phase power supply instead of a single-phase supply
- Run power supply from a dc bus
- Change the trip settings
- Slow down the relay setting, e.g. EMO circuit

FIXING VOLTAGE DIPS (3)

- Utility can enhance reliability of supply
  - Avoid cable damages
  - Condition monitoring of power equipment
  - Improved T&D network configuration
  - Improved fault clearance time
  - Provides PQ data to consumers and consultants
  - Reliability-centred maintenance
  - Employs dynamic voltage restorers.

FIXING VOLTAGE DIPS (4)

- Mitigation methods available include:
  - Power conditioners
  - Voltage regulators
  - UPS
  - Rotary UPS
  - Dynamic voltage restorer

FIXING VOLTAGE DIPS (5)

- Other mitigation methods to enhance the ride-through capability:
  - Use semiconductor controlled rectifier that phase forward during a voltage dip
  - Chopper boost regulators to regulate the bus voltage
  - Capacitance back-up (limited to smaller power).

VSDs- VOLTAGE SAG RIDE-THROUGH

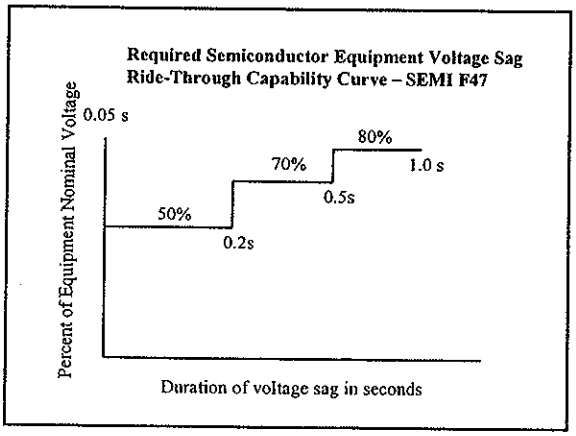
- Drive topology modification to stabilise dc link voltage - active rectifier, boost converter
- Use load inertia for regeneration mode of operation during short duration voltage sag
- Use energy storage options to interface with dc link - flywheels, TMF lead acid batteries, supercapacitors

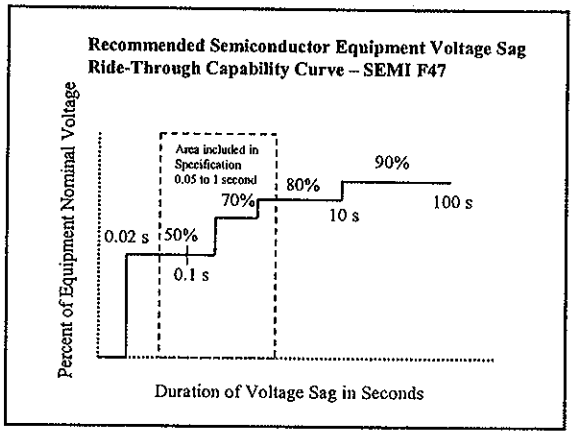
SEMI F47 – SAG IMMUNITY STANDARDS

- SEMI, the industry association for the semiconductor industry, has developed two voltage sag immunity standards:
  - SEMI F47 sets out the required voltage sag tolerance for semiconductor fab equipment
  - SEMI F42 sets out compliance tests

SEMI F47

- Equipment must tolerate sags up to 50% for up to 200 ms
- Sags to 70% up to 0.5 s
- Sags to 80% up to 1 s.
- It recommends (not part of requirements)
  - Sags to 0% for one cycle
  - Sags to 80% for 10 s
  - Continuous sags to 90





EQUIPMENT MANUFACTURERS

- Needs to understand the types of power quality problems and the general environment in which the system will operate, in order to build systems that can withstand the disturbances or to recommend appropriate protection
- Develop equipment testing procedures for verification of PQ performance

THE UTILITY

- Has to meet the customers requirements for "clean" power and to protect customers from the power disturbances of other users, and to protect the system from user-generated disturbances
- Benchmark performance
- Provides PQ data for users

REGULATORS

- Develop evaluation procedures for PQ
- Standardise PQ performance index
- Develop data of PQ variation characteristics that can be used to evaluate equipment performance
- Benchmark utility supply

LICENSED ELECTRICAL ENGINEERS

- Prevent failure of HV equipment
- Ensure that equipment are operating in suitable environment
- Monitoring for predictive maintenance
- A good maintenance program in place
- Understanding of PQ & reliability issues

PUB's MEASURES

- From 1st Nov 2000, PUB introduced measures to control voltage dips caused by failure of consumers' HV equipment
- Apply to both LEEs and the consumers

LEEs

- 3 voltage dips within 24 months will face Inquiry Committee
- LEE's licence will be suspended if he is found failing in duty
- Name of LEE and installation to appear in PUB web on 1st dip

LICENSED ELECTRICAL INSTALLATIONS

- LEI may have license suspended after 3 voltage dips within 24 months
- The suspension will be for a period deemed necessary for an independent maintenance audit to be carried out and for priority recommendations to be implemented.

PQ PROBLEMS (1)

- Outages
- Voltage dips/sags
- Undervoltages, brownouts
- Surges, impulses
- Switching transients
- Overvoltages, swells



PQ PROBLEMS (2)

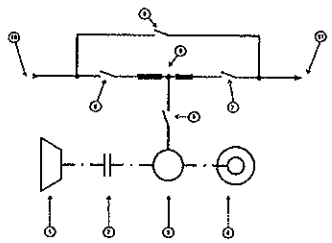
- Waveform distortion, harmonics
- Voltage unbalance
- Flickers
- Electrical noises, EMI/EMC issues
- Grounding problems
- Electrical wiring

PQ & MAINTENANCE

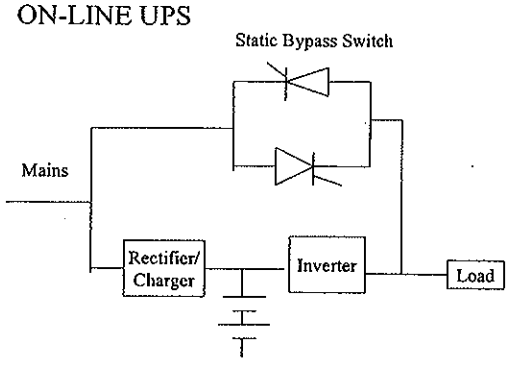
- Impact of O & M on PQ
- Diagnostic/ preventive maintenance
  - Infrared thermal imaging or themography
  - Electrical testing
  - Dielectric tests
- Condition monitoring
  - Partial discharge monitoring
- Total productive maintenance
- Root cause analysis

DESIGN FOR PQ/RELIABILITY

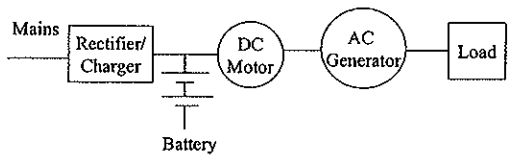
- Site selection
- Redundancy of power sources, primary feeders, transformers, UPS modules
- Paired or duplicated UPS distribution panels
- Automatic transfer switch
- Protection devices
- Dedicated supply
- FMEA, avoid single point of failure
- Design for growth



ON-LINE UPS



Battery-Rotary UPS



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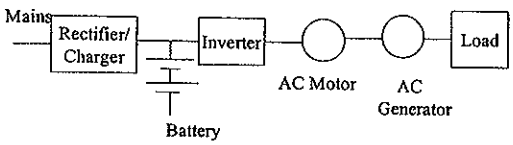

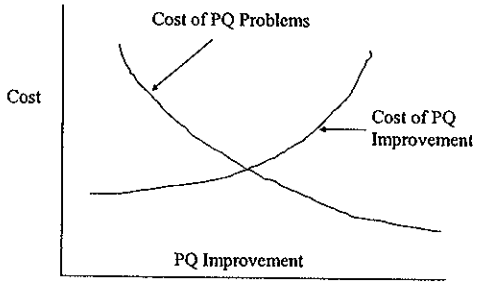

Minimizing PQ Improvement Cost