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Power Quality – A Subject of Increasing Interest

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AUSTRALIAN POWER QUALITY
AND RELIABILITY CENTRE

UNIVERSITY
OF WOLLONGONG
AUSTRALIA

Content

1. Background to power quality and why it is important
2. Elements of power quality management
3. Examples on power quality management

Synopsis

By definition, there is a distinct difference between reliability and power quality (PQ) where power quality refers to the purity of the electricity that supplies the connected equipment. Similar to the impurities/nutrients and the associated concentrations in the water we drink or the food we consume, a range of features and their acceptable levels characterise the quality of electricity. Some PQ features will be persistent (continuing or sometimes they are known as variations) and some are events (they appear from time to time). Both variations and events have detrimental impacts depending on the environments in which the equipment operate. Some power quality problems cause slow deterioration of the connected equipment and some lead to their almost instant failure. This means that the associated economic consequences are sometimes hidden (and go unnoticed) and sometimes immediately evident. Hence, it is vital that stakeholders ranging from those who: generate, transmit, and distribute electricity, electrical equipment manufacturers, electrical system designers and operators, economists, the rule-makers and the lawyers and the like should aim to acquire adequate understanding on the subject. The aim of the first part of the presentation is to give a quick overview of the types of power quality problems, how they originate and propagate and how they impact on connected equipment. Some discussion will be presented on the responsibility sharing associated with power quality.

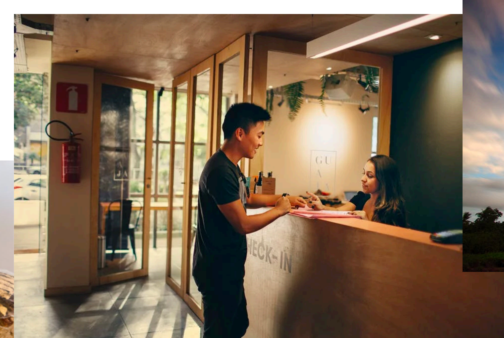
The second part of the presentation aims to highlight some of the power quality aspects related to changing electricity grids, ie those associated with the integration of renewable and distributed energy sources at all voltage levels, ranging from domestic solar photovoltaic systems to large scale wind and solar farms. Some efforts which aim to combat or minimise these problems are presented with examples and need for a holistic understanding is highlighted to ensure cost-effective solutions.

Reliability vs Quality

- In our daily lives we depend on a range of infrastructure, many services and goods - the terms 'reliability' and 'quality' apply to all these.






Reliability of Electricity Supply

- Crucial to the users
- At the very least, they are interested in knowing about yearly unexpected interruptions and their durations
- Network service providers (NSPs) keep records of planned and unplanned interruptions and their lengths for reporting purposes
- Indices used to quantify reliability: SAIDI, SAIFI, MAIFI, CAIDI and NSPs aim to meet set targets

Reliability of Electricity Supply

- In simple terms, 100% reliability implies availability of electricity continuously….

Quality of Electricity Supply or Power Quality (PQ)

Power Quality – what does it mean?

Power Quality (PQ) is associated with a range of disturbances that originate and propagate in the electricity supply network which lead to maloperation and/or pre-mature failure of equipment connected to the network

Quality of Electricity Supply or Power Quality (PQ)

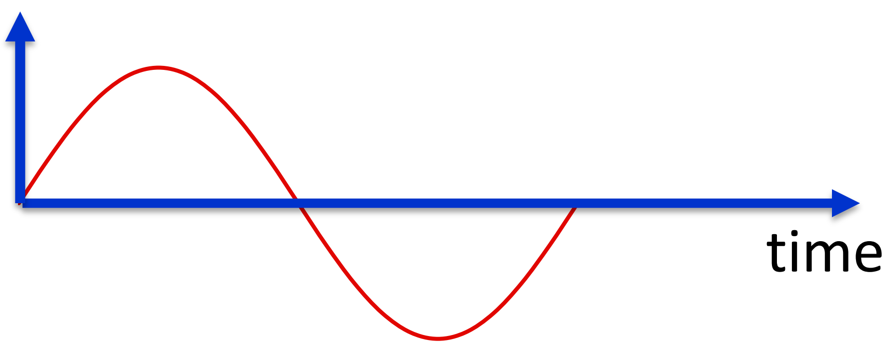
- Specifying power quality is rather complex as there are a number of features or disturbances (equivalent to impurities in drinking water) that need to be considered in relation to their limit values

Quality of Electricity Supply or Power Quality (PQ)

- These features or disturbances are categorised as:
  - Variations – always present to some degree - also known as quasi-stationary signals
  - Events – random or semi-random occurrences

The Power Quality Disturbances (Variation)

- **Steady State Voltage**: For example, at homes we should have 230 V (+10% - 11%) , 50 Hz (+0.15Hz, -0.15Hz).



waveform expected

230 V above refers to the root mean square value (or the effective value) of the waveform

The Power Quality Disturbances (Variation)

- The steady state voltage varies right throughout the day due a number of reasons including: network switching operations, load connection disconnection (varying voltage drop) etc
- Utilities attempt to maintain this voltage within limits

The Power Quality Disturbances (Variation)

- Undervoltage – motors may not start or may stall or overheat, equipment fail to operate
- Overvoltage – equipment loss of life, additional heating
  - ❖domestic solar photovoltaic inverters tripping



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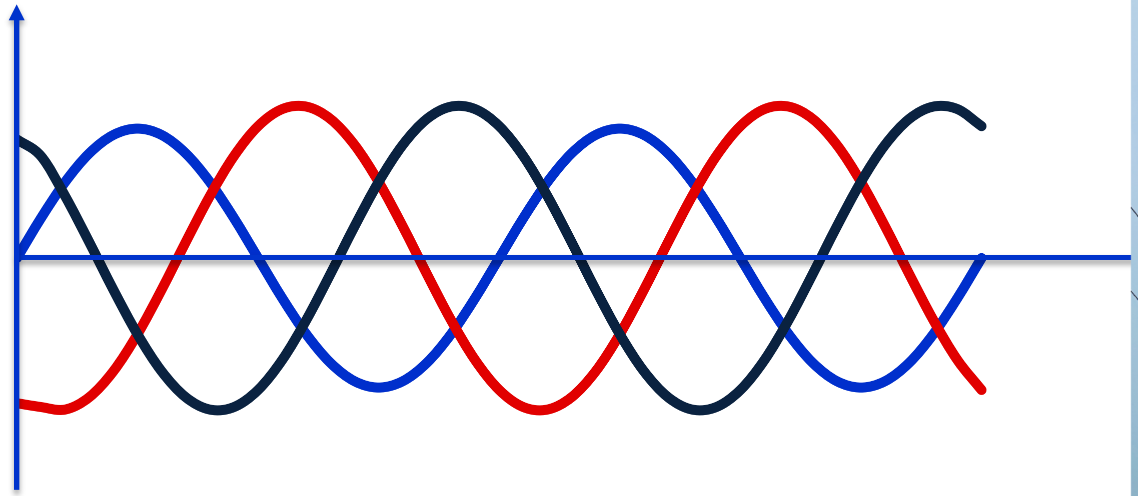
The Power Quality Disturbances (Variation)

- **Voltage Unbalance:** Three phase voltages are not equal in magnitude or separated by the same angle (120 degs)

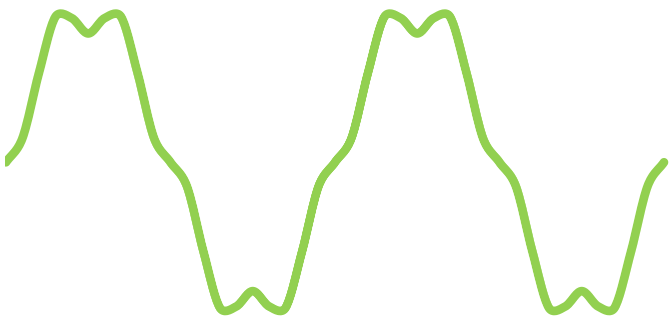


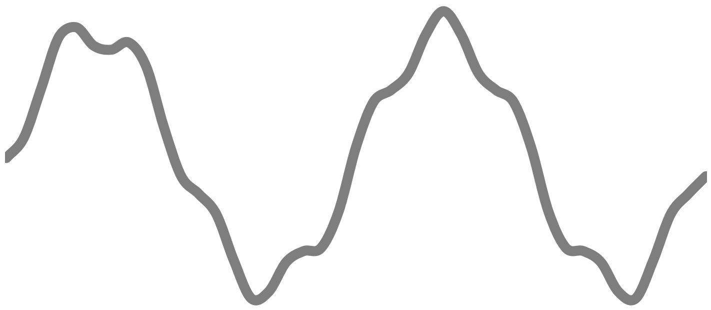
The Power Quality Disturbances (Variation)

- Caused by unequal loading (currents) on the three phases of the transmission and distribution system and asymmetry in the network
- Major impact is on three phase motors – overheating, vibration and noise and their pre-mature failure – motors cannot be loaded to their capacity

The Power Quality Disturbances (Variation)

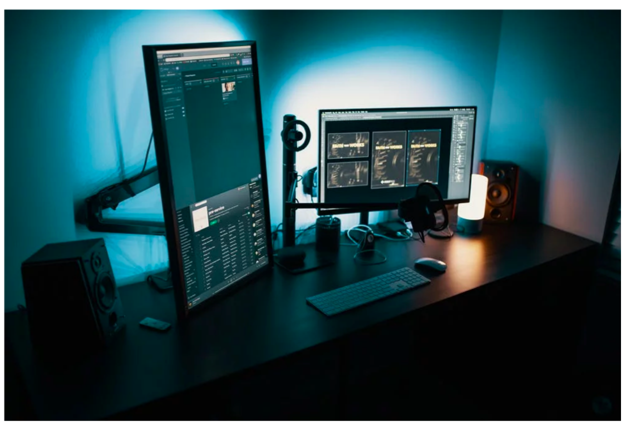
- **Voltage waveform distortion:** deviation from the sinusoidal shape – known as harmonic or interharmonic distortion
- Harmonic distortion – distortion is regular
- Interharmonic distortion - distortion is irregular

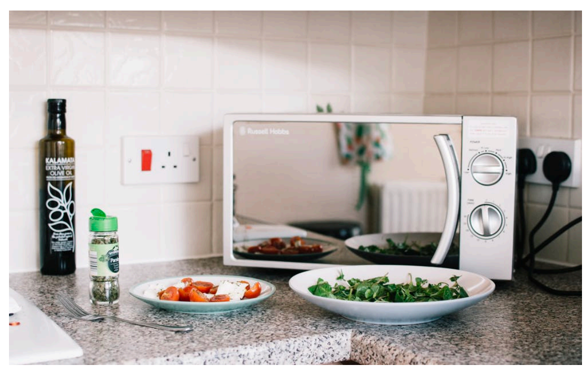




The Power Quality Disturbances (Variation)

- Caused by the non-linear elements and loads connected to electricity networks. These include consumer electronics, variable speed drives and many grid interconnection systems with high power electronic devices.



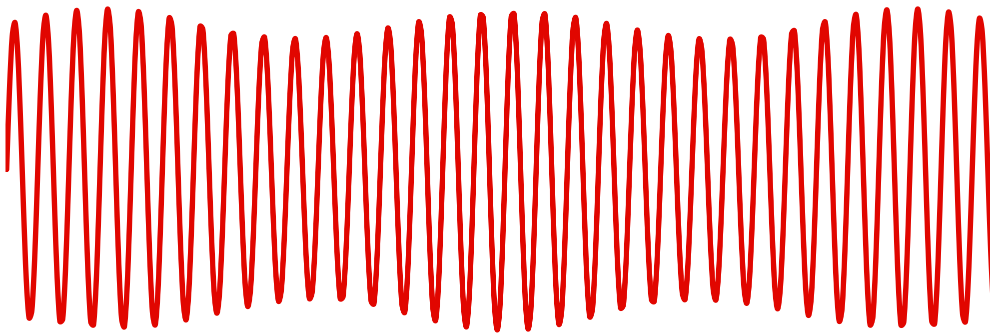


The Power Quality Disturbances (Variation)

- Distorted voltages can cause overheating of connected equipment, tripping and malfunctioning of connected systems and devices (eg. those depend on the natural zero crossings of the sinusoidal waveform)
- In worst cases control instabilities can occur within and between solar (and wind farms) in the presence of waveform distortion

The Power Quality Disturbances (Variation)

- **Voltage fluctuations:** regular and irregular variations of the voltage

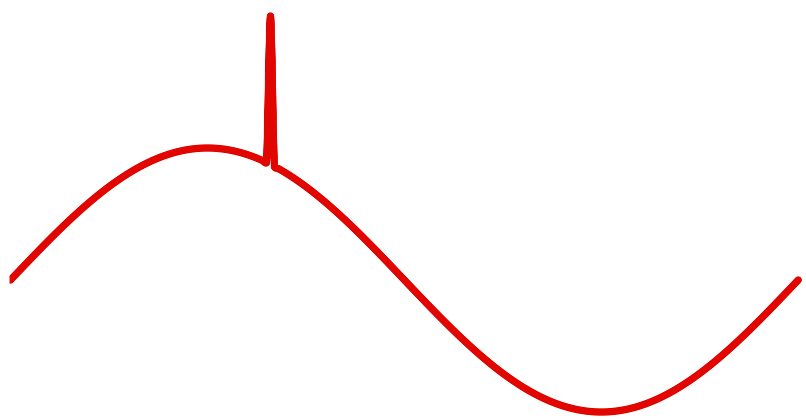


The Power Quality Disturbances (Variation)

- Voltage fluctuations are caused by random loads such as electric arc furnaces, welders, car shredders
- Major impact of voltage fluctuations is lamp flicker causing annoyance and headache in sensitive people

The Power Quality Disturbances (Event)

- Voltage transients: Oscillatory and Impulsive

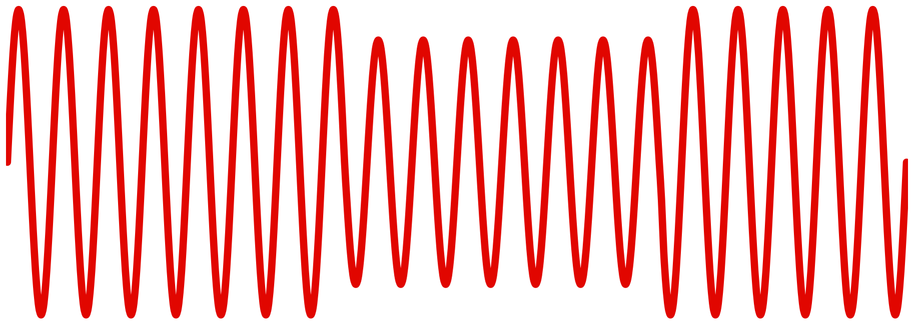


The Power Quality Disturbances (Event)

- Oscillatory transients are caused by network switching operation, particularly capacitor switching
- Impulsive transients are caused by lightning strikes. These transients are destructive due to their magnitudes and the fast rising nature

The Power Quality Disturbances (Event)

- Voltage sags: Sudden reduction and recovery of voltage after a brief period



The Power Quality Disturbances (Event)

- Voltage sags are usually caused by network faults and automatic clearing of the faults and large motor starting
- Can lead to plant and equipment tripping – recognised to be the power quality problem which has the greatest economic impact

Reasons for Increasing Interest on PQ

- **Competitiveness** in the power supply industry is making utilities more customer-focussed & customers are becoming "rights" conscious
- Greater interdependence & less lead-times in manufacturing
- Development of **standards** which more comprehensively describe different PQ disturbances with maximum acceptable values
- Decreasing cost & improved performance levels of power quality monitors
  - Now monitoring at locations which may not have previously been considered
- Renewable energy integration is driving many more connections at distribution, transmission and sub-transmission level – large connections at locations where the "system strength" is low

Power Quality Management Principles

Key ingredients of a holistic approach for power quality management

- Phenomena
- Regulatory framework
- Standards
- Emission allocation
- Emission assessment
- Mitigation
- Monitoring and reporting
- Benchmarking
- Economics

Power Quality Management Principles
(Regulatory Framework)

The three parties who need to work together and have the responsibility to deliver good power quality outcomes….

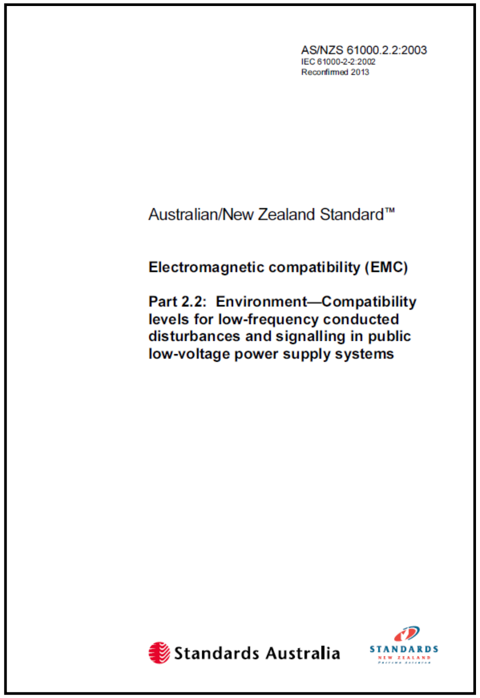
Network service provider

Customer/ Installation

Equipment manufacturer /supplier

Power Quality Management Principles
(Standards)

- Australia has (mostly) adopted the International Electrotechnical Commission (IEC) approach in the management of power quality
- Suite of standards to manage:
  - Acceptable power quality disturbance levels
  - Acceptable equipment emission and immunity levels
  - Allocation of emission limits to large customers
  - Measurement


AS/NZS 61000.2.2:2003
IEC 61000-2-2:2002
Reconfirmed 2013

Australian/New Zealand Standard™

Electromagnetic compatibility (EMC)

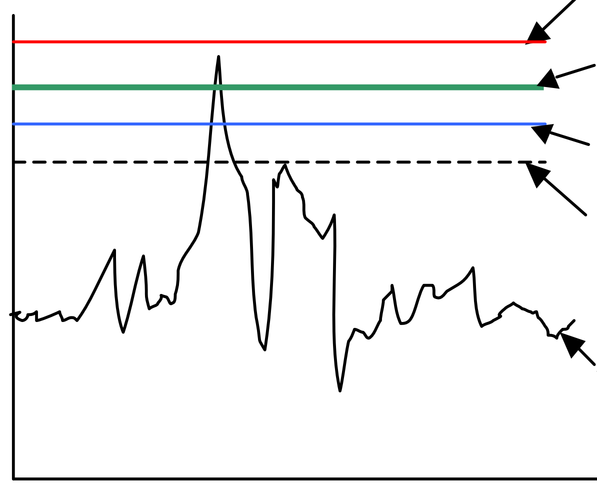
Part 2.2: Environment—Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems

Standards Australia

STANDARDS NEW ZEALAND

Power Quality Management Principles (Standards)

- Manage power quality by
  - selecting equipment with appropriate immunity levels – equipment manufacturer responsibility
  - adopting compatibility levels as per the standards
  - setting planning levels – utility responsibility
  - controlling **emission levels** – customer responsibility



Power Quality Management Principles (Standards)

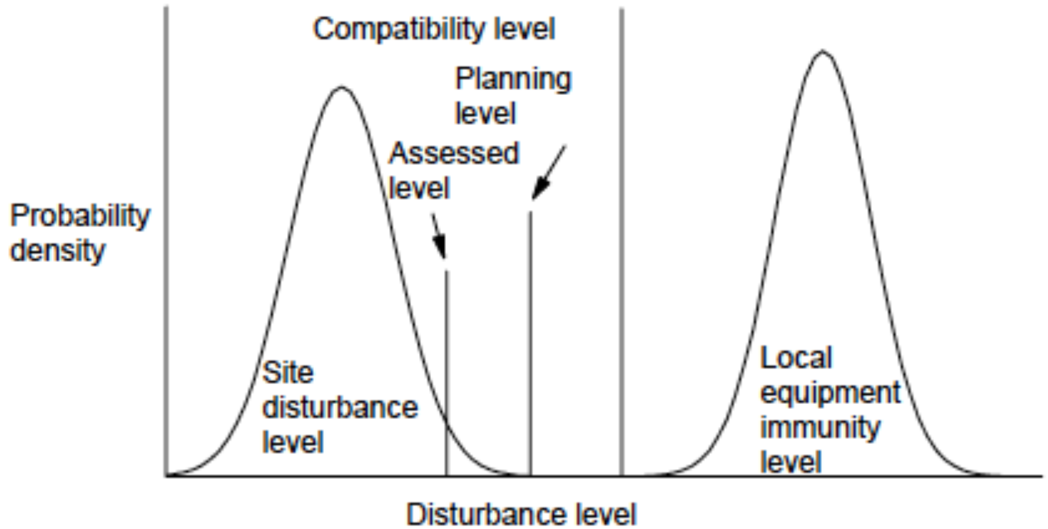


Figure 2: Illustration of basic voltage quality concepts with time statistics relevant to one site within the whole system.

Ref: IEC 61000-3-13: Electromagnetic compatibility (EMC) – Assessment of emission limits for the connection of unbalanced installations to MV, HV and EHV power systems, 2008

Power Quality Management Principles
(Standards)

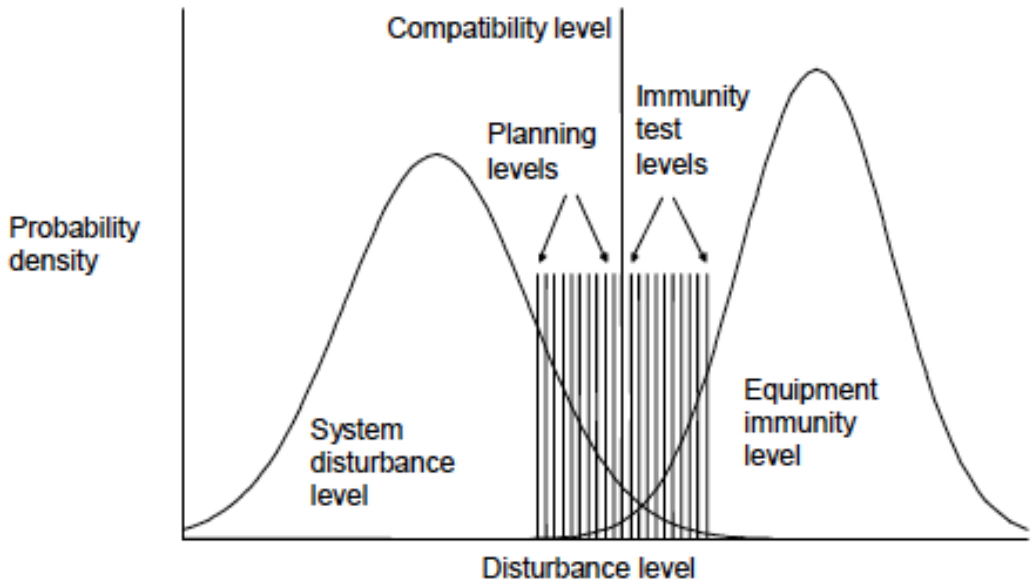


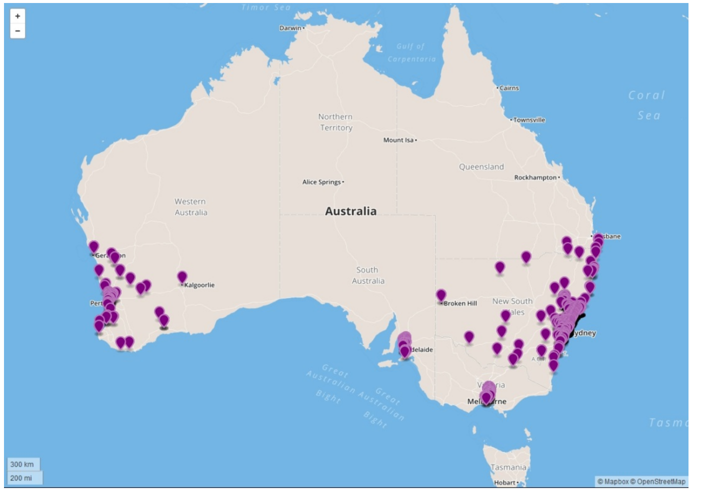
Figure 1: Illustration of basic voltage quality concepts with time/location statistics covering the whole system

Ref: IEC 61000-3-13: Electromagnetic compatibility (EMC) – Assessment of emission limits for the connection of unbalanced installations to MV, HV and EHV power systems, 2008

Power Quality Management Principles (Proactive Power Quality Monitoring and Benchmarking)

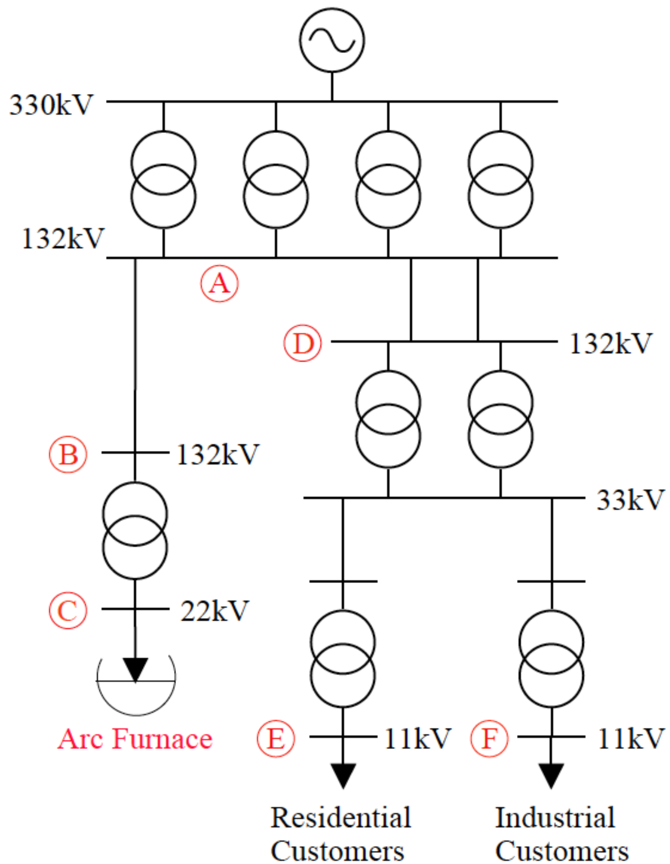
UOW commercial activity

- 12 distribution utilities (of 16) have been involved over the course of the project
- We estimate that these utilities supply 90%+ of Australian population
- Electricity distribution companies provide data from own instruments
  – Data analysis and preparation of reports
  – Includes benchmarking



Power Quality Management – Examples (phenomena)

Flicker propagation in power systems

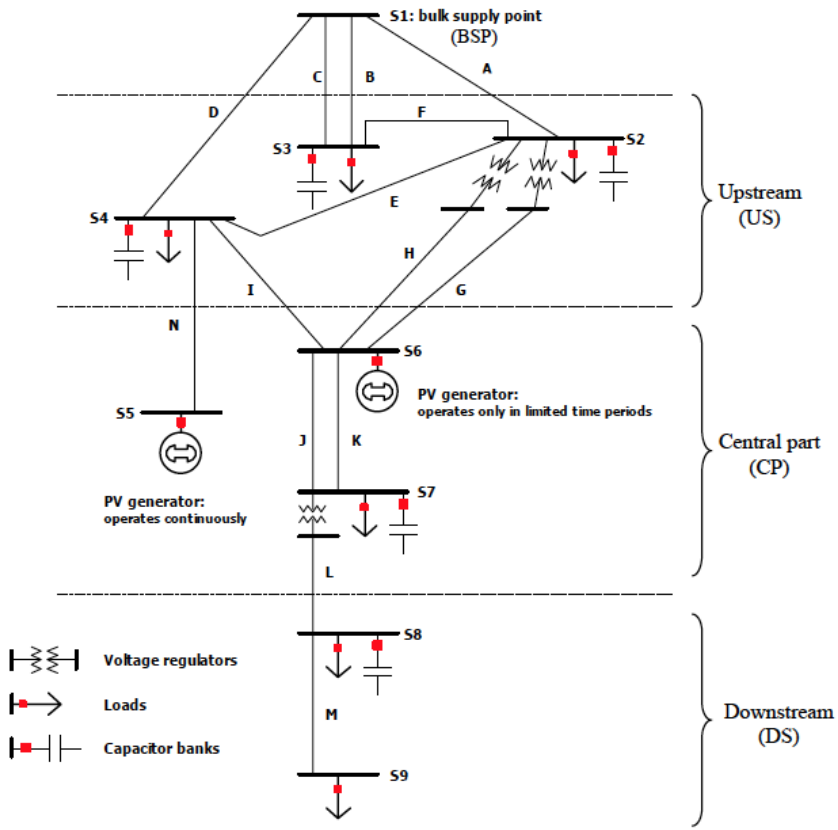


- Requirement to know how the voltage fluctuations (flicker) caused by the arc furnace propagated in the rest of the system
- Methodologies for measurement of flicker synchronously
- Less flicker at F compared to E.
- The reason being that the industrial loads attenuate the voltage fluctuations better than the residential loads

Ref: https://ro.uow.edu.au/infopapers/420/

Power Quality Management – Examples (Phenomena and mitigation)

Voltage unbalance in high voltage power systems

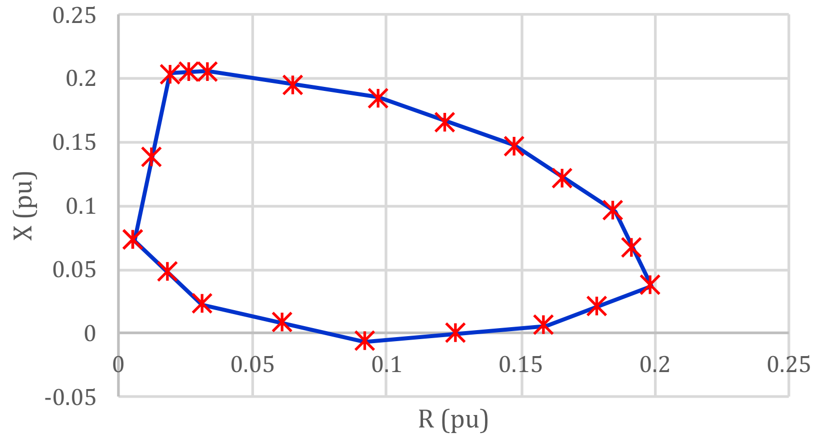


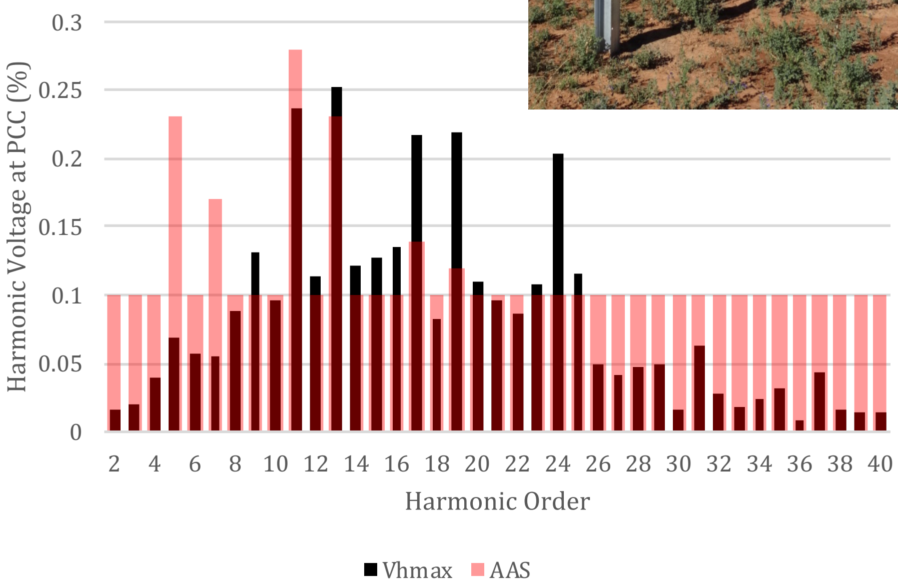
- Balancing of the loads did not eliminate the voltage unbalance and the network was still not compliant
- Asymmetrical lines contributed to this observation
- Development of a technique to select the candidate line to be balanced was not trivial – development of a new technique

Ref: https://ro.uow.edu.au/theses/834/

Power Quality Management – Examples (Emission allocation and assessment)

Harmonic Management in power systems



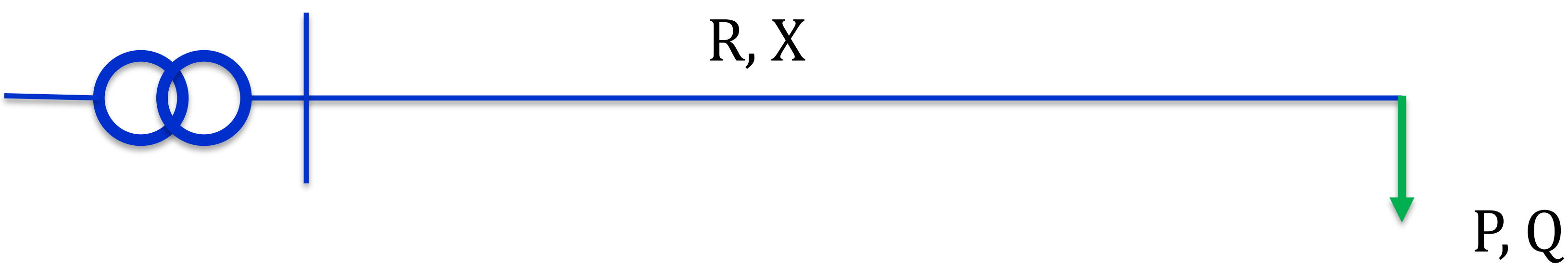


Large solar farm emission compliance studies before connection

Power Quality Management – Examples (Phenomena)

A pressing voltage issue in low voltage (LV) distribution systems

- LV Steady state voltages in Australia have traditionally been set high
  - Allows voltage drop along ‘long feeders’



$$\Delta V = PR + QX$$

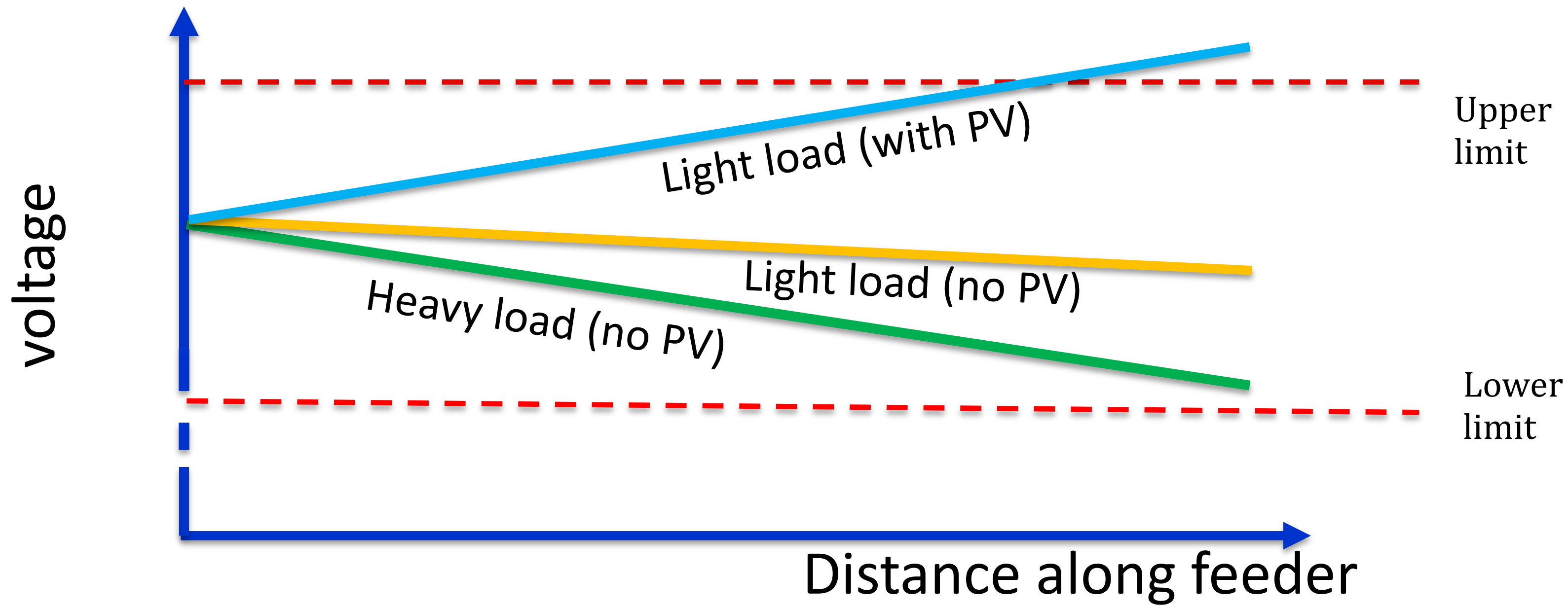
Power Quality Management – Examples (Phenomena)

A pressing voltage issue in low voltage (LV) distribution systems

- Survey shows that at least 30% of sites will not meet AS61000.3.100 limits for 99th percentile voltage
- High voltages are not desirable
  - Loss of equipment life
  - Little headroom for solar photovoltaic systems
  - Additional energy consumption and losses

Power Quality Management – Examples (Phenomena)

A pressing voltage issue in low voltage (LV) distribution systems – the mechanism



- Voltage rise is due to solar photovoltaic inverters injecting real power into the feeders in addition what is being consumed locally
- They will trip when the upper limit is exceeded

Power Quality Management – Examples (Mitigation)

A pressing voltage issue in low voltage (LV) distribution systems – the mechanism

- Recent changes to the inverter standards allow voltage control by curtailing real power injection and reactive power control $\Delta V = PR \pm QX$
- Networkwide voltage control using utility owned devices DSTATCOMs are being trialled now (Q control)
- By lowering voltage energy consumption can be reduced (conservation voltage reduction – CVR)

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