SCHOOL OF ELECTRICAL AND ELECTRONIC ENGINEERING

DUBLIN INSTITUTE OF TECHNOLOGY · INSTITIÚID TEICNEOLAÍOCHTA ÁTHA CLIATH · D·I·T

Coping Smartly !!

with Harmonic Penetration, Propagation and Interaction in the Distribution Network

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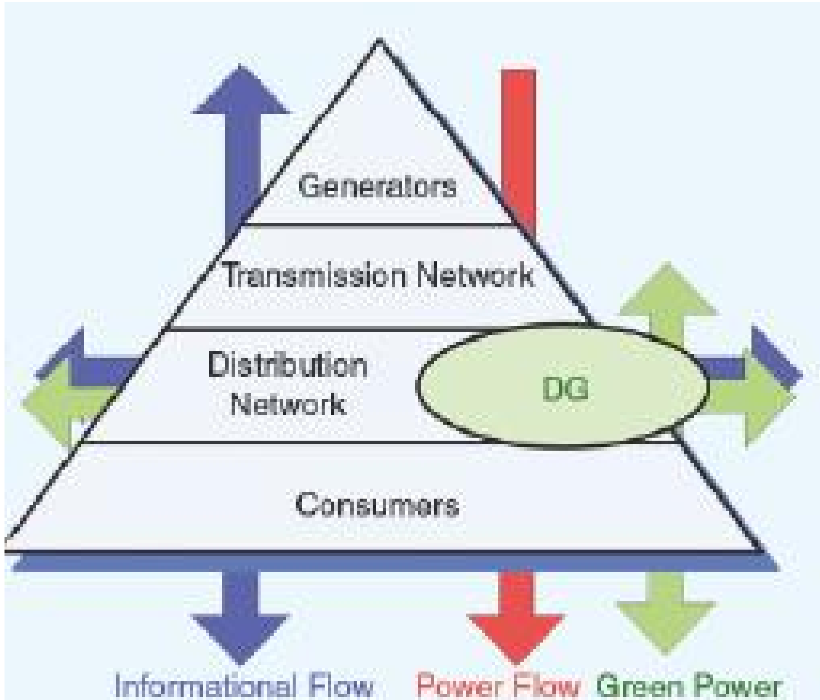
EPRC Electrical Power Research Centre

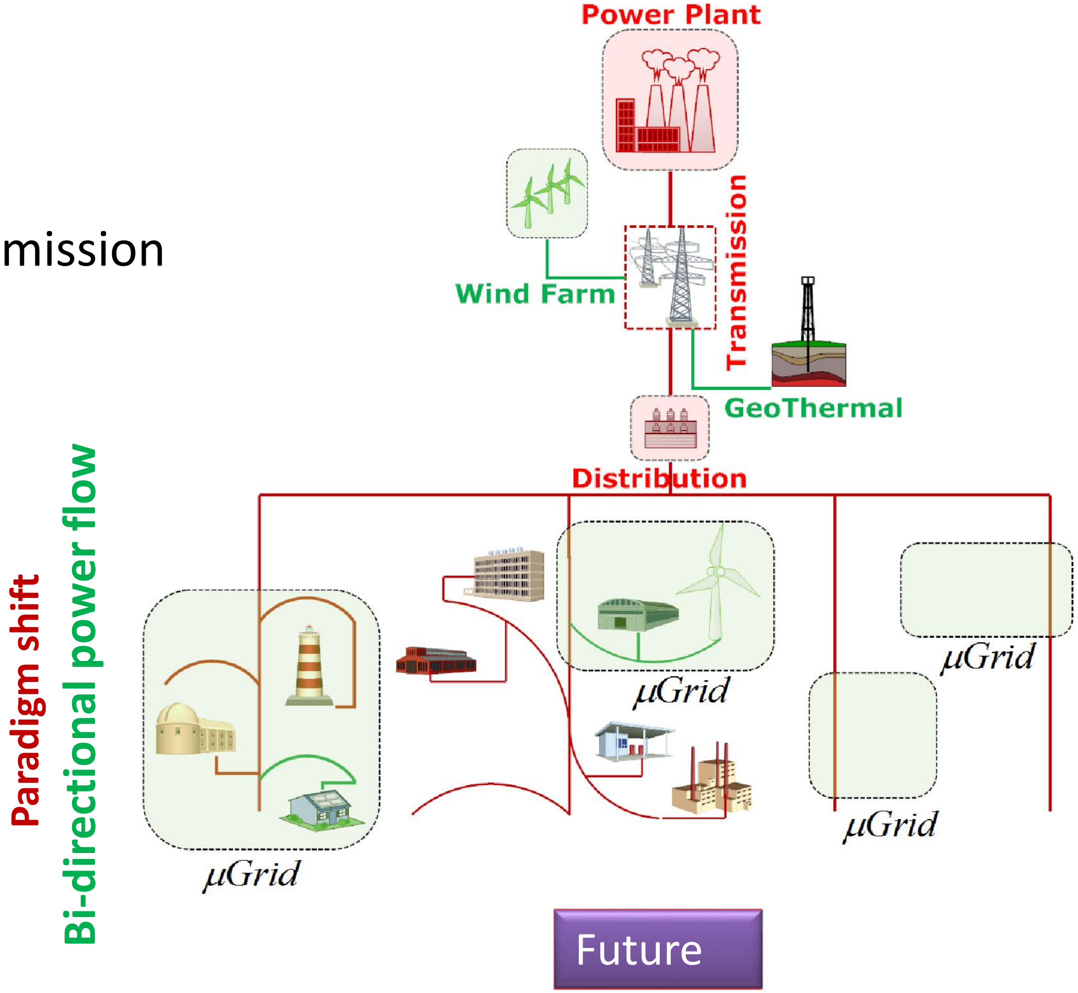
Today’s agenda

Challenges and
Opportunities with
inevitable harmonic
presence in the network …

Future grid network should be –

- ❑ Flexible,
- ❑ Accessible,
- ❑ Reliable,
- ❑ Economic and
- ❑ Lower in Green House Gas emission



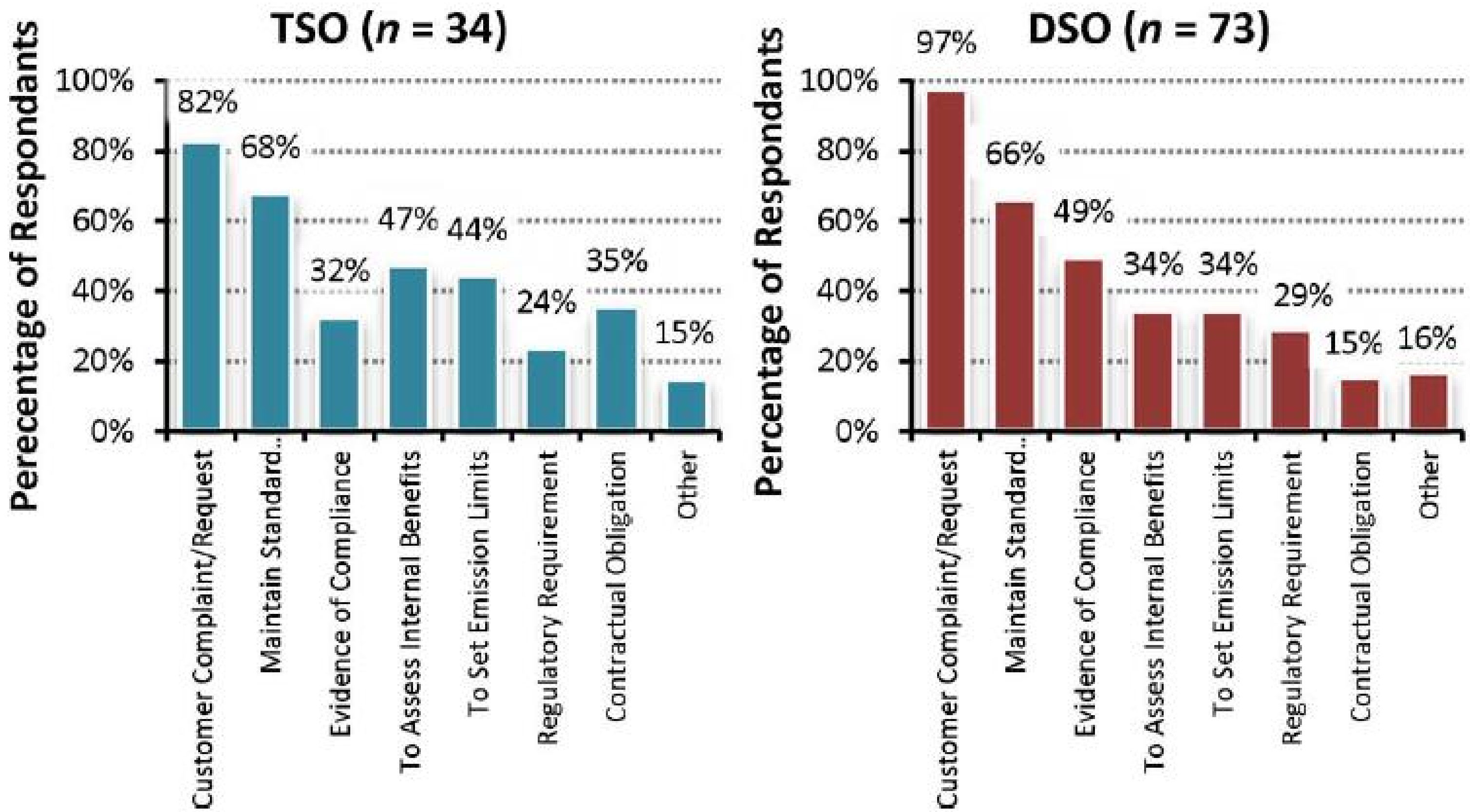


Evolution of Electrical Power System Architectures

What are the current PQ challenges?

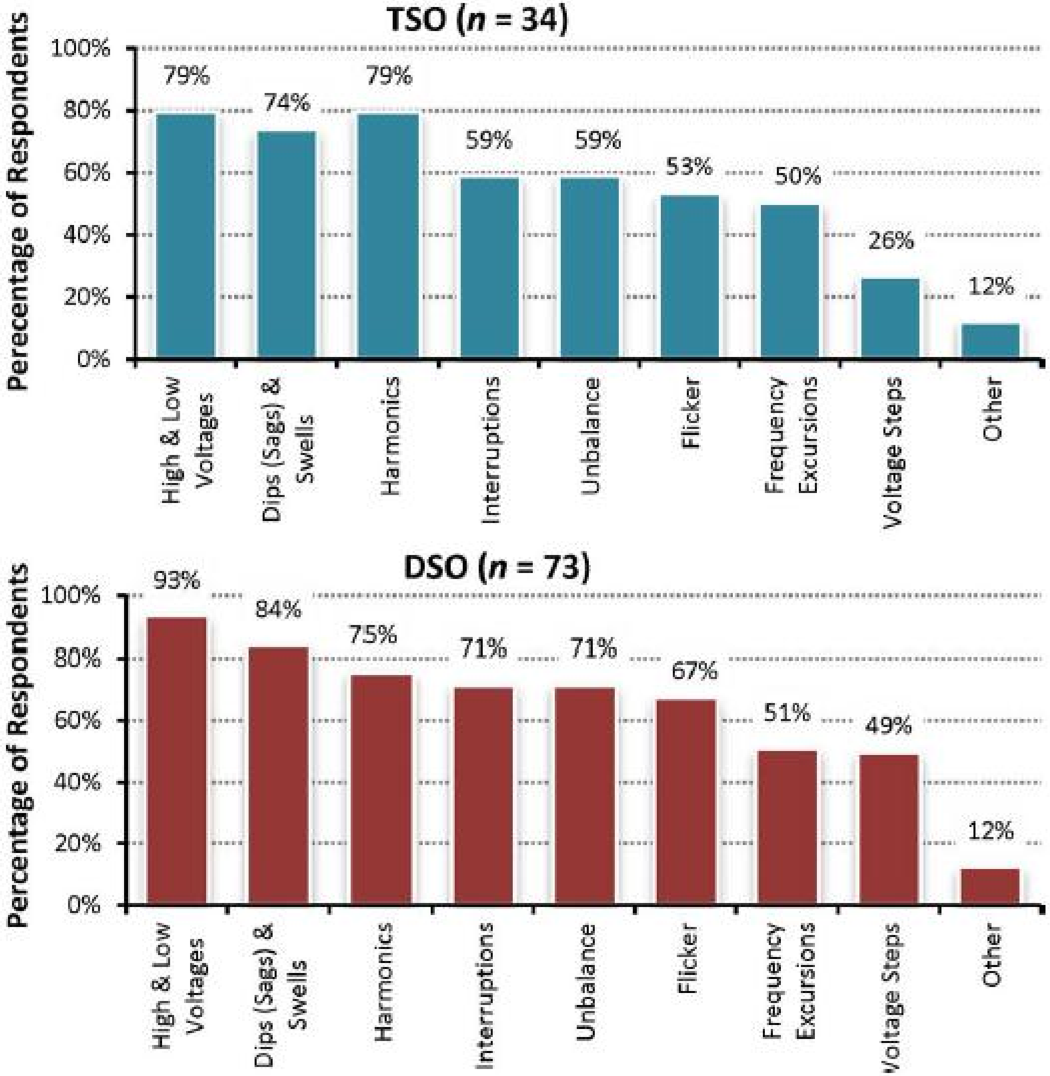
- **Harmonics due to connection of wind and solar power to the grid**
- **Resonances** at **lower frequencies** due to the replacement of overhead lines by AC cables at transmission level.
- Voltage and current distortion in the frequency range 2 to 150 kHz, referred to here as "**supraharmonics"** by some and as "**high-frequency harmonics**" by others.
- The urgent need for methods to **automatically analyse large amounts of power quality data,** including mapping of existing levels of harmonic voltage and current distortion
- The need for new and improved standardization.

Were those analysis were relevant?



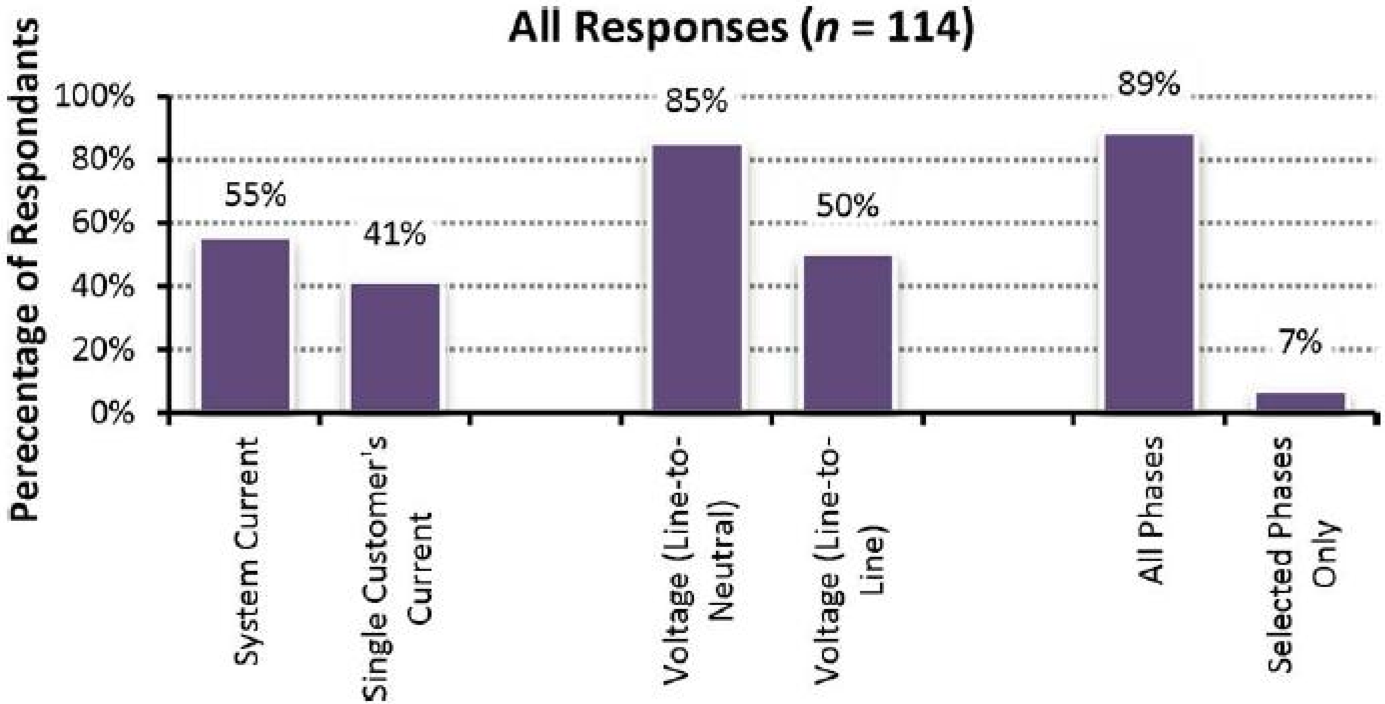
Milanovic et al, IEEE, Power Delivery April 2014: International Industry Practice on Power Quality Monitoring

Which aspects of PQ are of interest?



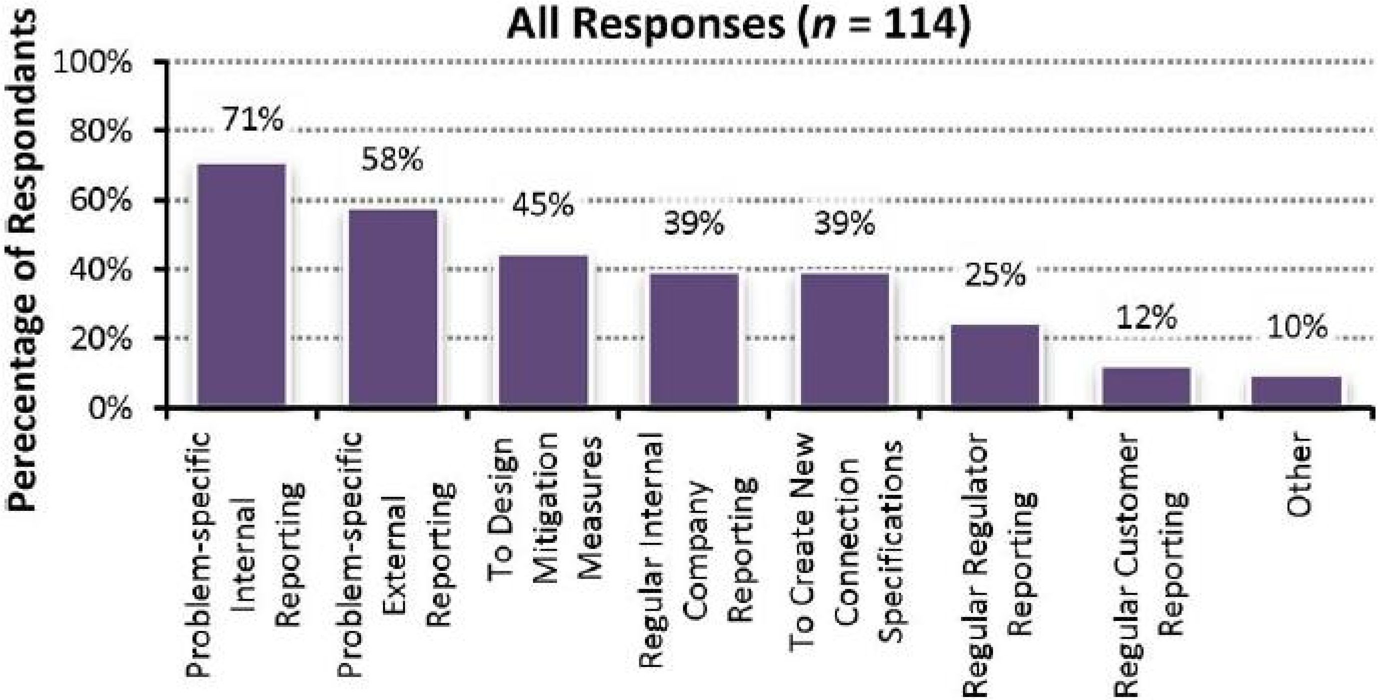
Milanovic et al, IEEE, Power Delivery April 2014: International Industry Practice on Power Quality Monitoring

What are the most commonly monitored signals?



Milanovic et al, IEEE, Power Delivery April 2014: International Industry Practice on Power Quality Monitoring

How’s the PQ information used?



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Presence of Supraharmonics (2 – 150 kHz)

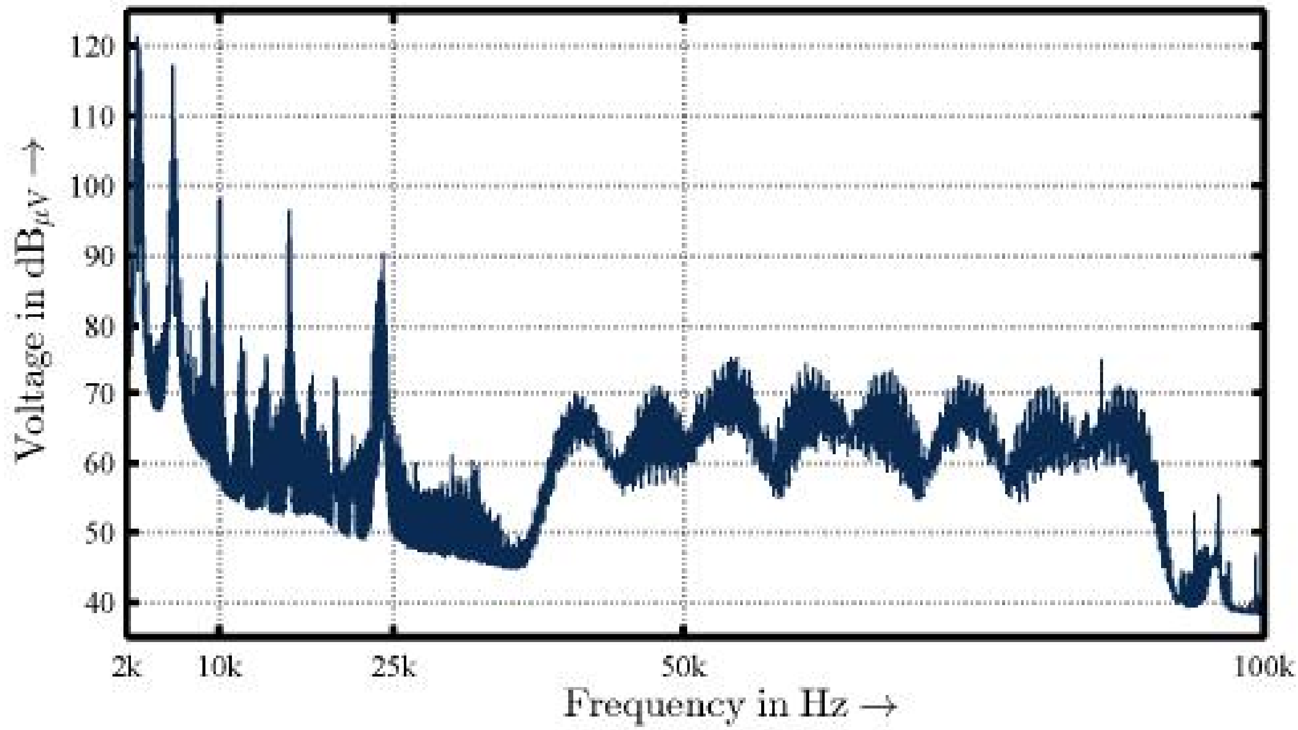


Fig. 5. Voltage spectrum measured at a 1-MW solar campus including narrow-band power-line communication.

Though low at present and will not propagate in network, can influence the nearby capacitors

Bollen etal, "Future Work on Harmonics – Some Expert Opinions Part I – Wind and Solar Power", IEEE ICHQP-2014

Variation in measurement

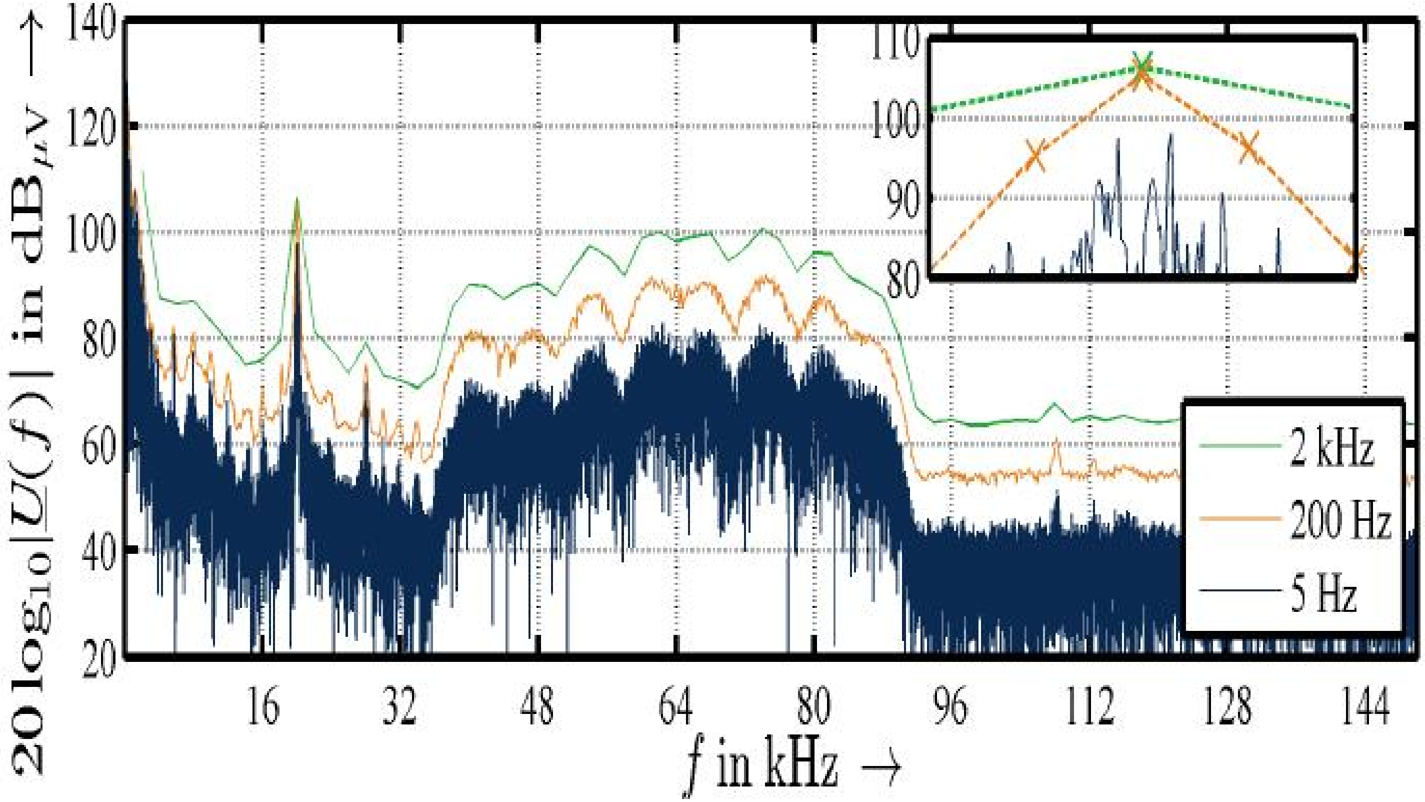


Fig. 10. Measurement results with different bandwidth

Accuracy due to Measurement procedure can differ significantly

Meyer et al, “Work on harmonics – Some Expert Opinions Part II – Supraharmonics, Standards and Measurements”, IEEE ICHQP 2014

Renewable penetration

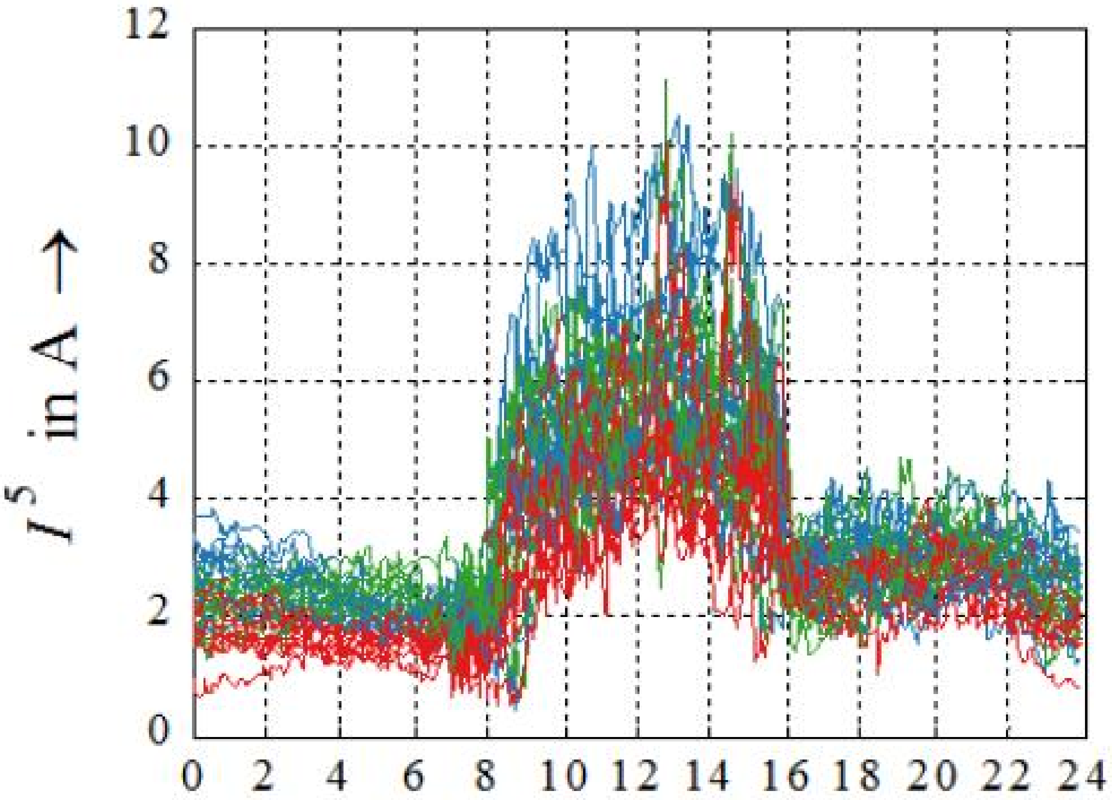


Fig. 6. Total 5th harmonic current as a function of time of day, measured at the busbar of a public LV grid with installed PV power of 332 kW

Bollen etal, “Future Work on Harmonics – Some Expert Opinions Part I – Wind and Solar Power”, IEEE ICHQP-2014

Use of Active Filtering: shaping supply current

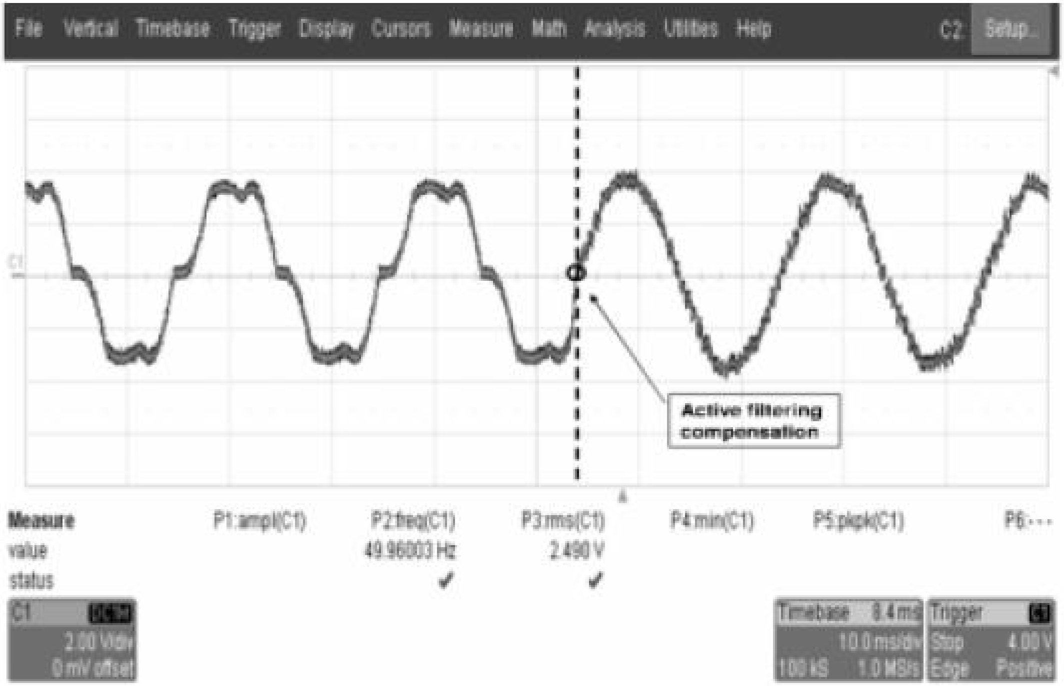


Fig. 3. Grid current before and after the compensation

Bollen etal, “Future Work on Harmonics – Some Expert Opinions Part I – Wind and Solar Power”, IEEE ICHQP-2014

Presence of higher harmonics

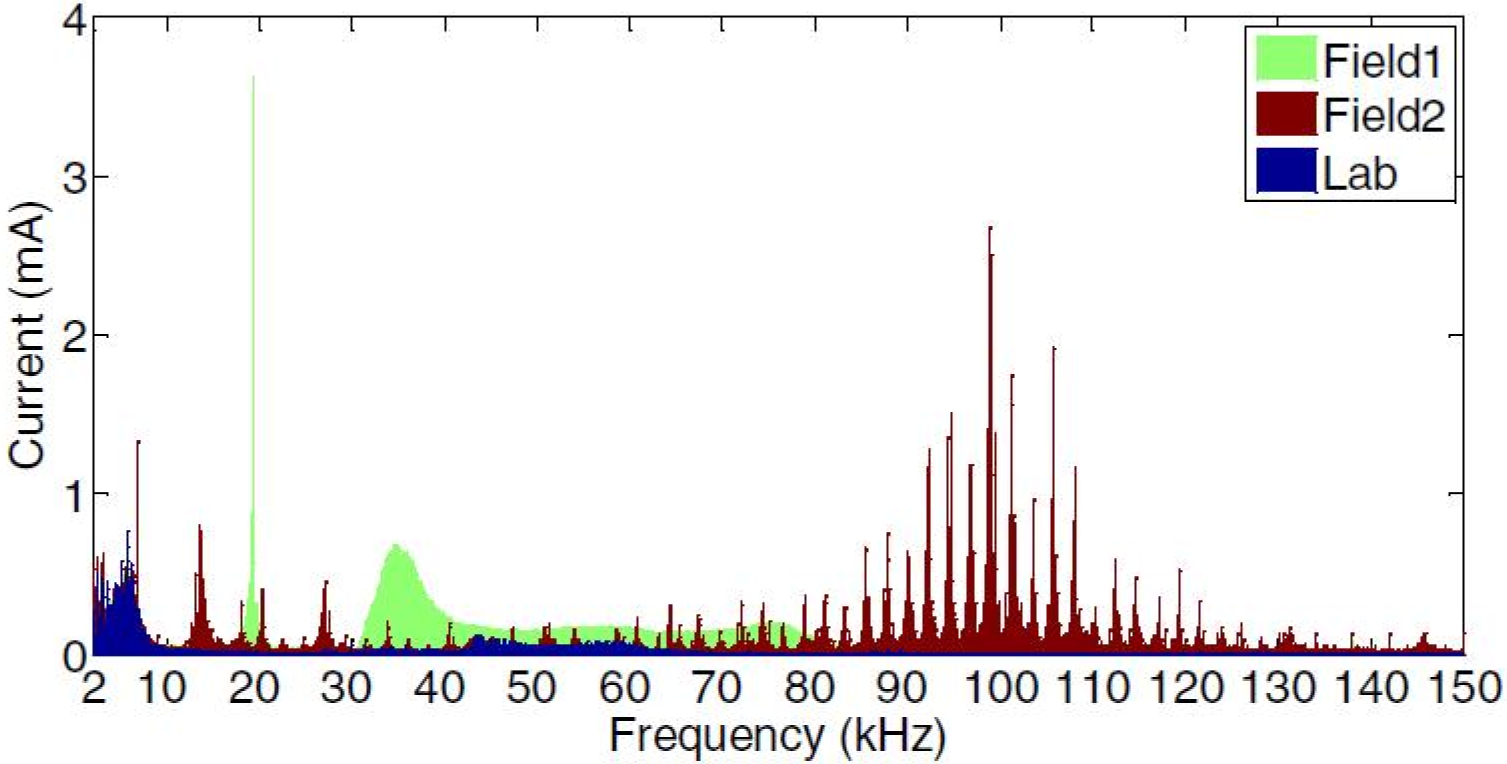


Fig. 2. Emission, 2 to 150 kHz, measured in a laboratory environment (blue) and at two locations in the field (red, green).

Meyer et al, "Work on harmonics – Some Expert Opinions Part II – Supraharmonics, Standards and Measurements", IEEE ICHQP 2014

Variation in voltage signals

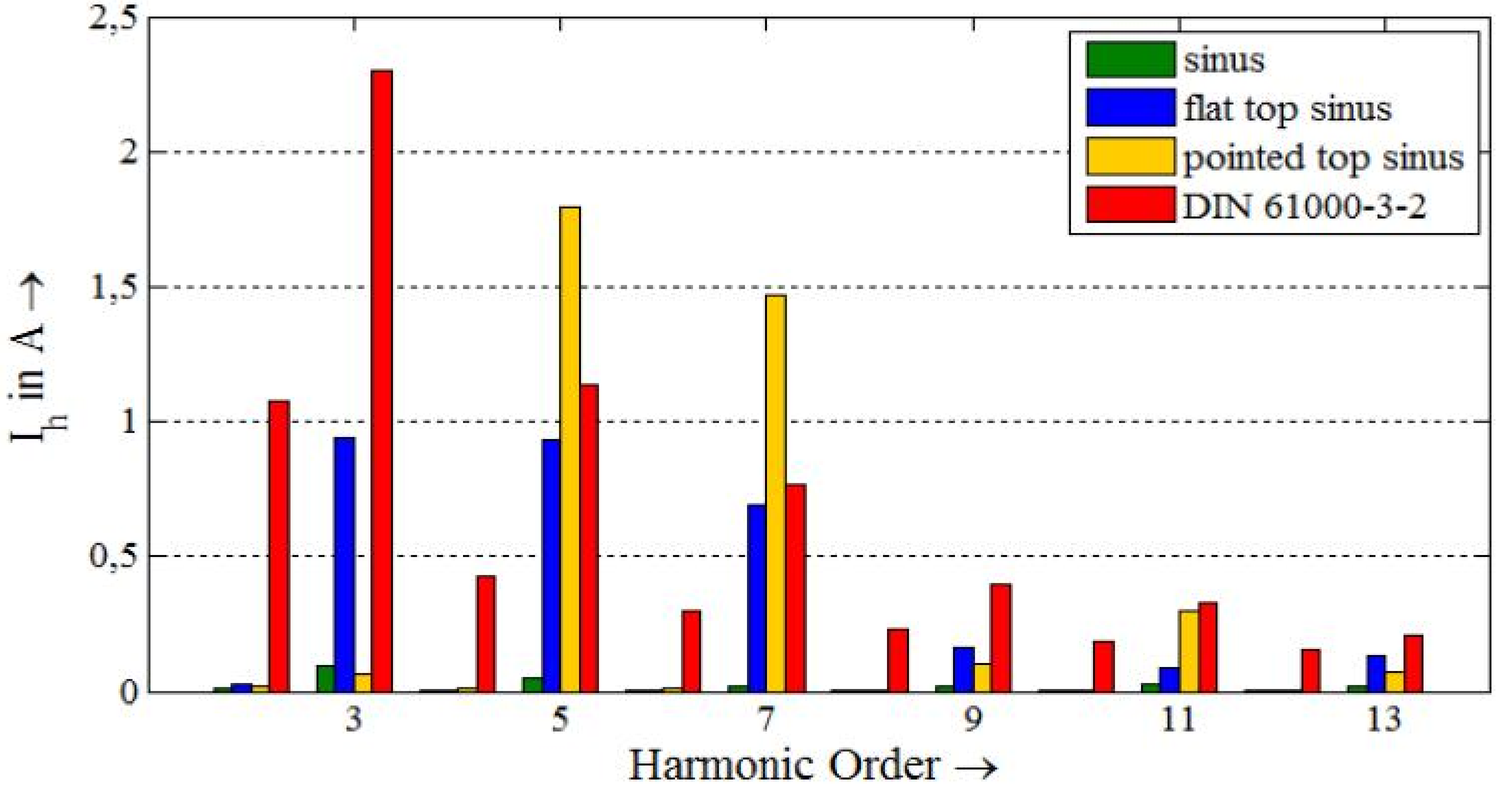


Fig. 4. Spectrum of PV inverter for different voltage distortions compared with IEC 61000-3-2 class A limits.

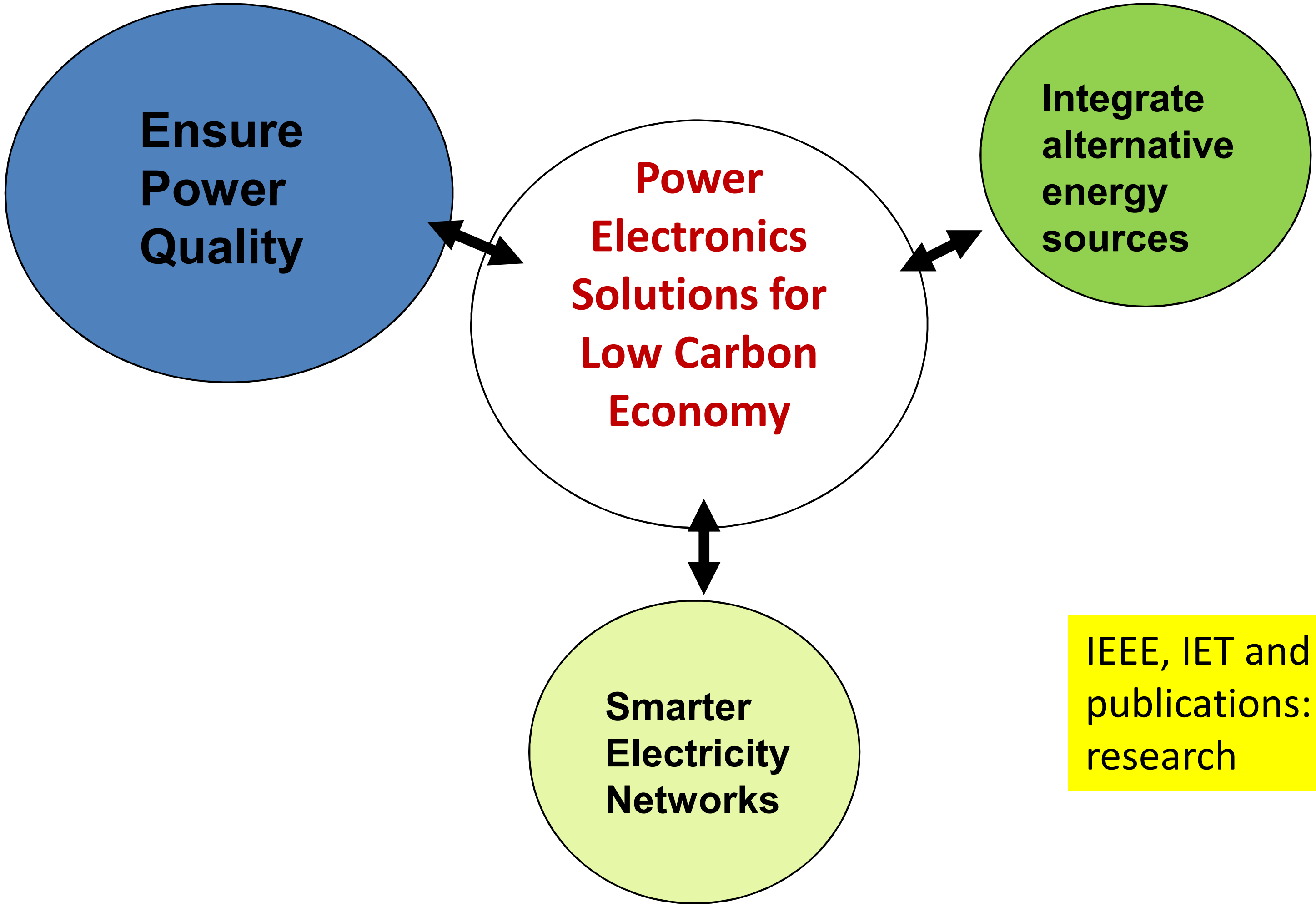
Meyer et al, "Work on harmonics – Some Expert Opinions Part II – Supraharmonics, Standards and Measurements", IEEE ICHQP 2014

Further PQ matters to resolve

- **How to measure higher frequencies at higher voltage**, e.g. above 2 kHz for voltage levels above 20 kV. (Conventional voltage and current transformers do not give an accurate value in these cases.)
- **Assessment of uncertainties in harmonic measurements** at all frequencies , harmonics evaluation (e.g. modelling) and harmonic mitigation (e.g. filtering) which can constitute a basis for reliable risk management
- A **reduction in efficiency** of end-user equipment was reported in cases with high voltage distortion. This phenomenon should be urgently studied further. If it is shown that this reduction in efficiency is significant, it could form the basis for new voltage-distortion limits.
- The **use of active filters instead of passive filters.** APFs can improve overall control system design robustness (e.g. through active damping). They may however also introduce emission at higher frequencies and introduce a risk of "harmonic instability".. It is important that this risk is studied and that measures are introduced to guarantee a sufficiently low probability ..
- The **impact of harmonics, interharmonics and supraharmonics** on **protection and metering.**
- **Power quality issues** in **relation to microgrids (during island operation).**
- **Differences in power-quality disturbance levels between countries**. Are there are significant differences and how can they be explained?

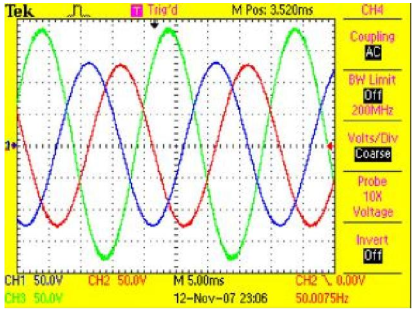
Bollen etal, "Future Work on Harmonics – Some Expert Opinions Part I – Wind and Solar Power", IEEE ICHQP-2014

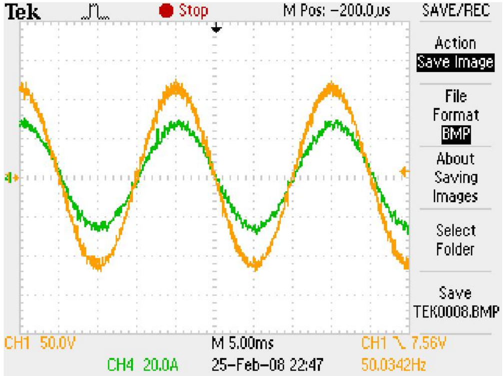
Powerful tool of The Future of Electricity Supply



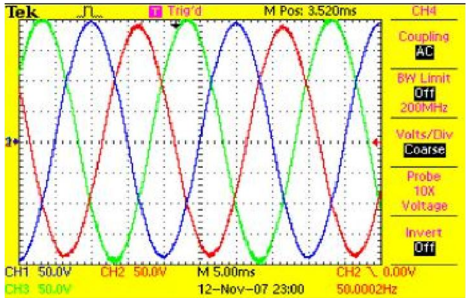
IEEE, IET and Elsevier publications: EPRC research

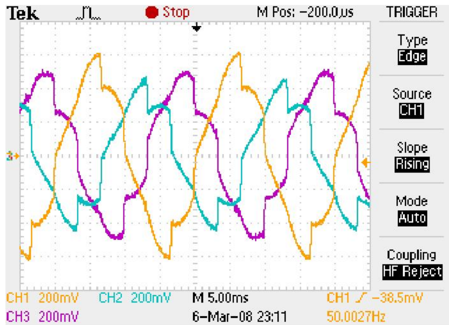
The Unified Power Quality Conditioner Provides an All in One Solution to Supply Side and Load Side Power Quality Problems





12 kVA UPQC





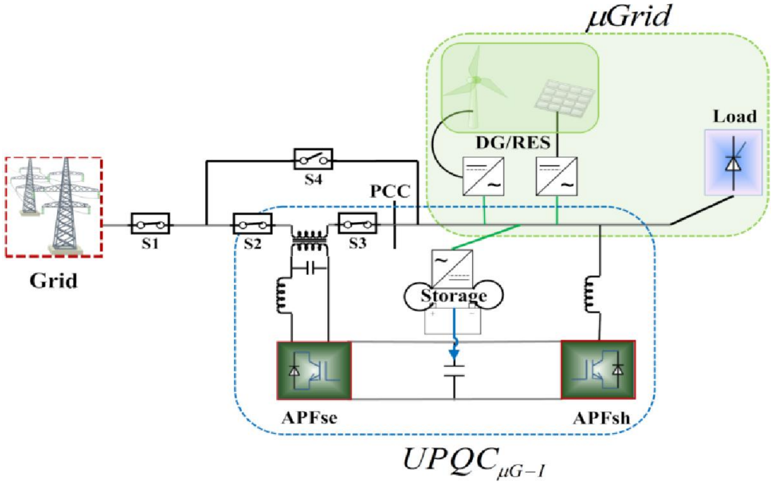
UPQC can aid

- ✓Utilities (system services, grid code compliance, voltage control, dynamic reactive response etc)
- ✓Demand Side Management, Smart Grid, smart houses and network with ensured Power Quality

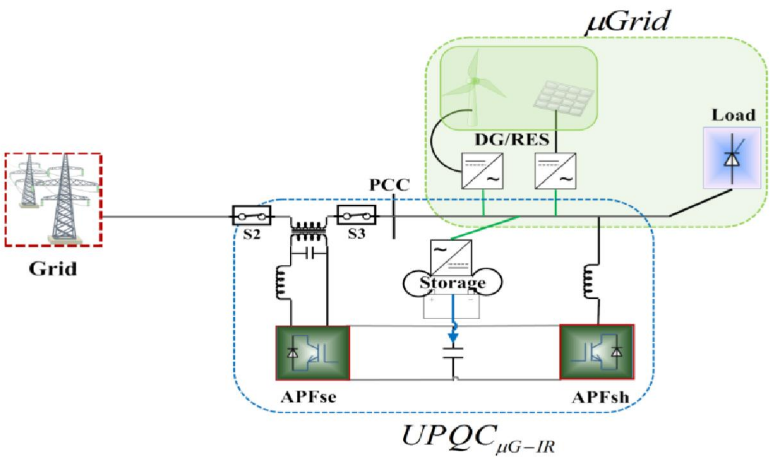
I. Axente, N. G. Jayanti, M. Basu, K. Gaughan and M. F. Conlon, **"Development of a 12 kVA DSP-controlled laboratory prototype UPQC"**, IEEE Trans. Power Electronics, vol. 25(6), pp. 1471- 1479, June, 2010.

- UPQC$_{\mu G\text{-}I/IR}$: A new proposal for integration of UPQC in DG connected µG network
- Operational flexibility of the µG network

Integration Technique
- µG and APFsh are in parallel to grid and placed at PCC
- APFse is in series
- DC link can be connected to storage



Control Features
- Voltage sag/swell
- Reactive and harmonic current
- Islanding (UPQCµG-I & UPQCµG-IR)
- Reconnection (UPQCµG-IR)



Advantages
- µG can be connected to the system during grid fault
- µG achieves operational flexibility in islanding and reconnection process
- µG provides only the active power to the load. Therefore, it reduces the control complexity
- µG can even work in the presence of a phase jump or a phase difference between the grid and µG (UPQCµG-IR).
- Provide high quality power for all time

S.K. Khadem, M. Basu, M.F. Conlon, "Intelligent Islanding and Seamless Reconnection Technique for Microgrid with UPQC", **IEEE Trans Journal of Emerging and Selected Topics in Power Electronics**, 2015, (in press)

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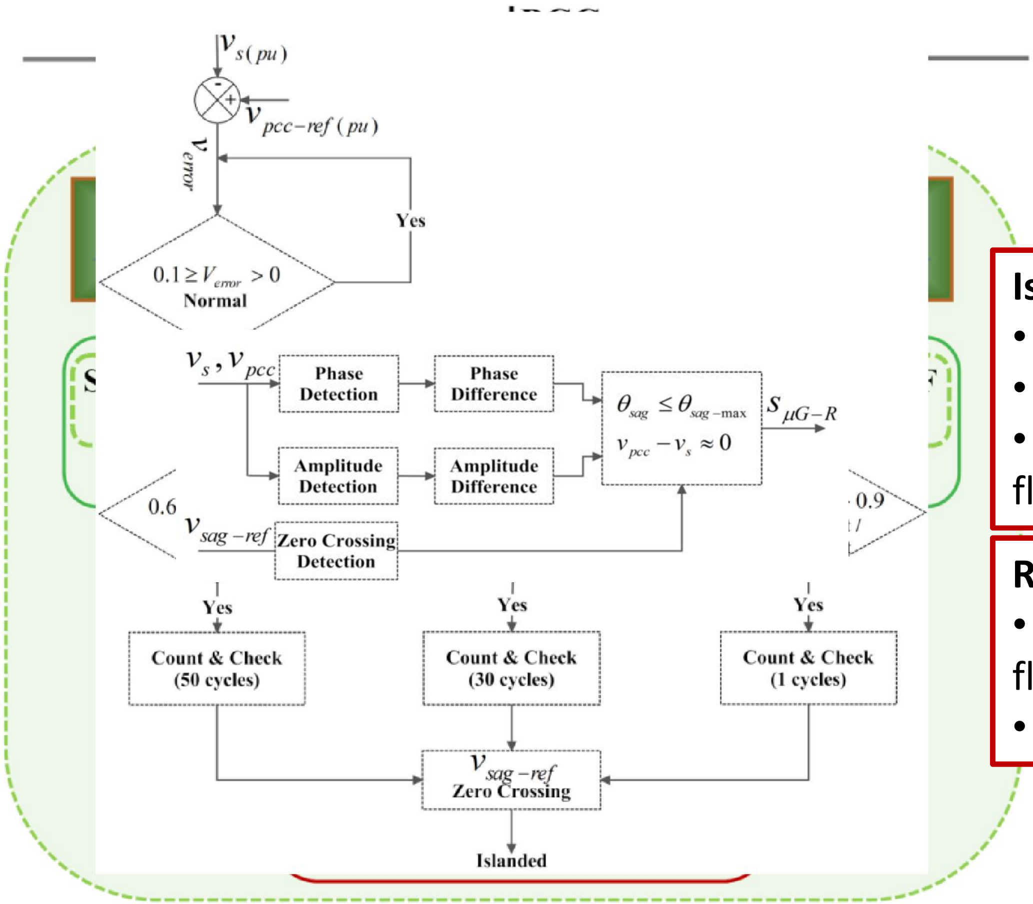
Control



UPQCμG - Controller

Islanding detection
- Easy algorithm
- Intelligent
- Time & control flexible

Reconnection
- Time & control flexible
- Phase jump control

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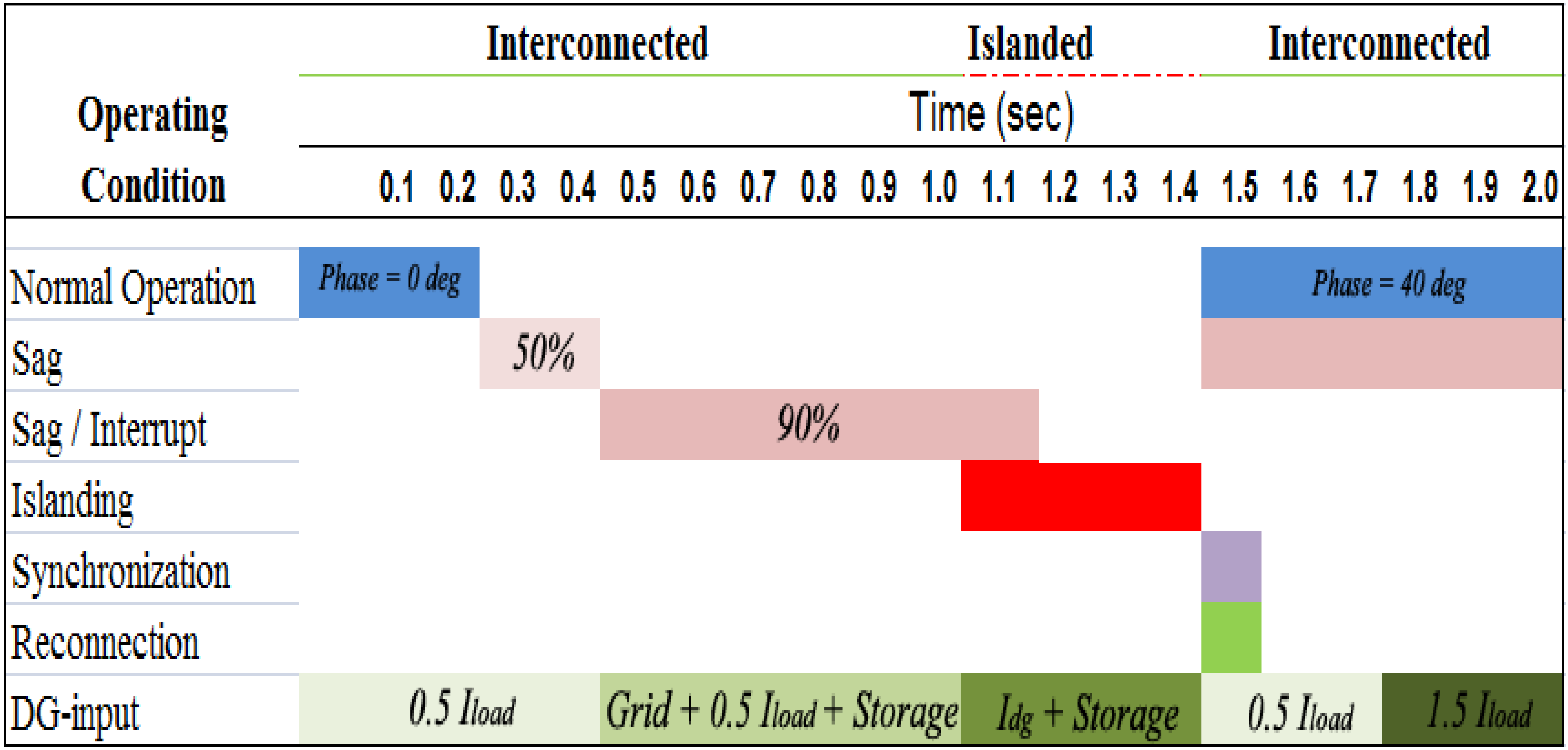
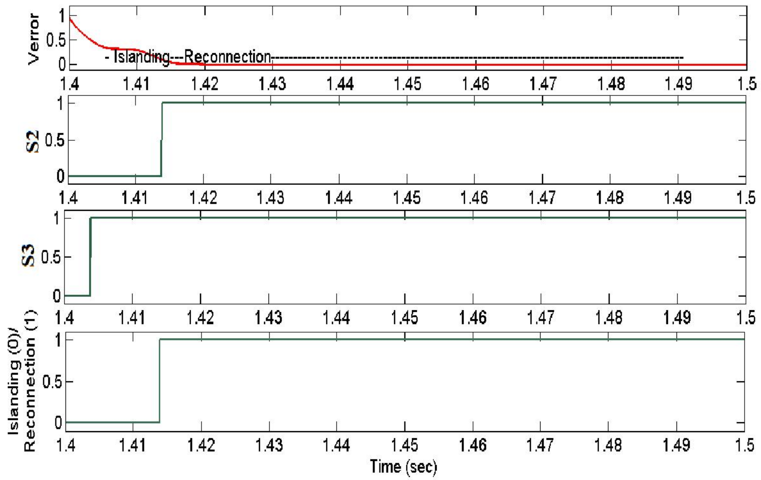


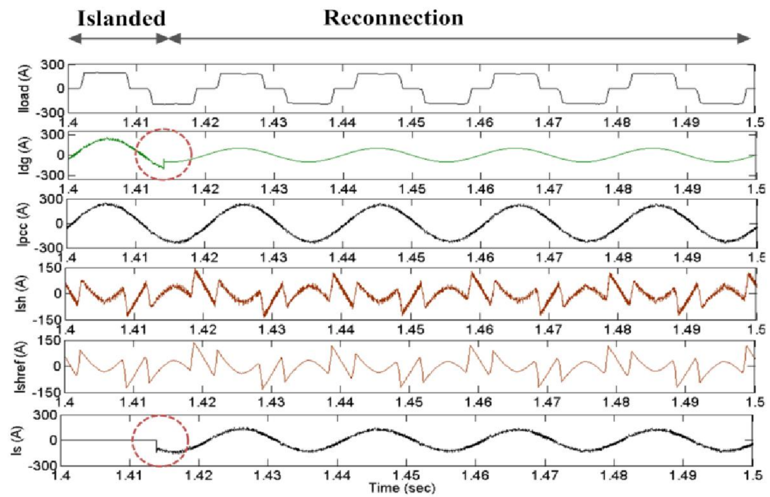
•$UPQC_{\mu G\text{-}I/IR}$: A new proposal for integration of UPQC in DG connected μG network

•Operational flexibility of the μG network

$UPQC_{\mu G\text{-}I\ R}$

Reconnection





$UPQC_{\mu G\text{-}I}$

Real Time Performance

Voltage sag with DG current forward & reverse flow

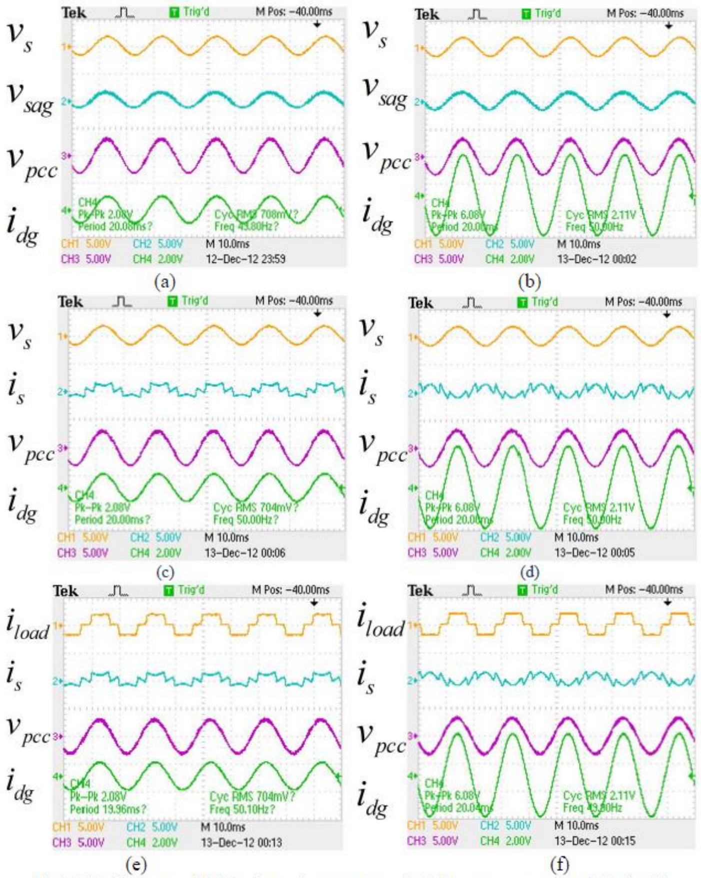


Fig 5.36 Performance of APF_{se} ; (a, c, e) $i_{dg} < i_{loadf}$; (b, d, f) $i_{dg} > i_{loadf}$ when APF_{sh} is off

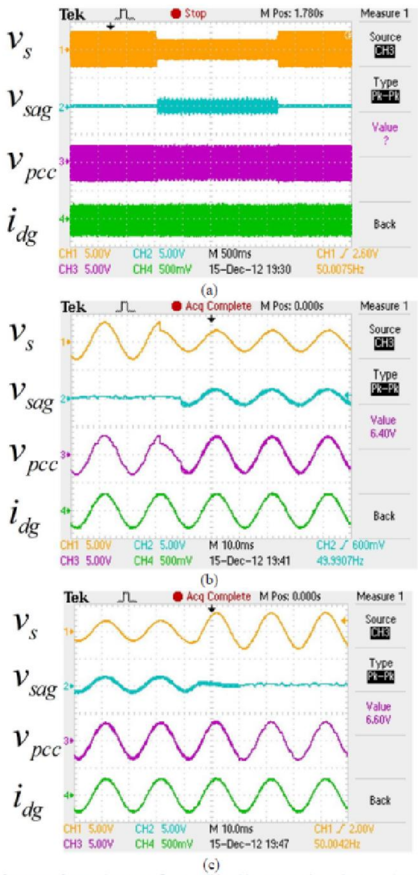


Fig 5.38 Performance of APFse in reverse flow condition (a) compensating voltage sag (40%), pre-sag and (c) post -sag condition

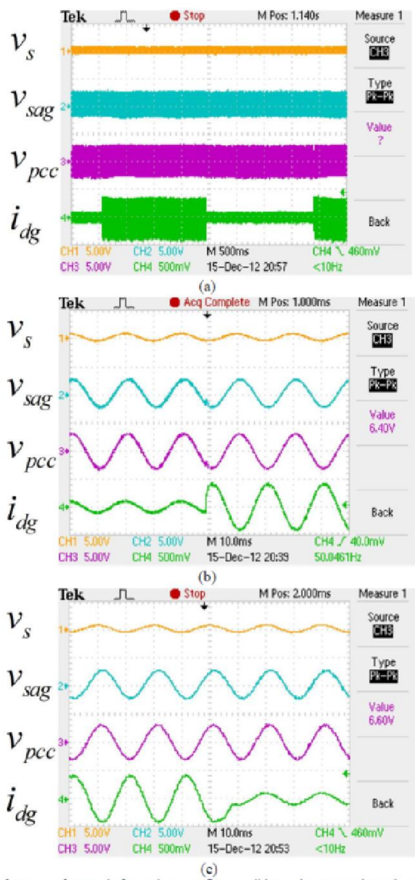


Fig 5.41 Performance of APFse in forward-reverse flow condition and compensating voltage sag (80%) (a) dynamic change of i_{dg} (b) i_{dg} increasing: forward-reverse, (c) i_{dg} decreasing: reverse-forward flow

Steady state

Dynamic

Recap on PQ matters to resolve

- ❑ **higher frequencies at higher voltage** are the new entrants
- ❑ **Assessment of uncertainties in harmonic measurements** at all frequencies , harmonics evaluation (e.g. modelling) and harmonic mitigation (e.g. filtering) which can constitute a basis for reliable risk management
- ❑ Adding intelligence with the **use of active filters and various power conditioning devices.**...has promising future
- ❑ The **impact of harmonics, interharmonics and supraharmonics** on **protection and metering.**
- ❑ **Power quality issues** in **relation to microgrids (during island operation).**
- ❑ **Differences in power-quality disturbance levels between countries**. Are there are significant differences and how can they be explained?

Further thoughts

- What is the current harmonic emission in public grids?
- How will new equipment influence these levels?
- How can the efficiency of network be improved with intelligent active devices like UPQC, STATCOMs?
- How will they impact cost of service?

Happy to discuss collaboration possibilities…

Thank You!