TAMPEREEN TEKNILLINEN YLIOPISTO

Vision of the power system in 2035

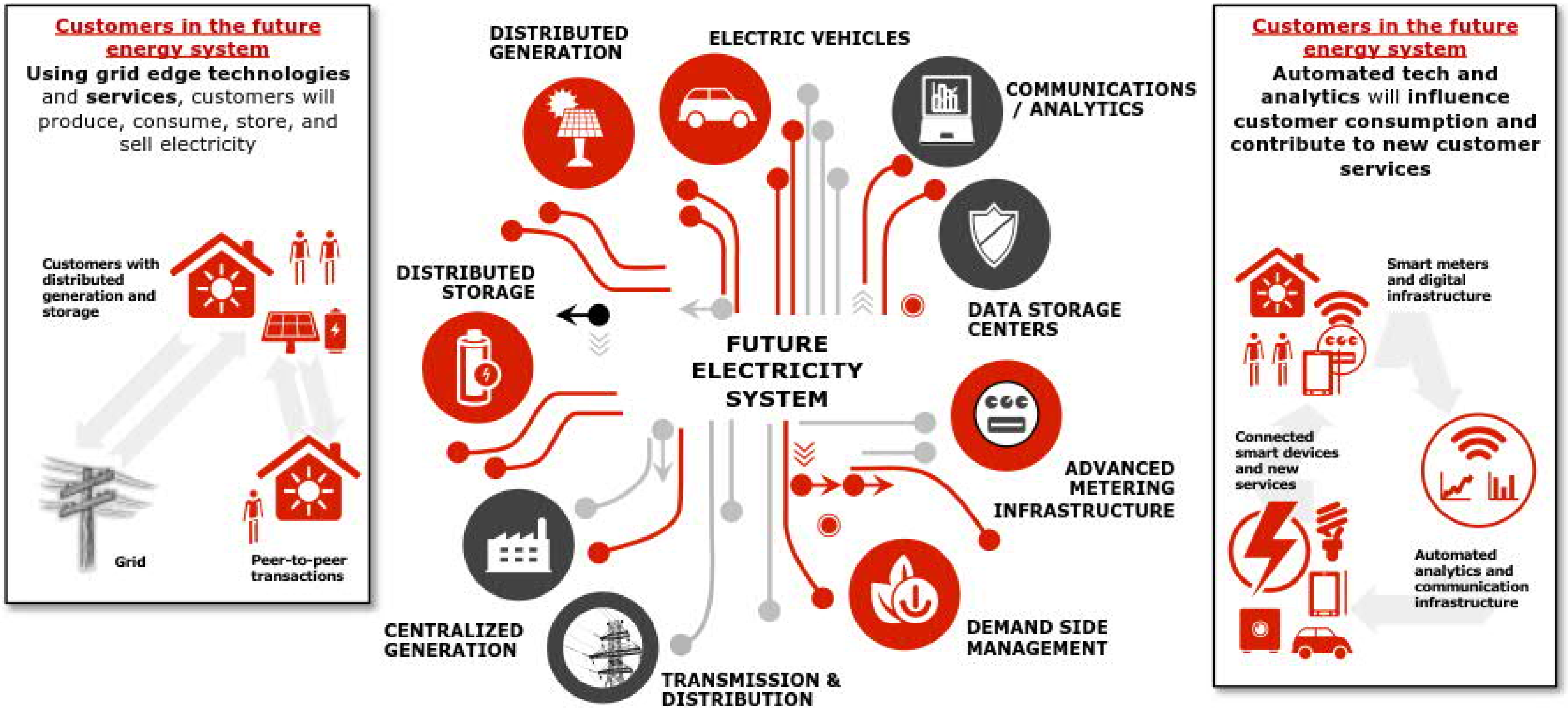
PhD Jenni Rekola
Tampere University of Technology
Finland
jenni.rekola@tut.fi

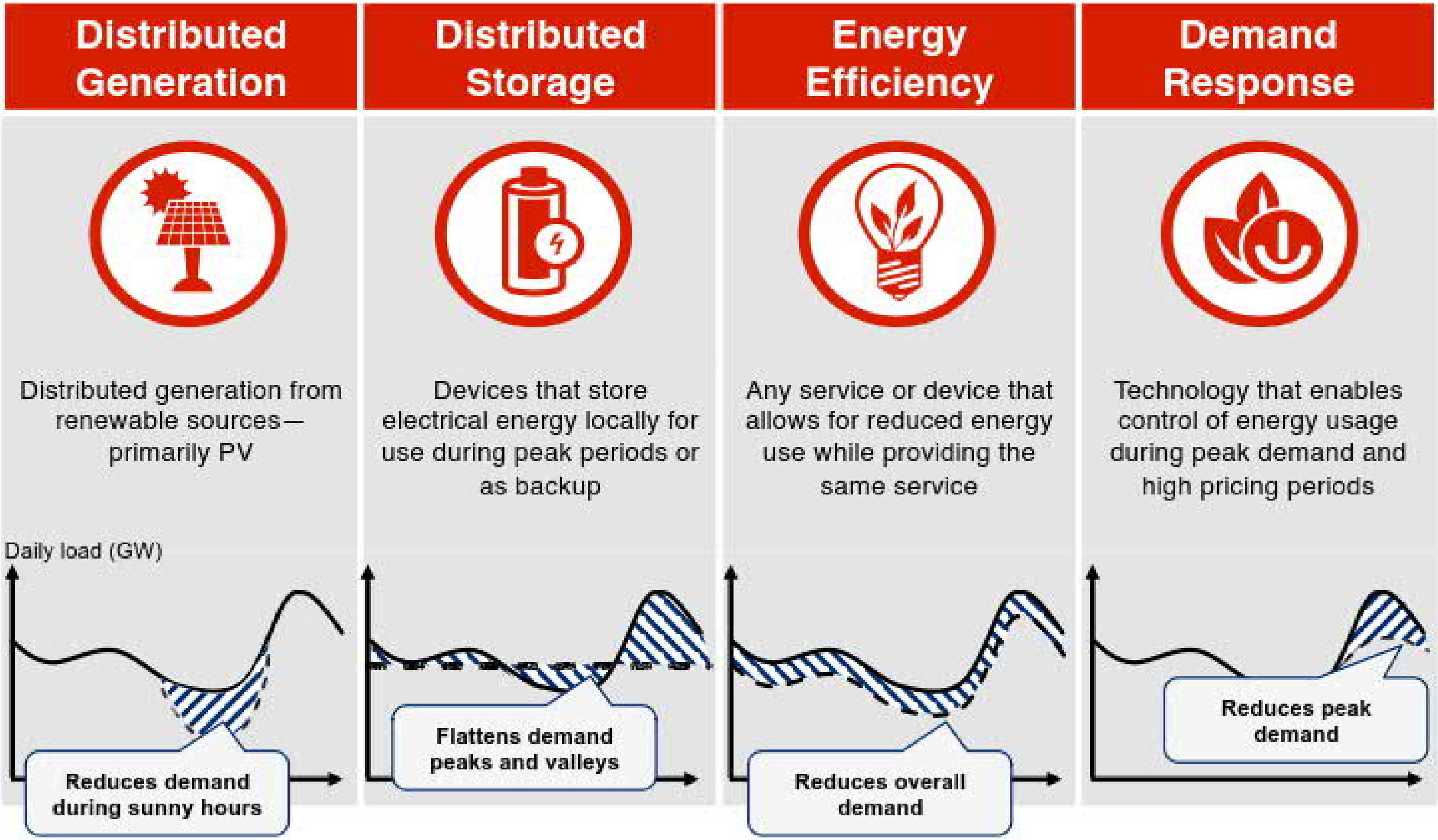
Co-funded by the Erasmus+ Programme of the European Union

Agenda: Day 2

Time	Topic
9-10	Recap of day 1 Tools for grid design
10-10.15	Coffee break
10-12	Discussion about power quality and reliability in the future power system
12-13	Lunch
13-14	Discussion about the electricity price - Tariff models - Regulation
14-14.15	Coffee break
14.15-15	Possibilities related to the future power grid - How the curricula needs to be changed in the university? - Research topics?
15-16	Conclusion, discussion, comments and feedback

Recap of day 1 – Discussions

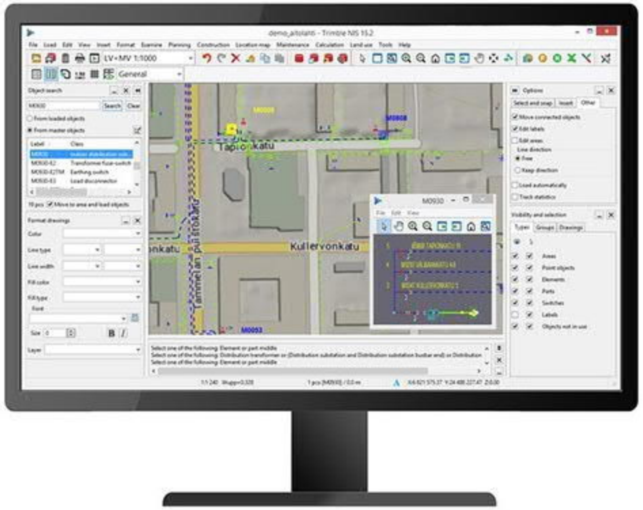

Customers in the future energy system
Using grid edge technologies and services, customers will produce, consume, store, and sell electricity
Customers with distributed generation and storage
Grid
Peer-to-peer transactions
DISTRIBUTED GENERATION
ELECTRIC VEHICLES
COMMUNICATIONS / ANALYTICS
DISTRIBUTED STORAGE
DATA STORAGE CENTERS
FUTURE ELECTRICITY SYSTEM
ADVANCED METERING INFRASTRUCTURE
CENTRALIZED GENERATION
TRANSMISSION & DISTRIBUTION
DEMAND SIDE MANAGEMENT
Customers in the future energy system
Automated tech and analytics will influence customer consumption and contribute to new customer services
Smart meters and digital infrastructure
Connected smart devices and new services
Automated analytics and communication infrastructure


Distributed Generation
Distributed Storage
Energy Efficiency
Demand Response
Distributed generation from renewable sources—primarily PV
Devices that store electrical energy locally for use during peak periods or as backup
Any service or device that allows for reduced energy use while providing the same service
Technology that enables control of energy usage during peak demand and high pricing periods
Daily load (GW)
Reduces demand during sunny hours
Flattens demand peaks and valleys
Reduces overall demand
Reduces peak demand

Tools for grid design

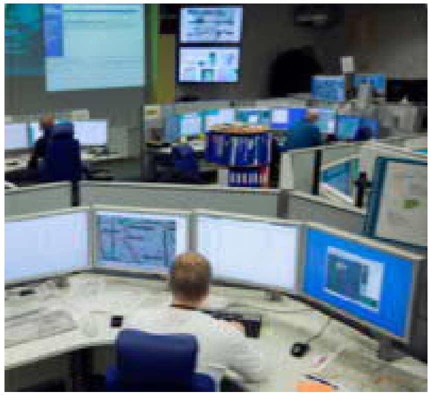
1. Design in electricity distribution company e.g. Trimble NIS

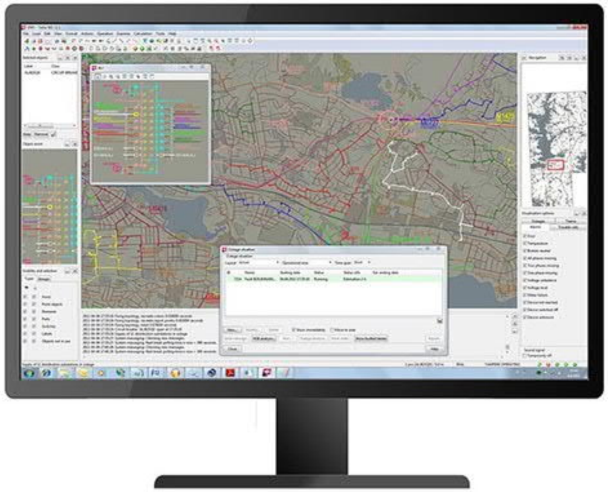
- Provides geographically based network views
- The customer information can be integrated
- Used for grid design the electric grid, for property management, for handling grid investments and for maintenance
- Dimensioning of transformers, cables etc.
- Calculation of short-circuit levels and ground-fault current levels to design protection devices
- The supposed components lifetimes are integrated into the model

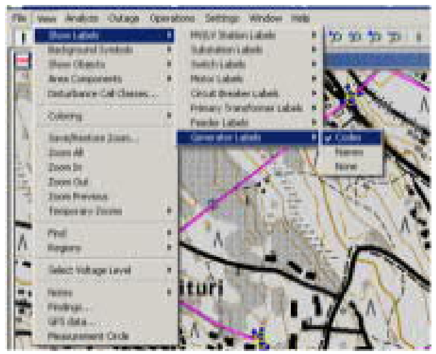


2. Use in electricity distribution company
DMS SCADA

- Distribution Management System (DMS) integrated to supervisory control and data acquisition (SCADA)
- Provides geographically based network views and distribution management functions over the entire distribution network -> remote control of substation automation and AMR-measurements
- Assist the operation's personnel of electric companies in monitoring and operating their networks.
- Strengthens control procedures, improves supply and customer service quality, and saves costs in network operation -> ensure safe network operation in outage situations (faults and maintenance)
- The effects of distributed generation to voltage levels and relay protection can be analyzed
- Smart meters can be used for outage management and power quality monitoring.

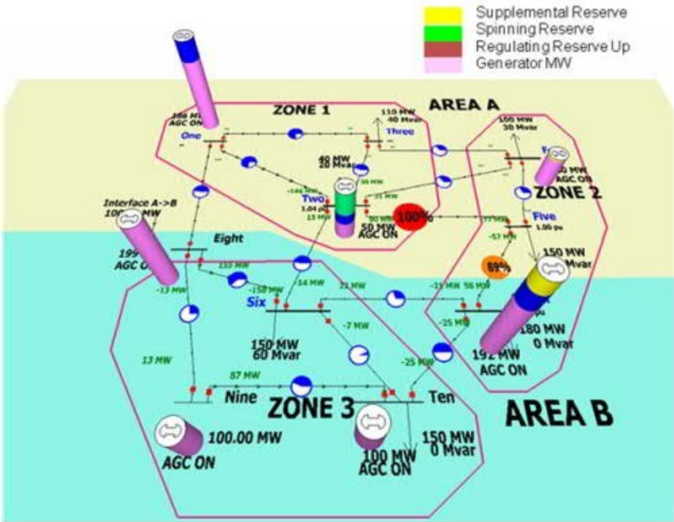


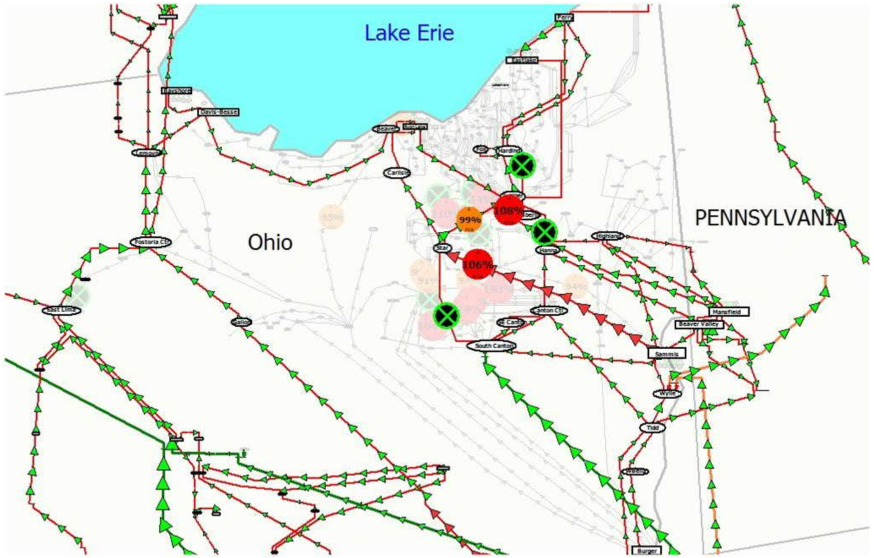




3. Use in research and planning of power systems
Power World

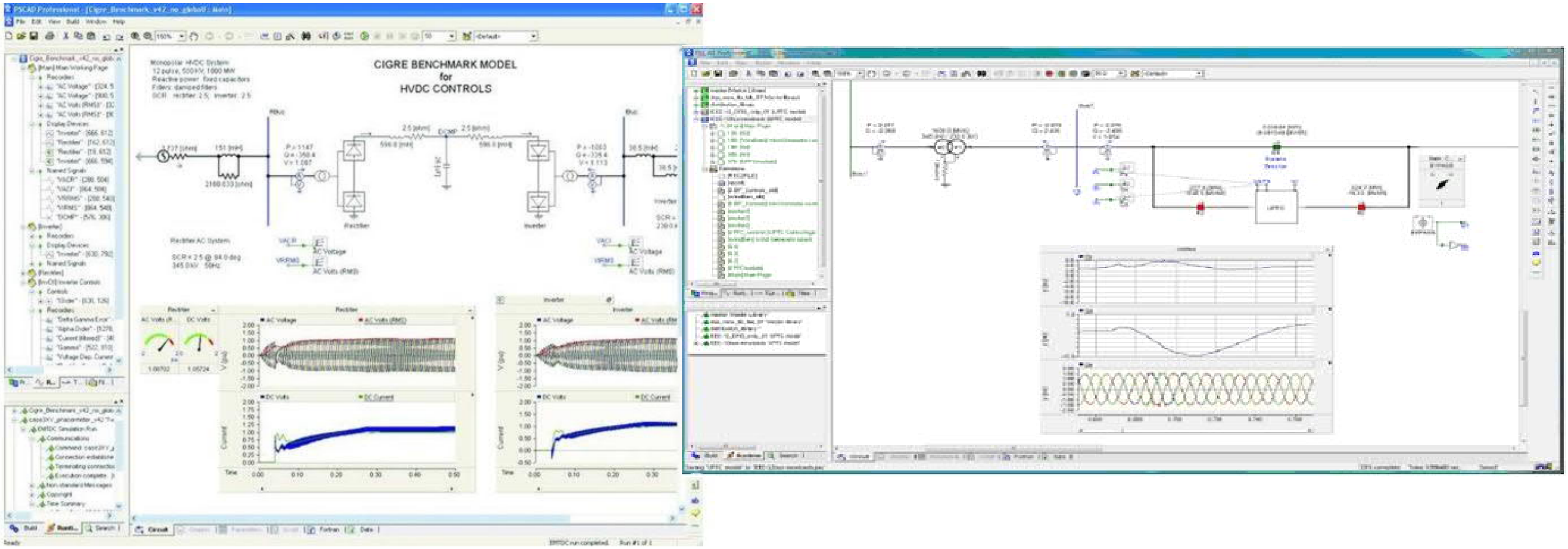
- PowerWorld's products provide the tools needed by transmission planners, power marketers, system operators and trainers.
- PowerWorld Transmission Line Parameter Calculator compute characteristic line parameters given the type of conductor and the tower configuration of a three-phase overhead transmission line. The parameters computed are the resistance R, reactance X, susceptance B, and conductance G.
- The effects of distributed generation to voltage levels can be analyzed





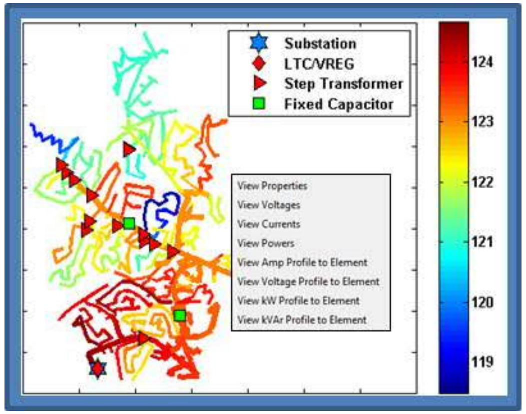
4. Use in research and planning of power systems PSCAD

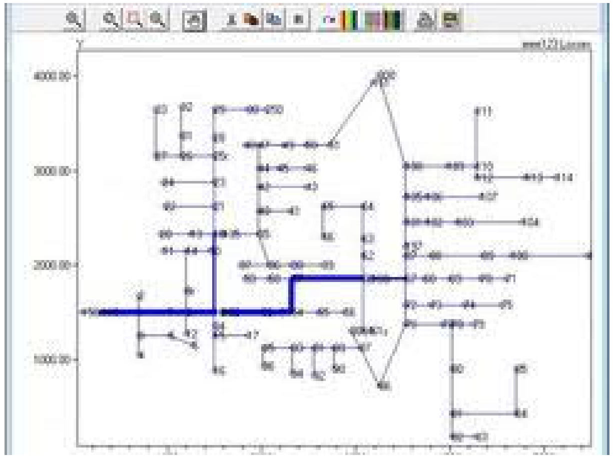
- Ready-made, validated models for components of electric grid (synchronous generators, transformers, cables…)
- Models of renewable power generation included
- Calculation optimized to be fast and accurate for power system calculations



5. Use in research and planning of power systems Open DSS

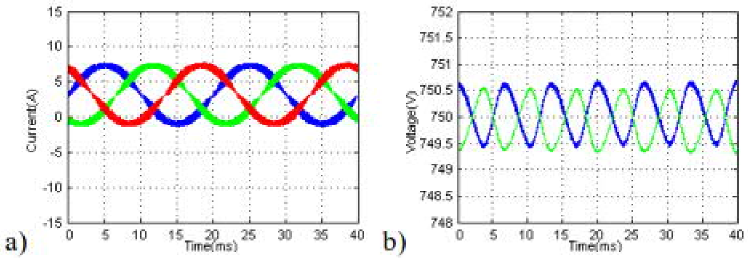
- OpenDSS is extensively used for Quasi-Static Time Series studies, where the distribution system dynamics can be observed over any required time period.
- This is especially important in the smart grid paradigm because power flow will change based on factors such as temperature and solar irradiation level. Additionally, the impact of slow controllers such as voltage regulators and fast inverter-based distributed grid ancillary services such as volt-VAr control will have a significant impact on the temporal variation of the system state.
- Graphical user interface (OpenDSS-G).
- https://www.facebook.com/events/237122813499171/
- http://sites.ieee.org/pes-day-2018/pes-yp-cep-online-course/

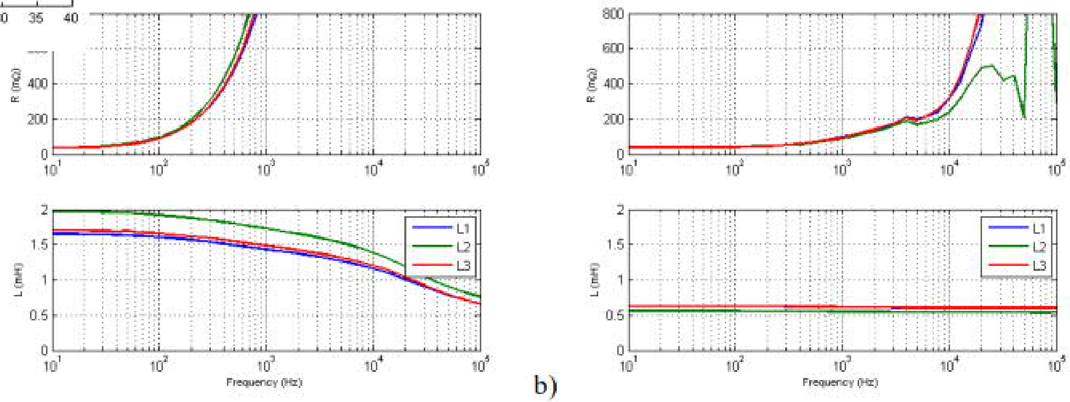




6. Use in research and design of Power Electronics Matlab

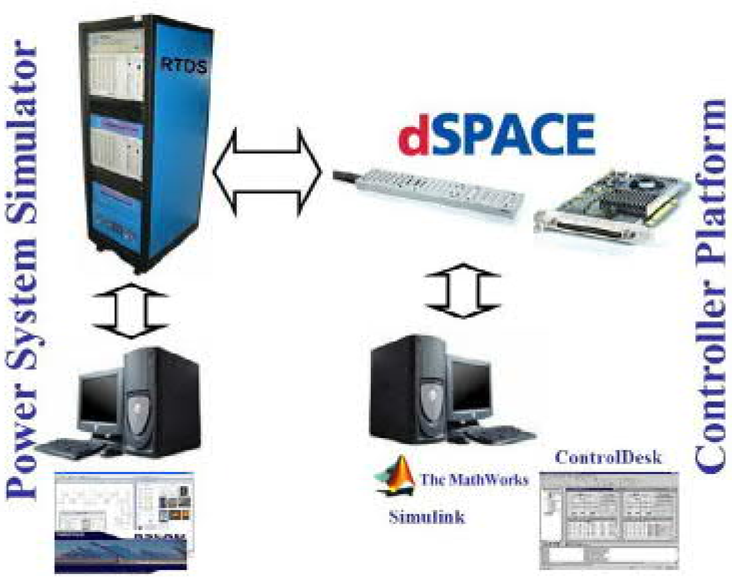
- Analyze in time and frequency domain
- Able to simulate power electronics as well as control systems very accurately
- The ready-made models for power system are not validated as in PSCAD
- Calculation is not optimized for power system calculations. The user needs to have the knowledge about the correct solver-type and maximum calculation time step



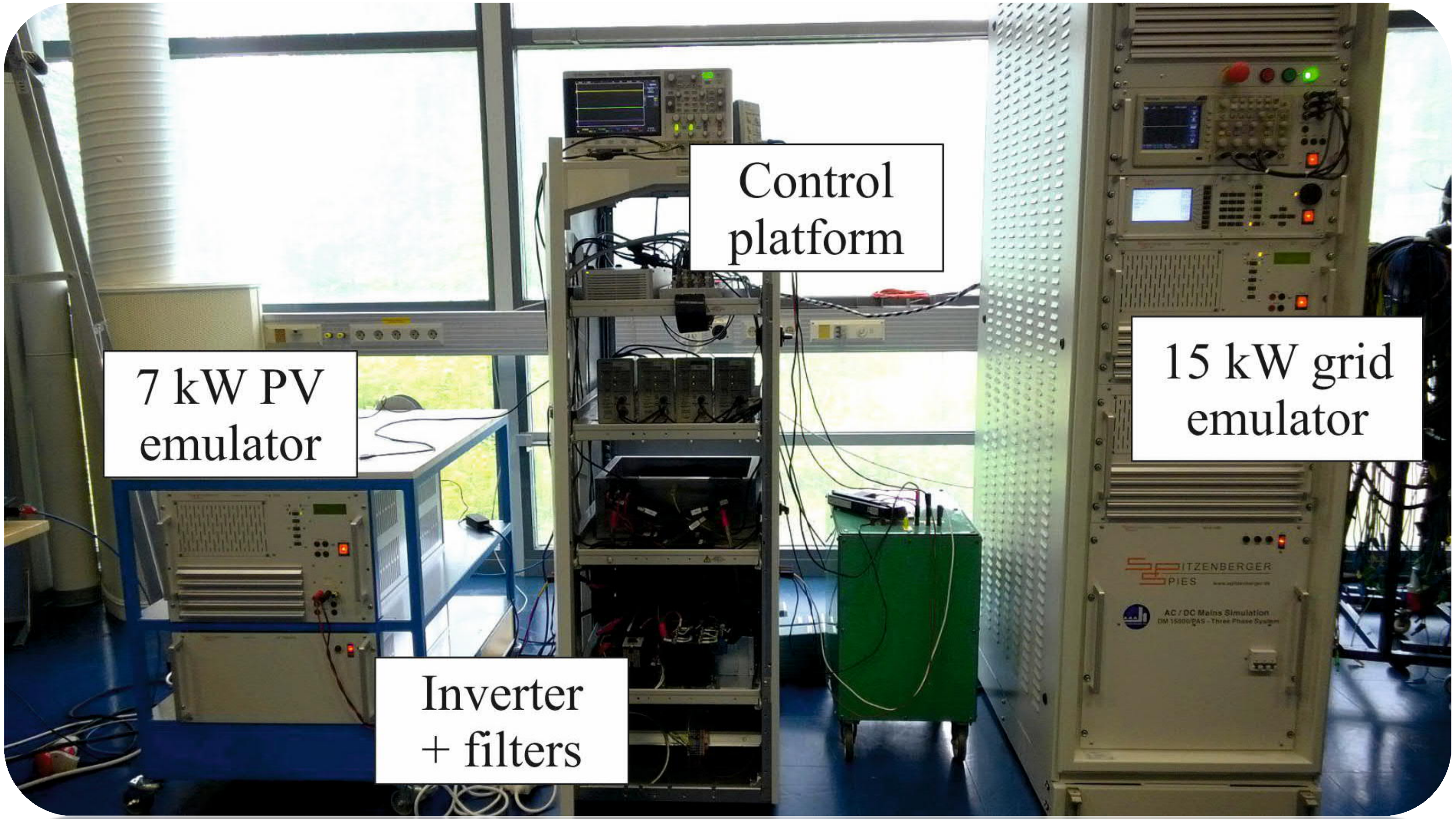


7. Use in combined research of Power Electronics and Power System
RTDS real time simulator and OPAL RT

- The power system can be modeled in real time by using RTDS or Opal RT
- The real hardware, e.g. relays can be connected to the system
- The power electronics can be modeled in PSDAD (RSCAD with RTDS) or dSPACE/Typhoon HIL can be connected to the system



Example: Grid-Connected Inverter



Discussion about power quality in the future power system

The subject of power quality

- The subject of power quality is very broad. It covers all aspects of power system engineering from transmission and distribution level analyses to end-user problems.
- Deviations in voltage, current, frequency, temperature, force, and torque of particular supply systems and their components.
- Good power quality = maintain sinusoidal waveform of power distribution bus voltages and currents at rated magnitude and frequency.

- Note the difference between power quality and power system reliability (reliability of electric power supply)

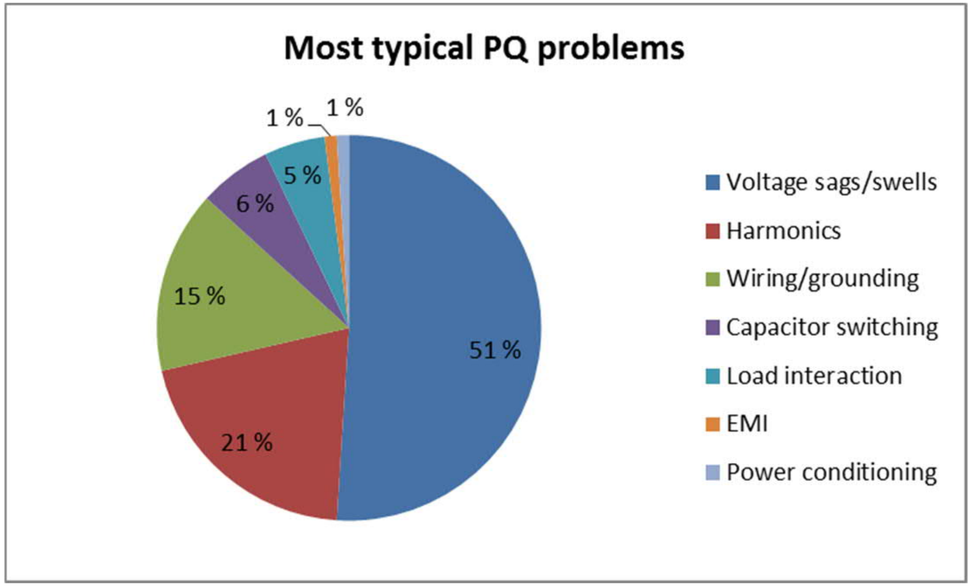
Reason to increased power quality problems

- the increased use of power electronic components within the distribution system
- Increased renewable power generation
- Open electricity markets, not local production and consumption
- Increased use of microprocessors etc. which are sensitive to power quality

Reasons of poor power quality – an overview

- Natural pollution (60%): lightening, flashover, equipment failure, and faults
- Forced pollution (40%): voltage distortions and notches

- Harmonic currents along with the grid impedances cause harmonic voltages
  -> Non-sinusoidal voltage: extra heating, misoperation of other devices, early aging of the devices, extra losses



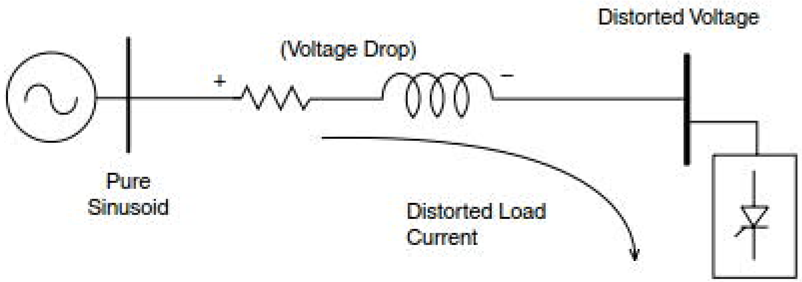
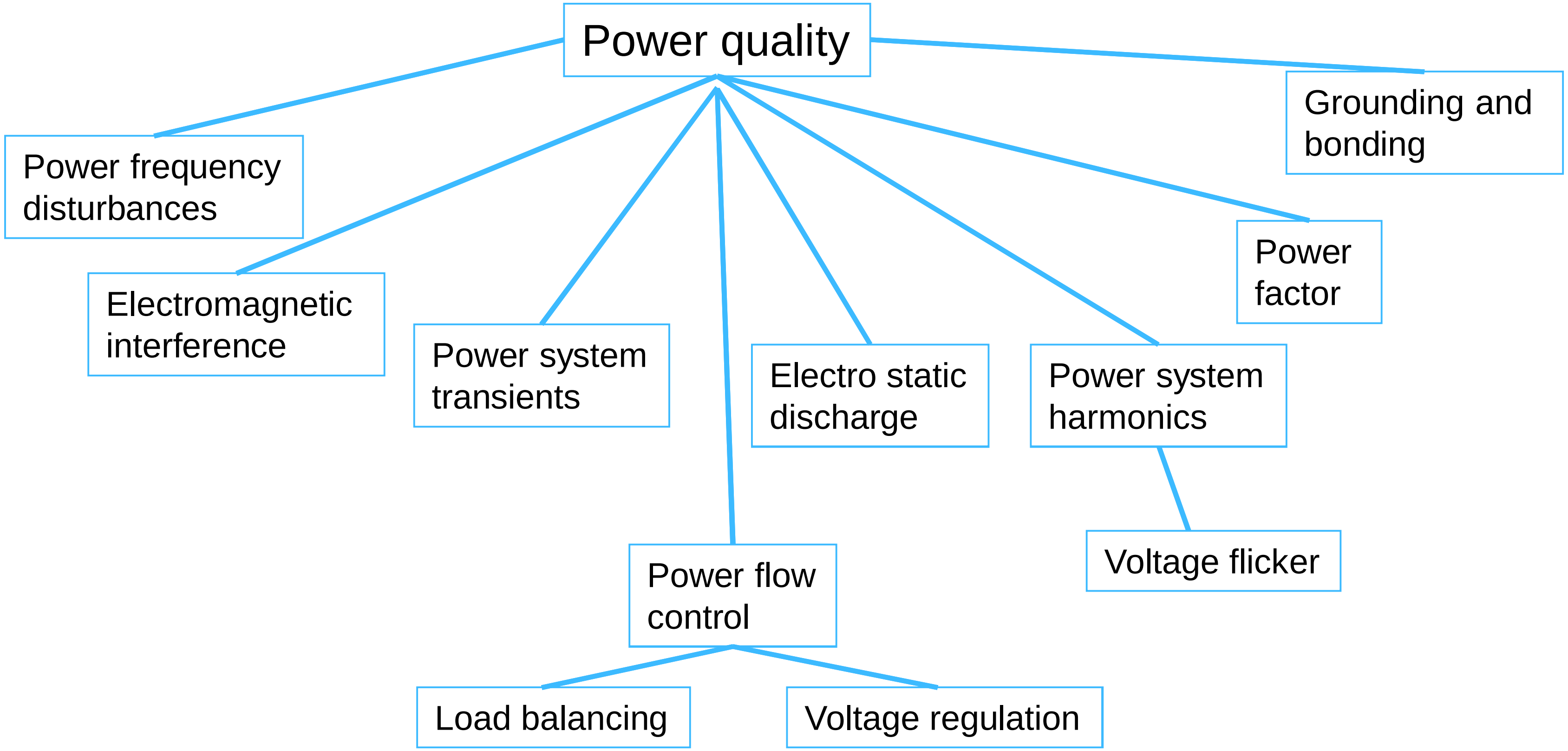


Figure 5.3 Harmonic currents flowing through the system impedance result in harmonic voltages at the load.

Andreas Ebernhard: Power Quality, 2011

Power quality concerns



The subject of power quality

- **Voltage stability** refers to the ability of a power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition. It depends on the ability to maintain/restore equilibrium between load demand and load supply from the power system. Instability that may result occurs in the form of a progressive fall or rise of voltages of some buses.

- **Frequency stability** refers to the ability of a power system to maintain steady frequency following a severe system upset resulting in a significant imbalance between generation and load. It depends on the ability to maintain/restore equilibrium between system generation and load, with minimum unintentional loss of load. Instability that may result occurs in the form of sustained frequency swings leading to tripping of generating units and/or loads.

Challenges in today's power grids

The construction of new power lines is very expensive, time-consuming and often complicated by legal and land proprietary issues.

-> FACTS devices are used to increase the controllability and transfer capacity of the power system by controlling power flows and improving the stability

The factors which limit the line loadability of a power line:

1. Thermal limits, the limiting factor for lines up to about 80 km.

2. Voltage limits, the limiting factor for lines between approximately 80 km and 320 km.

3. Stability limits, the limiting factor for lines longer than about 320 km.

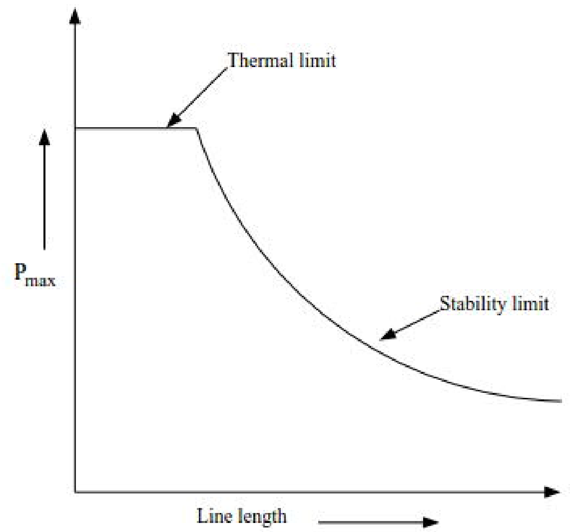


Figure 1.4: Power transfer capacity as a function of line length

Renewable energy production connected to distribution network

- The integration of renewable electricity production in the grid is the main new challenge for many network operators, at distribution as well as at transmission level

- Connecting limited amounts of renewables improves the grid performance as the production compensates for the consumption and in that way reduces the actual loading of the grid.

Challenges

1. The injection of active power will reduce the voltage drop and may result in an overvoltage especially in rural networks
2. The grid can become overloaded when the amount of local generation becomes bigger than the sum of maximum and minimum consumption especially in rural areas with low consumption.
3. Uncontrolled island operation becomes a possibility. After the disconnection of a feeder (due to a fault or for maintenance purposes), the generators connected to the feeder may be able to supply the local consumption.
4. The protection coordination can be endangered.
5. Distributed generation could result in an increase of the harmonic levels.

Renewable energy production connected to transmission network

- Compared to distribution networks, the integration of renewable electricity production in transmission networks is easier because the transmission network is built for having production connected

- HVAC or HVDC transmission grids?

Challenges

1. The transmission system has high reliability requirements compared to distribution network
2. New production units -> new power flows that can result in an overload or insufficient operating reserves (uncertainty)
3. Large renewable electricity production units are often located in less-populated parts of the country where the transmission grid is weak -> the power-system stability?
4. Fault-ride-through: the ability of production units to remain connected and support the grid during large disturbances associated with serious drops in voltage or frequency.

Renewable energy production – solutions

1. Add more primary components to the network: lines, cables, transformers and substations.

2. Shunt and series compensation along the feeder

- Line voltage drop compensation on the transformer tap-changer, and automatic tap-changers for distribution transformers.
- SVC or STATCOM connected in PCC of wind-farm
- Passive compensation (passive filters to limit harmonics, shunt reactors to limit voltage rise)

3. Protection coordination: directional protection, distance protection and anti-islanding protection

4. Improved control of renewable energy production itself!

Source: Math H.J. Bollen, The Smart Grid, Adapting the Power System to New Challenges

Waveform distortion: Notching and noise, harmonics

- Caused by power electronic converters, arcing equipment (arc furnaces and welding equipment), improper customer wiring or grounding.
- Depends on impedance, stronger in weak grid
- Cause damage to capacitive components and disturbances to appliances. Increase rms value of the supply current -> increased power losses. Resonance (series/parallel) -> over voltage and overcurrent -> overcurrent protection. Poor power factor -> increased power losses
- Solutions: grounding and shielding, neutral wire size, filtering

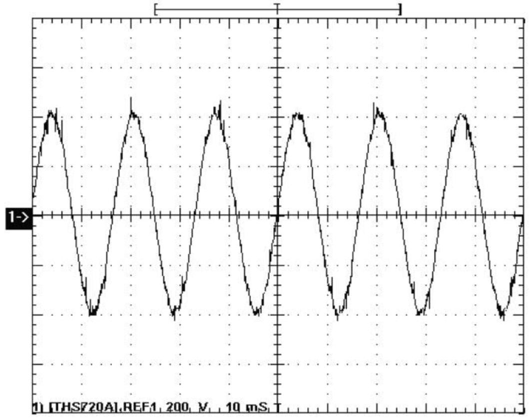


FIGURE 1.7 Notch and noise produced at the converter section of an adjustable speed drive.

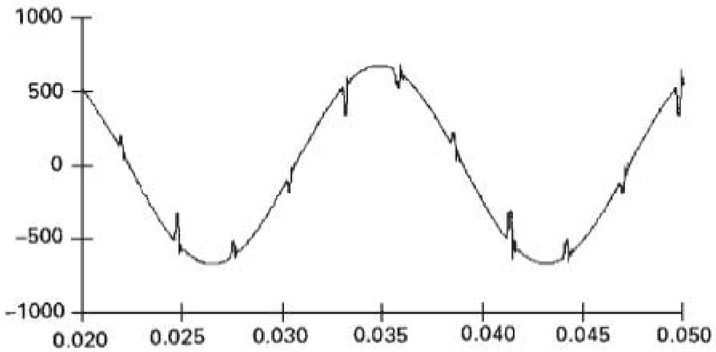


Figure 2.11 Example of voltage notching caused by a three-phase converter.

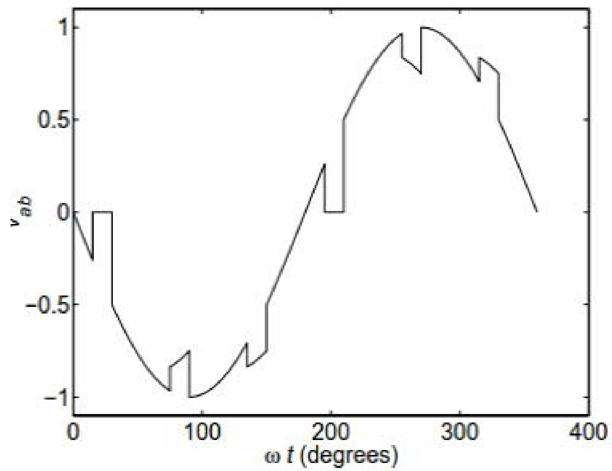


Figure 12.1: An example of voltage notching

Source: Dugan: Electrical power systems quality

Waveform distortion: Harmonics

- Defined by THD and TDD (IEEE Std 519-1992)
- According to International standard IEEE Std 519-2014 and GB/TI 14595-93 (China) the voltage THD < 5% and current THD < 5-20 %

Main sources

1. Non-linear loads (e.g. adjustable speed drives, welders, UPS, computers and lighting), semiconductor based power supply systems (battery chargers, inverter fed AC drives, thyristor controlled reactors, AC regulators).

2. Magnetization nonlinearities of transformer (normal excitation -> 3rd harmonic, symmetrical over excitation i.e. core saturation -> 5th, 7th and 11th harmonic, inrush current harmonics (strart/stop) -> 2nd harmonic, DC magnetization -> odd and even harmonics)

3. Rotating machines (magnetic nonlinearities of the core material, non-uniform flux distribution in the air gap, slot harmonics, reluctance etc.)

4. Arcing devices (electric arc furnaces, discharge type lighting, arc welders)

Effects of harmonics on electrical components

Name of component	Effect of harmonics
Motor and generator	Increased core and copper losses (harmonic losses) -> need to be oversized 5-10% Pulsating or oscillating torque -> torsional oscillations and heating (power losses) Increased voltage stress of insulators Increased leakage flux Noise and vibrations (resonance) Negative sequence currents, especially rotor heating
Transformer	Increased core and copper losses (no-load losses, harmonic losses)-> need to be oversized 5-10% core vibration (resonance), noise Increased voltage stress of insulators Saturation
Protective devices (relays and breakers)	Mal-tripping, inaccurate metering
Capacitor	Increased reactive power, heating, resonance, overvoltage, reduced lifetime, overload
Cables	Increased skin and proximity effects –copper losses - heating Voltage drop, dielectric stress, corona Overheating of neutral conductors -> unbalance
Consumer equipment (sensitive loads)	Malfunctions, decreased lifetime and efficiency, visual flicker in display devices
Communication circuits	Noise, interference

Problems caused by PV: Voltage unbalance

- Caused by single-phase loads (domestic loads and lighting), single-phase power production (PV), overhead transmission lines that are not transposed and blown out fuse in one phase
- Unbalance may cause

  - unbalanced heating and oscillation of motor drives -> shortened life-cycle of devices

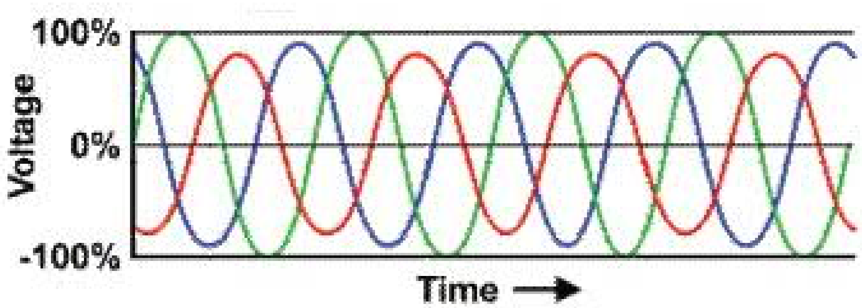
  - excessive drawl of reactive power -> reduce the transmission efficiency, increase power loss and temperature of transformers etc.

  - mal-operation of measuring instruments and other equipment

- Solutions

  Symmetrical connection of load/production

  4-wire STATCOM/active power filter



Problems caused by PV: Long duration overvoltage

- Increase in the rms ac voltage > 110 % at the power frequency > 1 min

- Caused by increased amount of distributed power generation in weak grid, switching off a large load or switching on a large capacitor bank(capacitor energization), incorrect tap settings on transformer, fault on another phase, load rejection

- Stress household appliances, computers, electronic controllers and motors

- Solution:
  - tap-changer transformer
  - SVC
  - passive shunt-connected inductor to limit voltage increase

Problems caused by wind: Voltage fluctuation and flicker

- Wind turbine (variable wind)-> rapid variations in load current can cause voltage variations i.e. flicker.
- Caused by wind turbines, arc furnace, arc lamps, arcing welder and large load changes and other switching events
- Cause protection malfunction and light intensity changes (disturb in lighting, TV and monitors), premature ageing, heating, malfunctioning of connected equipment
- Cause problems to human health, irritation, headache, migraine

- Solutions to power quality problems
  - Proper control of wind turbine
  - Filter
  - SVC or STATCOM
  - Stronger grid, bigger transformers

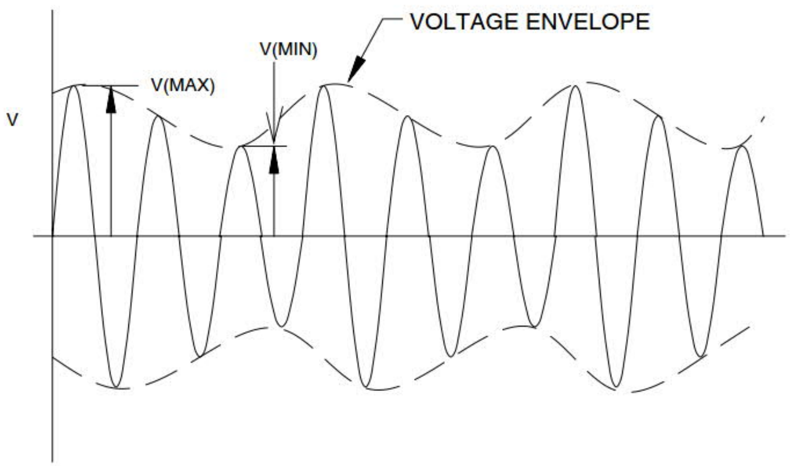
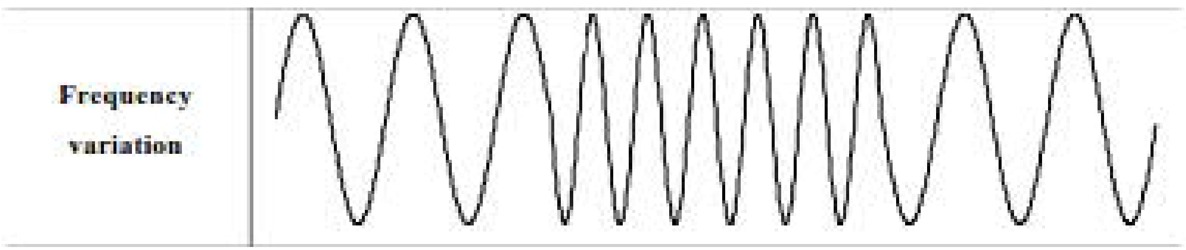


FIGURE 2.9 Typical arc furnace supply voltage indicating voltage fluctuation at the flicker frequency.

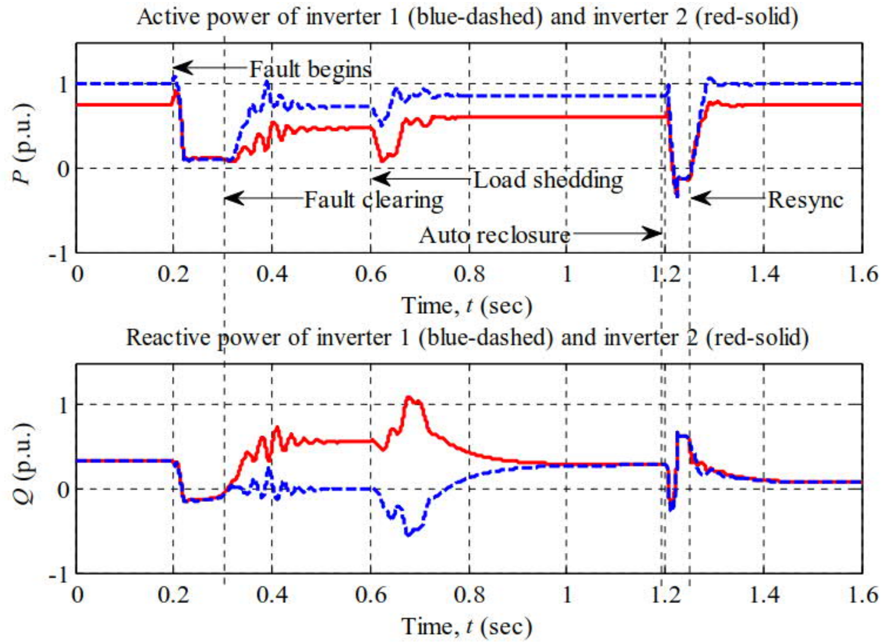
Problems caused by wind: Power frequency variations

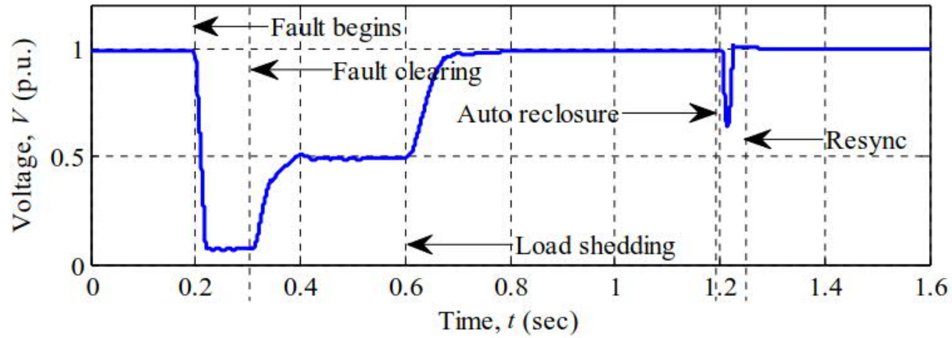
- The frequency depends on the balance between the load and the capacity of the available generation.
- Can cause frequency or timing errors on power electronic devices that count zero crossings to derive frequency or time (PLL)
- Can damage generator and turbine shafts



Change of power system caused by connection of renewable energy

- Reactive power compensation - power factor control
- Low voltage ride through requirements, grid control during interruptions based on **Grid code**
- **Island protection**
- Investment decisions: network extension and/or power compensation devices
- Possibility to use hydropower as energy storage
- **Pros and cons of centralized/decentralized renewable power plants**. What would be the good combination in grid stability point of view?

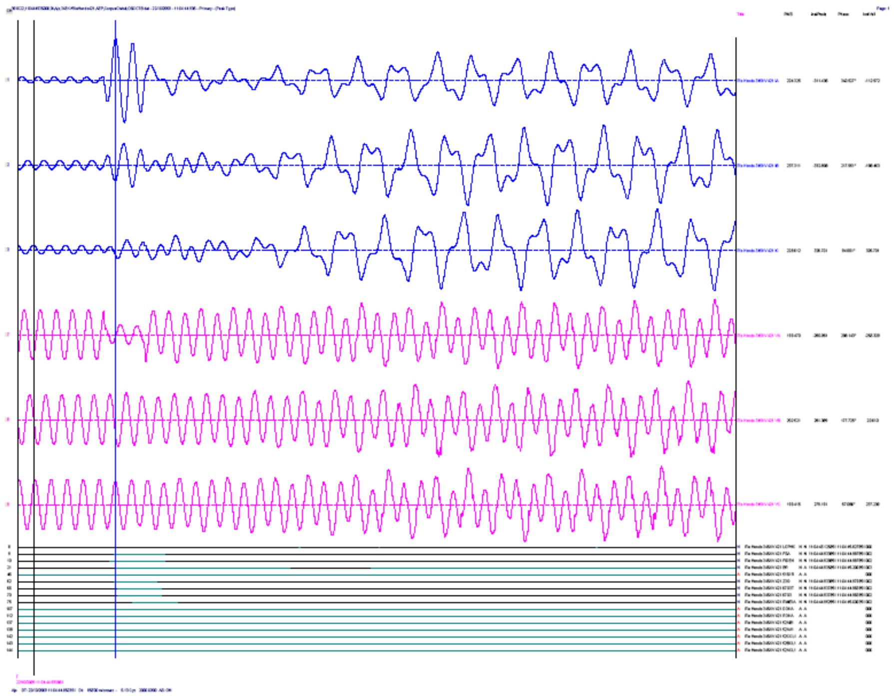




Examples of difficulties in connection of renewable power generation
1. “Harmonic resonance” in wind power plant

- A single line to ground fault on an adjacent line caused a condition that placed two wind farms on a radial connection to a set of series capacitors.
- The fault was recorded at the power converters of two 96 MW wind farms (345 kV). Fault was cleared in 2.5 cycles. 195 % over-voltages were experienced. Series capacitors were by-passed after 1.5 seconds.
- Sub-synchronous currents were reported. Numerous failures to crow-bar circuits of wind farms were reported.
- **Series capacitors likely interacted with the wind farm controls**

-> change in the control system of DFIG wind turbines



Belkin, P. (2010). Event of 10/22/09. CREZ TEchnical Conference, Electrical Reliability Council of Texas.

2. “Harmonic resonance” in photovoltaic plant

- Excessive harmonic currents are reported in grid-connected PV plant in Canada, which leads to inverter disconnection from the grid.
- 30 parallel inverters connected to the grid using 600V/44kV step-up transformer. Seventh harmonic is amplified significantly.
- Short-circuit ratio: SSC/Pnom > 200MVA/500kW = 400 -> Not a ”weak-grid” condition
- Maybe caused by interaction between parallel-connected inverters?
- The incidents were not caused by utility switching, outage or fault…

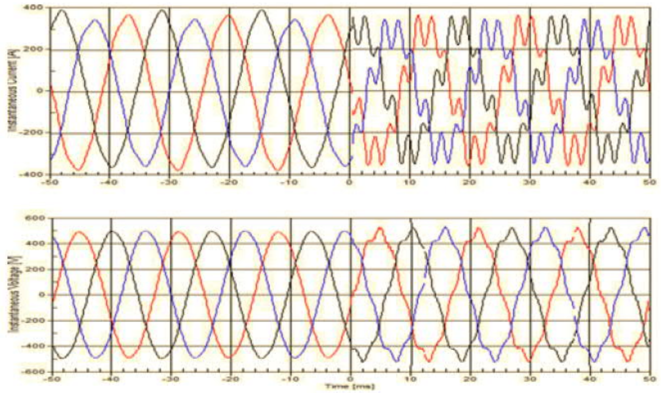


Fig. 1. Current and voltage waveforms under normal and unstable operations.

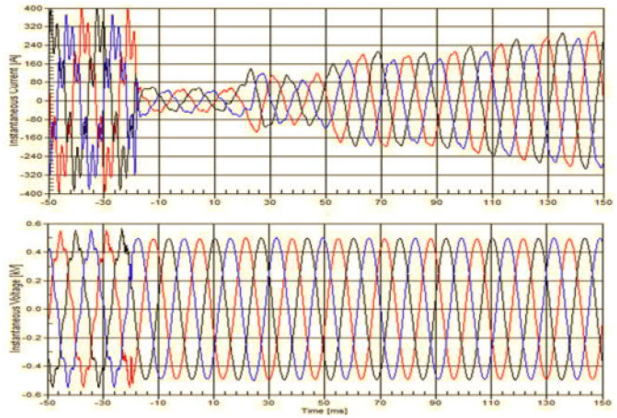


Fig. 2. Current and voltage waveforms under inverters restart.

C. Li, "Unstable Operation of Photovoltaic Inverter from Field Experiences," in IEEE Transactions on Power Delivery, vol. 33, no. 2, pp. 1013-1015, 2018.

2. "Harmonic resonance" in photovoltaic plant

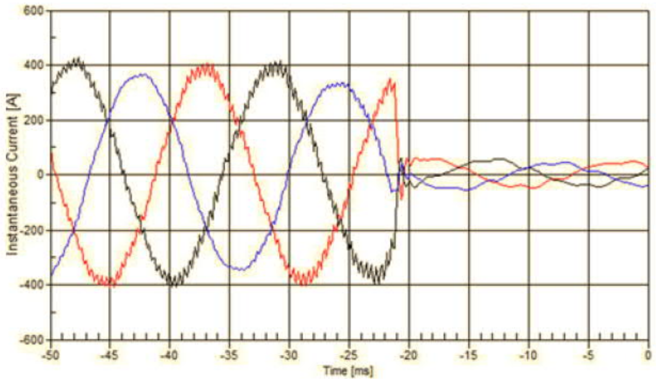


Fig. 4. PV current waveforms with high-frequency oscillations.

- Both low and high-frequency oscillations were observed: 420 Hz, 780 Hz, 2370 Hz.
- The high frequency problem vanishes after inverter restarts.
- Weakly-damped subharmonics (20 Hz) were observed after a 30 MVAr/44 kV capacitor is energized at a substation.

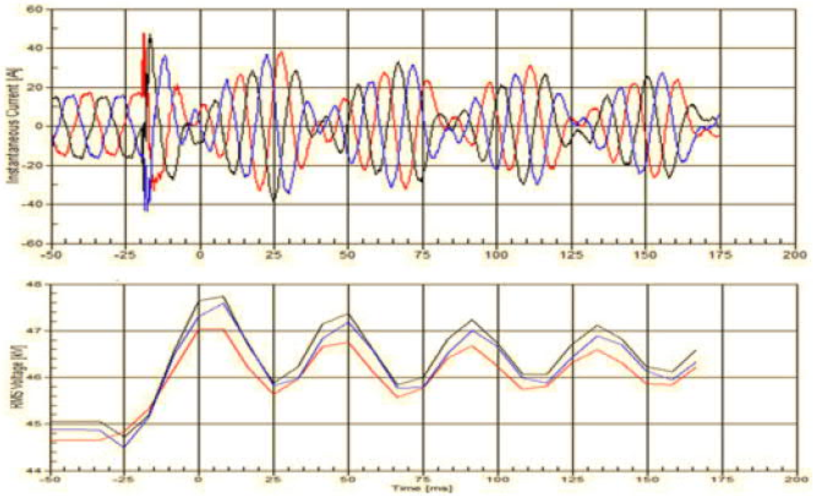


Fig. 6. PV current and voltage upon utility capacitor switching.

C. Li, "Unstable Operation of Photovoltaic Inverter from Field Experiences," in IEEE Transactions on Power Delivery, vol. 33, no. 2, pp. 1013-1015, 2018.

3. Loss of 1,200 MW generation capacity due to unwanted inverter disconnection

- On August 16, 2016 wild fire broke out near three 500 kV lines. The fire caused 13 line faults. The most significant event was the unscheduled loss of 1,200 MW PV generation.
- The frequency dropped down to 59.867 Hz and recovered after 420 seconds.

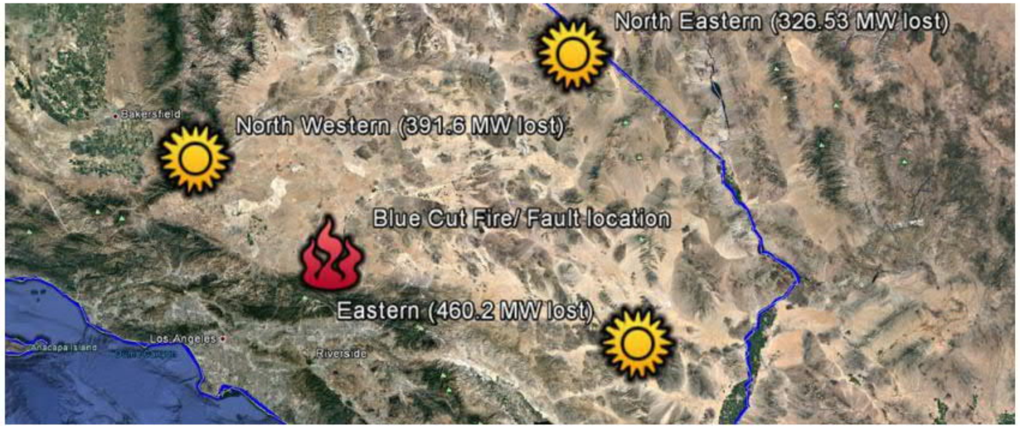
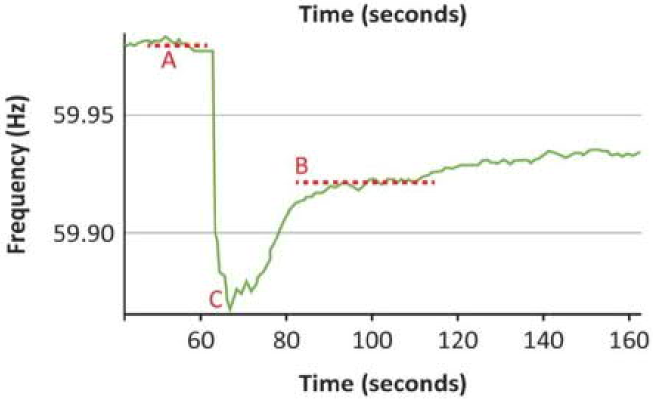


Figure 1.1: Map of the Affected Area and Blue Cut Fire Location



Technical Report, "1,200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report," North American Electric Reliability Corporation, June 2017.

3. Loss of 1,200 MW generation capacity due to unwanted inverter disconnection

- 400 MW of PV generation did not return before the next day.
- The recorded frequency did not go lower than 59.867 Hz. However, 700 MW of inverters disconnected, because their internal PLL detected frequencies below 57 Hz. The trip was instantaneous and there was no hold period programmed. This could have prevented the fault.

-> More accurate way to measure frequency using inverter than PLL (phase-locked-loop)

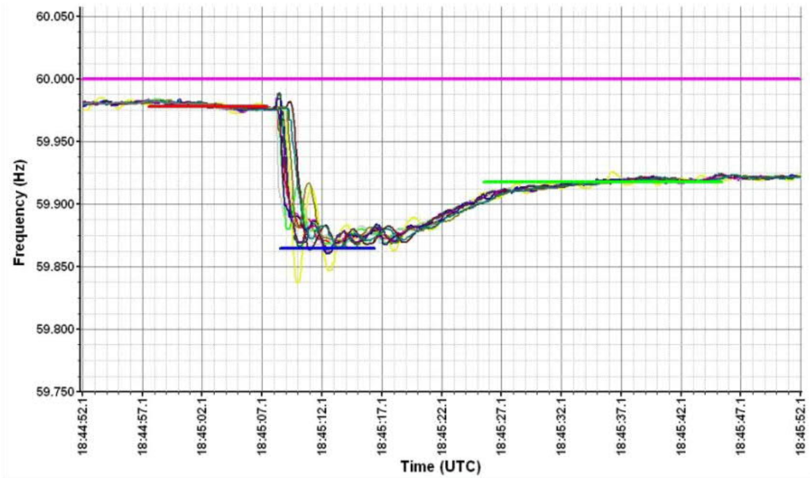


Figure 2.3: FNET Data for Large Resource Loss Event (August 16, 2016)

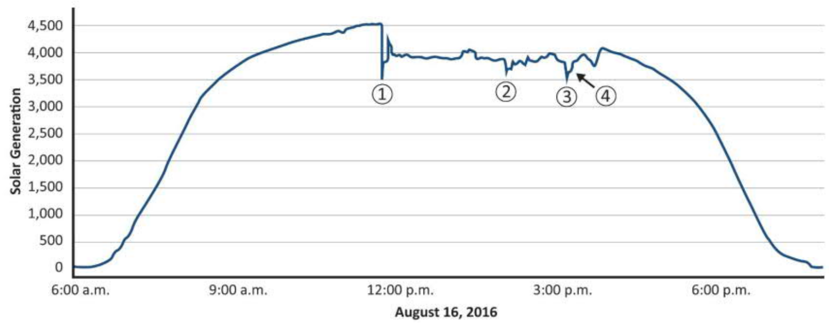


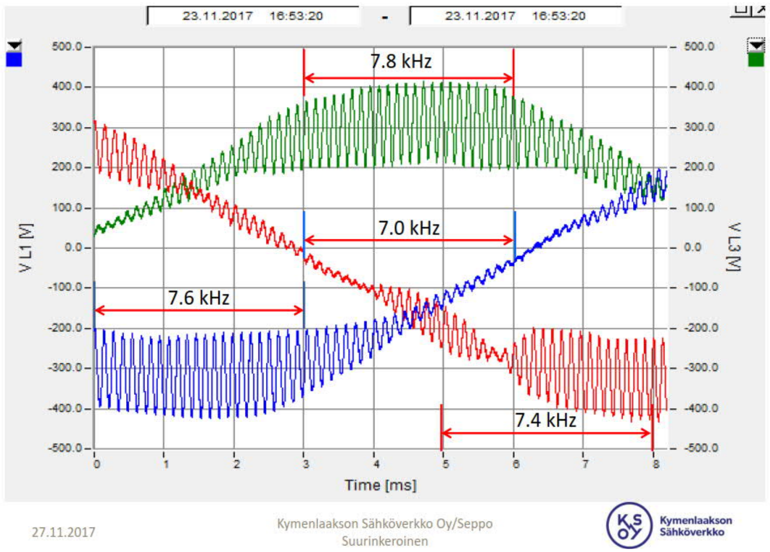
Figure 1.3: Utility-Scale Solar PV Output in SCE Footprint on August 16, 2016

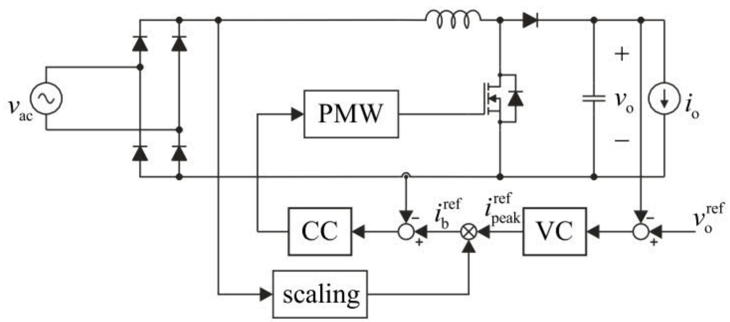
Technical Report, "1,200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report," North American Electric Reliability Corporation, June 2017.

4. Sustained resonance in data-center due to non CE-marked single-phase converters

- Multiple non-CE-marked single-phase rectifiers were installed to feed a data center, 2,4 kW each. Grid waveforms experienced sustained oscillation between 7 and 8 kHz.
- The resonance was mitigated when lights of the facility were turned on. Apparently the lights have some input capacitance.
- The converters are PFC-Boost AC-DC converters with isolated step-down output DC-DC converter

-> The input impedance of this topology is actually prone to series resonance!

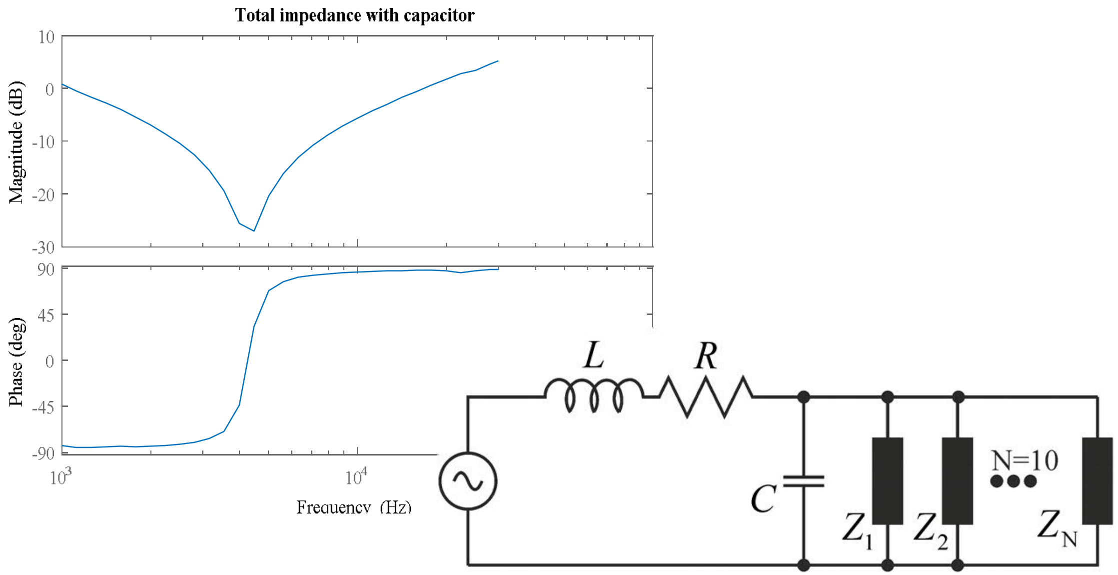


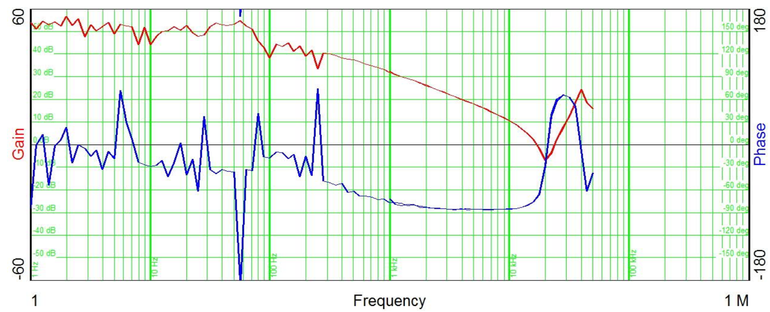


J. Sun, "Input Impedance Analysis of Single-Phase PFC Converters", IEEE Transactions on Power Electronics, vol. 20, no. 2, pp. 308-314, 2005.

4. Sustained resonance in data-center due to non CE-marked single-phase converters

- The input impedance of the converter was measured using frequency response analyzer. Results indicate series resonance at 20 kHz
- The measured impedance was imported to MATLAB and 10 converters were assumed in parallel. Moreover, a line impedance L=10μH with X/R ratio of 10 was assumed as the grid impedance.
- A parallel capacitor of 100 μF was added to approximate the effect of light units. The series resonance is shifted down to 5.5 kHz.





Measured input impedance.

5. Blackout in Europe 4.11.2006

- More than 15 million clients did not have access to electricity during about two hours.

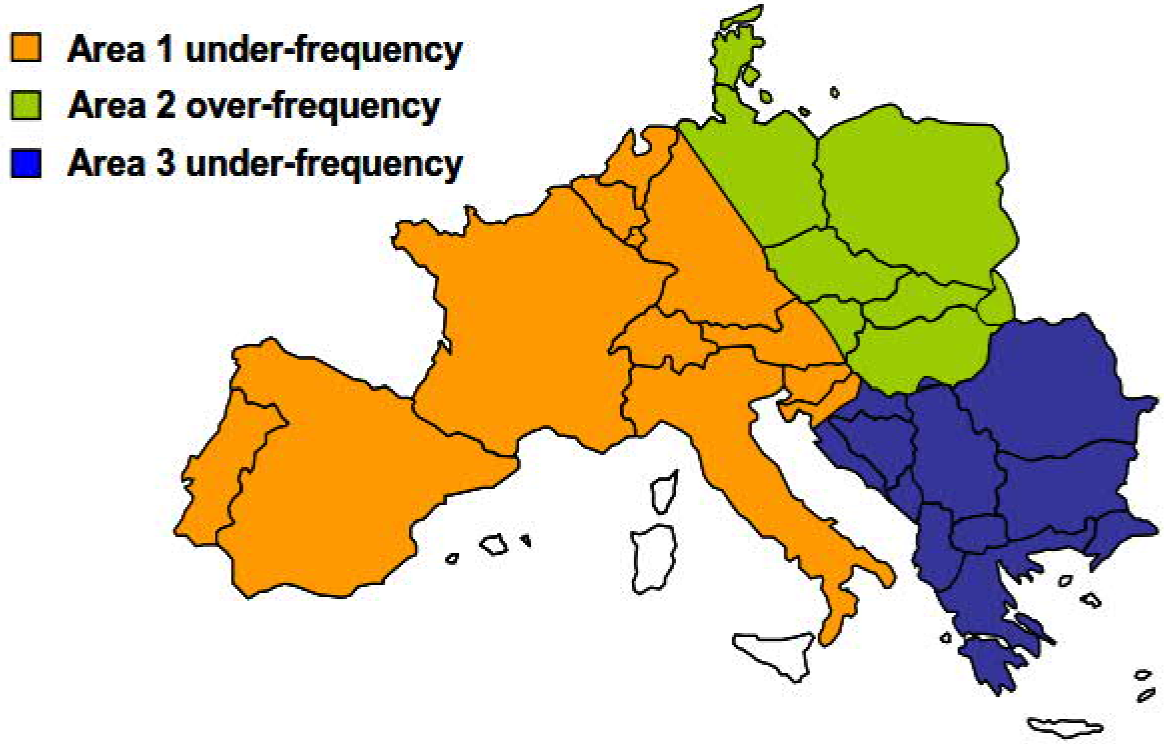


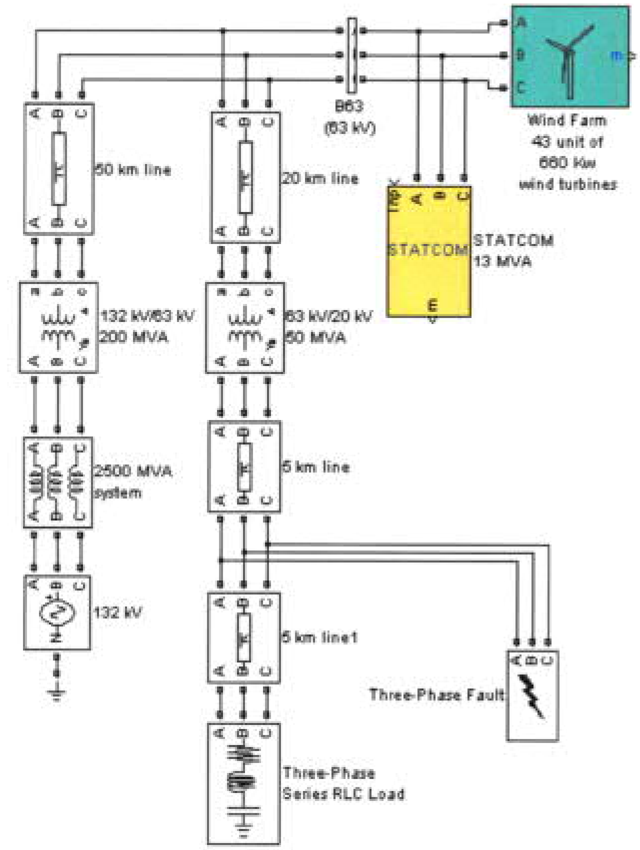
Figure 4: Schematic map of UCTE area split into three areas

Grid codes

- The grid code requires that the wind turbine system should stay connected with the grid and provide reactive power support under grid faults, which is also mentioned as the fault ride-through (FRT) requirement.

1. Frequency dependent active power supply
   (active power control -> frequency control)

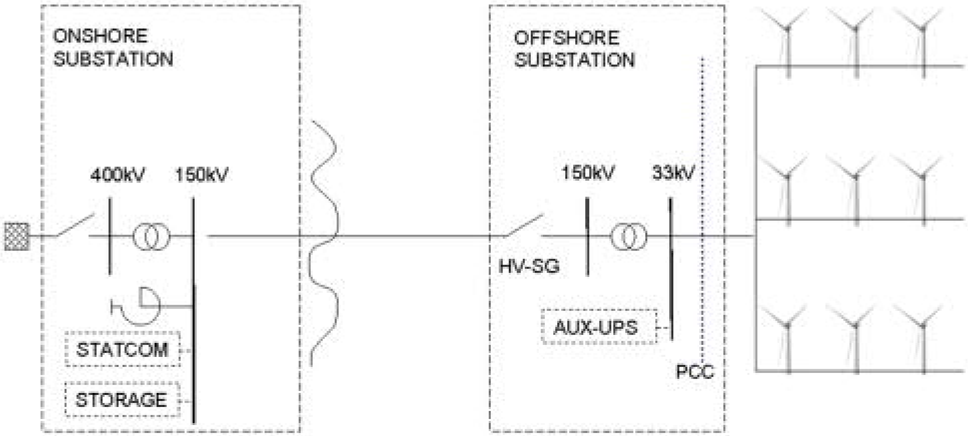
2. Voltage dependent reactive power injection/absorption
   (reactive power control -> voltage control)



Grid requirements

- Stability at grid faults
- Power quality
- Provision of inertia
  (virtual inertia)

180MW Robin Rigg Offshore Wind Farm Substation



STATCOM with DFIG wind turbine

- DFIG have limits in terms of achieving Grid Code compliance in several countries. The medium voltage STATCOM needs to be added to fulfill Grid Code, particularly the low voltage ride-through (LVRT) requirement.
- The LVRT requirement basically demands that the windfarm remains connected to the grid for voltage dips as low as 5% retained voltage.
- The compensating current of STATCOM does not depend on the voltage level of the PCC as with SVC. Thus the compensating current is not lowered as the voltage drops. STATCOM feeds capacitive reactive power into the network, increasing voltage at the PCC, so helping the DFIG to stay connected for as long as it takes to isolate the short circuit.
- To help a DFIG ride through a fault event, over-load capability 10-20 seconds is crucial. An effective overload capability helps reduce the STATCOM's installed power capability, which reduces its cost.

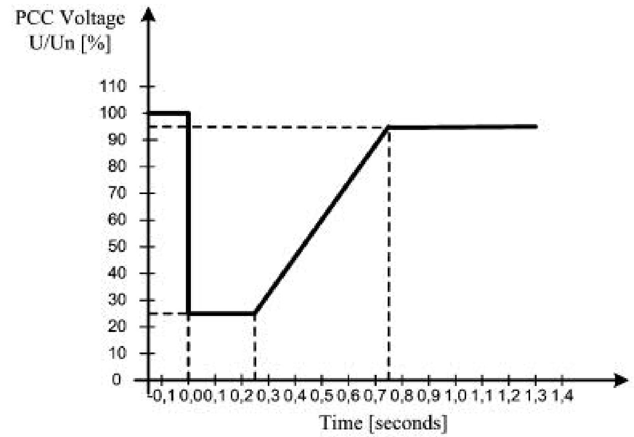


Fig. 1. Ride through profile from the Nordel grid code for the Nordic countries Norway, Denmark, and Sweden.

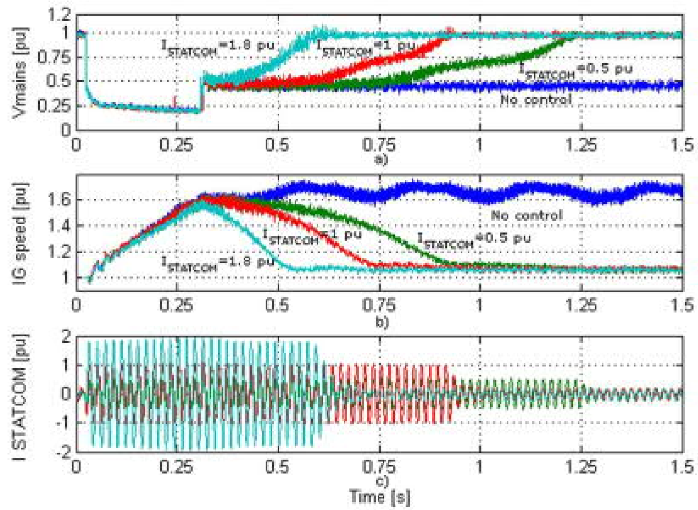


Fig. 7. Measurement results of a 300ms, 80% voltage drop at PCC under several control conditions.

Reading

- H. Akagi, E. H. Watanabe, M. Aredes: Instantaneous Power Theory and Applications to Power Conditioning, 379 pages, Wiley 2007
- Bhim Singh, Ambrish Chanda, Kamal Al-Haddad: Power quality: Problems and Mitigation Techniques, Wiley, 2015, 596p.

- R. Sastry Vedam and Mulukutla S. Sarma: Power quality – VAR compensation in power systems, CRC Press, 2008, 304p.
- K.R Padiyar: FACTS controllers in power transmission and distribution, 2007
- Narain G. Hingorani, Laszlo Gyugyi: Understanding FACTS: Concepts and technology of flexible AC transmission systems, Wiley- IEEE Press, 2000

- Remus Teodorescu, Marco Liserre, Pedro Rodríguez: Grid converters for photovoltaic and wind power systems

Reading

- A. Moreno-Munos: Power quality- Mitigation technologies in a distributed environment, Springer 2007, 438p. (basics)
- Surajit Chattopadhyay, Madhuchhanda Mitra, Samarjit Sengupta: Electric power quality, Springer, 2011, 193p. (only about power quality, not compensation methods)
- Mohammad A.S. Masoum and Ewald F. Fuchs: Power quality of power systems and electrical machines, 2nd edition
- Xiao-Ping Zhang, Christian Rehtanz, Bikash Pal: Flexible AC transmission systems: Modeling and control, Springer, 2012, 569p. (Acha's course)
- C. Sankaran: Power quality

- Chi-Seng Lam and Man-Chung Wong, Design and control of hybrid active power filters, Springer 2014, 168p. (difficult, e-library)

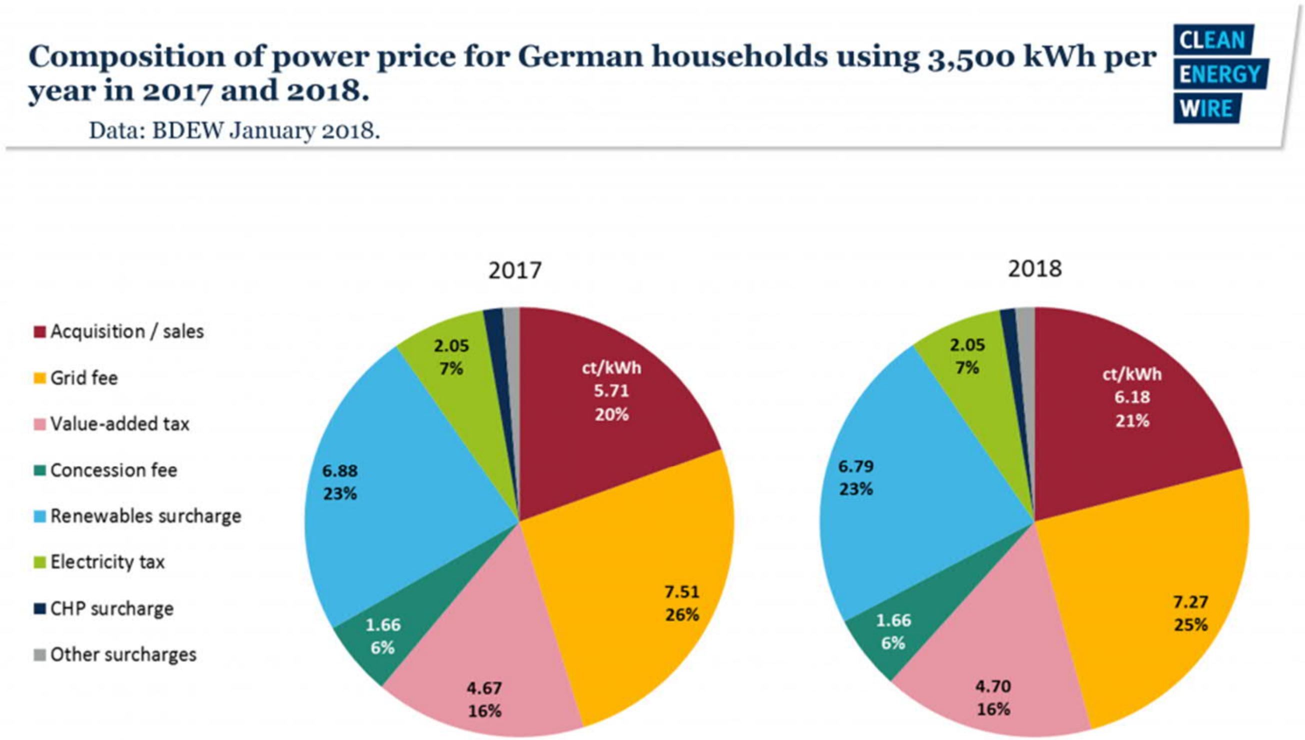
- Roger C. Dugan, Surya Santoso, Mark McGranaghan, Mark F. McGranaghan, H. Beaty, H. Wayne Beaty: Electrical Power Systems Quality, 2002
- Barry Kennedy: Power quality primer

Discussion about the electricity price

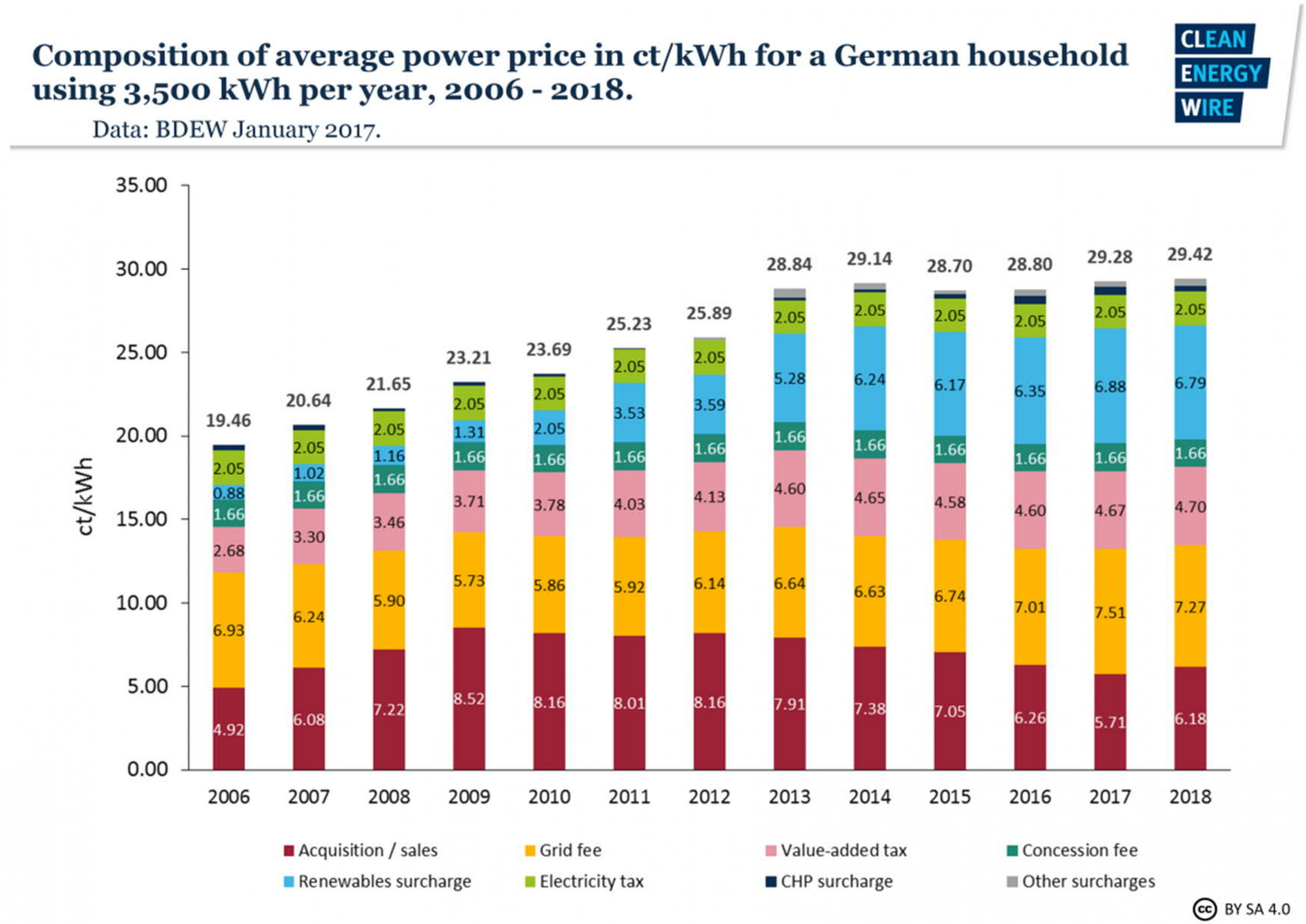
Tariff models

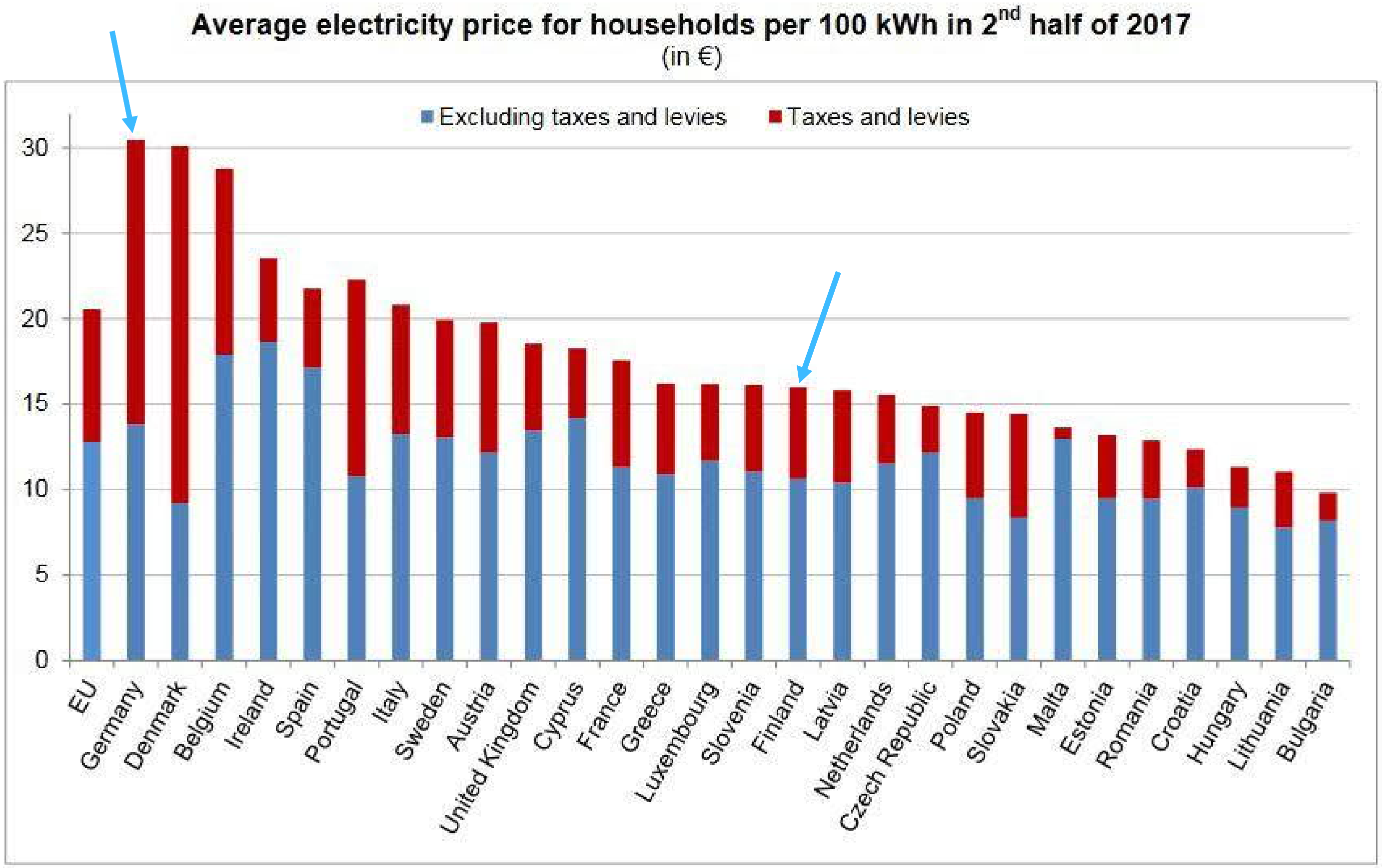
Regulation

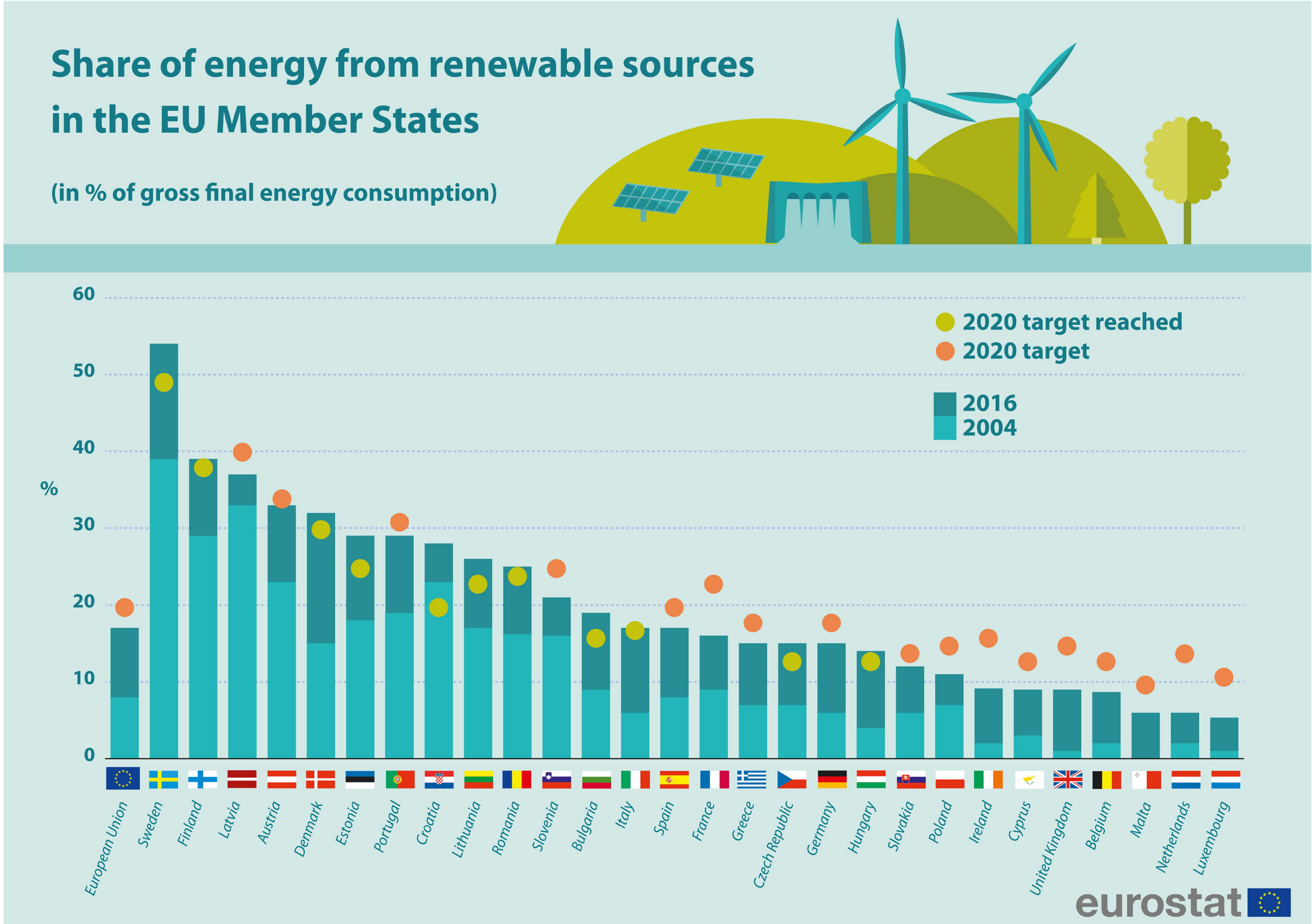
Tariff models



Renewable energy surcharge (23.1 %)
Pays the state-guaranteed price for renewable energy to producers.
Offshore liability levy (0.1 %)
Grid operators must pay damages if they fail to connect offshore wind farms in a timely manner in order to sell the power they produce.
Surcharge for combined heat and power plants (1.2 %)
Operators of CHP plants receive a guaranteed price on the electricity they sell.


Composition of average power price in ct/kWh for a German household using 3,500 kWh per year, 2006 - 2018.
Data: BDEW January 2017.
CLEAN ENERGY WIRE
ct/kWh
2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
19.46 20.64 21.65 23.21 23.69 25.23 25.89 28.84 29.14 28.70 28.80 29.28 29.42
Acquisition / sales
Grid fee
Value-added tax
Concession fee
Renewables surcharge
Electricity tax
CHP surcharge
Other surcharges
BY SA 4.0


Average electricity price for households per 100 kWh in 2nd half of 2017
(in €)
Excluding taxes and levies
Taxes and levies
0
5
10
15
20
25
30
EU
Germany
Denmark
Belgium
Ireland
Spain
Portugal
Italy
Sweden
Austria
United Kingdom
Cyprus
France
Greece
Luxembourg
Slovenia
Finland
Latvia
Netherlands
Czech Republic
Poland
Slovakia
Malta
Estonia
Romania
Croatia
Hungary
Lithuania
Bulgaria


Share of energy from renewable sources
in the EU Member States
(in % of gross final energy consumption)
2020 target reached
2020 target
2016
2004
%
60
50
40
30
20
10
0
European Union
Sweden
Finland
Latvia
Austria
Denmark
Estonia
Portugal
Croatia
Lithuania
Romania
Slovenia
Bulgaria
Italy
Spain
France
Greece
Czech Republic
Germany
Hungary
Slovakia
Poland
Ireland
Cyprus
United Kingdom
Belgium
Malta
Netherlands
Luxembourg
eurostat

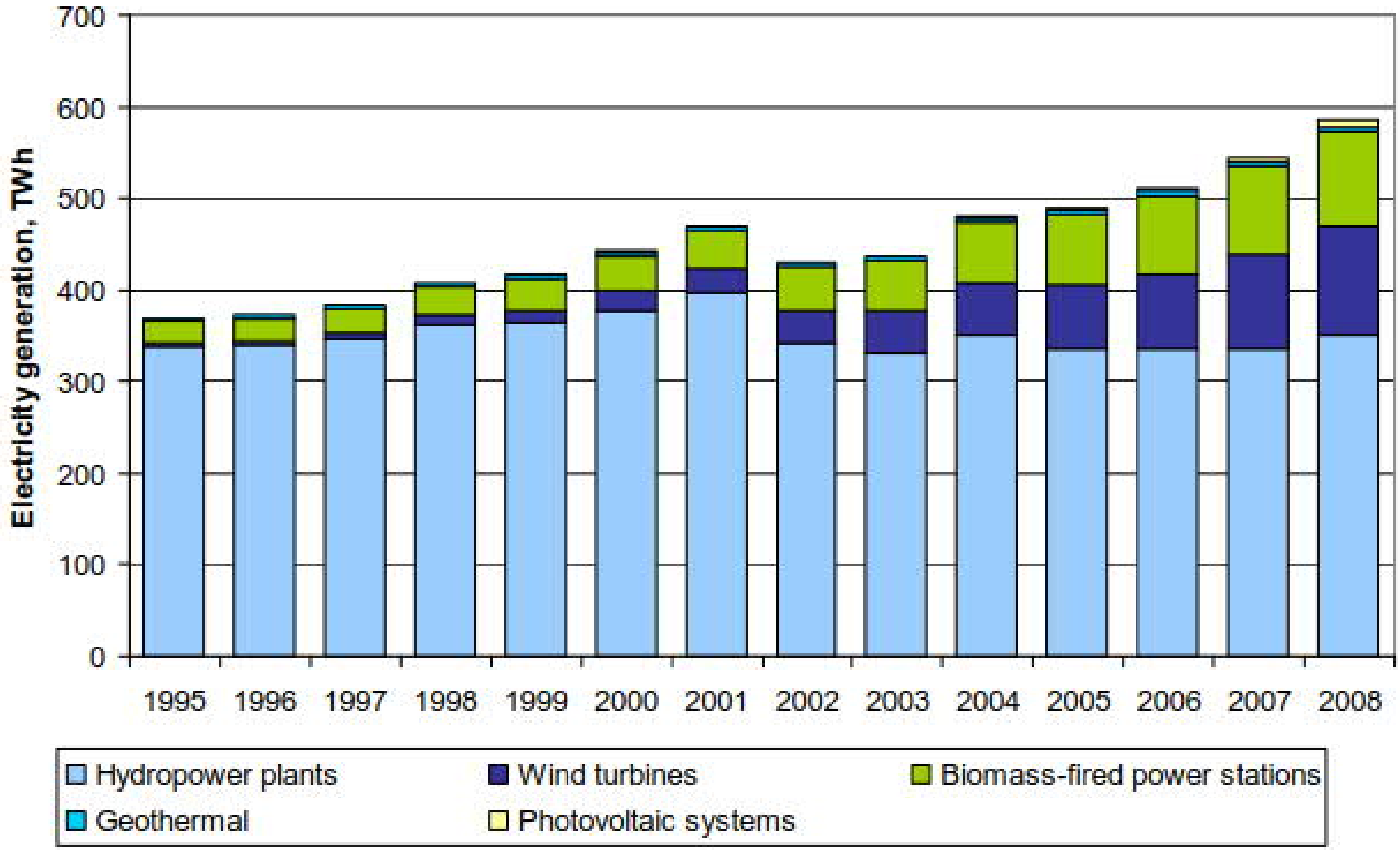


Figure 3. Electricity generation from renewable energy sources in the European Union (EU-27).

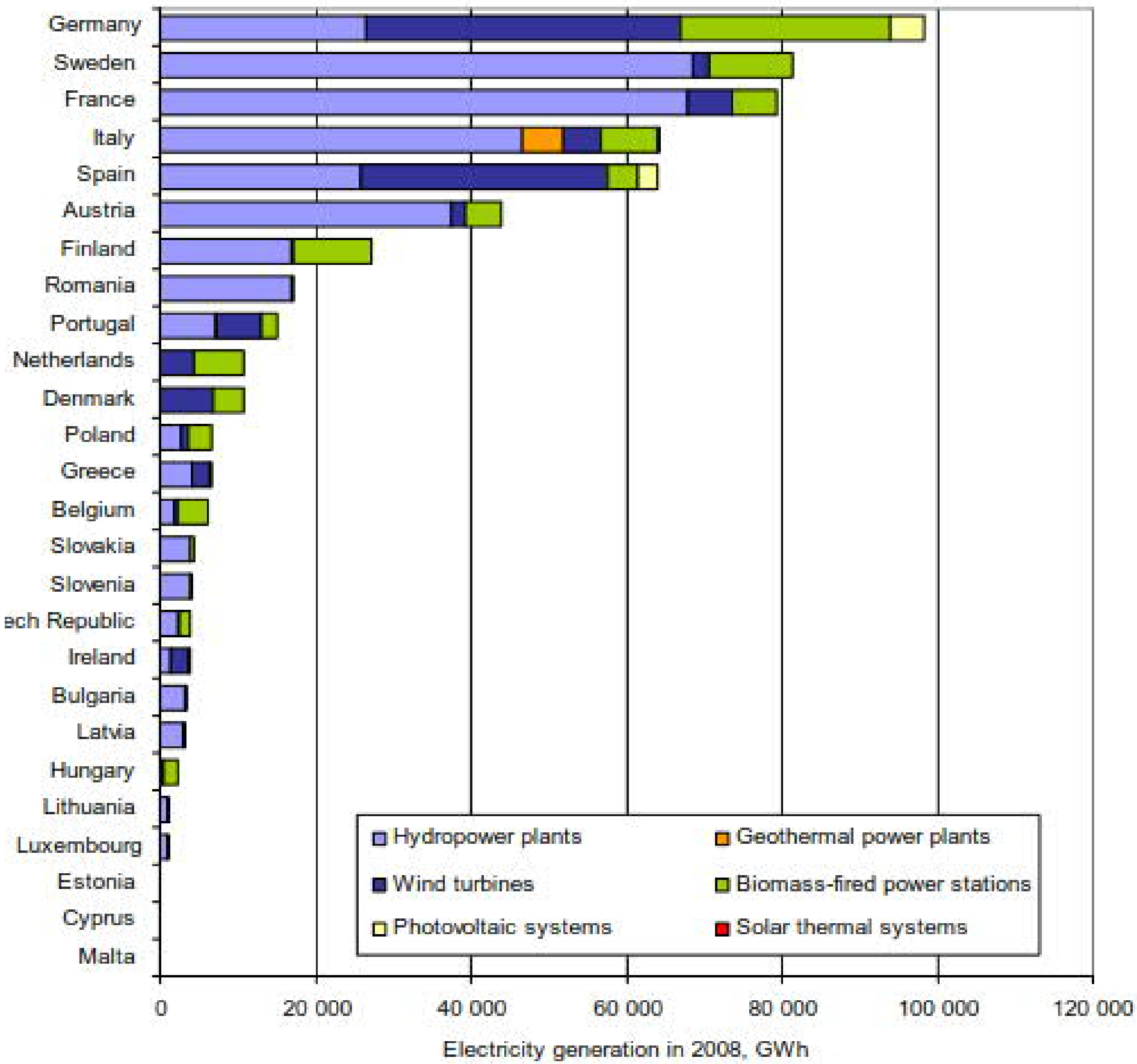


Figure 8. RES-E generation in 2008 in the European Union.

Technical challenges related to the future power grid

How the curricula needs to be changed in the university?

What research topics are interesting?

Research topics

- Environmental effect
- Energy management
- More accurate prediction of loading conditions based on smart meters
- Business models and peak shaving opportunities if electricity price varies every hour
- Grid reliability – minimizing blackouts

Conclusion, discussion, comments and feedback

Recap

- Did you learn something new or did you get some new way of thinking?
- What was the most important thing?
- What issues are not related to power system of Laos at all?
- What kind of steps are needed in the future to move toward the future grid vision?

Feedback

https://goo.gl/forms/QxZYvFIKN9NvP3NJ3