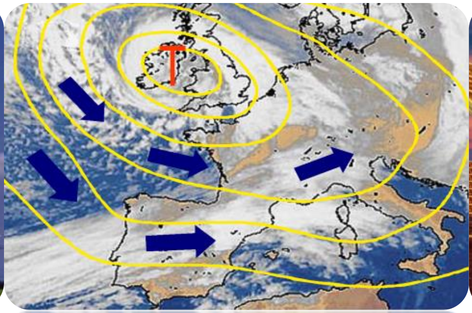




Photovoltaic Systems team up with Smart Grids

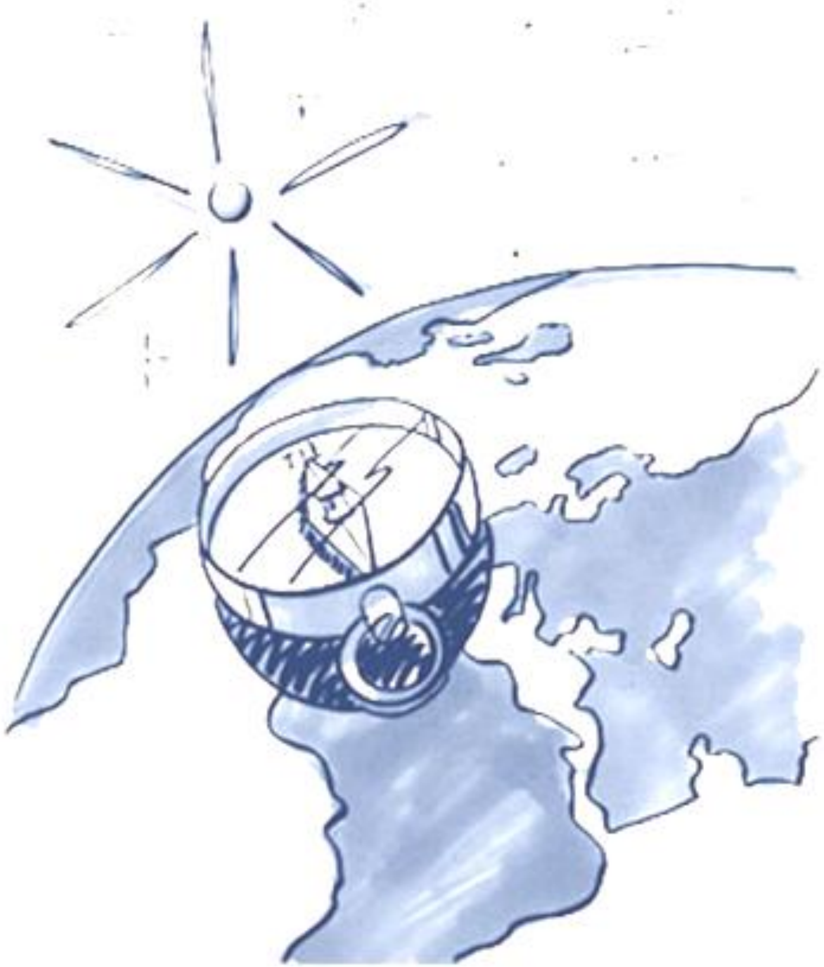
Gerd Heilscher

Prof. Gerd Heilscher - Ulm University of Applied Sciences

Technik
Informatik & Medien
Hochschule Ulm
University of Applied Sciences

Agenda

- **Introduction**
  - **Electric Energy System**
  - PV System Grid Integration
- Today's and Future Challenges
- PV Systems & Smart Grids
- Conclusion



Balancing Load and Power Input

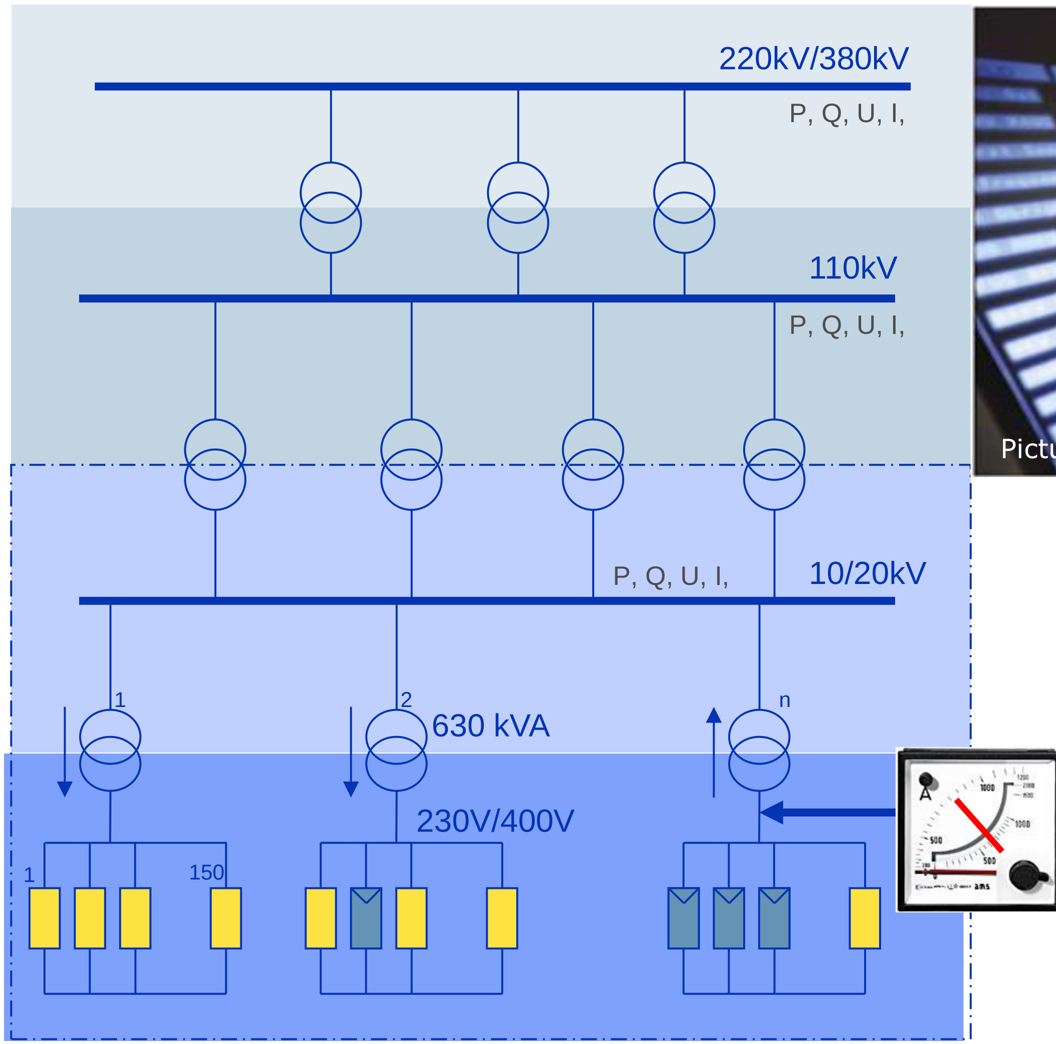
- Quarter hourly forecast of supply for all power input

- Quarter hourly forecast of load profiles for each single client
- Based on measured and synthetical load profiles

- Differences between supply and demand have to be matched with backup power stations in real time

There is only a monetary value of electricity when its needed
This has to be respected also by solar electricity!

Electricity Network Operation Today



Network Operator (TSO/DSO)

- Balancing
- Frequency control
- Voltage control

- Network operators have no measurements at the low voltage level

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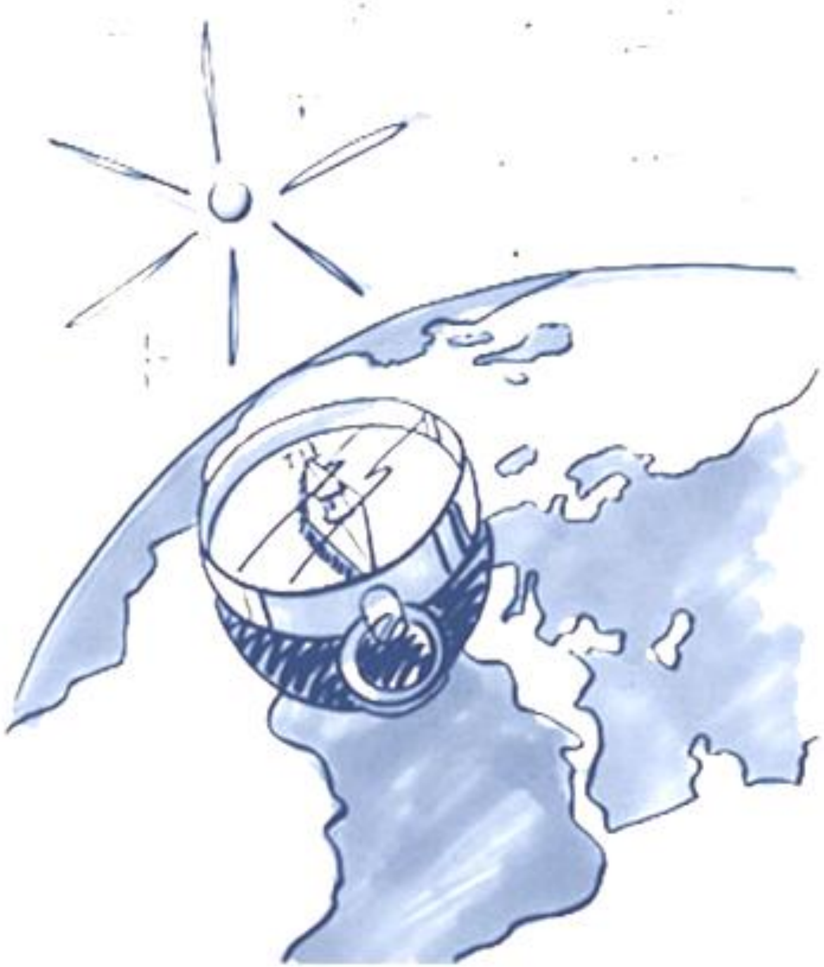
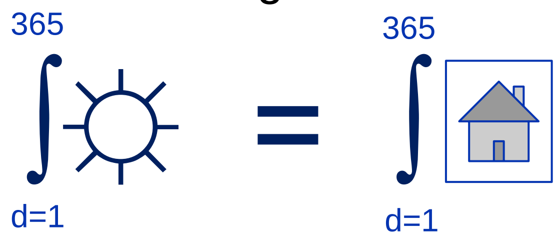
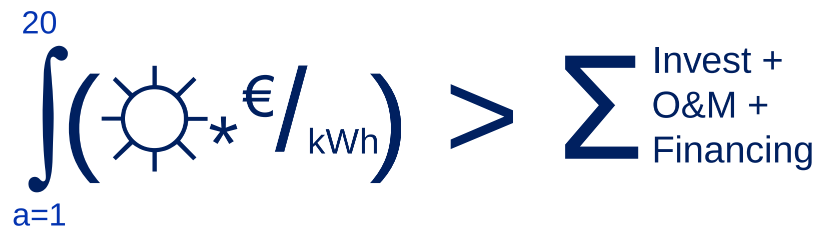


PV Systems - Grid & Market Integration

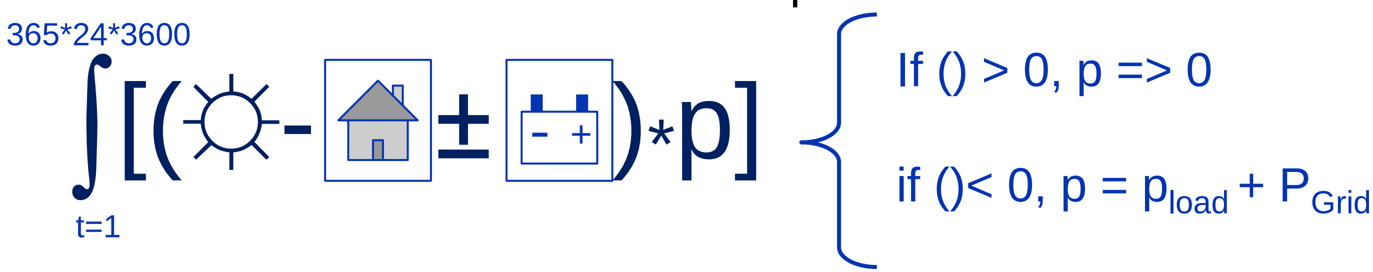
- Net Metering



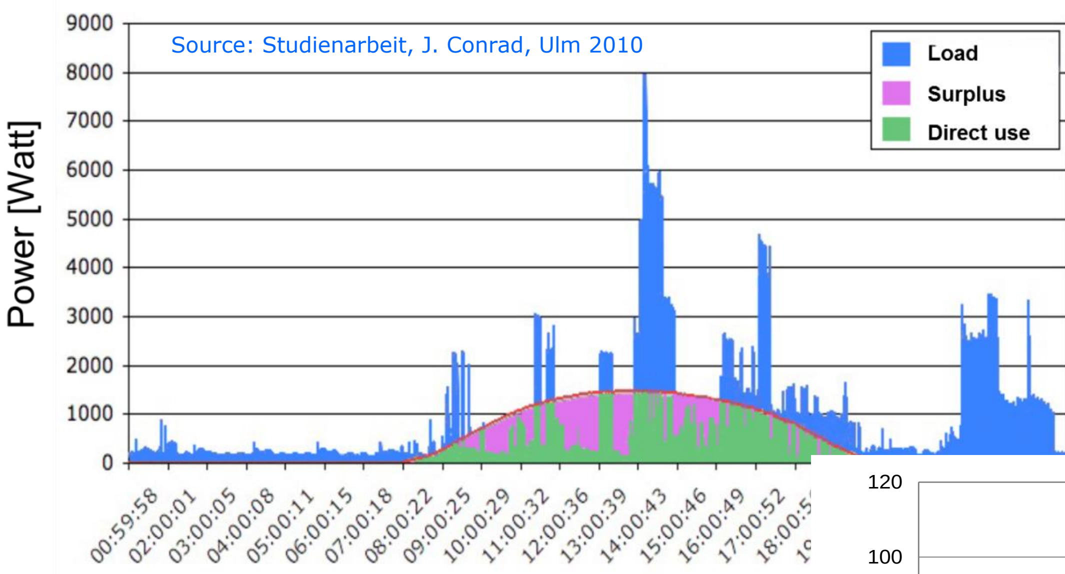
- Feed in Tarifs

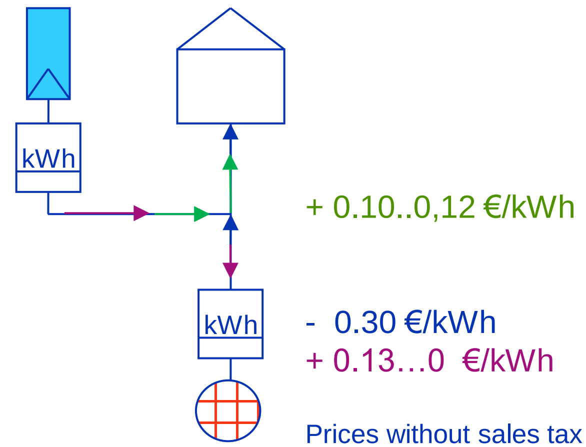


- Self Consumption

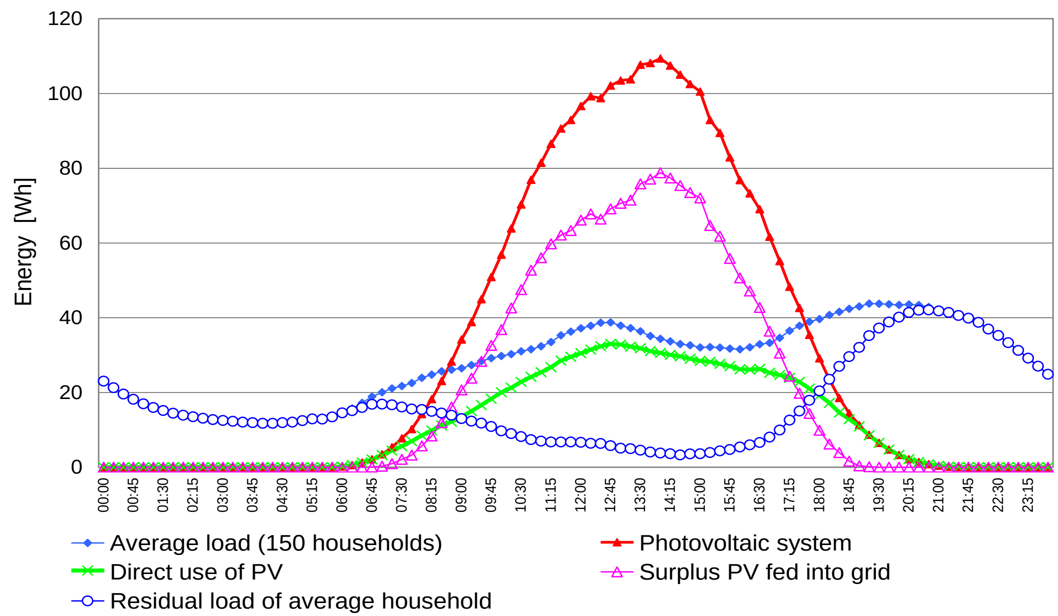


Solar Energy Input in Real Time

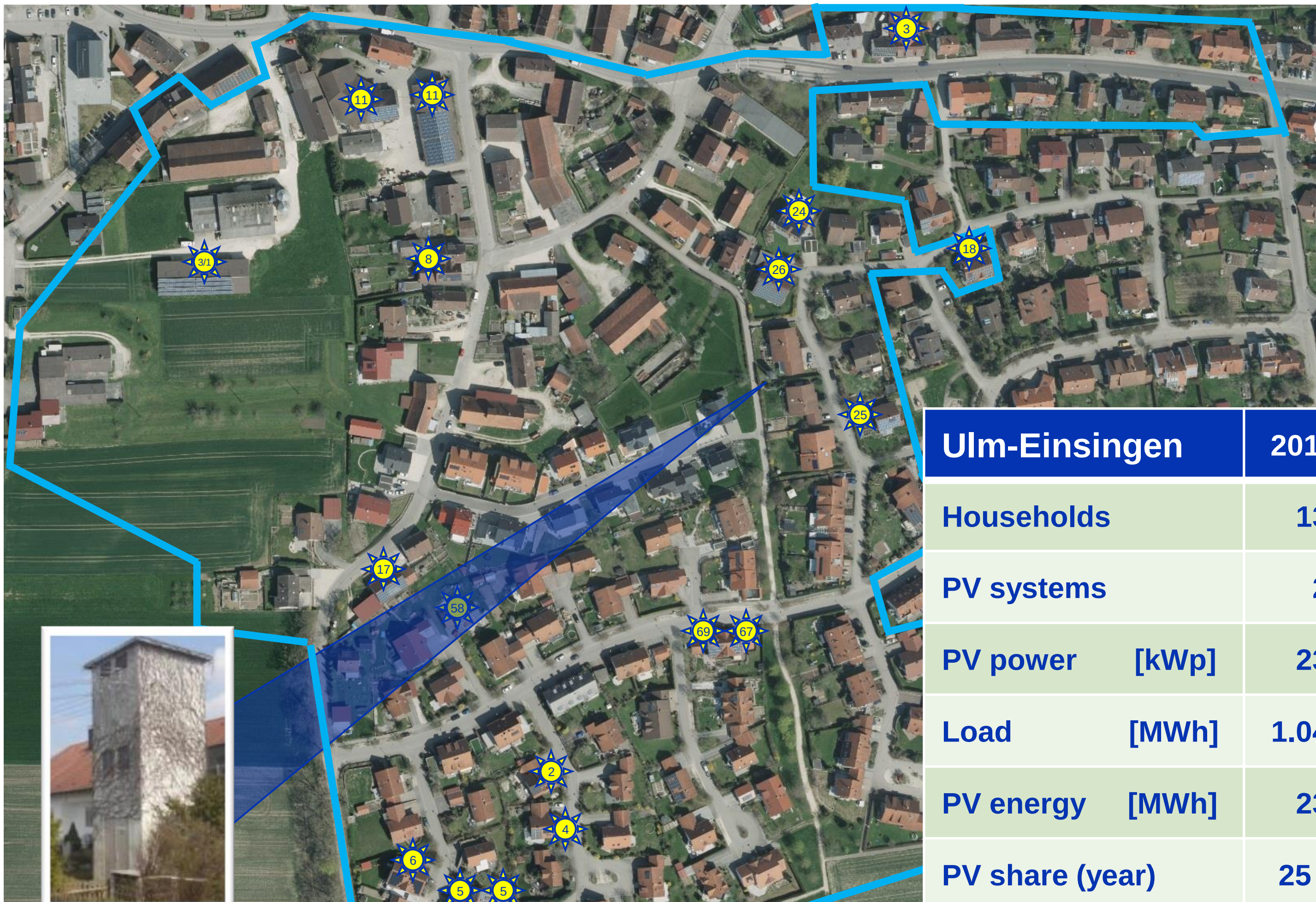




- Only 30..40% of solar energy is used directly
- Significant change of load profiles
- Standard load profiles no longer useful
- Load forecast gets wrong

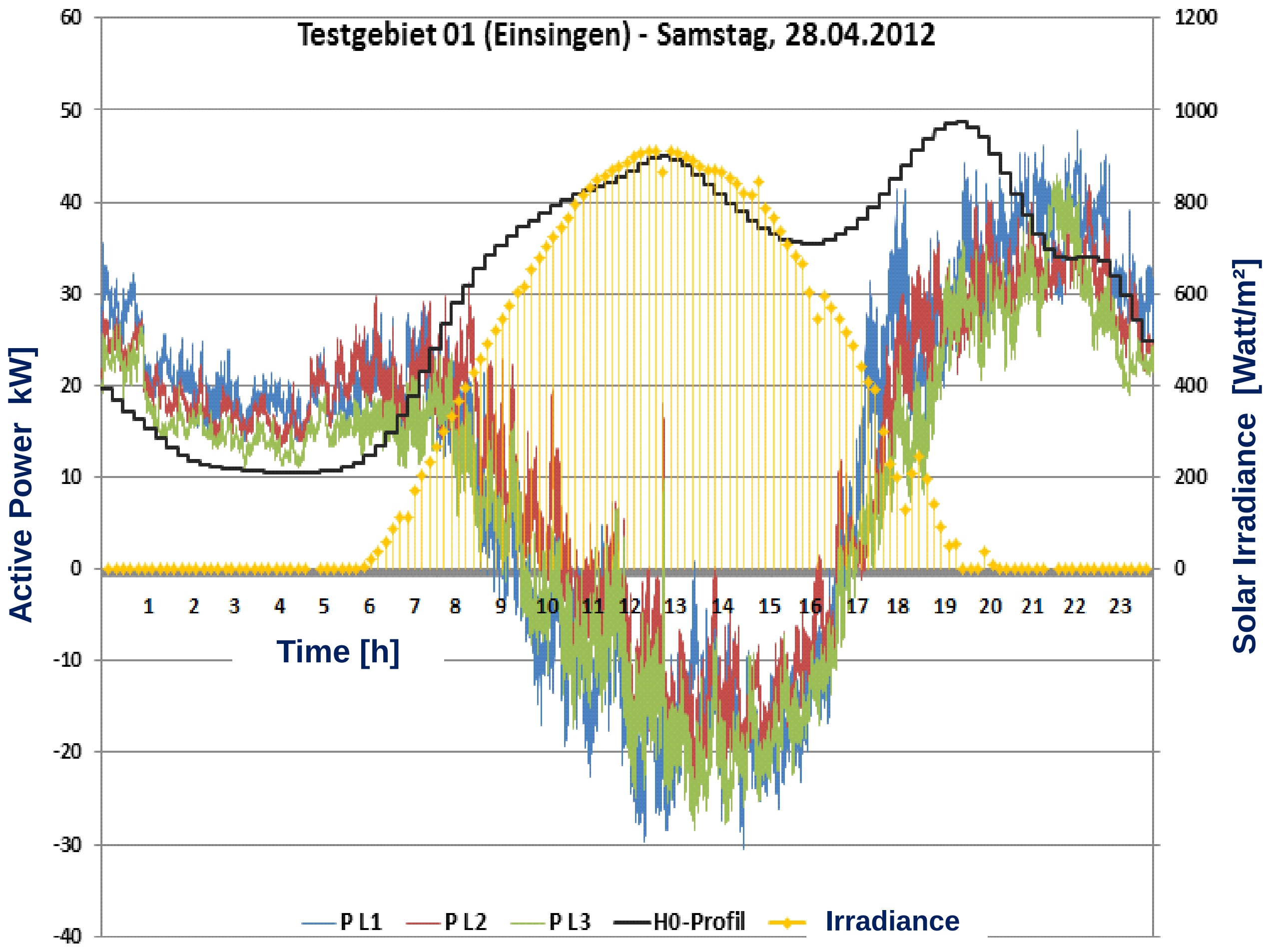


From Single PV-Systems to LV Transformer Level



Ulm-Einsingen	2013	2050
Households	134	150
PV systems	21	150
PV power [kWp]	233	2.000
Load [MWh]	1.047	1.100
PV energy [MWh]	230	2.200
PV share (year)	25 %	200 %

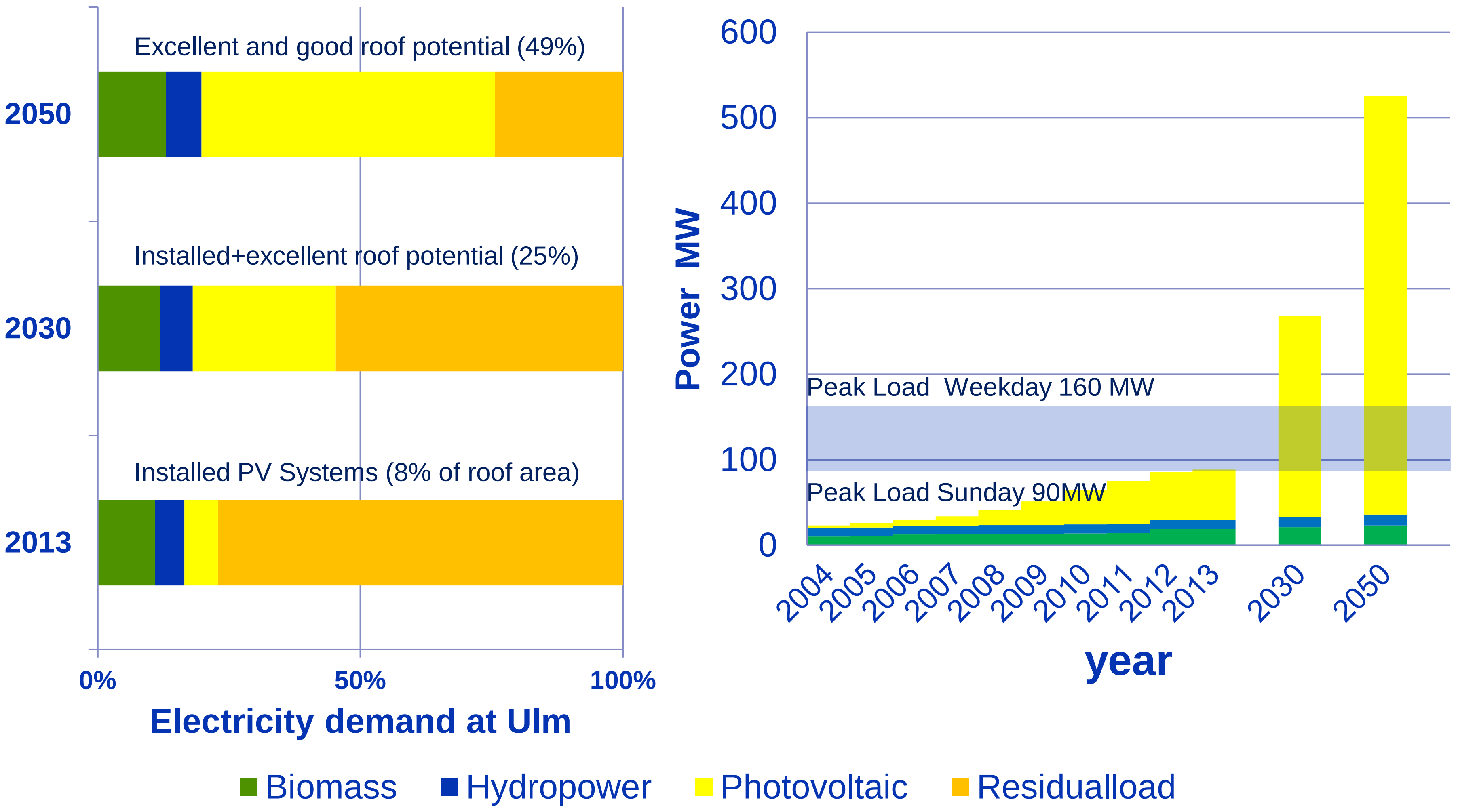
Reverse Energy Flow at Distribution Level



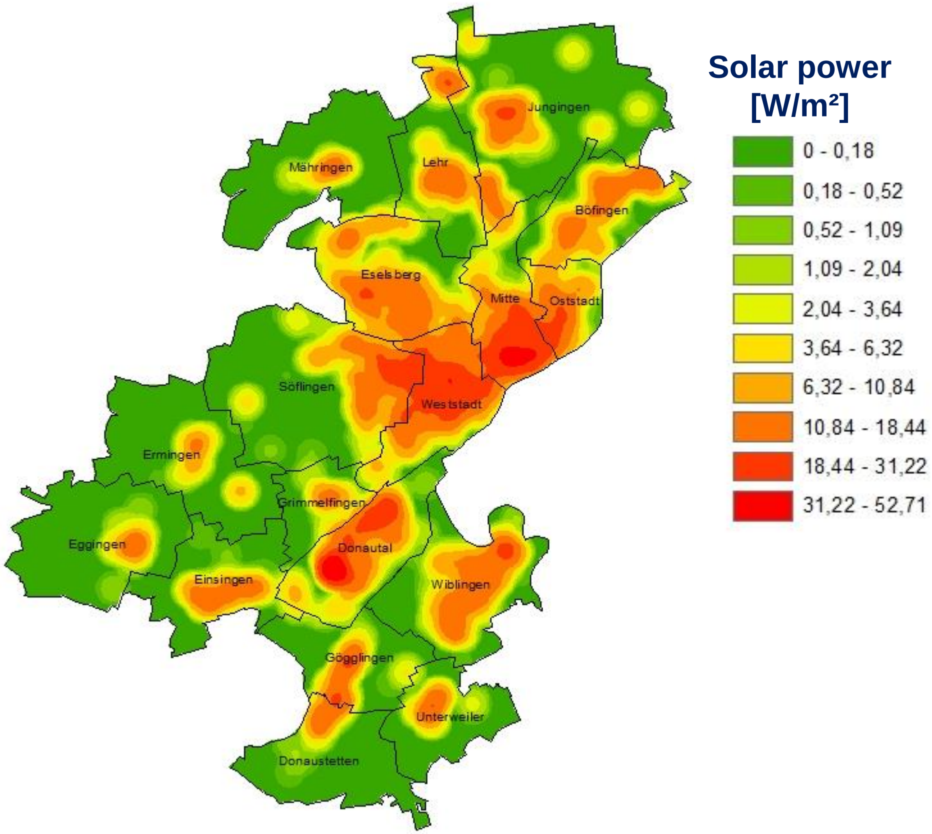
Source: G. Heilscher, H. Ruf: Ulm University of Applied Sciences, 2012

- Black line indicates the average load curve of the 134 households
- Yellow background quarter hourly solar radiation at the test site
- The load measured at the low voltage transformer drops during daytime due to feed in of solar power (1 second resolution)
- Between 9 AM and 5 PM load flow is reverse at the transformer

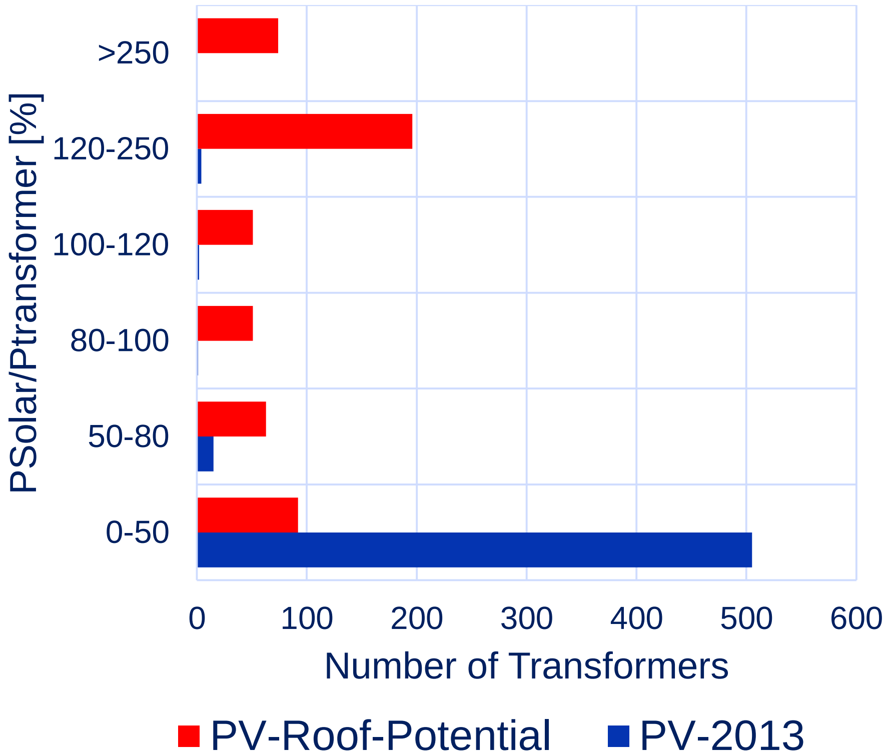
Outlook Solar Roof Potential at Distribution Level



Outlook Solar Roof Potential



- LV Transformer Analysis



- Lidar 3D-Profile 5 pixel/m²
- Useful solar roof potential 540 MWp
- Power input at LV transformer

- LV transformers changed since 2010
- 50% of Transformers overloaded with total solar roof potential

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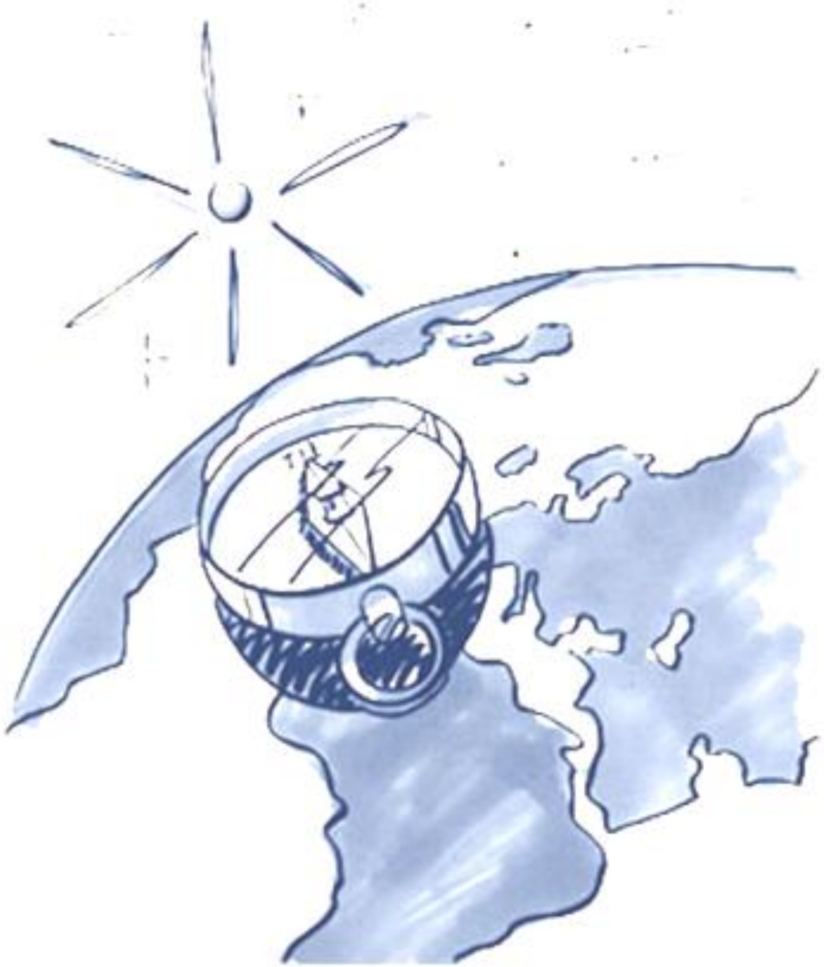
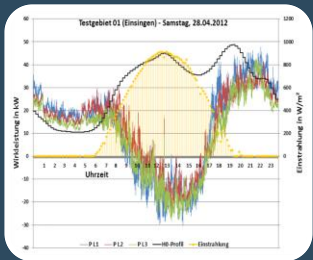
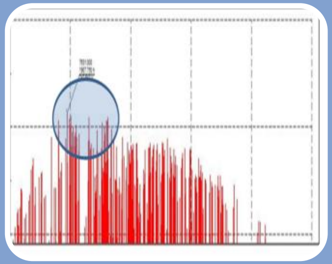


Today‘s & Future Challanges

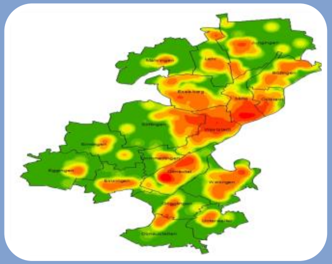


Photovoltaic > Load

Balancing becomes difficult due to growing error in load forecast

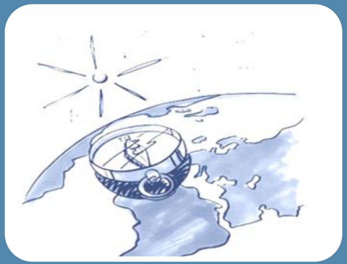


Feed in Management
Is a potential solution
needs Standards



High invstements to prepare grid for distribute generation

Information misssing from LV network



Market design for solar electricity

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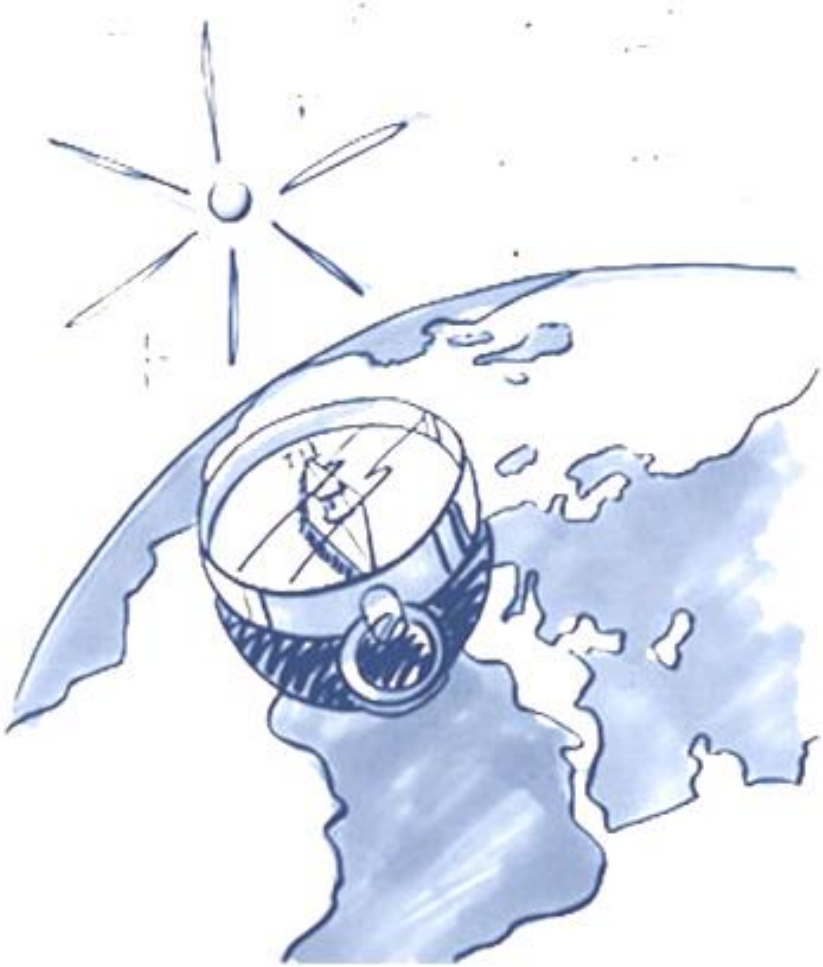
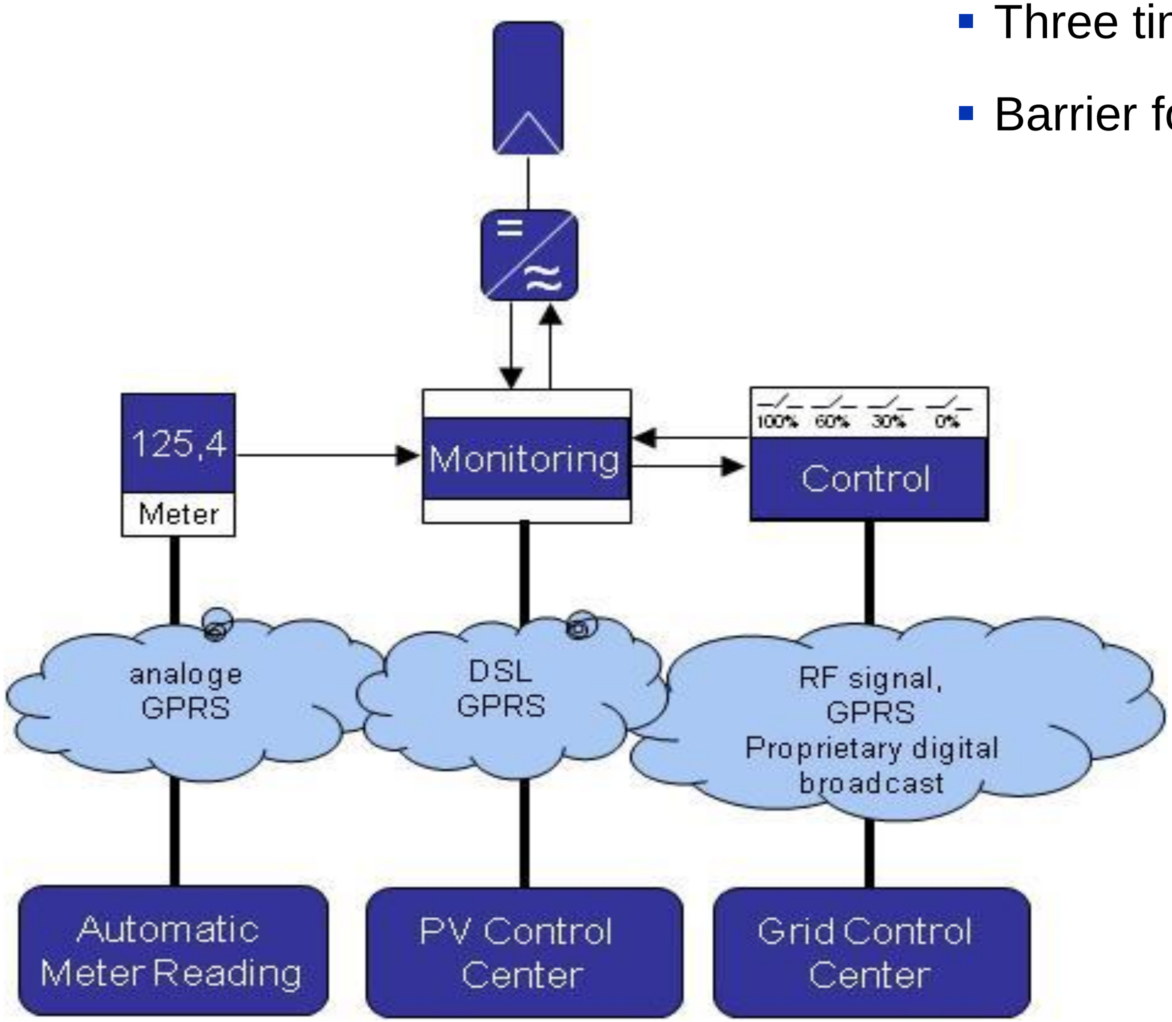


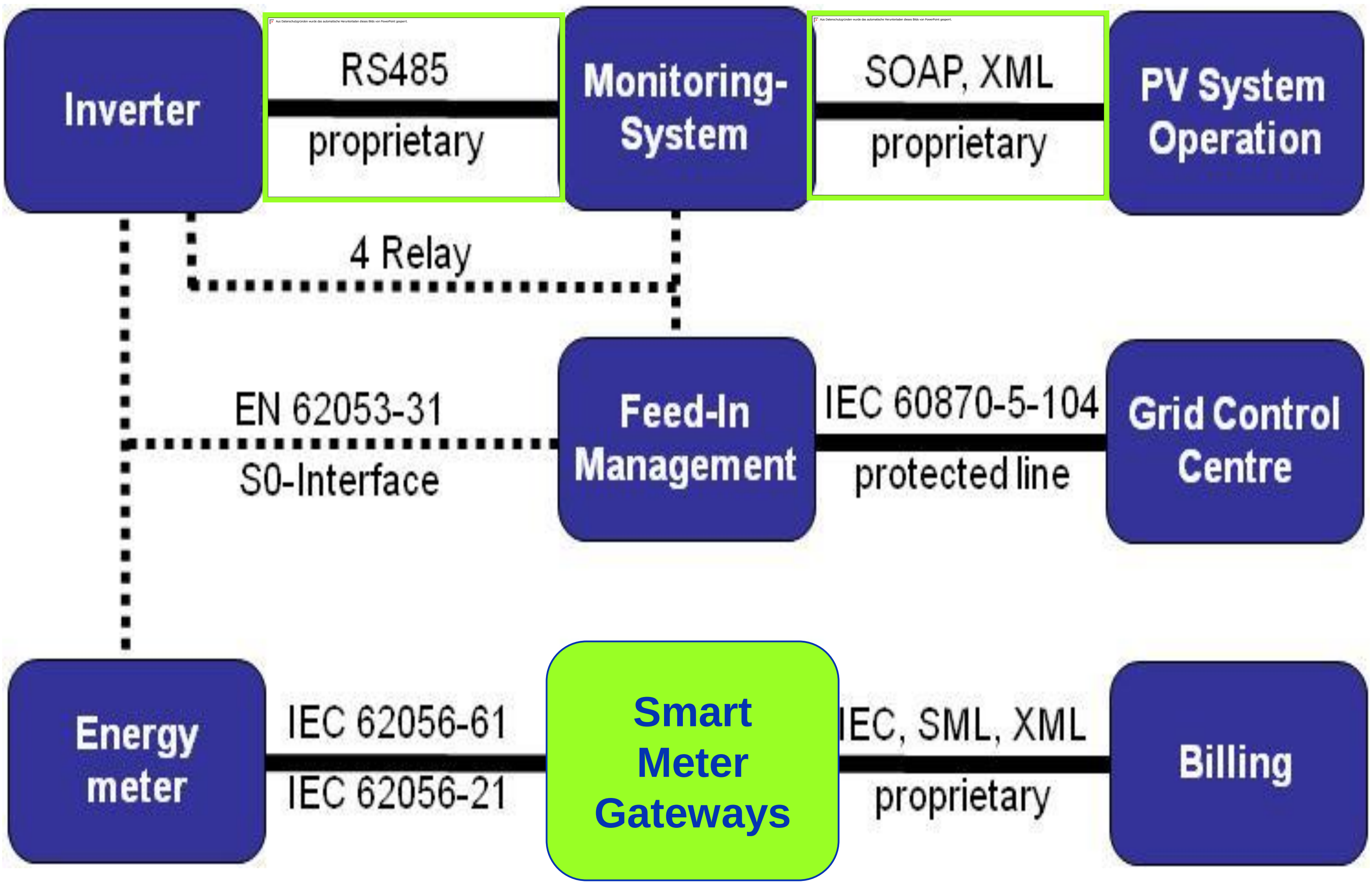
PV Systems Communication Today



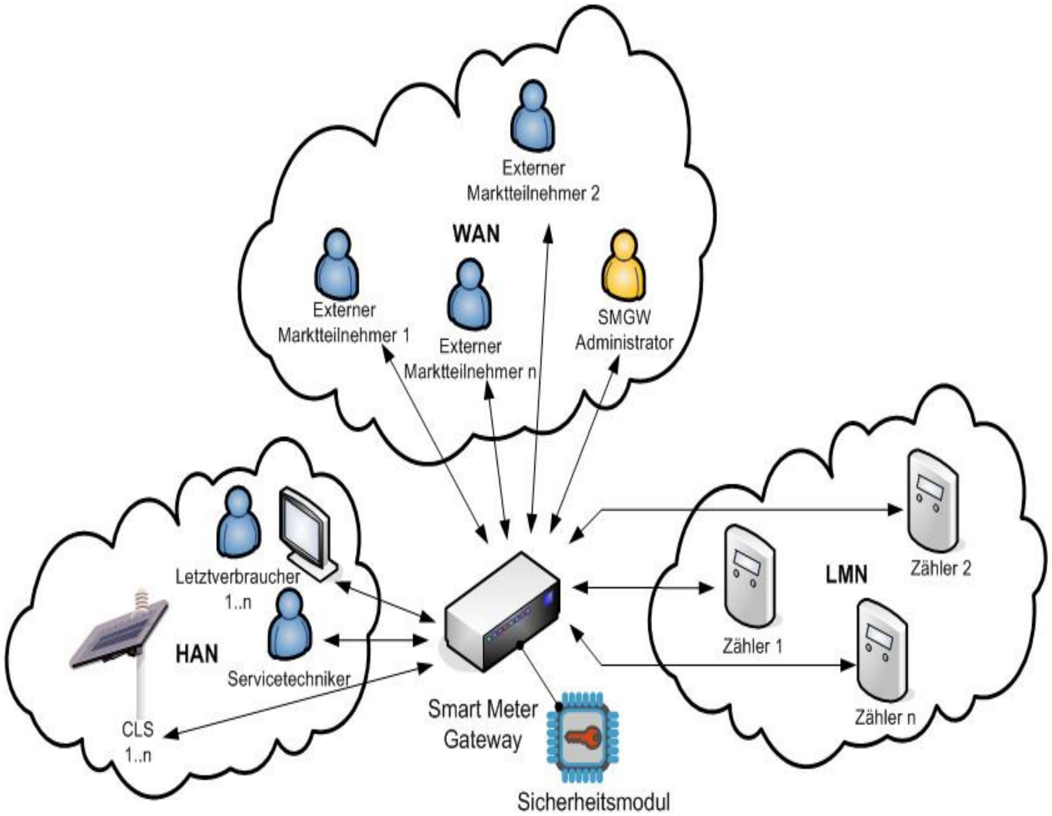
- Three times investment cost
- Barrier for further market development

First Steps towards a DER-Communication Standard

From SunSpec to IEC61850

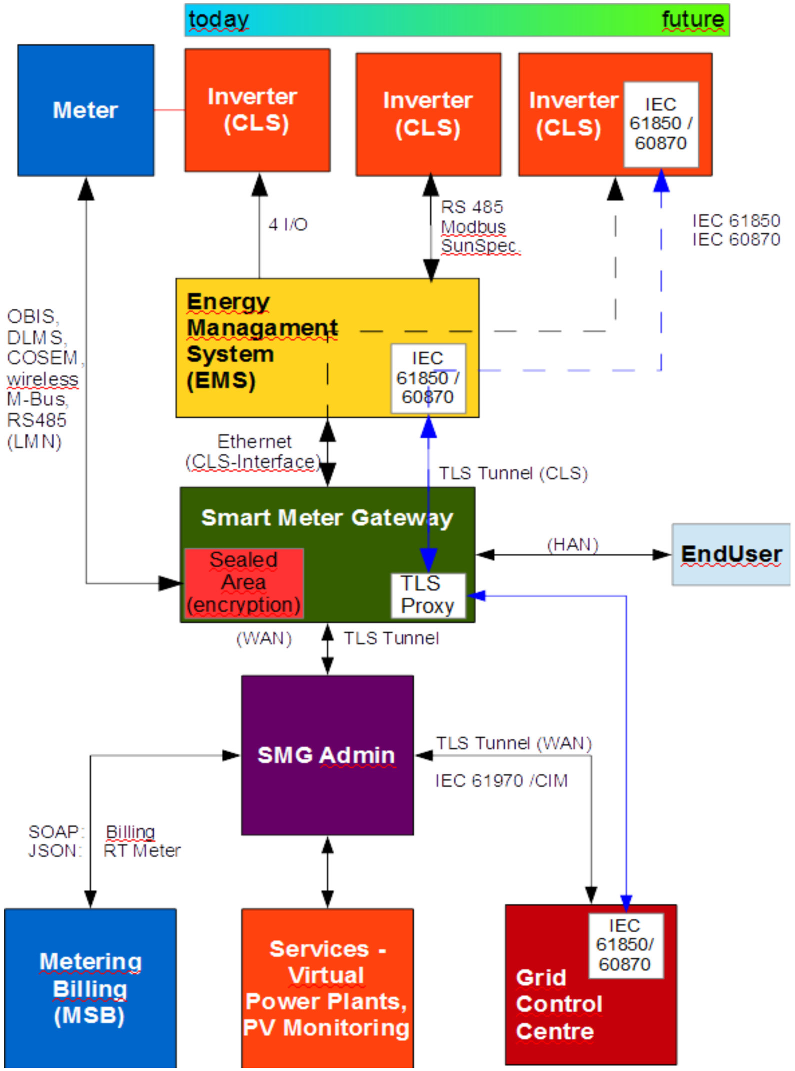


Smart Meter Infrastructure Development



- BSI defining Protection Profiles
- Security Module in the Smart Meter Gateway
- Controlable Local Systems (CLS) connected to Smart Meter Gateway (PV Systems, switchable loads)
- Distributed PV-Systems are first useful application for this infrastructure
- Will drive down costs

PV Systems within the Smart Meter Infrastructure



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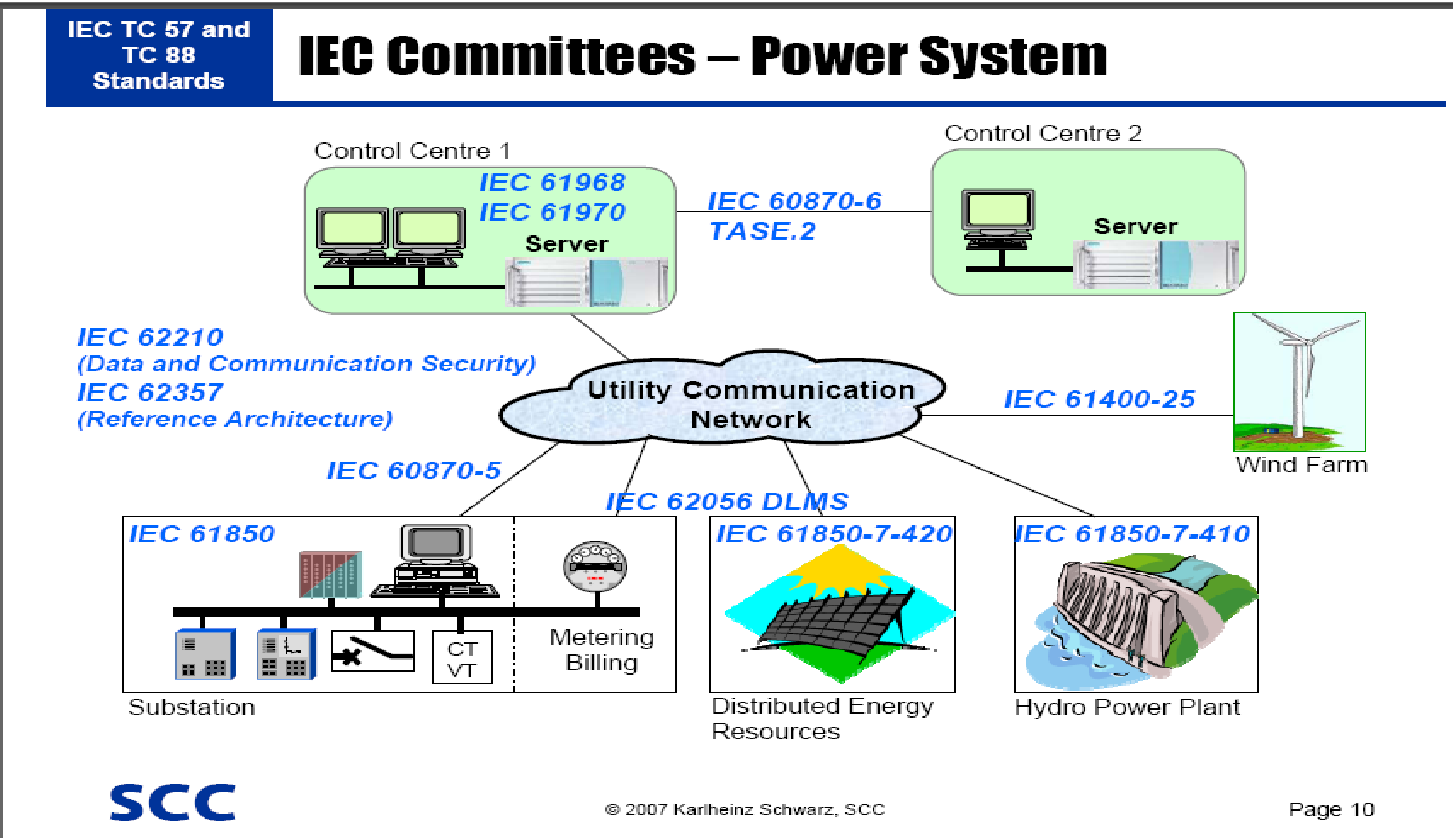
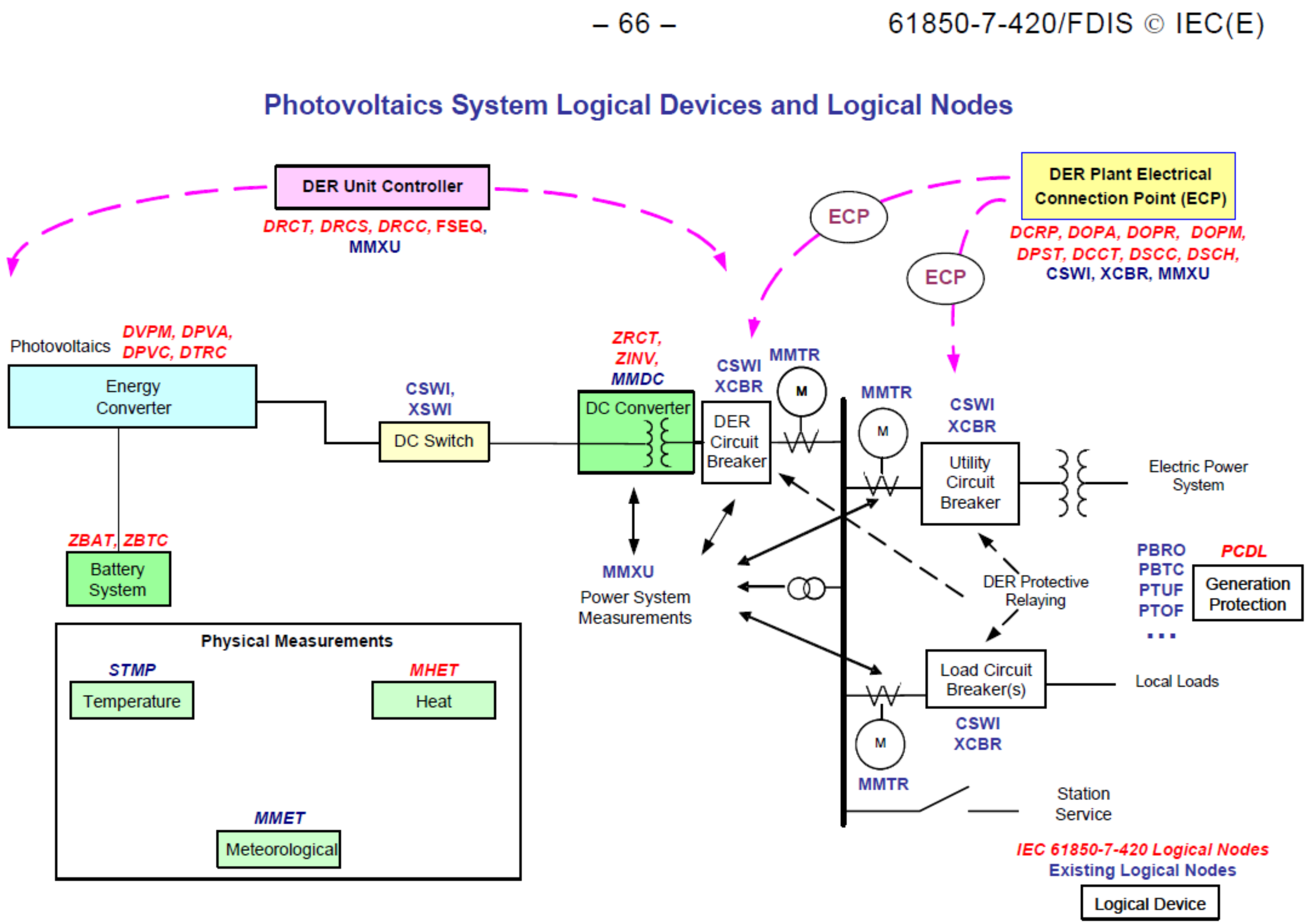
Existing Standards for Communication in Power Systems in Place



IEC 61850 PV Model defined



Smart Grid International Facility Network

- **Primary goal**: Develop and demonstrate a consensus-based interoperability certification standard for advanced Distributed Energy Resources (DERs).
  - Design and compare advanced interoperability test-beds.
  - Perform round-robin testing of advanced DER.
  - Compare test results, communications methods, and automation procedures.
  - Gradually improve draft test procedures for advanced DER with the goal of becoming an internationally-accepted standard.

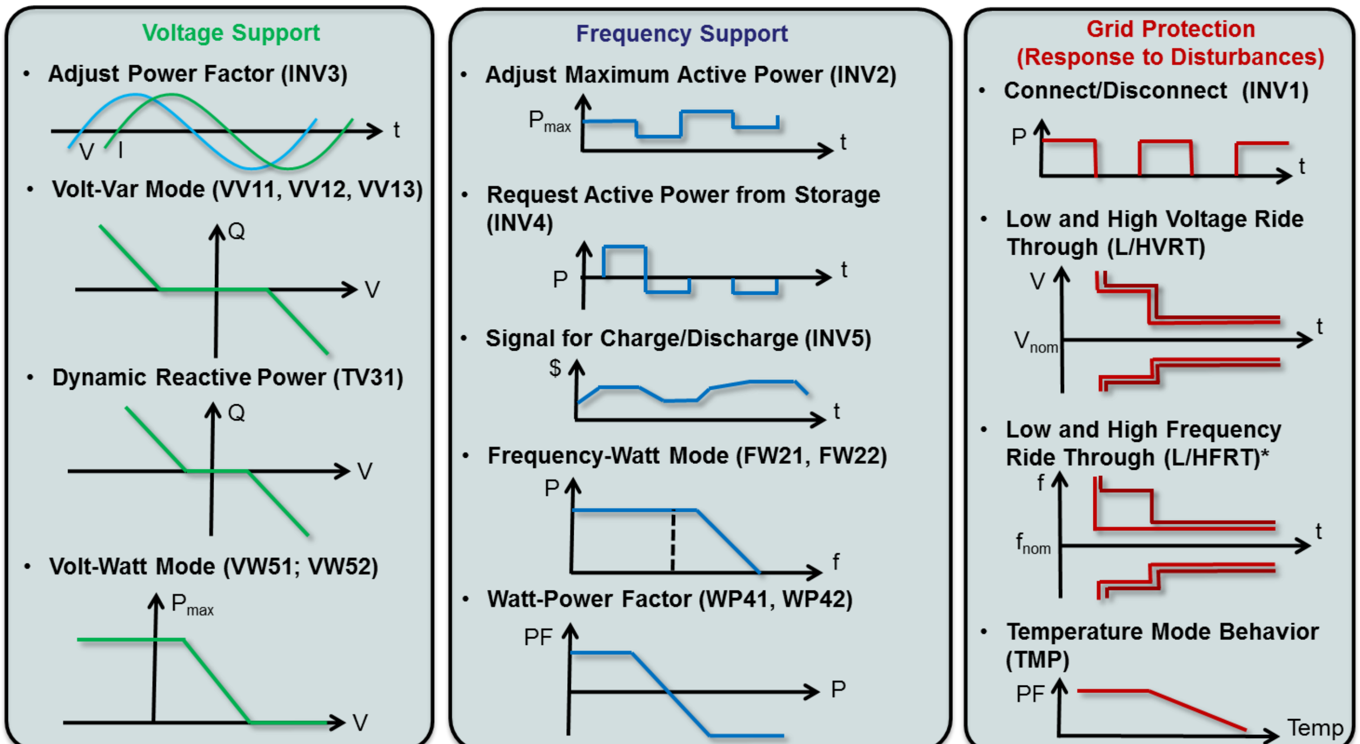
SIRFN - A coordinated network of smart grid research facilities from:

Sandia National Laboratories

Advanced Inverter Functions

- New ‘smart’ inverters will include multiple advanced functions
  - Autonomous: Inverter response to local voltage and frequency conditions
  - Commanded: Remote control (e.g., on/off, set power factor)
- Utilities will modify distributed energy resource (DER) behavior using communications. Reliable interoperability will be required.

IEC 61850-90-7



Source: J. Johnson, Sandia Laboratories

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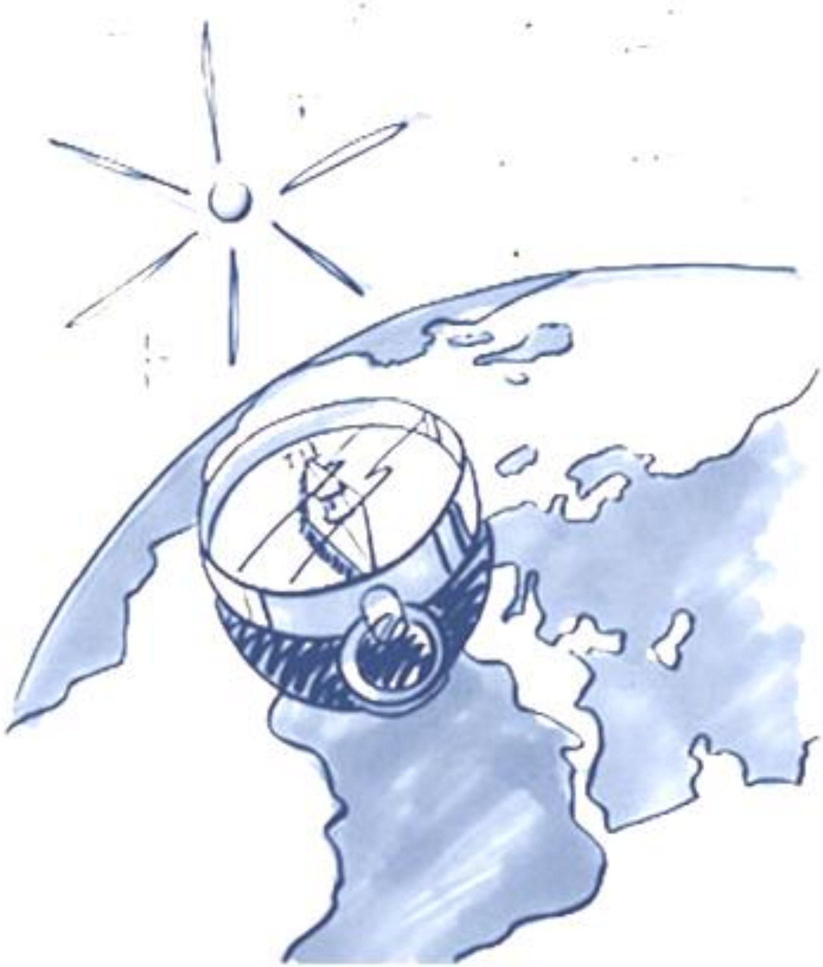

Conclusion and Outlook

- Automatic registration of new PV systems
- PV systems deliver information on the grid status of the low voltage grid
- PV systems support grid services (voltage & frequency stability)
  - Certification, configuration and administration of these grid services
- Feed in management cost will drop significantly
- Make use of secure energy information networks
- Connect PV system with markets
- PV systems work together with the grid in the distribution network automation
- Communication skills are a prerequisite for micro grids and power cells

Questions ?

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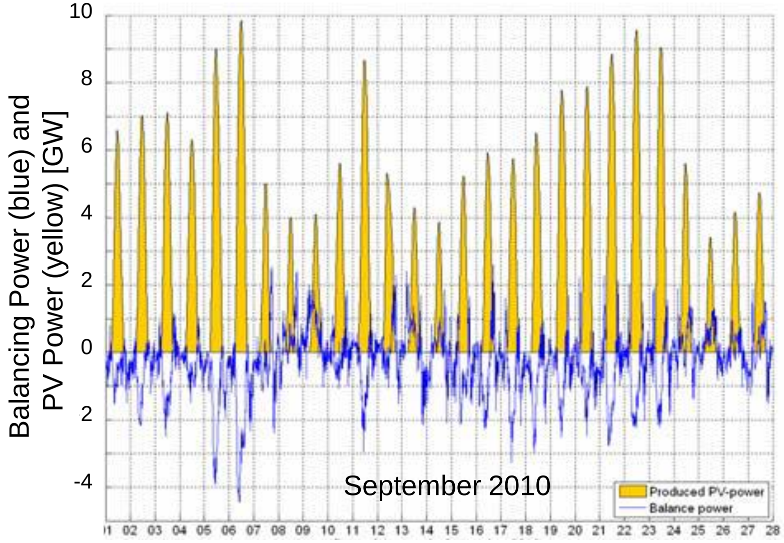
Photovoltaic Systems team up with Smart Grids

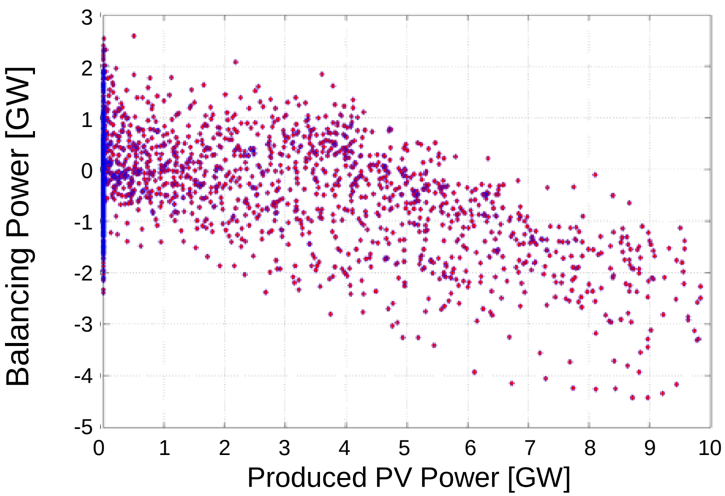
Backup

Personal Background

- Since 2006 Ulm, University of Applied Sciences, Professor on energy data management for decentralized renewable energy systems
- 2002-2006 meteocontrol GmbH – Energy & Weather Services, director
  - Monitoring services for renewable energy systems
  - Weather forecast services for 50 utilities in Germany
- 1998-2001 IST EnergieCom GmbH, director and main shareholder
  - Monitoring of PV systems for several utilities in Germany
- 1991-1998 IST Energietechnik GmbH, shareholder and director
  - Intensified Monitoring within the 1000-Roof-Photovoltaic-Programme
- 1989-1991 IST Energietechnik GmbH, project engineer
- 1988 University of Oldenburg, Master of Science in Renewable Energy
- 1987 Munich, University of Applied Sciences, Bachelor in Electrical Engineering

Impact of Distributed Generation on Network Stability

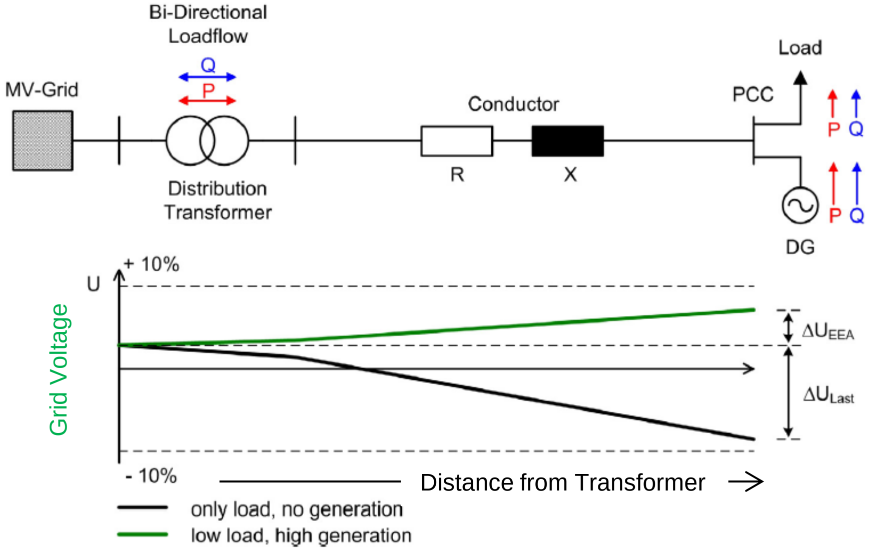


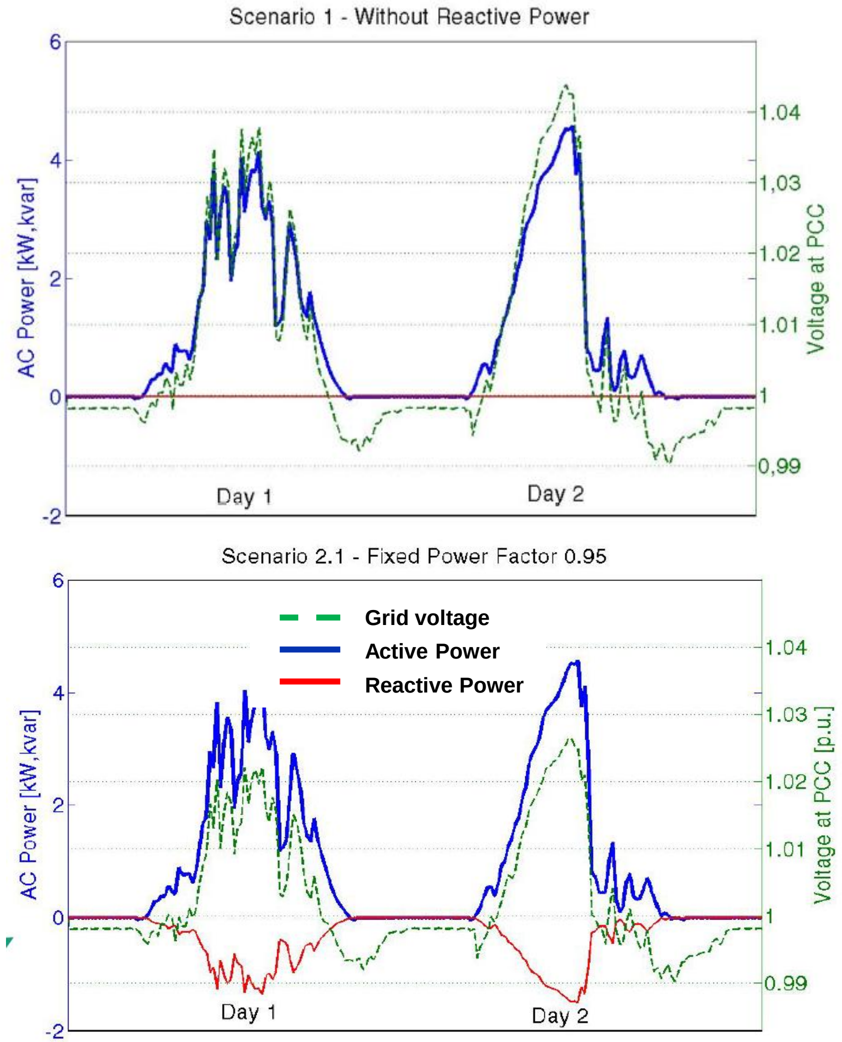


- Unexpected high overproduction of PV-power in September 2010
- Complete negative balancing reserve power (4.3 GW) plus balancing power of neighboring countries (2.8 GW) was used to balance the grid
- Renewable Energy balancing accounts had not been up to date
- Since April 2011 management of the RE balancing accounts is improved
  - Actual number and size of installed PV power is registered and updated monthly
  - Actual power from RE input is measured at reference systems and calculated for the total portfolio
  - 15 Min day ahead forecasts for most DSO RE account is in place

Source: http://www.vde.com/en/fnn/pages/50-2-hz-study.aspx; September 2011

Reactive Power from Distributed Inverters

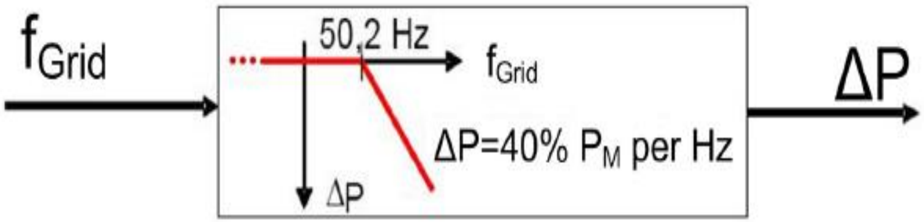




- Active power feed-in increases voltage magnitudes
- Violation of local voltage limitations might lead to cost intensive network reinforcements
- Reactive power provision by PV inverters ensures to stay within limits cost effectively

Source: T. Stetz, Fraunhofer IWES, 2011.

Frequency Stability



$$\Delta P = 20\, P_M \frac{50{,}2\ Hz - f_{Grid}}{50\ Hz}$$ at 50.2 Hz <= f_{Grid} <= 51.5 Hz

P_M = Generated Power

ΔP = Power Reduction

f_{Grid} = System Frequency

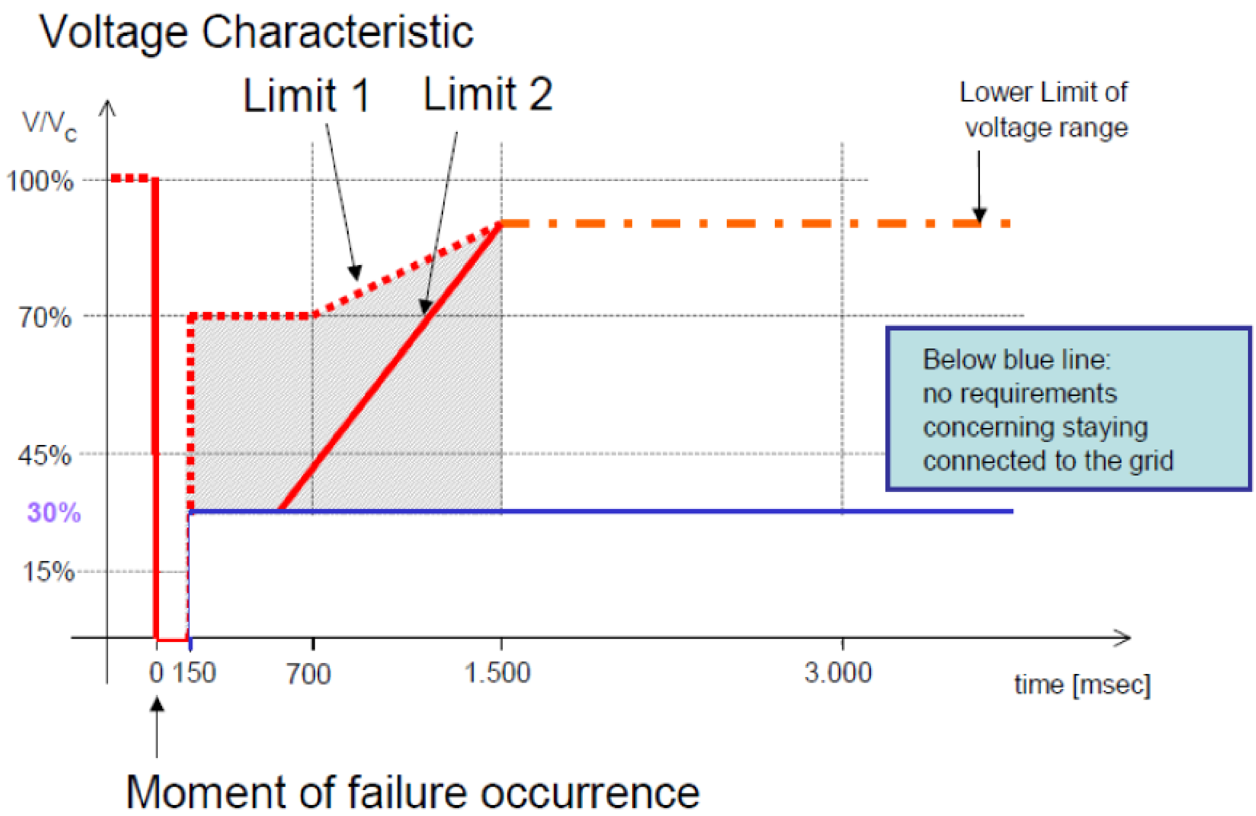
at 47.5 Hz <= f_{Grid} <= 50.2 Hz → No restrictions

at f_{Grid} <= 47.5 Hz or f_{Grid} >= 51.5 Hz → Disconnection

- In the beginning cutout at fixed limits
- This regulation became a danger for grid stability
- Cutout limits have been changed
- Active power limitation at over frequency supports frequency stabilization

Source: BDEW/VDN 2004, translation SMA

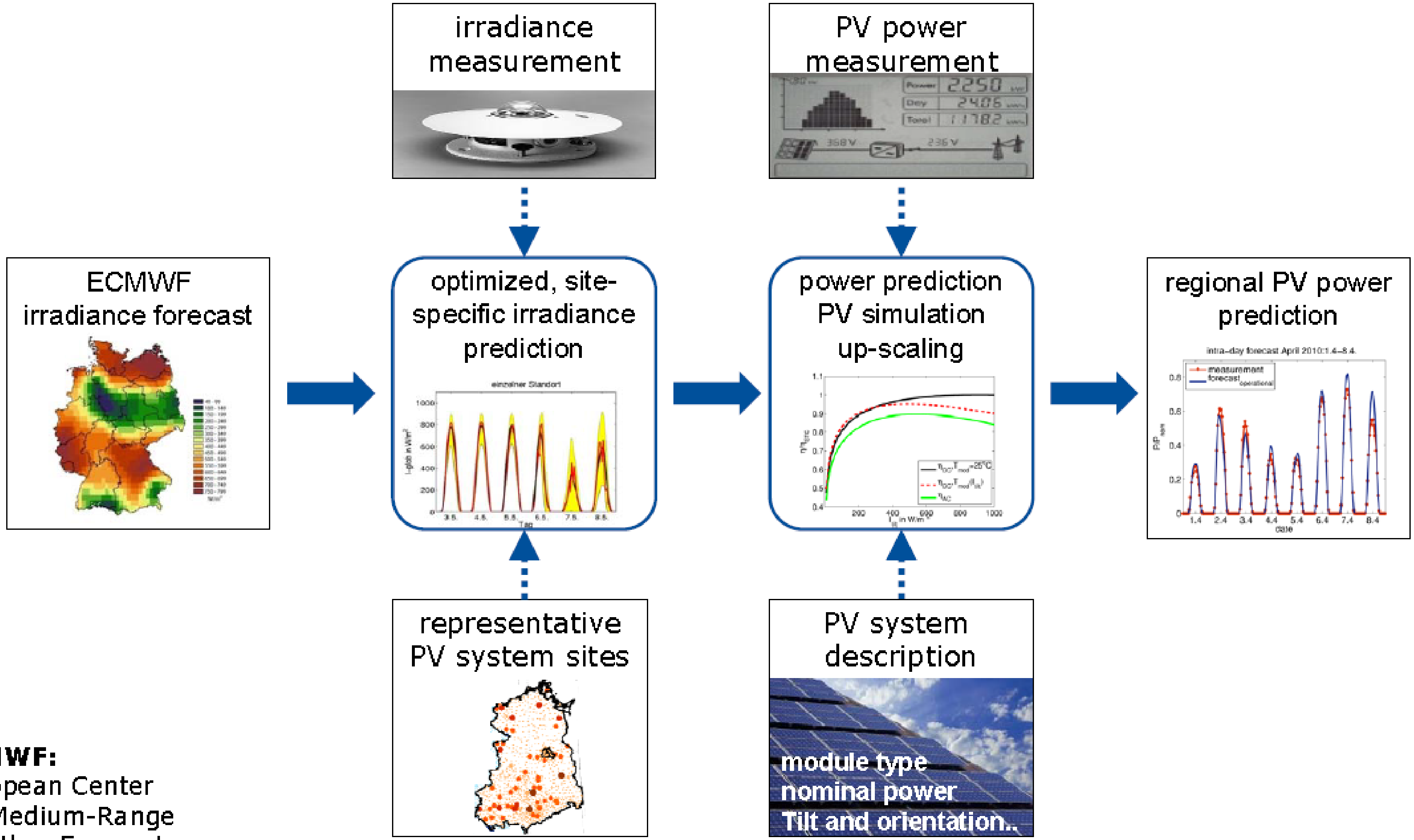
Low Voltage Ride Through at Grid Failure



- Generator at the **medium voltage grid** have to operator also in case of grid failure
- Generator must remain operational above red line

Source: BDEW/VDN 2004, translation SMA

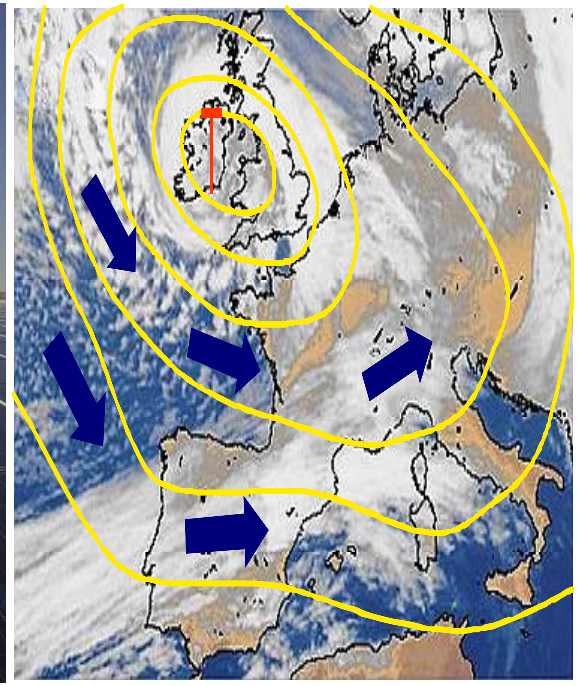
Solar Power Prediction Scheme



ECMWF:
European Center for Medium-Range Weather Forecasts

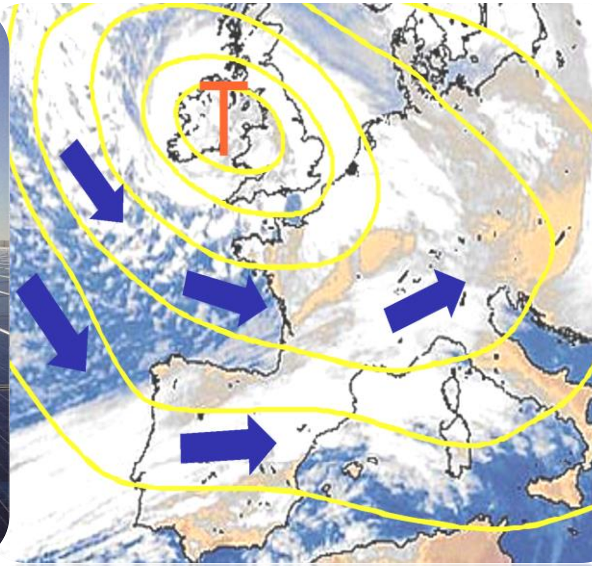
Source: E. Lorenz at al, University of Oldenburg, 2010.

Three different Disciplines… have to Understand Each Other



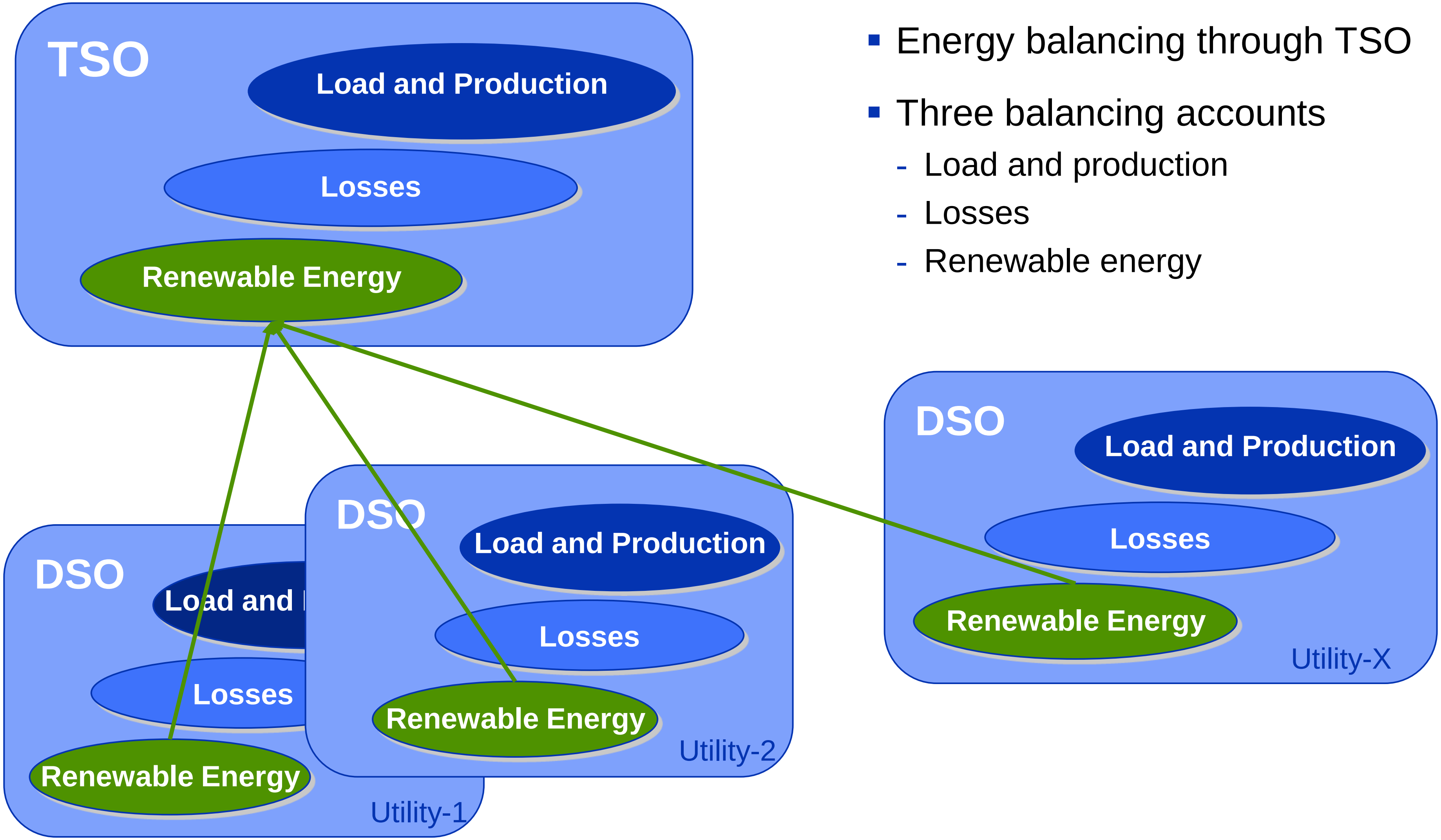
	Photovoltaic	Meteorology	Utility Network
Main topic	Financial break even	Weather of tomorrow	Load Balancing
Heartbeat	1 Second	1 Hour	15 Minutes
Forecast	years	days	Tomorrow 8h00, 8h15,…

Energy Meteorology



- Adapt PV systems to the energy economy and utility system management aspects
  - Real time data for observe ability
  - Interaction
  - Grid assistance
- Develop forecast products to the needs of the variable renewable power
  - Higher time resolution
  - New forecast parameters (ramps)
- Invest into energy meteorology
- Adapt utility grid to variable distributed power input

Renewable Electricity Market Integration



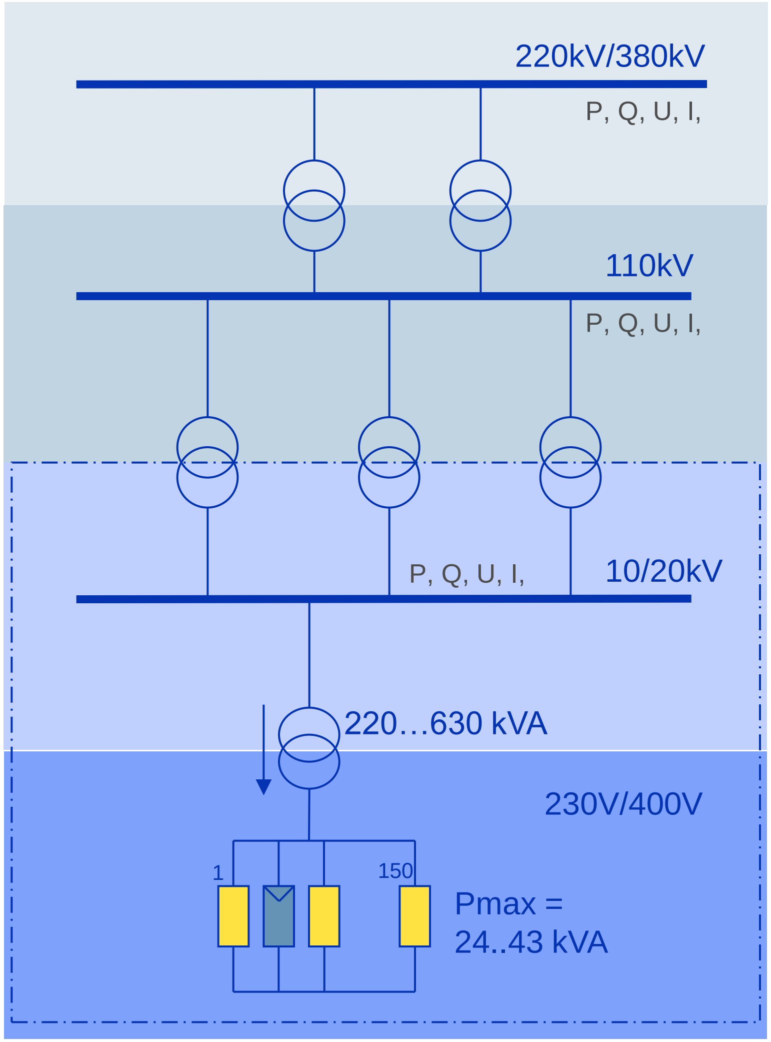
- Energy balancing through TSO
- Three balancing accounts
  - Load and production
  - Losses
  - Renewable energy

Evolution of PV grid services in Germany

	Medium Voltage			Low Voltage		
	2007	2008	2012	2007	2008 / 2011	2012
Grid Connection	• PV systems have to be connected • Definition of grid access point in shortest dist. • Feedback on schedule and cost of grid connection within 8 weeks			• PV systems <30kW use existing grid connection • Cost of grid connection with PV owner • Cost of grid extension with grid operator		
Metering	• Daily quarter hourly forecast of PV input by DSO and TSO		• PV > 100kW need meter communication	• Every PV system has a meter • Daily quarter hourly forecast of PV input by DSO and TSO		• PV > 100kW need meter communication
Feed-in management (curtailment)	No curtailment for PV systems	• P > 100kW Curtailment to e.g. 60%, 30%,0%	• All systems Curtailment to 60%,30%, 0%	No curtailment for PV systems	P > 100kW Curtailment to 60%,30%, 0% of Pn at grid overload	• Curtailment for every system • P<30kW power reduction to 70% (option)
Frequency stability	Cut off at f > 50.2 Hz f < 49,5 Hz	• Stay on! 47,5Hz < f < 51.5Hz • Reduce P if f > 50.2Hz • Cut off at f < 47,5Hz, f > 51.5Hz		Cut off at f > 50.2 Hz f < 49.5 Hz	• Stay on! 47,5Hz < f < 51.5Hz • Reduce P if f > 50.2Hz • Cut off at f < 47,5Hz, f > 51.5Hz	
Voltage stability	No grid stability services	cos φ = =+/- 0.95 Characteristic of profile and gradient defined by local utility		No rules for PV systems	S_{Emax}< 3.68kVA φ= +/-0.95 3.68kVA < S_{emax} < 13.8kVA φ= +/-0.95 S_{Emax}> 13.8kVA φ= +/-0.9	
Grid Failure	No rules	Low voltage ride through		No rules for PV systems		

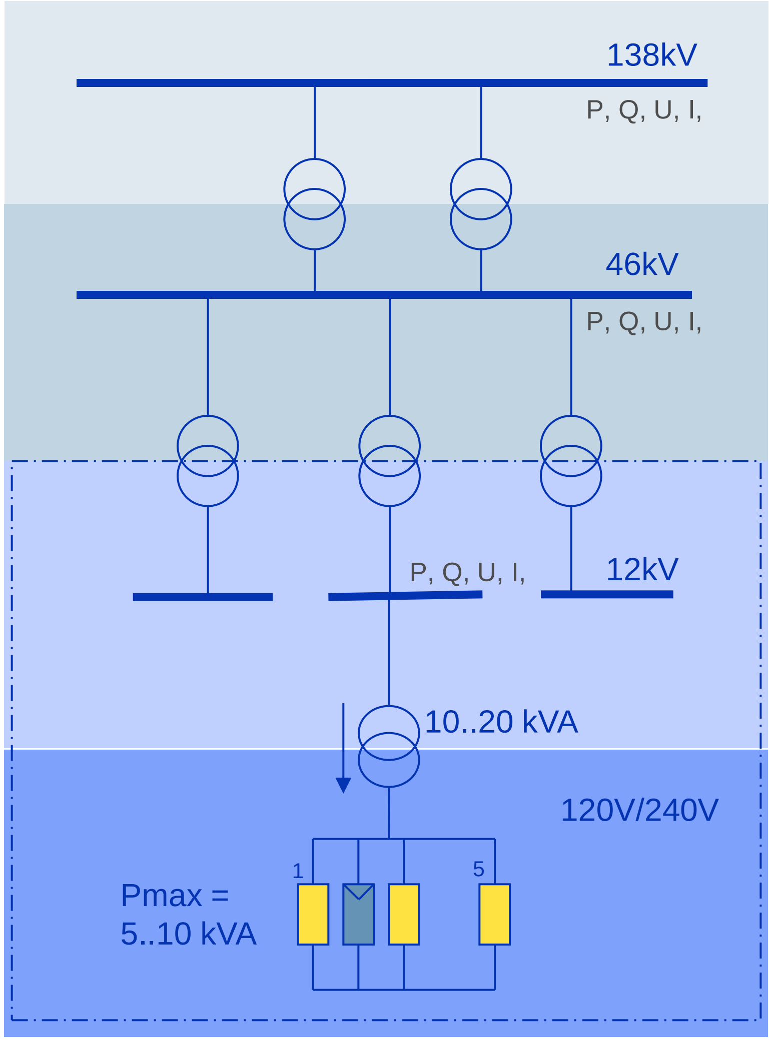
Comparison Germany - Hawaii

Grid Layout



Main Differences

- Transformer capacity
- Voltage Level
- Number of households per LV transformer
- Household connection capacity



Operation Control Centre – RED, Spain

Source: Hidalgo, RED Electrica de Espana, 2010

Renewable Energy Input

Transmission Grid

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