Photovoltaic Systems in Grid Connected Applications and Mini-Grids

Technical Solutions, Requirements and Trends

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Fraunhofer Institute for Solar Energy Systems ISE

Director:
Prof. Eicke R. Weber

Staff: 830

Budget: €52.4 million

Established: 1981

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Fraunhofer ISE
Research & Development, Services

Fraunhofer ISE Areas of Business

- Energy-Efficient Buildings and Technical Building Components
- Applied Optics and Functional Surfaces
- Solar Thermal Technology
- Silicon Photovoltaics
- Alternative Photovoltaic Technologies
- Renewable Power Generation
- Hydrogen Technology

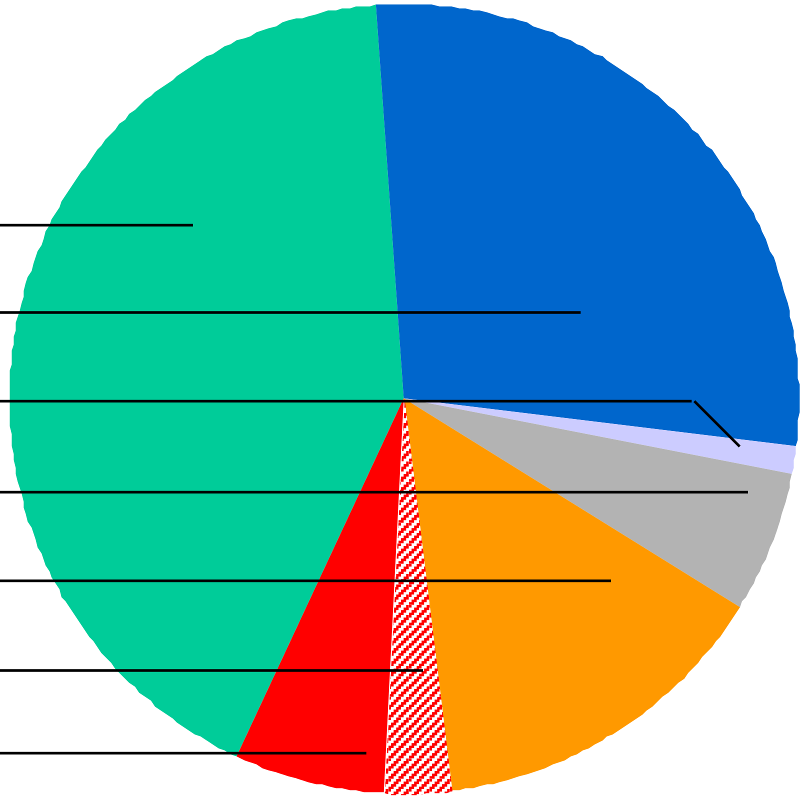
Test Facilities

- Solar Cell Calibration Laboratory (ISE CalLab)
- PV Module Calibration Laboratory (ISE CalLab)
- VDE-Fraunhofer ISE Test Center for Photovoltaics (TZPV)
- Testing Center for Thermal Solar Systems (PZTS)
- Thermal-Optical Measurement Laboratory (TOPLAB)
- Battery Testing Laboratory (BTL)

Revenue Structure, Operation 2008

Operation:	€40.2 million
Investment:	€14.4 million
Total:	€54.6 million

Industry	42%
Fed. Gov. Projects	28%
Regional Gov. Projects	1%
European Union	6%
Others	14%
Special Programs, FhG	3%
Basic Funding*	6%



* of which 90% Federal Government
10% Regional Government, BW

Status: 14 May 2009

Photovoltaic Systems in Grid Connected Applications and Mini-Grids

- Systems: Small distributed systems, PV plants, PV backup systems, PV in mini-grids
- Standards and regulations
- Power quality
- Grid control / grid stabilization
- Feed-in tariffs, e.g. German renewable energy act
- Market developments
- Scenario of European PV industry association
- Vision for developing countries

Distributed, grid-connected photovoltaic systems

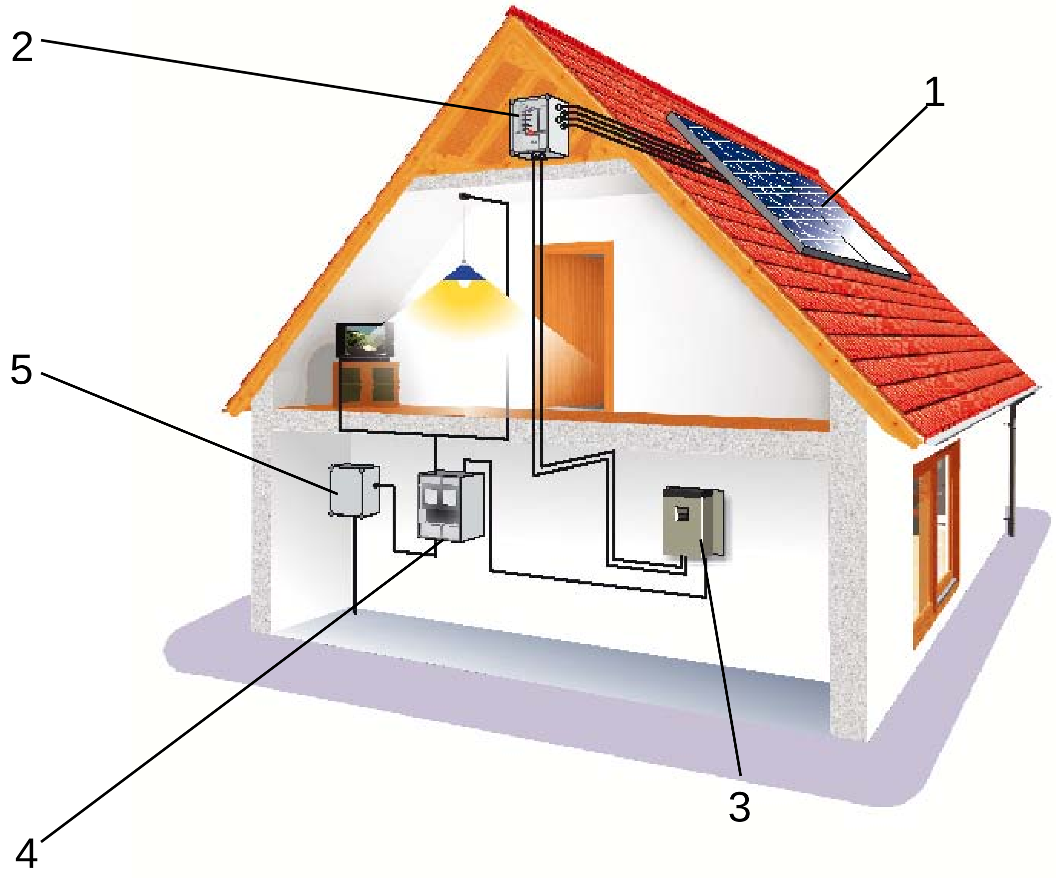
- House in Kirchzarten, Germany

Distributed, grid-connected photovoltaic systems

- Central train station in Freiburg, Germany

System outline and application modes

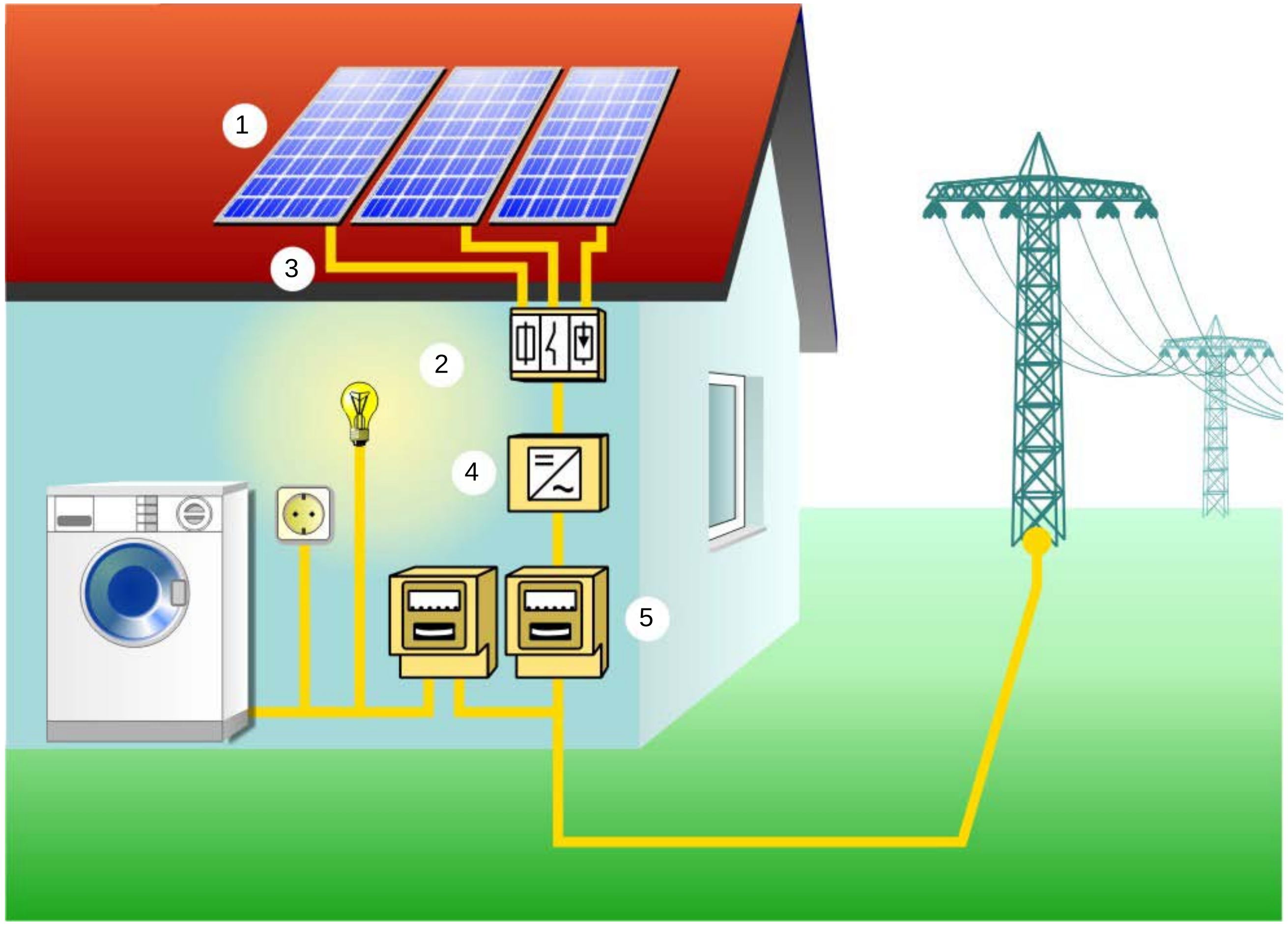
- Small distributed systems
- simple structure of grid-connected PV systems:
  PV ⇒ inverter ⇒ grid
- mostly private operators in low power range
- Installations mainly on roofs
- Connected to low voltage grid



PV generator 1
generator connection box 2
inverter 3
meters 4
grid connection box 5

Image: Solarpraxis AG, Berlin, Germany

Direct feed-in of electricity into the public grid



1 PV generator
2 connection box
3 DC cabling
4 DC-AC inverter
5 meters

Image: Solarpraxis AG, Berlin, Germany

Feed-in to an intermediate sub-grid (e.g. building)

Example for meter readings:

1 solar meter 100 kWh

2 total consumption of building: 1000 kWh

3 consumption meter: 910 kWh

4 delivery meter: 10 kWh

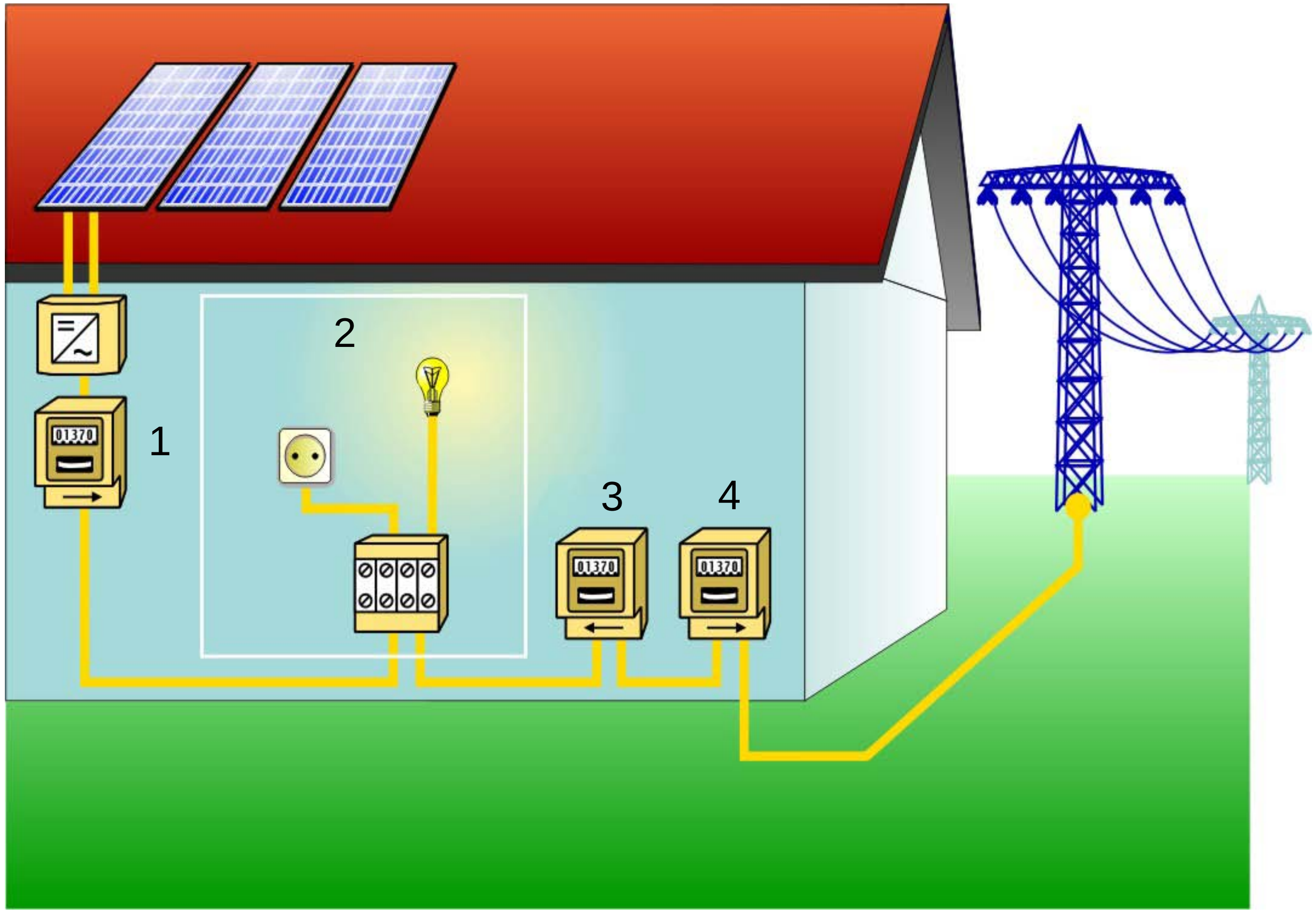
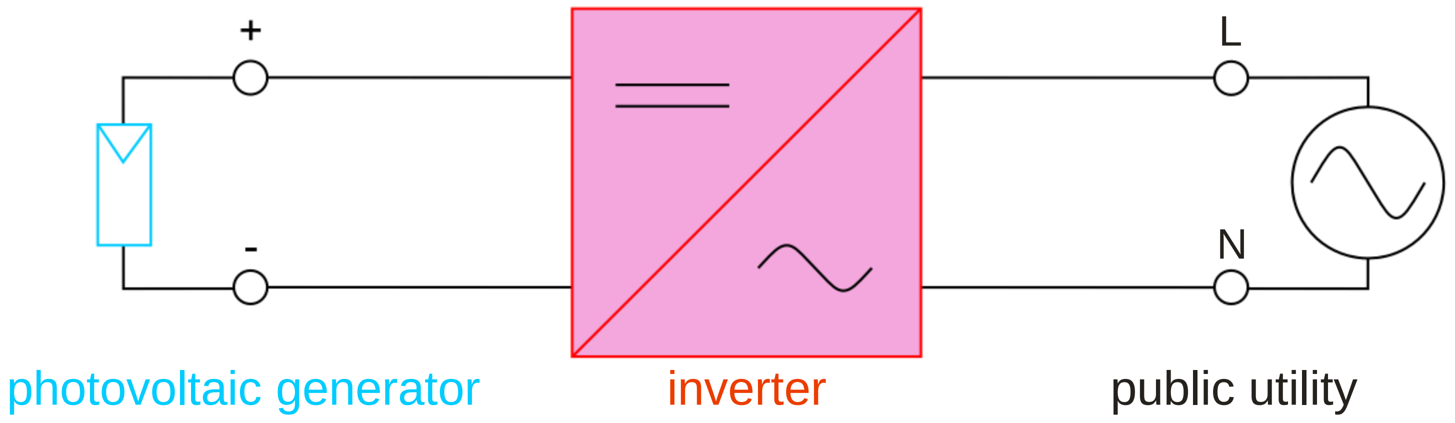


Image: Solarpraxis AG, Berlin, Germany

Requirements for grid feeding inverters



Technical Requirements

- high efficiency → find and stay at MPP
  → minimizing grid interference
- simple system monitoring → access to operating data

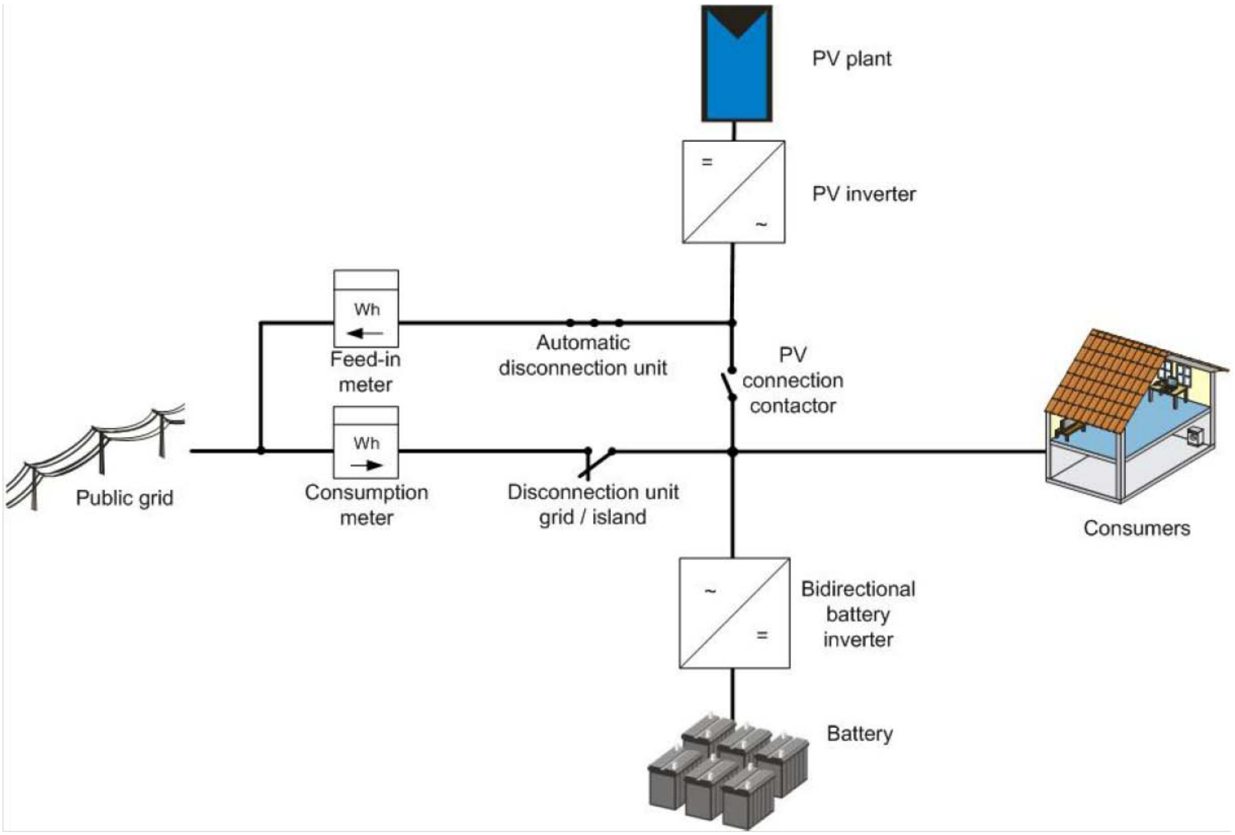
Economic Requirements

- low price → simple technical solution
- high reliability → heavy duty equipment

Image: SMA Regelsysteme GmbH, Niestetal, Germany

Back-up systems with two energy meters AC

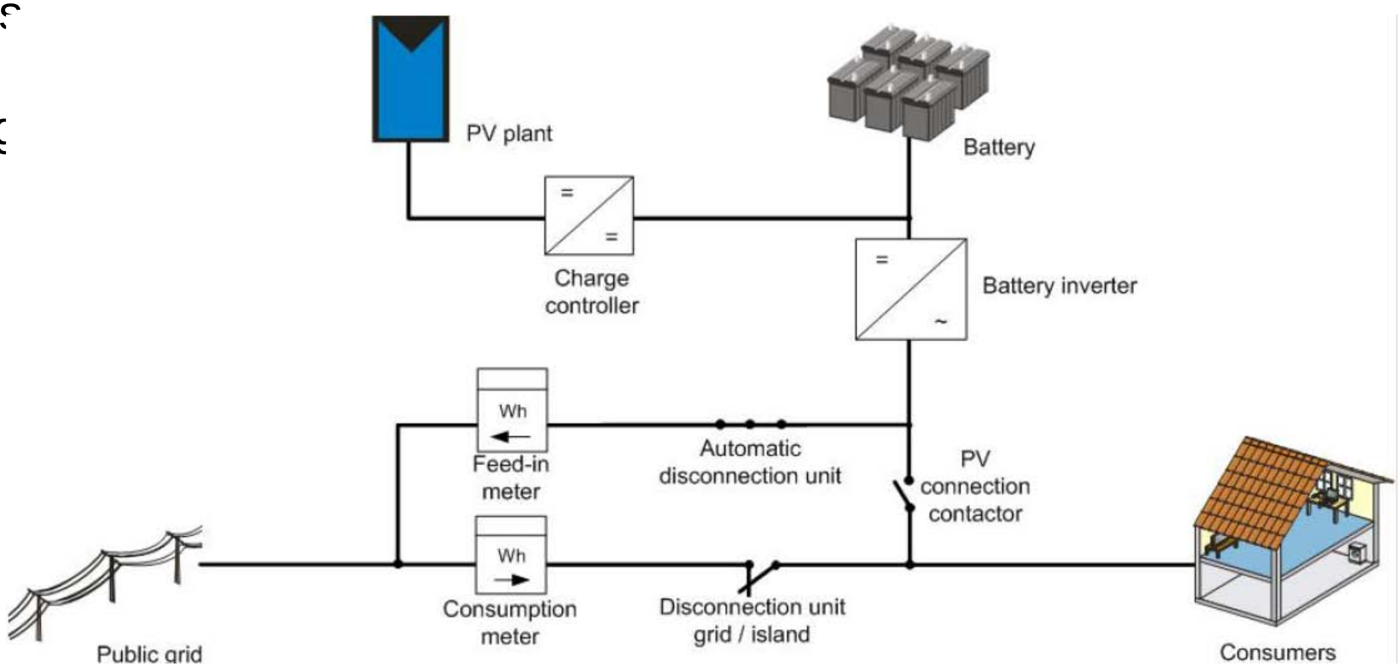
- Back up systems with separate electricity meters for generation and consumption



Source SMA

Back-up systems with two energy meters DC

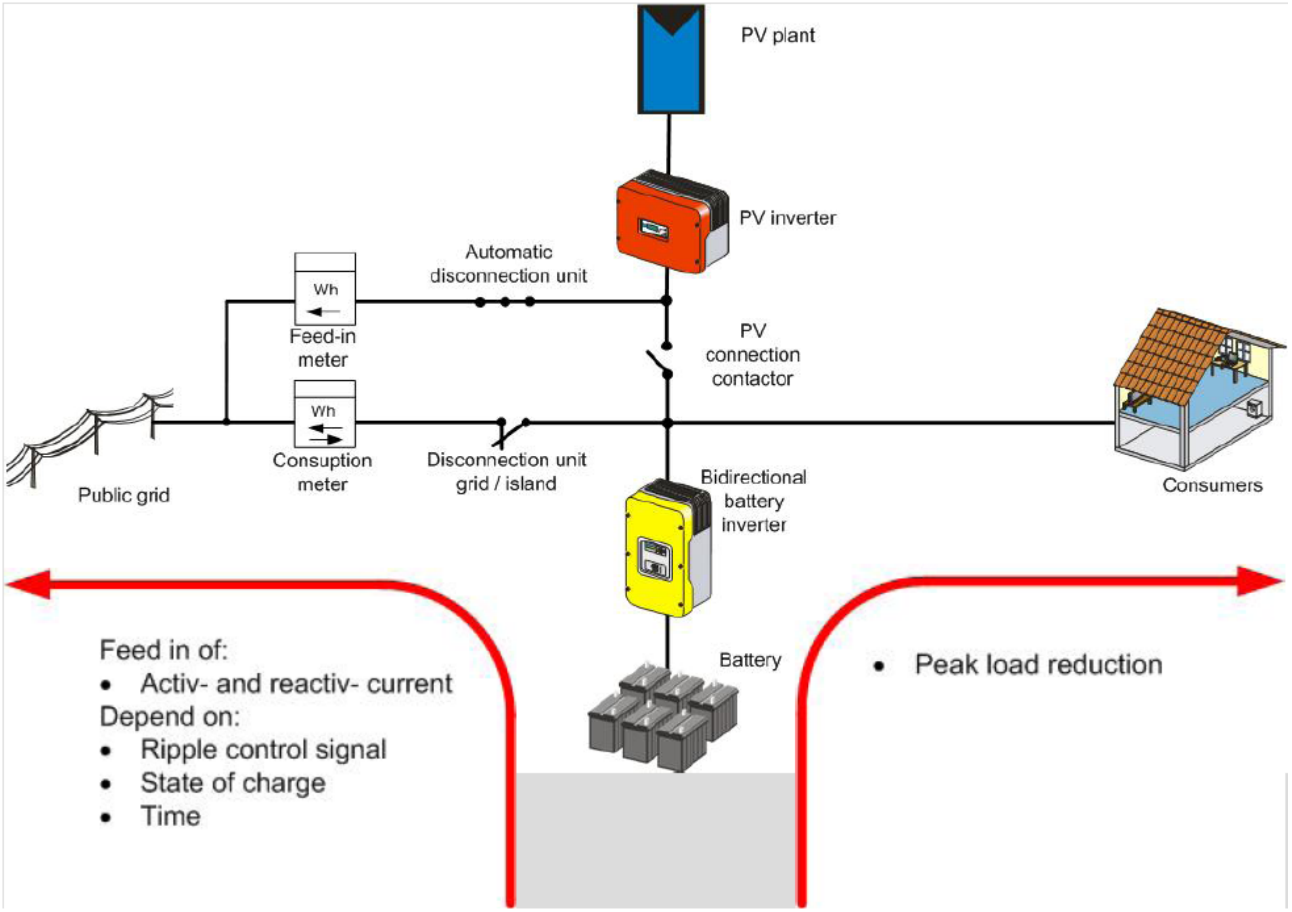
- Back up systems with separate electricity meters for generation and consumption and coupling of PV over charge controller



Source SMA

Benefits in case of grid availability

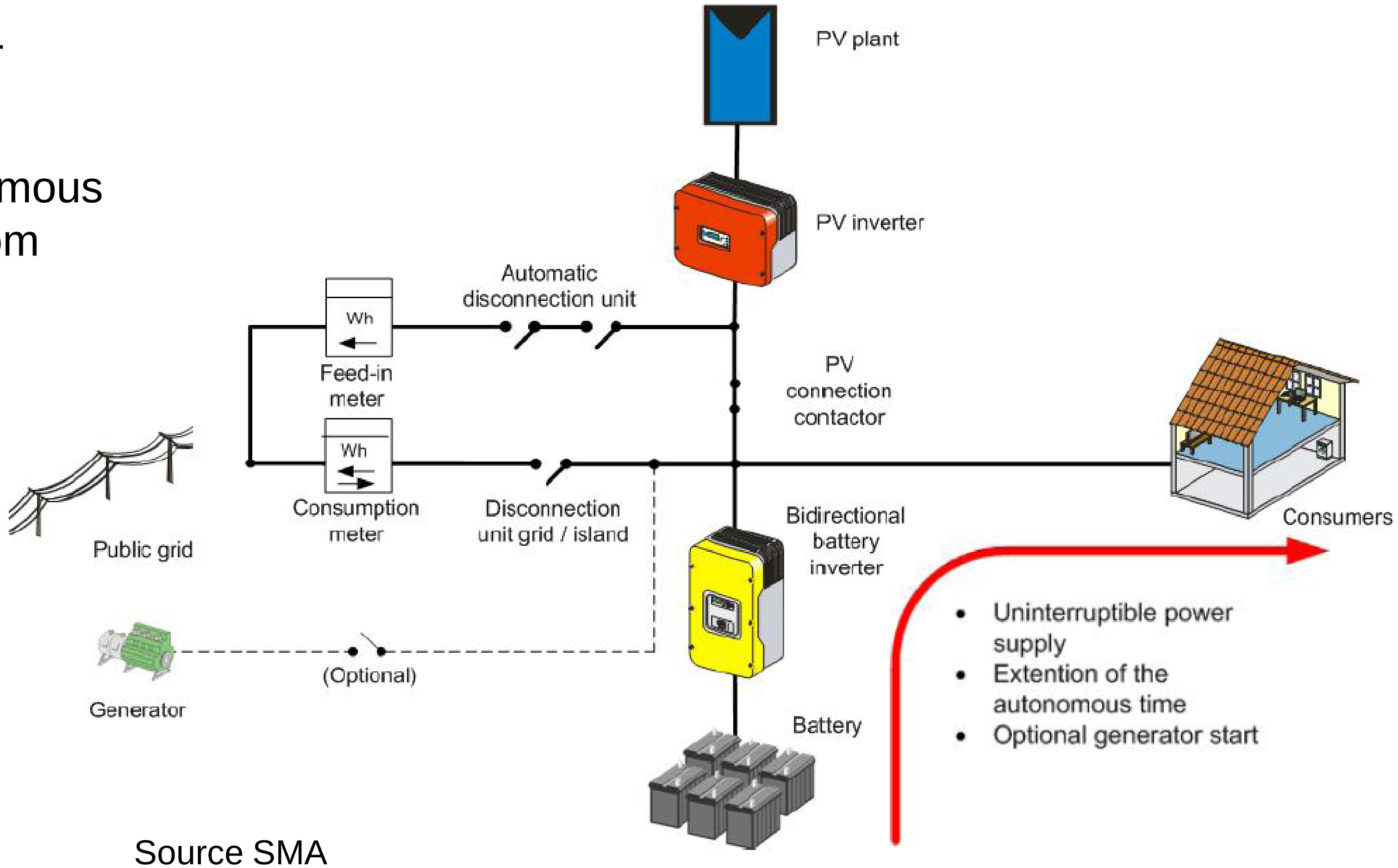
- Ability to feed an active or reactive current into the public grid



Source SMA

Customers benefits in case of grid failure

- Uninterrupted power supply
- Extension of autonomous time with support from renewable energies



Source SMA

Large systems for commercial business operation

- Commercial operators only in high range: > 100 kWp
- Installed on the ground, on flat roofs or integrated into buildings
- Direct feed-in to the medium-voltage grid
- Additional benefits possible (peak load supply, voltage stabilization)

Photo: Voltwerk AG, Hamburg, Germany

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Grid-connected photovoltaic power plant (Freiburg)

Photo: Fraunhofer ISE, Freiburg, Germany

Grid-connected photovoltaic power plants

- Concentrated photovoltaics CPV

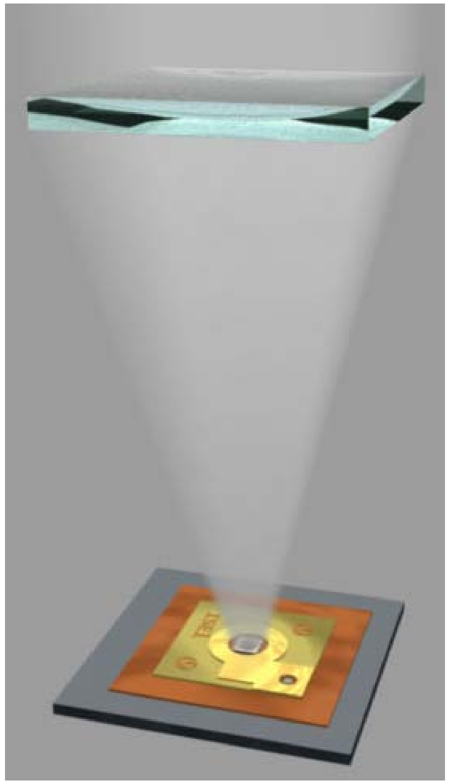
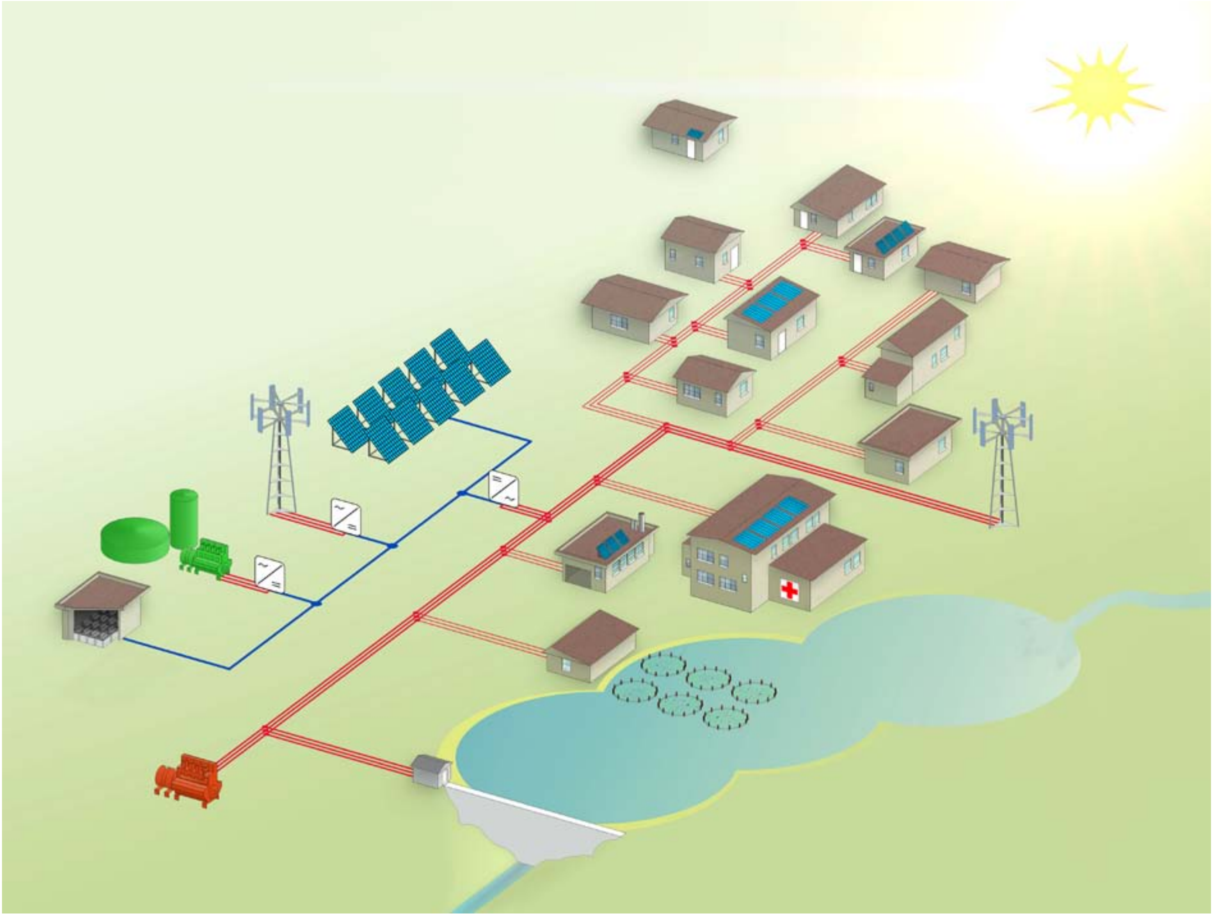


Photo: Concentrix Solar

Electrification based on next generation of hybrid PV mini-grids

- Integration of different energy sources (PV, Wind, Hydro, etc.)
  → Least cost option
- Increasing quality of energy services
- Promoting local infrastructure and economic development
- Complement to the national electricity network / grid



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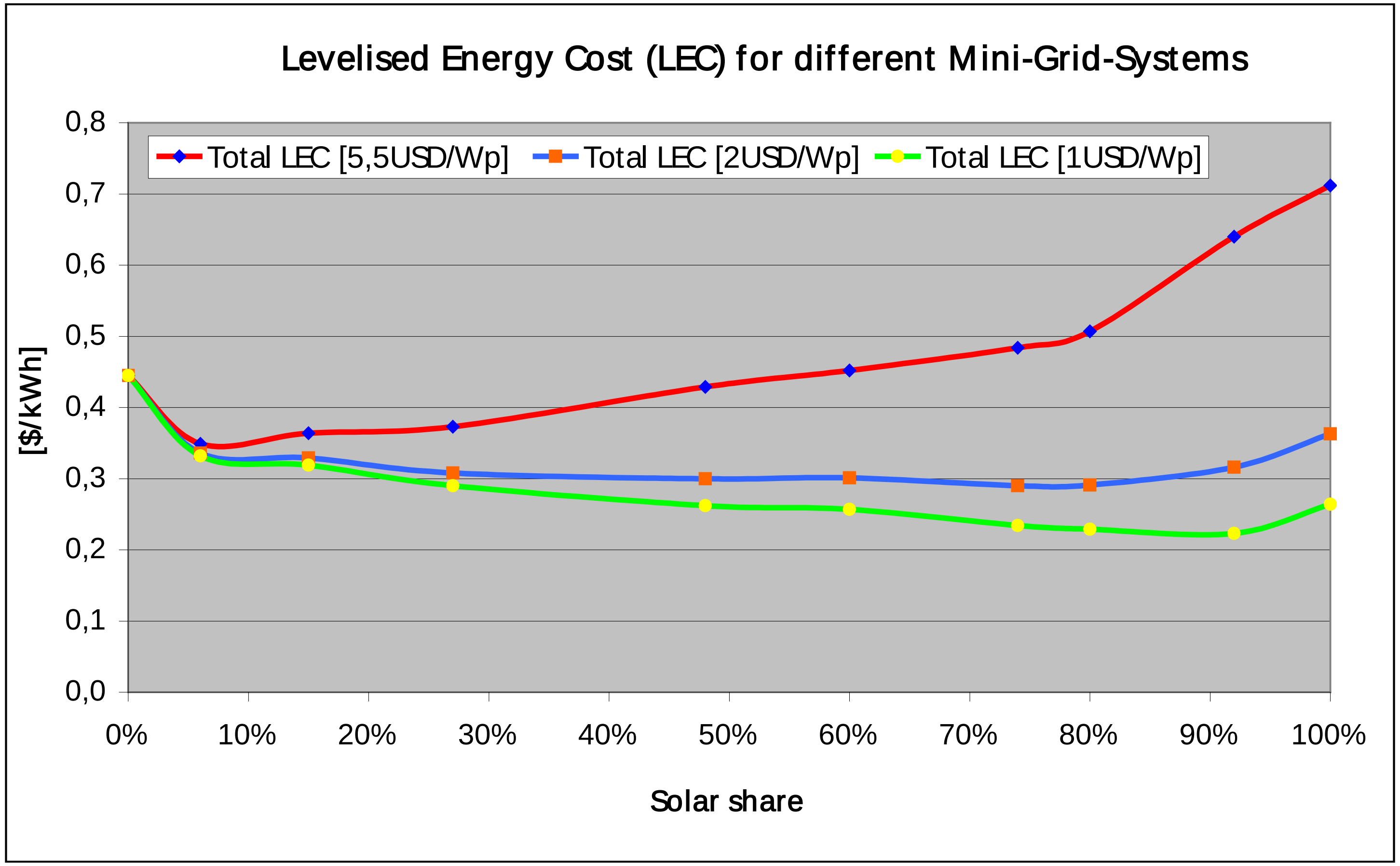
System analyses – Example Mexico

→ Variation of module price

Reference case:

- 99 Households, classified in four groups, a rural clinic and a fish factory
- Daily consumption: 2849 kWh
- Peak power: 200 kW
- Diesel price: 0,7 $/l



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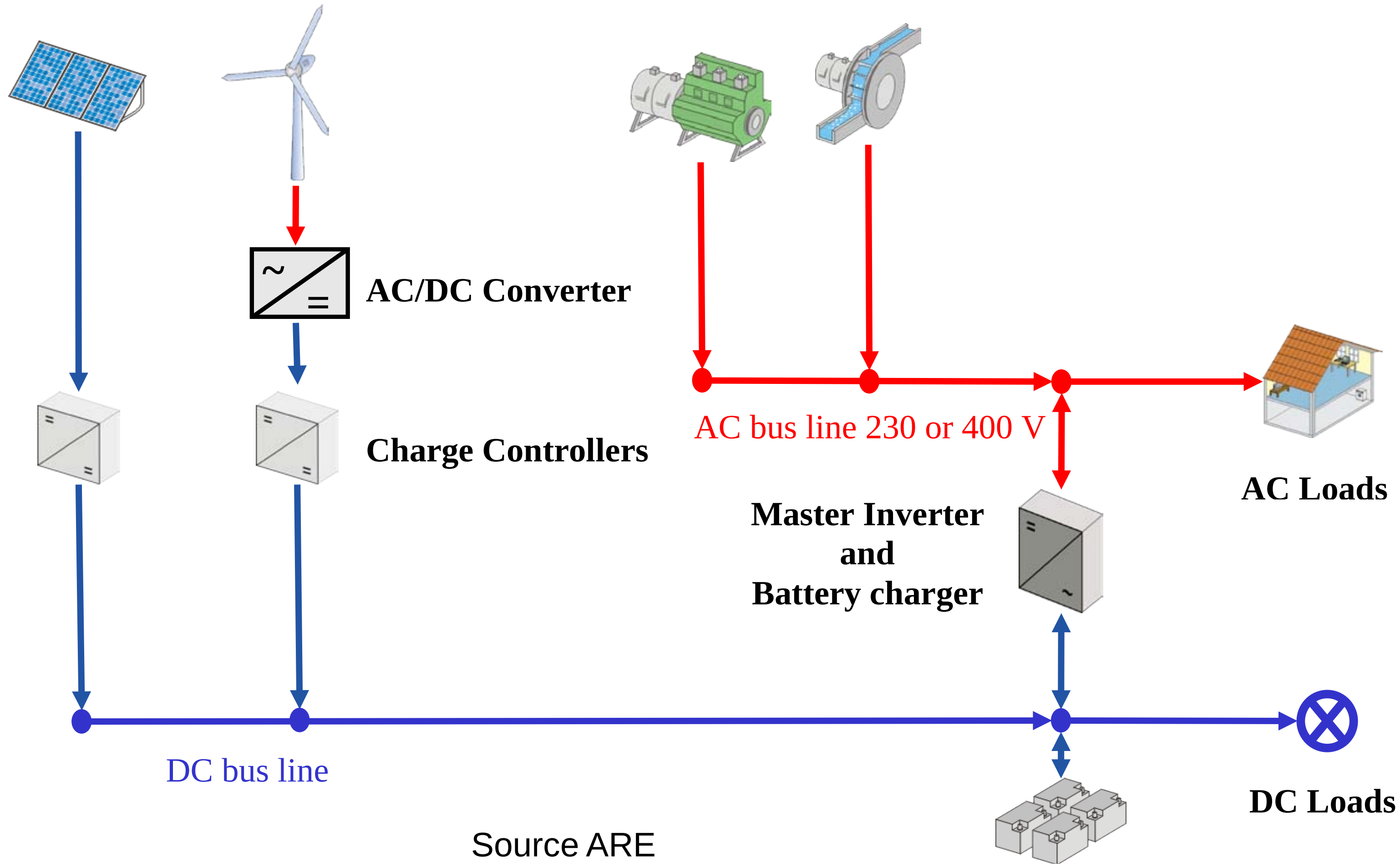
System design

DC/AC mixed

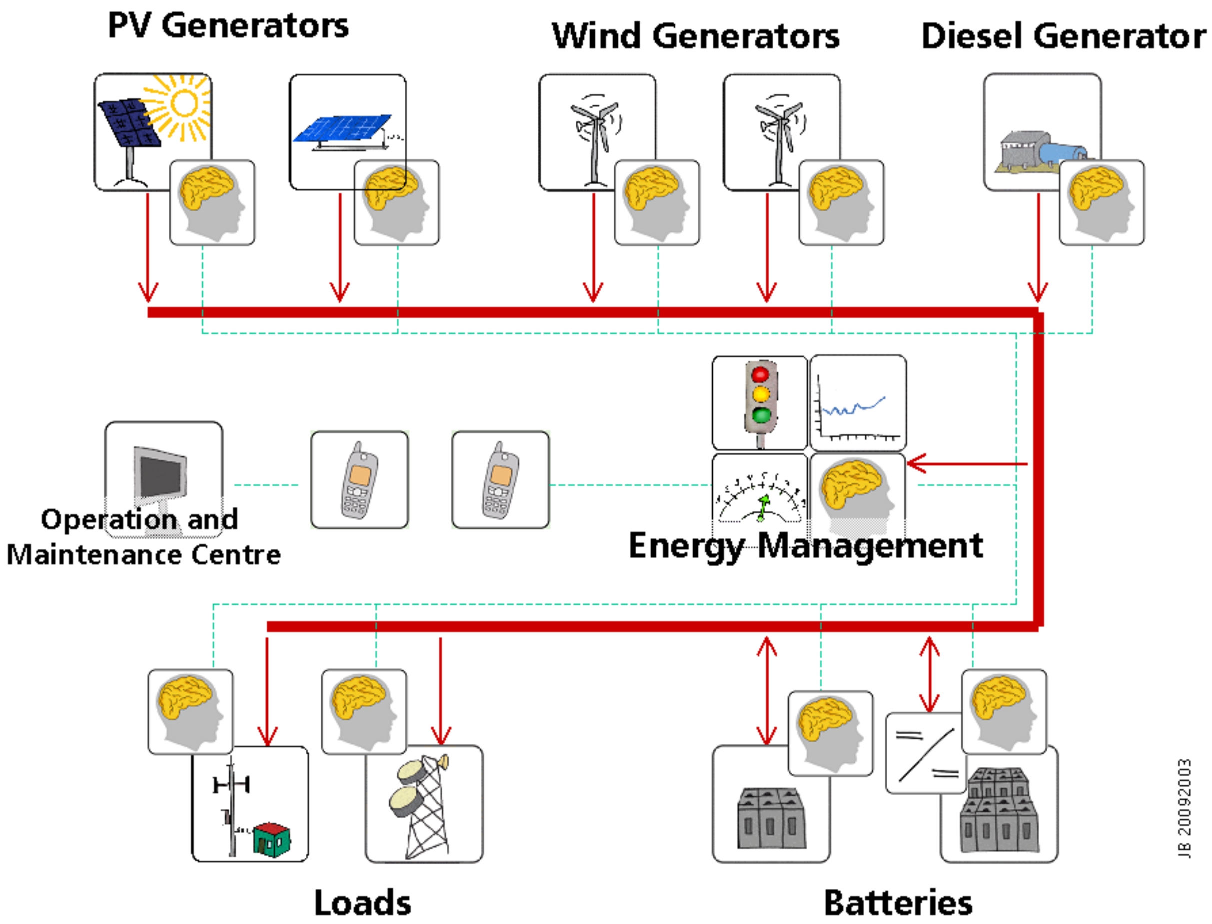


Source ARE

Standardised communication concept

- Supervisory energy management system
- Intelligent components
  - Power generation
  - Battery management
  - Demand-side
- Communication bus
- Standardised “universal energy supply protocol”

→ Modular, flexible and expandable



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PV system with central inverter

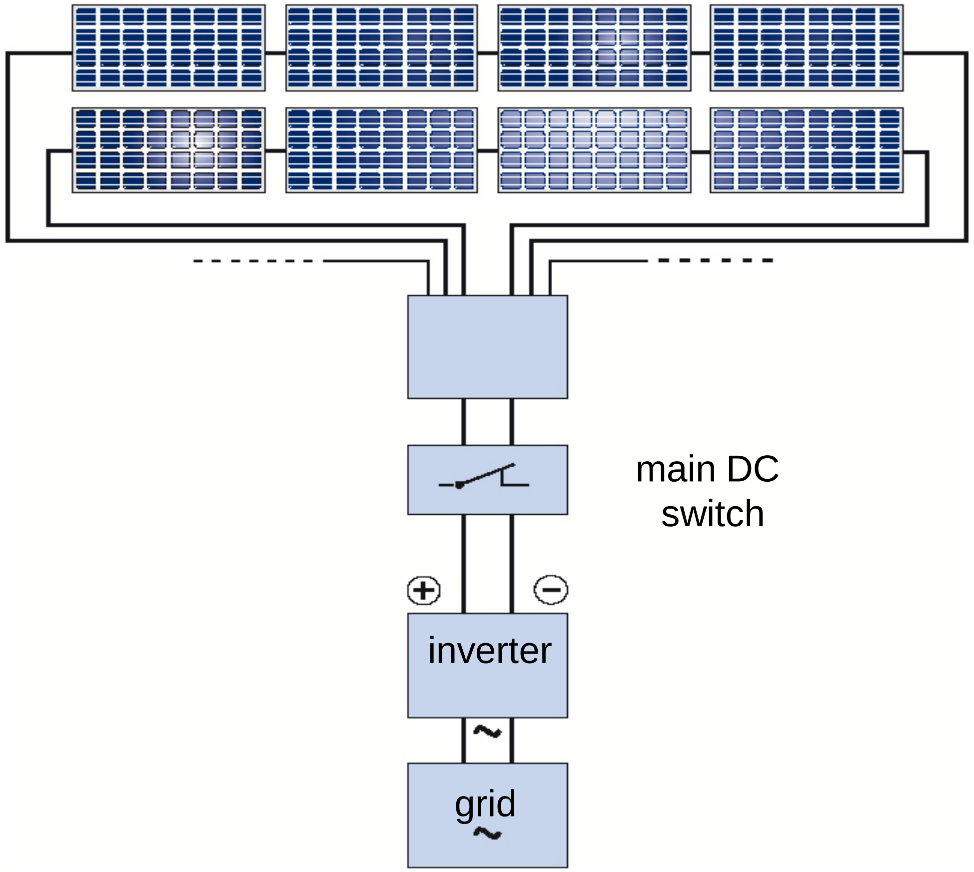

Image: Solarpraxis AG, Berlin, Germany

Series-connected PV system with string-orientated inverters

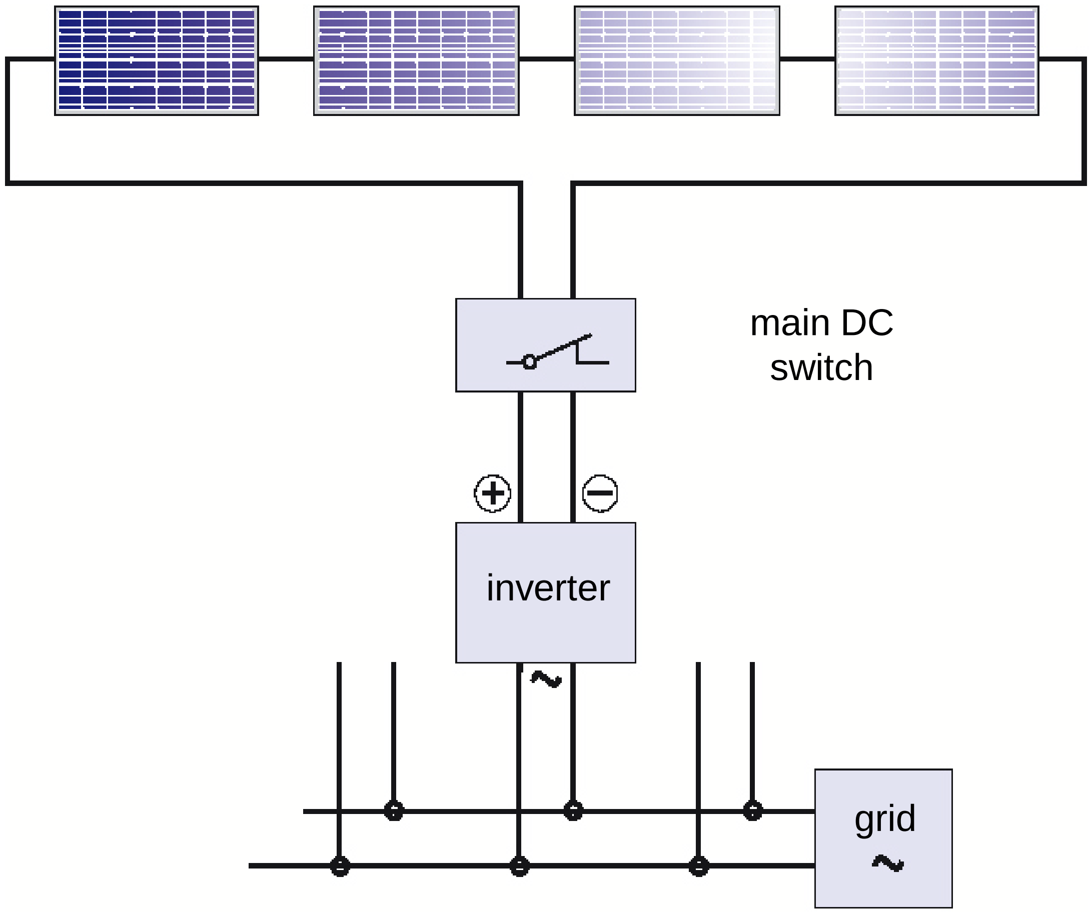

Image: Solarpraxis AG, Berlin, Germany

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Parallel-connected PV system with string-orientated inverter

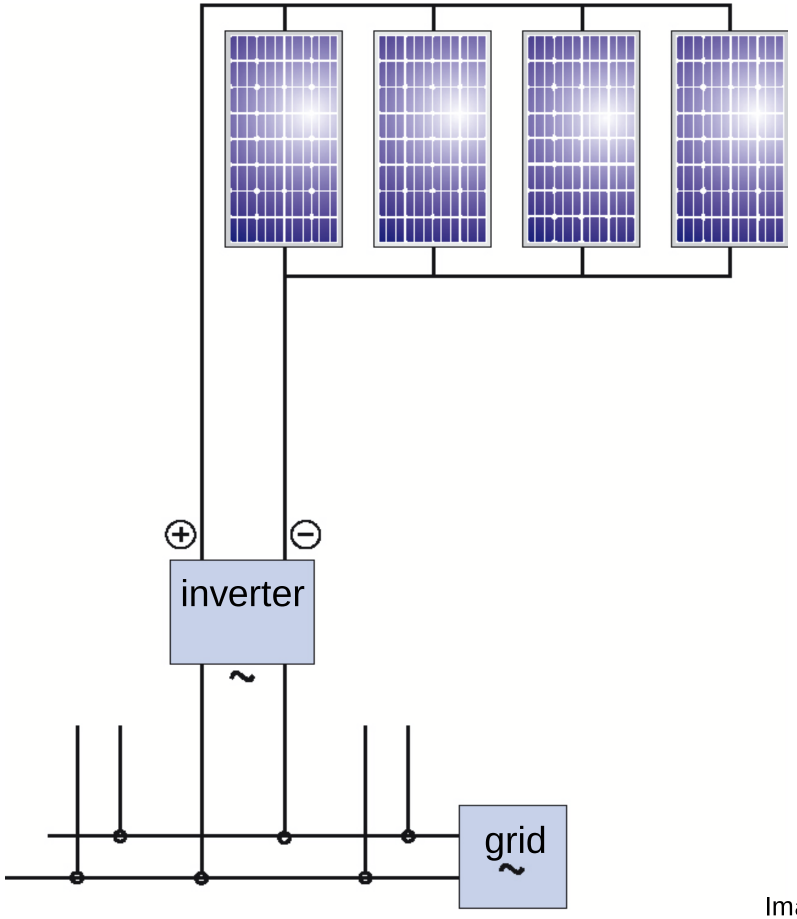

Image: Solarpraxis AG, Berlin, Germany

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PV system with module-integrated inverters

- For example the inverter is integrated by the manufacturer into the junction box of the module

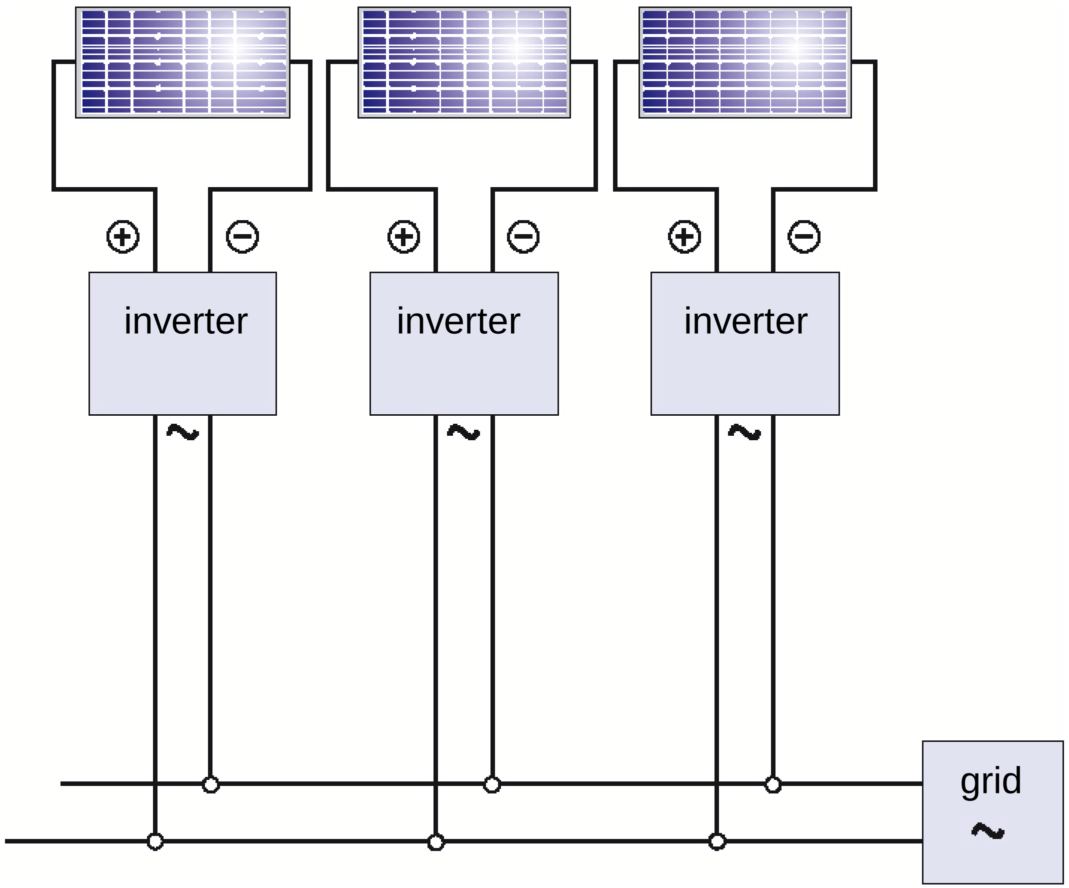

Image: Solarpraxis AG, Berlin, Germany

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Standards and regulations for feed-in of electricity to the grid

The following rules and regulations apply for the installation and commissioning of grid-connected photovoltaic systems:

- legal and official regulations
- national and European regulations and standards
- regulations for safety at work
- conditions and guidelines of the local or regional utility

Standards and regulations

PV systems may have different national regulations and standards (building regulations, personal safety, etc.), however EU is trying to harmonize standards

- For example: DIN, VDE, CENELEC and IEC standards
- lightning and surge protection
- building regulations and authorization
- technical rules for constructions with glass
- conservation laws applying to historic buildings

Definitions: Power quality and voltage quality

Power quality

- adequate connection power to supply electric loads without reducing comfort and convenience
- continuous availability of the power required at each connection point (e.g. power interruptions total 15 minutes per year in Germany)

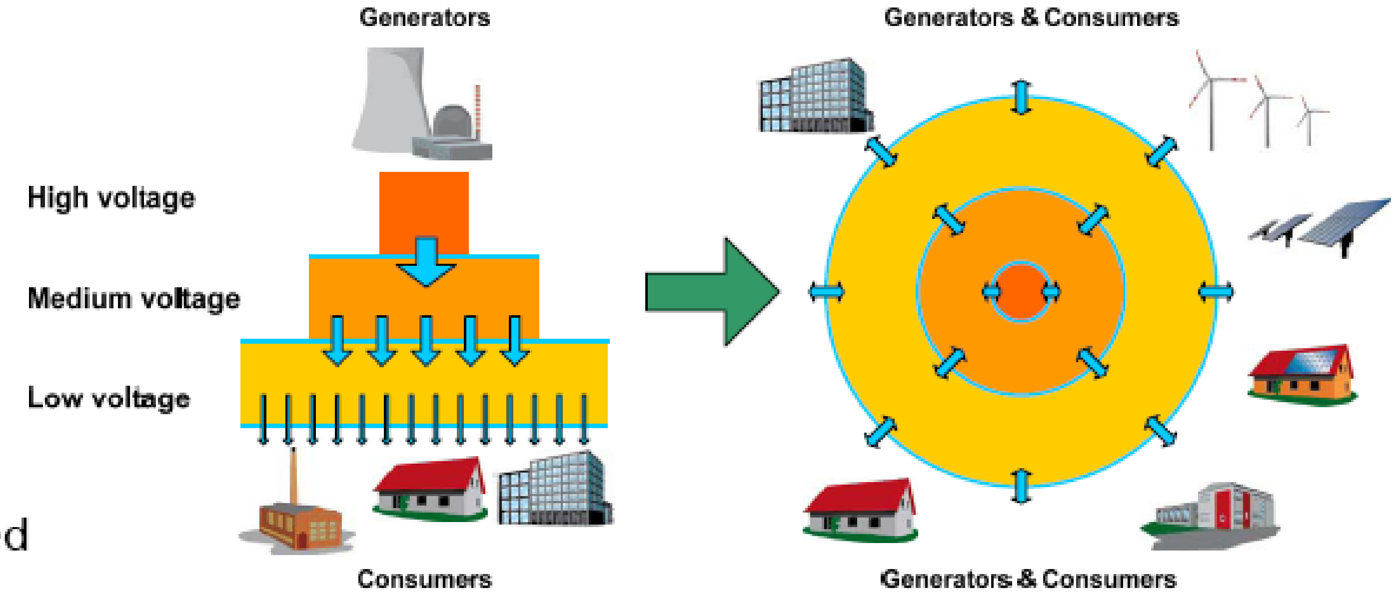
Voltage quality

- waveform and quality of grid voltage conforming to standards
  - frequency
  - average voltage level
  - transient effects
  - harmonics

⇒ High quality is needed to ensure uninterrupted operation and long lifetimes for equipment

Change in the grid structure

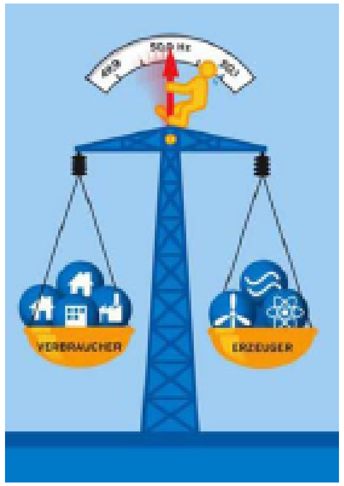
- Change in the grid structure due to distributed generation
- Necessary integration of all generators into the control of the gird
- New grid codes for distributed energy resources (DER) connected to the medium and low voltage grid



Source S. Reichert, ISE

Grid control / grid stabilisation

[1] active power balance between generation and consumption

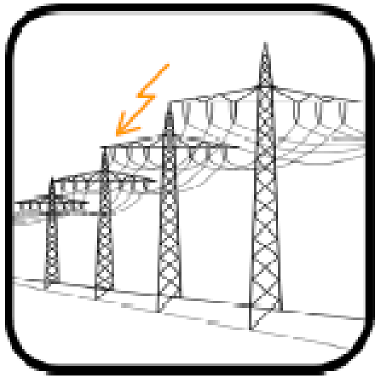


Conventional power plant (synchronous generator)	*New grid codes (e.g. PV inverter)*
• active power/frequency - droop for primary control • rotating mass equalizes short- term unbalances	• active power derating when grid frequency to high • active power derating at request by grid operator (P_N > 100 kW)

Source S. Reichert, ISE

Fraunhofer ISE

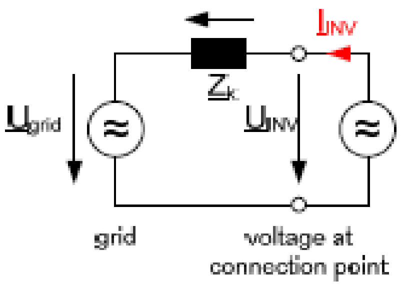
Grid control / grid stabilisation
[2] behavior during fault condition (short circuit)



Conventional power plant (synchronous generator)	*New grid codes (e.g. PV inverter)*
• synchronous generator delivers short circuit current	• fault ride through – generator stays grid connected – generator feeds reactive current to support grid

Source S. Reichert, ISE

Grid control / grid stabilisation
[3] reactive power exchange between generators, grid utilities and consumers



Conventional power plant (synchronous generator)	*New grid codes (e.g. PV inverter)*
• reactive power / voltage - droop Q(U) • reactive power supply by changing the excitation voltage (over or under excited generator)	• reactive power supply – cos φ (P) – cos φ_{fix} – Q (U) – Q_{fix}

Source S. Reichert, ISE

The Erneuerbare Energie Gesetz EEG in Germany

(Renewable Energy Act)

- Grid operators are obliged to connect PV-plants to their grids
- Fixed feed-in-tariff for 20 years
- Costs associated with connecting installations pay the operator of the PV system
- A compensation between all transmission grid operators exists
- The costs are shared by all users

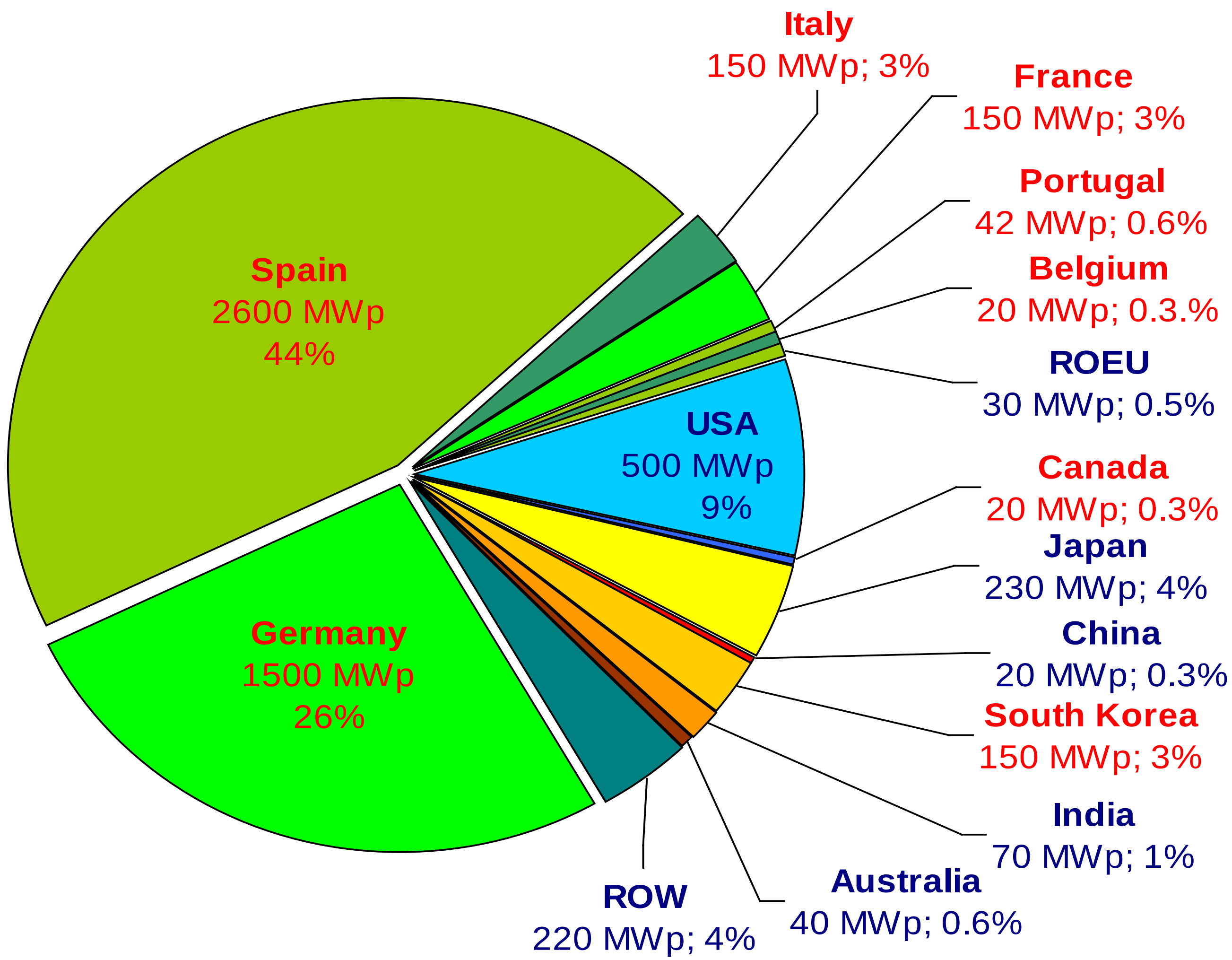
The Erneuerbare Energie Gesetz EEG 2

(Renewable Energy Act)

New law eligible since 1.1.2009:

- Minimum for feeding into the grid 31.94 €-Cent/kWh
- Building integrated:
  - Up to 30 kWp : 43.01 €-Cent/kWh
  - Up to 100 kWp : 40.91 €-Cent/kWh
  - Up to 1 MWp : 39.58 €-Cent/kWh
  - Above 1 MWp : 33.00 €-Cent/kWh
- Direct use by the operator up to 30 kWp: 25.01 €-Cent/kWh + avoided costs of ~21 €-Cent/kWh (typical price in the low voltage grid)
- Annual decreasing for new installations in the next two years between 8-10 % in dependence of the size and the accumulated installations

Photovoltaic World Market 2008



New installed
PV Power

2006: 1600 MWp

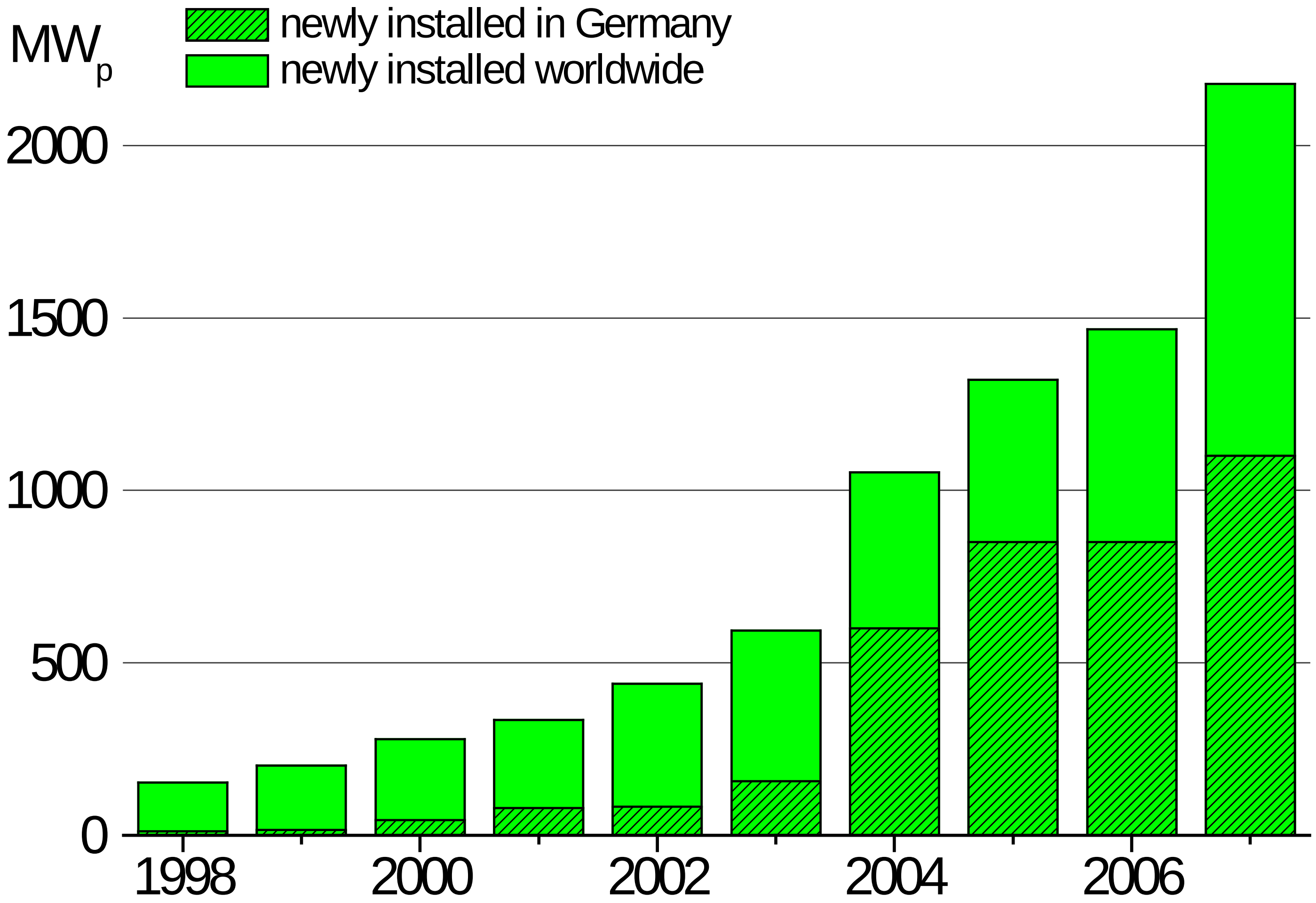
2007: 2650 MWp
(+66%)

2008: 5750 MWp
(+117%)

Red Letters: Countries with Feed-in tariff schemes

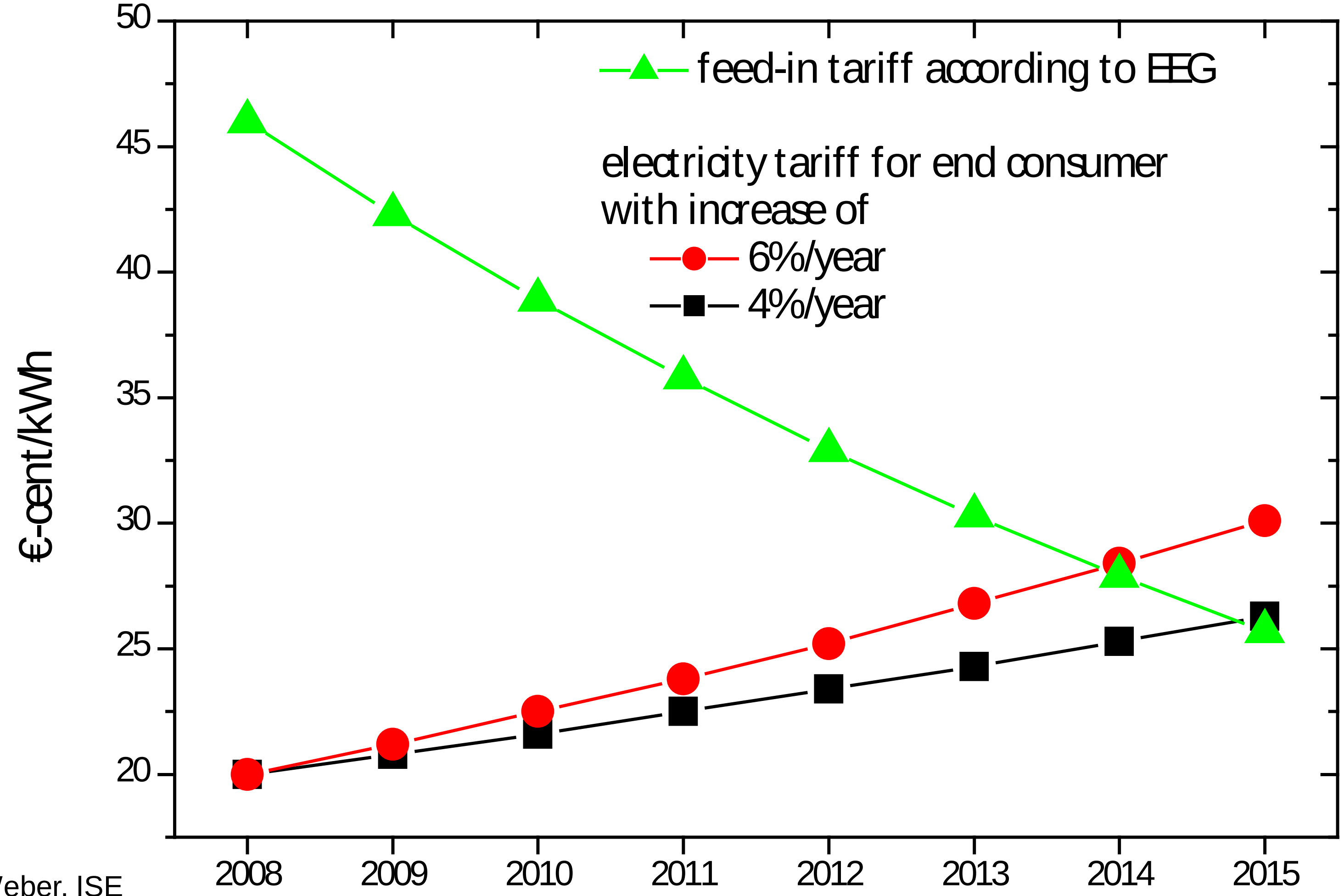
Slide courtesy G. Stryi-Hipp, January 2009,
Source: Preliminary figures of different National PV Associations.

PV-Installation



Source: EPIA, BSW

Path to Grid Parity in Germany (!)



Source: Prof. Weber, ISE

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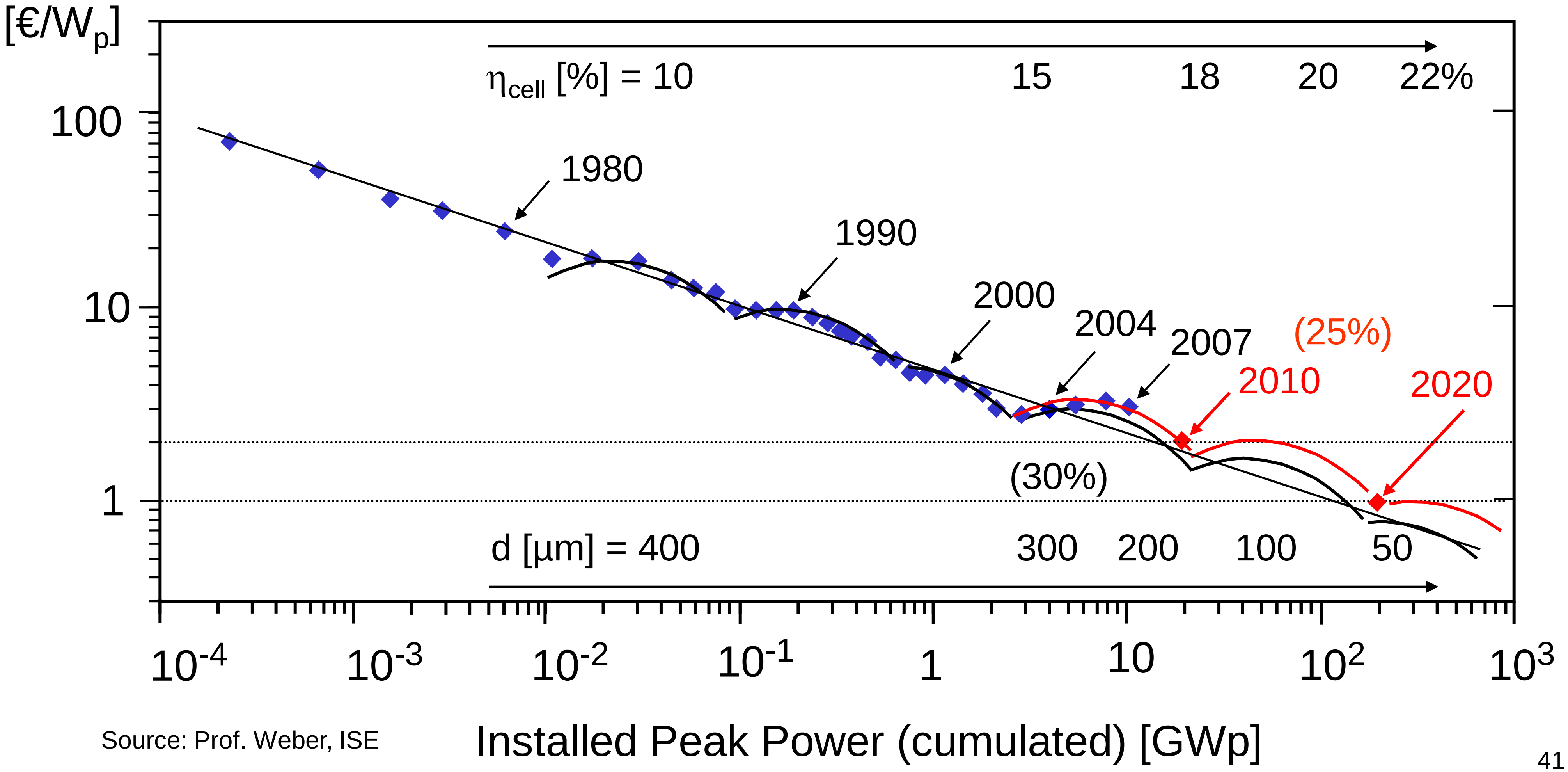
Price learn curve of crystalline Si PV-modules



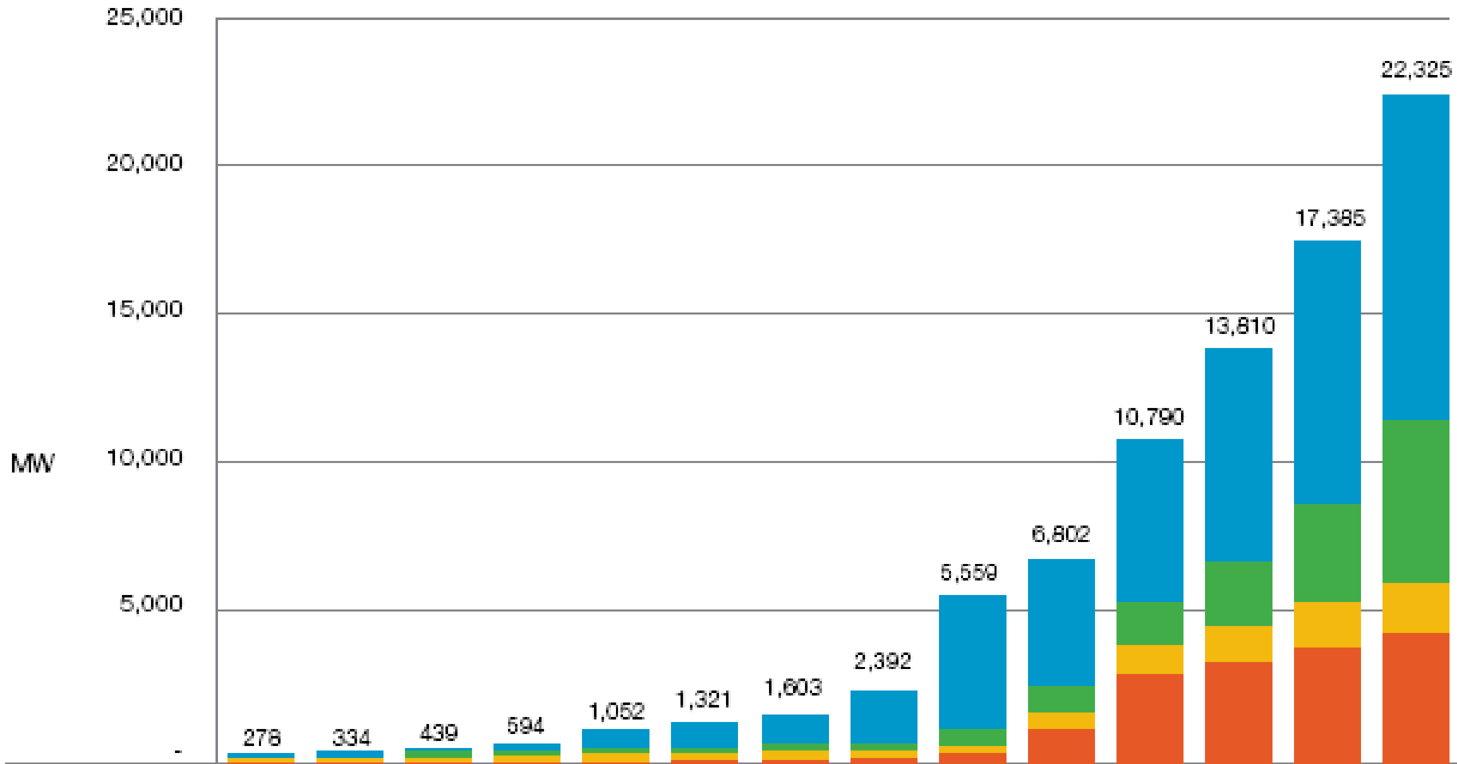
Source: Prof. Weber, ISE

Policy driven scenario of European PV industry association EPIA

"The policy driven scenario is based on the assumption of the follow-up and introduction of support mechanisms, namely FiT, in a large number of countries."

Source: EPIA

Figure 4: Global annual PV market Outlook per Region (Policy-Driven scenario)



MW	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009E	2010E	2011E	2012E	2013E
Europe	50	96	106	210	637	906	975	1,768	4,503	4,302	5,490	7,110	8,785	10,925
Rest of the world	94	75	104	98	53	12	196	207	485	800	1,300	2,100	3,200	5,200
Japan	112	135	185	223	272	290	287	210	230	500	1,000	1,200	1,500	1,700
USA	22	29	44	63	90	114	145	207	342	1,200	3,000	3,400	3,900	4,500
TOTAL	278	334	439	594	1,052	1,321	1,603	2,392	5,559	6,802	10,790	13,810	17,385	22,325

Energy supply system with distributed power generation

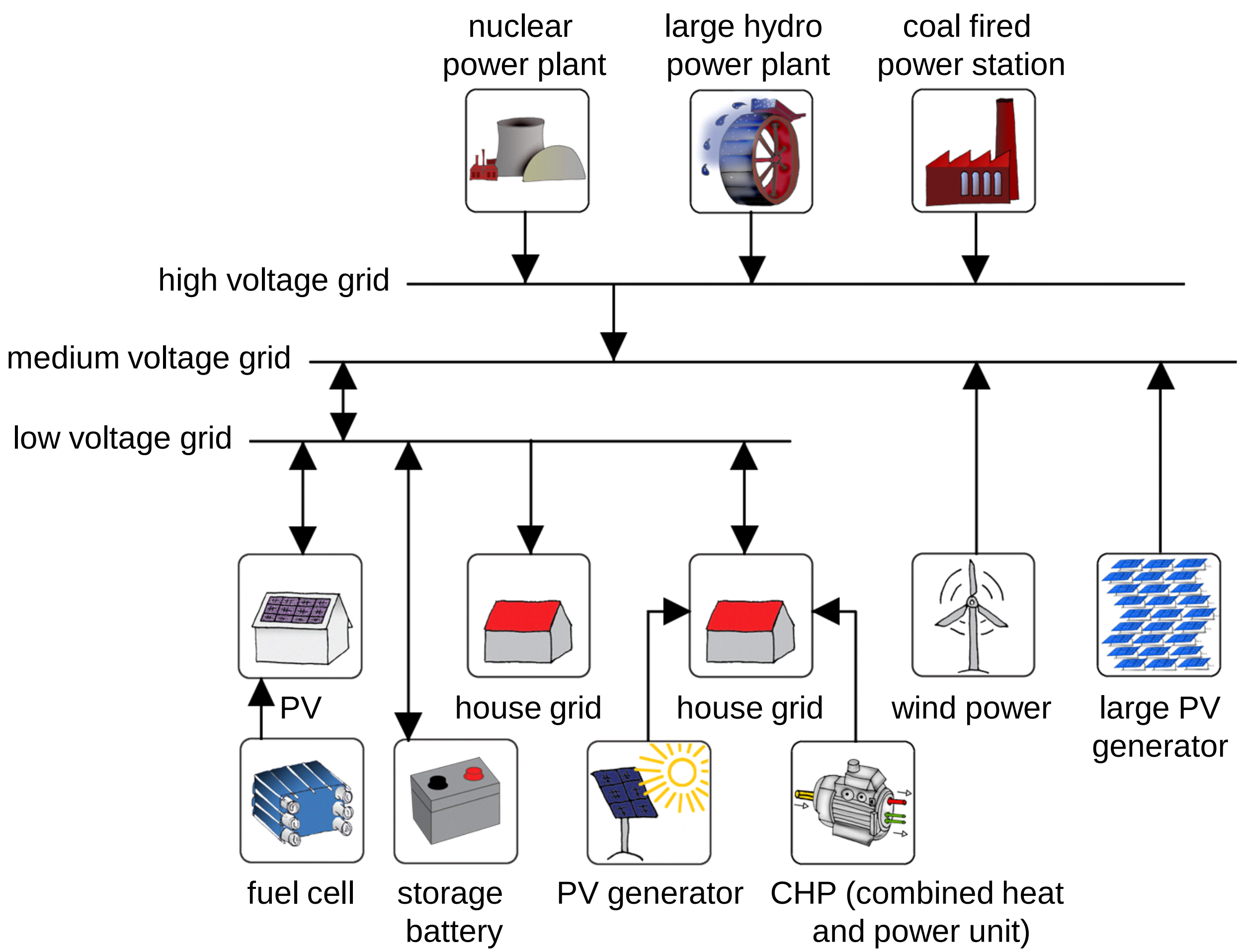
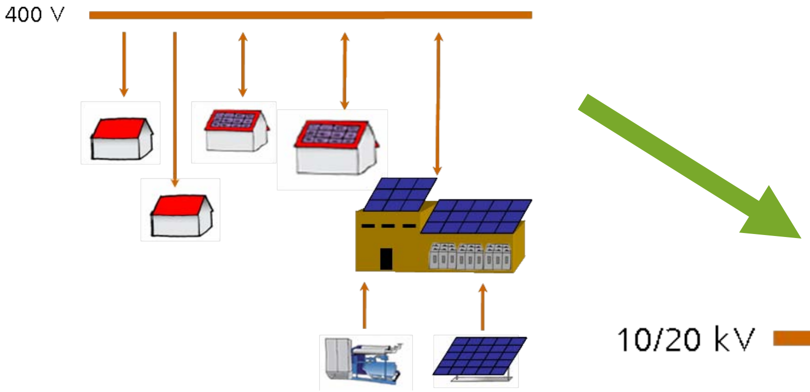
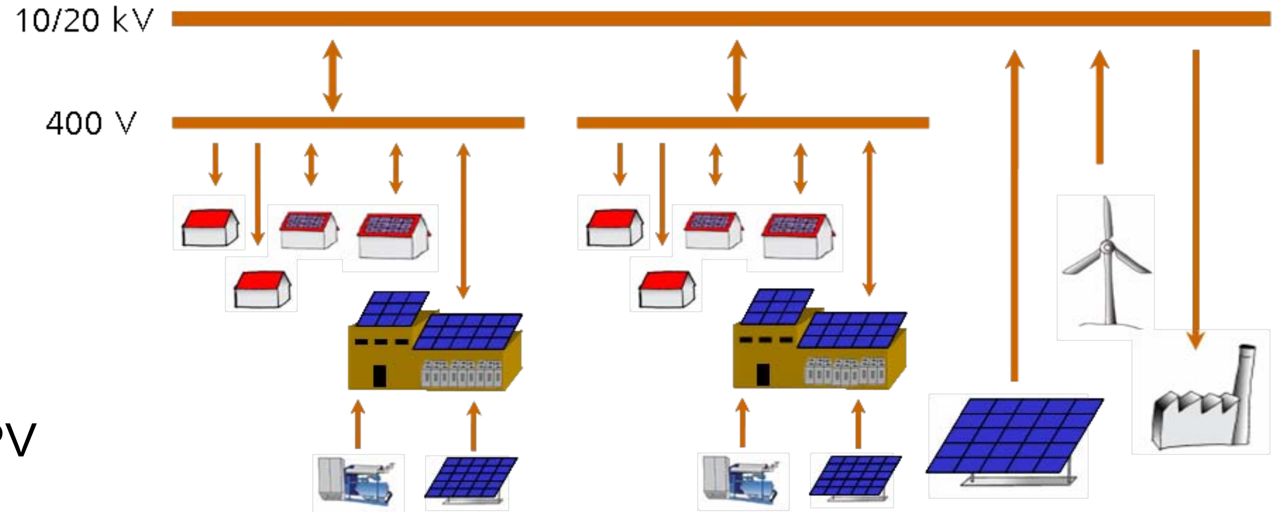


Image: Fraunhofer ISE, Freiburg, Germany

Vision: Interconnection of hybrid PV mini-grids



Source: J. Luther, E. Kituyi: International Science Panel
on Renewable Energies (ISPRE) - A Scientific Panel in Formation



- Support weak grids
- Security of supply via PV backup systems
- Independence of fossil fuels



Thanks for your attention



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