Smart Grids

Energy and Grid Management with flexible Tariffs

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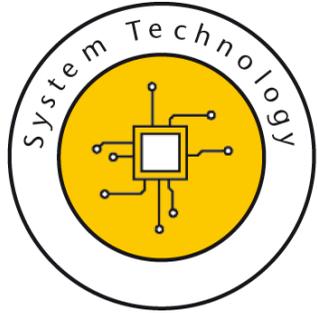www.ise.fraunhofer.de

Initial Position

Energy supply systems change from former centralised structures to decentralised, distributed ones, and new challenges rise. Decentralised generation (DG) had its initial incentives from federal supply mechanisms such as feed-in tariffs. Now it needs to adjust its operation management to demands of various energy market actors, e.g. consumers or grid operators.

Until now, smaller DG and consumers/loads have no possibilities to participate in direct electricity trading and entering the big markets due to missing low cost information and communication technology (ICT) infrastructure. Such ICT can also be used for implementing locally optimised operation management, including fluctuating renewable energy sources.

The DEMAX project (Decentralised Energy and Grid Management with flexible Tariffs), funded by the German Ministry of Economy, aims at integration of decentralised electricity generators and loads by developing ICT infrastructure and internet based communication platforms – the Smart Grid approach.

Smart Grids

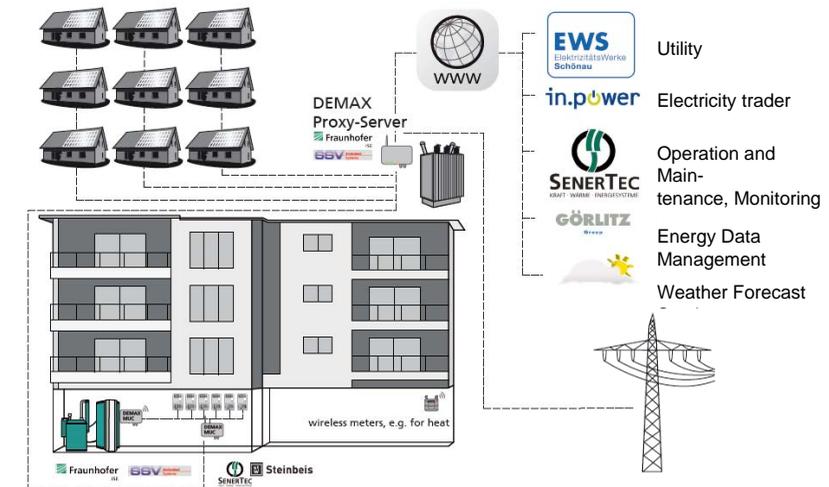## Energy and Grid Management with flexible Tariffs

Research

Different hardware and software concepts as well as model based, intelligent energy management algorithms have been developed so far. The ICT infrastructure is shown in the graph.

Examples are
• the MUC (Multi Utility Controller) concept in the form of an open specified, standardised MUC (DEMAX gateway)
• flexible tariff systems for decentralised generators and consumers/loads
• an energy management system for optimised calibration of consumers and generators

Still under construction is an equally open specified, standardised internet based platform (DEMAX proxy) that provides access for different service providers such as Electricity Sales (billing, flexible tariffs), Grid Operator (billing, monitoring), Plant Manufacturer (Monitoring, Operation & Maintenance), Direct Electricity Traders (Control), and others (Feedback, Visualisation)

Recently, the system developed is being tested in a small distribution grid in Southern Germany.

ICT concept developed and implemented in DEMAX
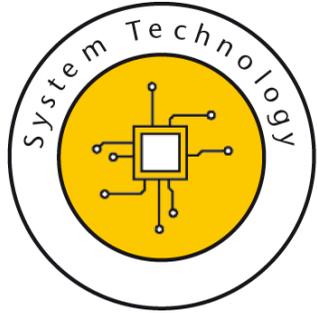
Smart Grids

Energy and Grid Management with flexible Tariffs

System Technology

**1.**

Smart Grid

Initial Position

Research
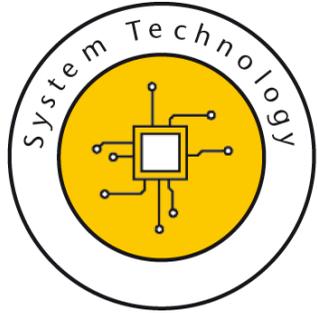
▶ **Results**

Results

Preliminary results show that grid oriented optimisation of decentralised operation management is able to balance local grid loads in a cost-efficient way. Furthermore, flexible tariffs with local components depending on local grid loads facilitate the integration of especially fluctuating renewable energy sources into distribution grids.

Application of smart metering infrastructure is the basis for smart grid functionalities such as energy data information access for multiple users (utility, grid operator, electricity traders, other service providers), and increased hardware efficiency ensures overall efficiency of smart metering systems. Costs for hardware and software components have declined and seem to guarantee feasibility of smart metering application in smart grids.

Finally, as the German regulative framework for smart metering / smart grids still is under construction, the project supports the regulator with substantial input from technical experience in his work.
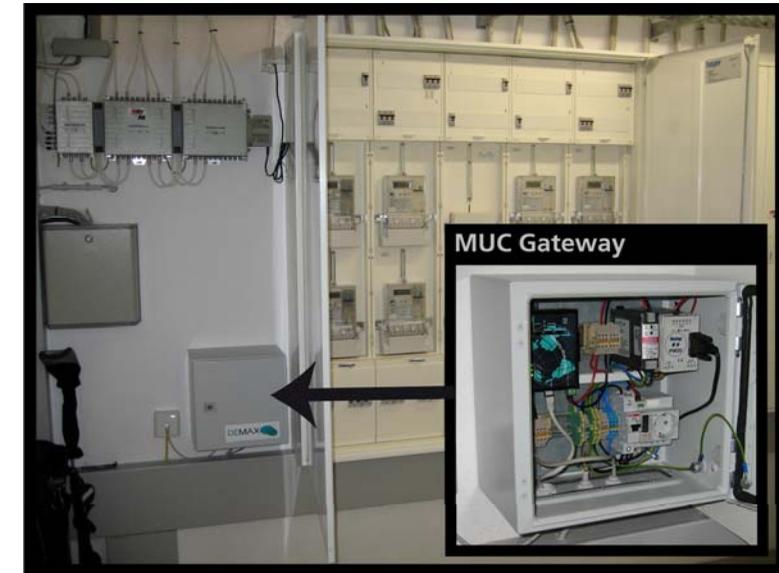
MUC gateway developed and installed in DEMAX demonstration object for connecting smart meters.

Bidirectional Energy Management Interface BEMI

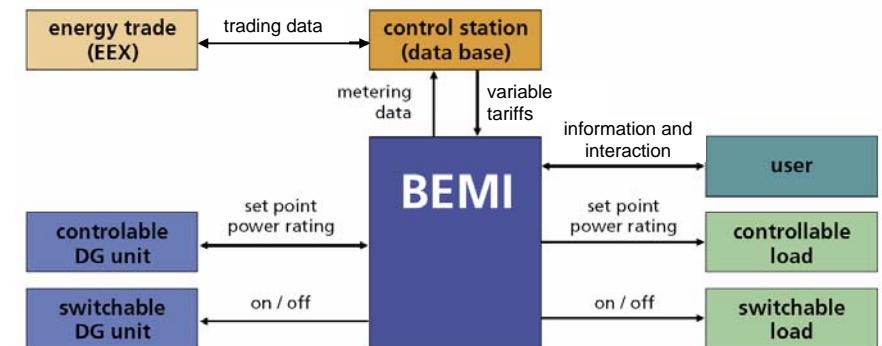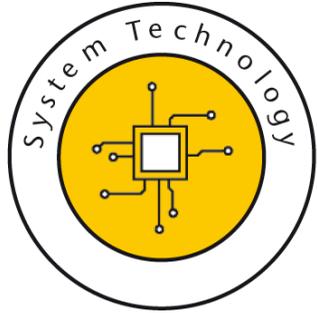## Initial Position

Within the DINAR project Technical and Economical Integration of Distributed Renewable Energy Supply Systems, the concept of decentralised decision was developed, which is based on a local energy management taking into consideration relevant centralised and decentralised information.

The grid connection point of the end customer is expanded to a Bidirectional Energy Management Interface (BEMI).

Communication structure of the Bidirectional Energy Management Interface BEMI
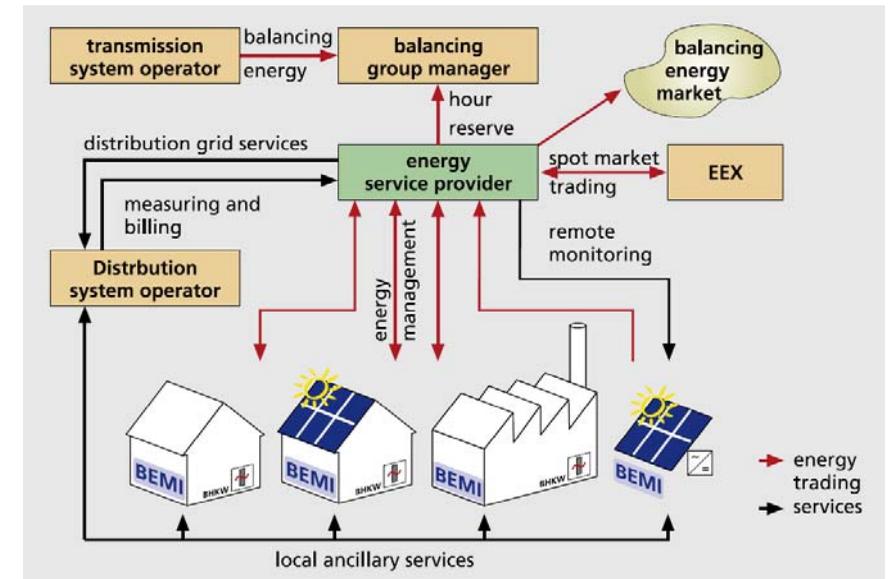
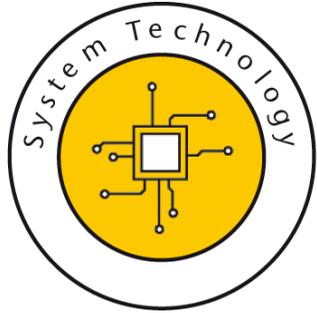# Bidirectional Energy Management Interface BEMI

Research

The BEMI receives incentive signals from a central control station, e.g. the price profile for the next day.

Based on this information, the requirements of the occupants of the building and the parameters of the connected generators and consumers, the BEMI core computer calculates optimised schedules for all connected units.

The operator of the interface can access information about rates and costs as well as about the schedules on a user display. Thus the BEMI makes decentralised decisions based on local data (load and generator parameters), decentralised information from the grid connection point and centralised information from the control station.

BEMI in the context of a deregulated electric energy market

Bidirectional Energy Management Interface BEMI

System Technology

2.

BEMI Energy Management

Initial Position

Research

▶ **Results**

Results

As part of the DINAR project the concept was put into practice and implemented into hardware. Also a field test was performed using the technology.

At the same time, the overall behaviour of a large number of residential households with decentralised energy management (up to 10,000) is being examined using a simulation programme.

In a pool of decentralised plants which comprises grid customers equipped with BEMI (residential, commercial, markets, industry, etc.) as well as other decentralised generators, additional advantages can be developed for the market participants if a super ordinate manager, a "pool BEMI", is operated by the energy provider that collects decentralised information from the distributed BEMI. This also allows to provide services to the operator of the distribution grid.

Interaction of the Bidirectional Energy Management Interface BEMI in the test area of Fraunhofer IWES

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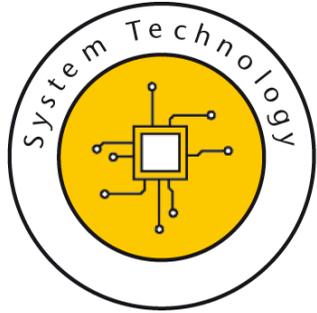
Combined Power Plant with 100% Renewables

System Technology

3.

Power Plant 100% RES

▶ **Initial Position**
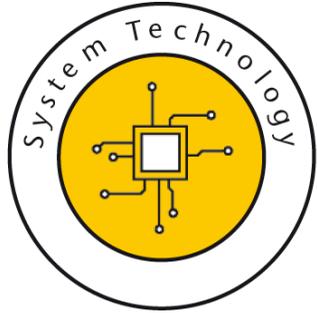
Research

Results

Initial Position

Fraunhofer IWES in this project proved the feasibility of a 100 % electricity supply for Germany in the long term. In cooperation with the companies Enercon, Schmack Biogas and SolarWorld, future-proof scenarios were developed and tested by a major experiment including real energy generators.

The project started in 2007 and was initiated in order to rebut a main argument against the application of renewable energy (RE) production, namely the insufficient controllability due to fluctuations of wind and solar power plants.

Wind turbine, photovoltaic generator and biogas plant of a virtual power plant with 100 % renewables

Combined Power Plant with 100% Renewables

System Technology

3.

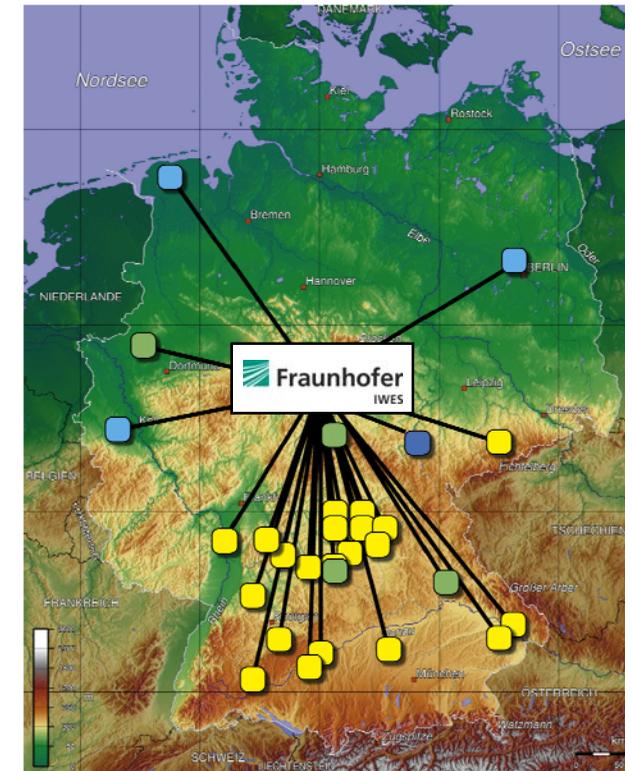**Power Plant 100% RES**

Initial Position
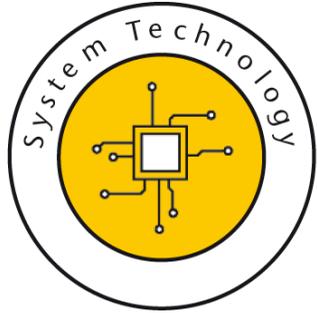
▶ **Research**

Results

Research

The test case shows the energy demand and a realistic expansion of regenerative energy producers in Germany in a scale of 1:10,000.

The goal of this project is to demonstrate that the demand for electric energy can be covered at any time by combining different forms of renewable energy generators.

RES plants of a virtual power plant to cover 1/10000 of the German energy demand blue= wind farms, yellow = PV generators, green = biogas plants, dark blue = hydro pump power station

Combined Power Plant with 100% Renewables

System Technology

3.

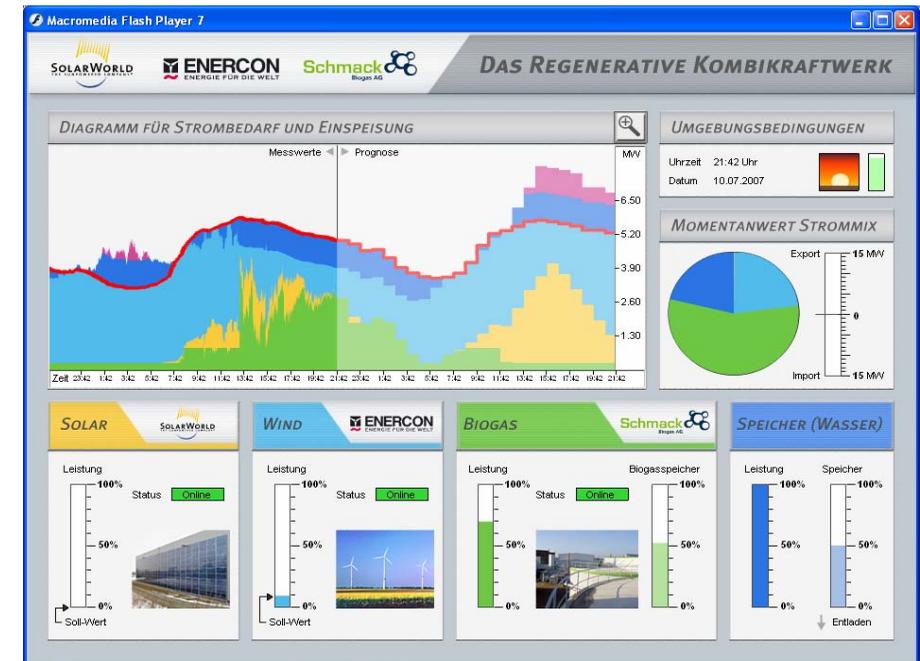### Power Plant 100% RES

Initial Position
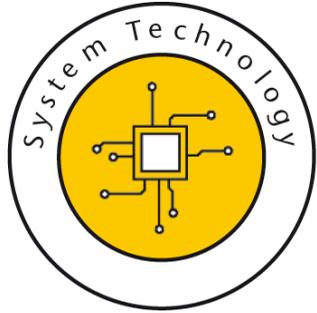
Research

▶ Results

Results

Fraunhofer IWES has developed the central control unit (CCU) and has connected it to the individual components (wind farms, photovoltaic panels, biogas CHP.

Using a control algorithm, the CCU determines the optimum energy mix at any given point in time. The usage of resources from controllable biogas power plants is scheduled based on wind and solar forecasts.

Control display of the combined power plant with 100 % renewables

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Power Electronics

- PV Inverters for the Global Market
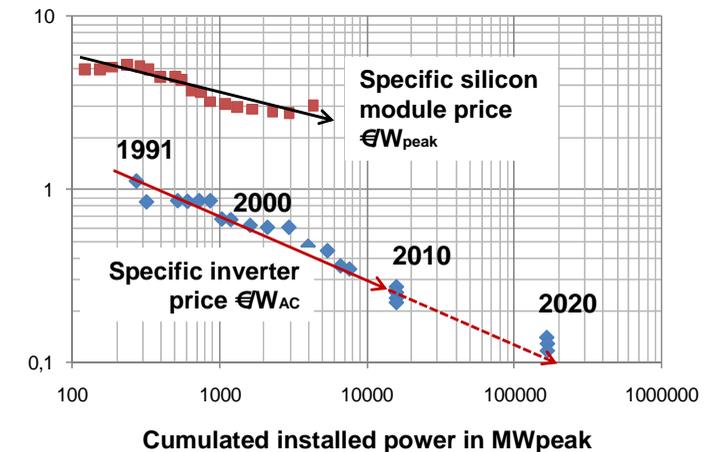
Initial Position

German PV inverters are very successful at the worldwide market. With more than 98% efficiency there is only little space for efficiency improvements.

Future main targets of inverter development will be:

- Reduction of **total cost of ownership** *(see right hand side)*
- Further improvement of **reliability**
- Increase of switching frequency to minimise **passive components** and overall size
- Implementation of additional **system services** into inverters to improve power quality and stabilise the electricity grid (**smart grid** capability)
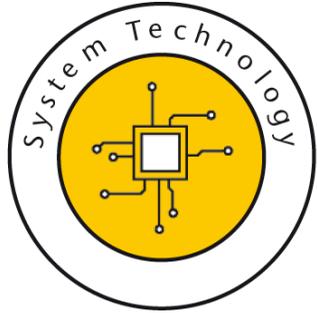

GLEICHSTROM (DC) SOLAR-WECHSELRICHTER WECHSELSTROM (AC)

Solar Park Waldpolenz (40MWp) (SMA)

Cumulated installed power in MWpeak

Learning curves of Si-Modules and PV Inverters *(PSE, SMA)*

FVEE ForschungsVerbund
Erneuerbare Energien
Renewable Energy Research Association

Power Electronics

- Tailored topologies for new semiconductors

Fraunhofer ISE   **Fraunhofer** IWES   **KDEE** Kompetenzzentrum für Dezentrale Elektrische Energieversorgungstechnik
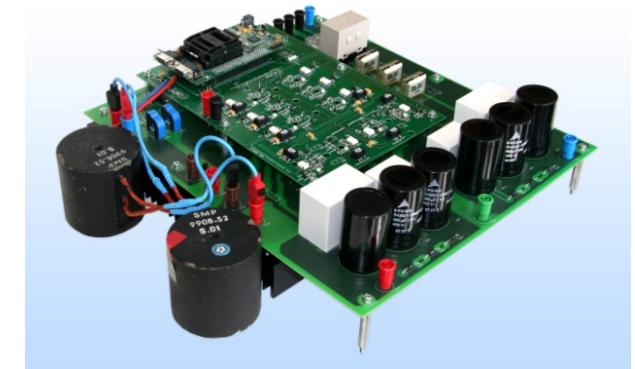
Research

New semiconductors
Silicon Carbide (SiC) material is characterised by electrical field strength almost 9 times higher than common Si, allowing the design of semiconductor devices with very thin drift layers. As a consequence, SiC transistors have low on-state resistance and reduced switching losses.

New topologies
SiC transistors can be considered as one of the future trends in photovoltaic inverter technology. However, their inherent characteristics call for specially tailored topologies and layouts are being researched and developed.

New efficiency benchmark
Inverter efficiencies up to 99% have been demonstrated with new SiC semiconductor devices, causing international furore.

New circuits for SiC semiconductors (KDEE)
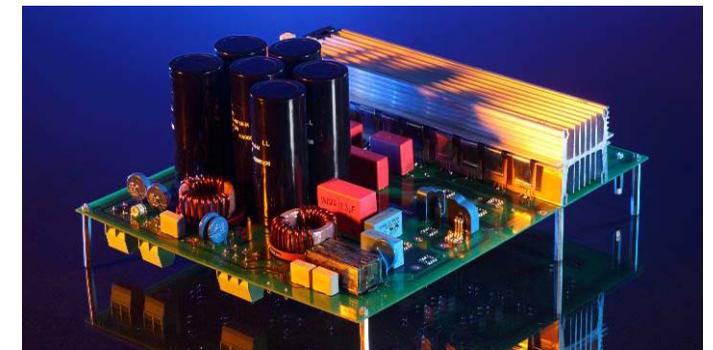
Inverter with 99% efficiency (Fraunhofer ISE)

Power Electronics –

Enable systems for AC island grids

System Technology

4.

Power Electronics

   Initial Position

▶ **Research**

   Results

Research

Power electronics enables the formation of local AC grids.
This has the following features:

• **World-wide standard**

• **No extra communication needed (selfsync™)**

• **Modular**

• **Easily expandable (Microgrid)**

• Can be **combined** with other **renewable sources**, such as Wind
  and Biomass generators
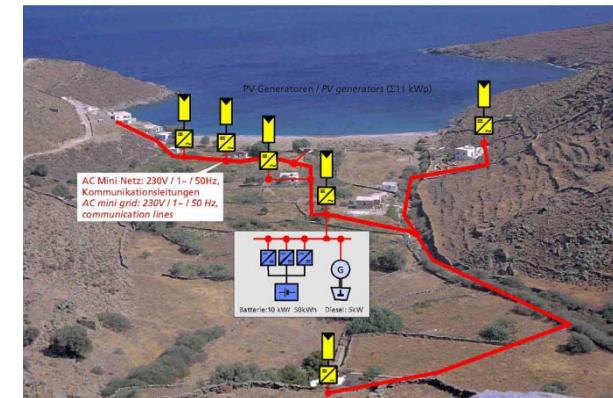
AC island grids: Pilot plant on Kythnos

Demotec: System technology test center / Kassel

Power Electronics –

Multifunctional Photovoltaic Converters

Research

Aim of R&D project:
Optimisation of industrial and public grid with Multifunctional PV converters.

Project Innovations:
Assessment of economical benefit for providing additional functionalities.
Development and laboratory tests of new hardware and software concepts.
Long term prototype testing at a real test site in the industrial grid of Hübner GmbH in Kassel.

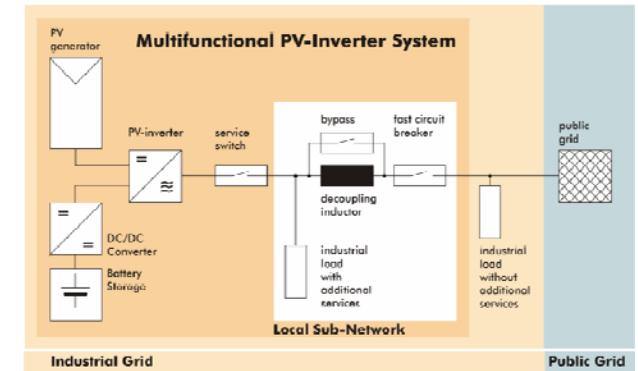### Additional Optimisation and Stabilisation Functionalities
Local power quality improvement for sensitive loads
Reactive power compensation
UPS functionality for sensitive loads
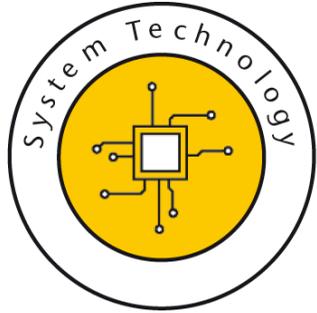Island operation of electrical grids
Peak shaving for reducing demand charges

Electrical concept and gird integration of the Multifunctional PV converter

Roof-mounted 100 kW photovoltaic plant at Hübner GmbH in Kassel

Power Electronics –

PV Inverters for the Global Market

System Technology

4.

Power Electronics

Initial Position

Research

▶ **Results**

Results

Reasons for the export success of German PV Inverters:

High Efficiency:
Germany has the pole-position in inverter efficiency worldwide. This is both in research and manufactured devices and systems

Transformerless Technologies:
Germany has the leading position concerning transformerless inverters. These combine low cost, low weight and high efficiency with high reliability.
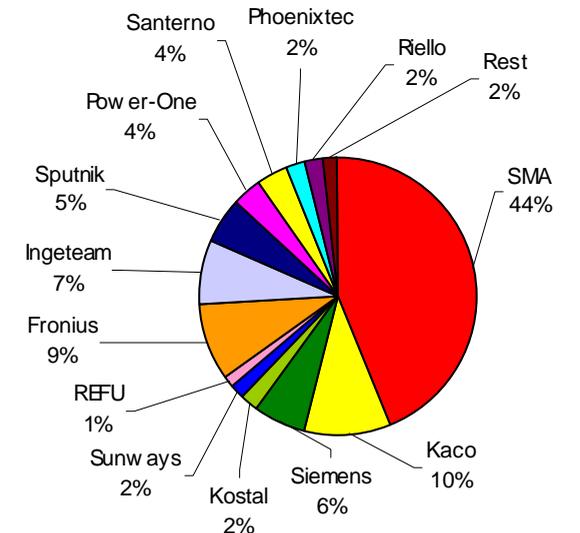
Electrical Safety and Standardisation :
Germany is guiding in development of safety concepts and standardisation. Many countries take over the according standards or take it as pattern.

System Technology
Generators equipped with power electronics enable additional system services to improve power quality and stabilize the electricity grid.

2/3 of all PV Inverters Made in Germany

Shares of the PV inverter market in 2008 (EuPD and Fraunhofer ISE)
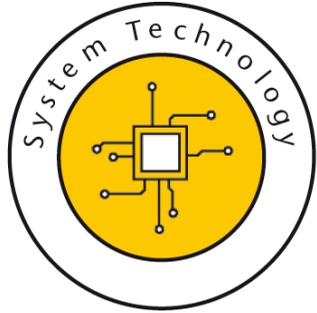
Pie chart values:
- SMA 44%
- Kaco 10%
- Siemens 6%
- Kostal 2%
- Sunways 2%
- REFU 1%
- Fronius 9%
- Ingeteam 7%
- Sputnik 5%
- Power-One 4%
- Santerno 4%
- Phoenixtec 2%
- Riello 2%
- Rest 2%

Renewable Energy System with Lithium-ion Battery for Residential and Small Commercial Applications (Sol-ion)

Hans-Dieter Mohring, Andreas Jossen, ZSW

Martin Braun, Markus Landau, Fraunhofer IWES

Armin Schmiegel, Voltwerk Electronics

System Technology

5.

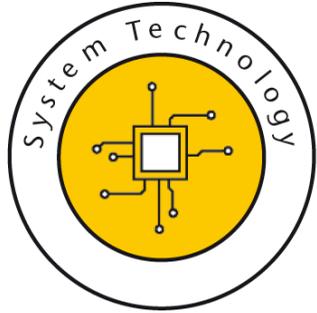**Grid connected PV-battery-system Sol-ion**

► **Initial Position**

Research

Results

Initial Position

- Amendment of German Renewable Energy Sources Act (EEG) contains incentive to use PV energy for energy management: a special tariff is guaranteed when the electricity is used in the immediate proximity of the installation.

- This option becomes attractive as soon as energy supplier's price of electricity exceeds costs of locally consumed PV electricity. Benefits are expected to rise due to increase of electricity prices and cost reduction of PV electricity.

- French-German research project Sol-ion focusses on the application of Lithium-Ion storage to optimize storage, feed-in and self consumption in a single system.

- An integrated, grid-connected PV-battery system is developed and tested by industrial partners (Voltwerk Electronics, Saft, Tenesol and e.on Bayern) and research organisations (ISEA, INES, Fraunhofer IWES, ZSW).

Renewable Energy System with Lithium-ion Battery for Residential and Small Commercial Applications (Sol-ion)

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System Technology

## Research

- The energy management system has to regulate from which source the actual electricity consumption is taken:
  - from the PV generator
  - from battery-stored PV energy, or
  - From grid energy.
- Features of the system:
  - charging strategy ensures maximum lifetime of battery.
  - back-up mode to make use of actually produced and/or stored PV energy in case of grid failure
  - additional functionalities for supporting electric power system.
- A Li-ion battery is connected via a DC-DC battery converter to the DC link of the DC-AC inverter.
- The converter balances the energy on the DC link depending on actual demand.
- The energy management system measures power demands and sets target values for the inverter and the battery converter.
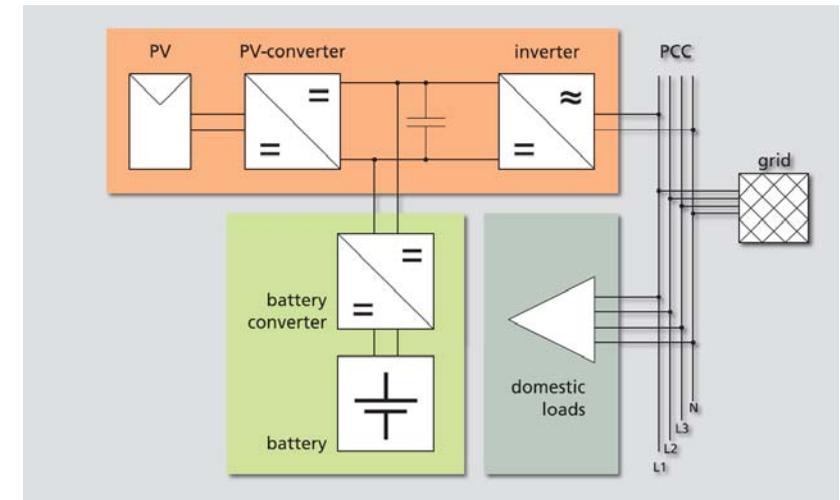
Schematic overview of the Sol-ion system

Renewable Energy System with Lithium-ion Battery for Residential and Small Commercial Applications (Sol-ion)

Hans-Dieter Mohring, Andreas Jossen, ZSW

Martin Braun, Markus Landau, Fraunhofer IWES

Armin Schmiegel, Voltwerk Electronics

System Technology

5.

Grid connected PV- battery-system Sol-ion

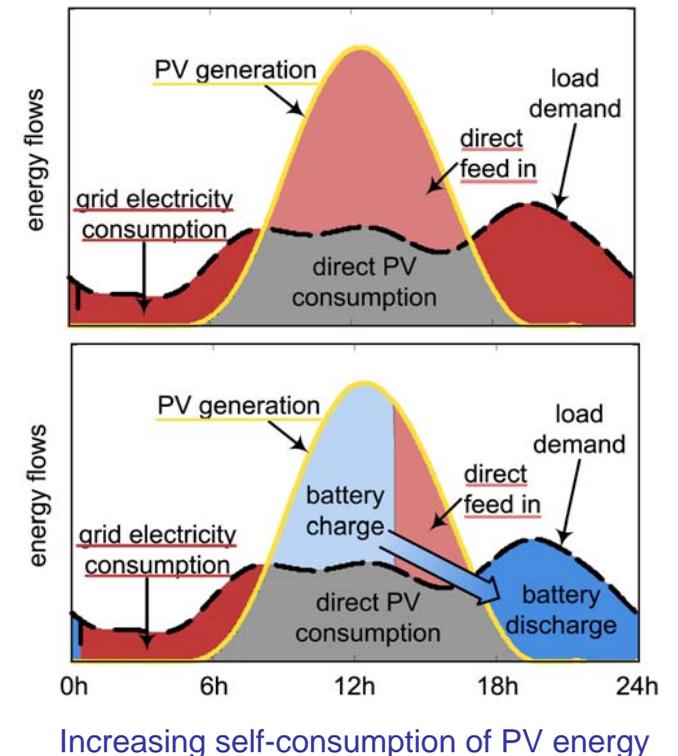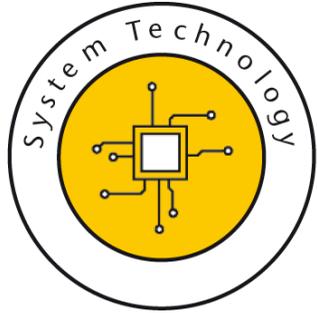Initial Position

Research

▶ **Results**

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Results

- A detailed system model has been developed.
- The system performance has been described by modelling all components with typical PV profiles and standard load profiles for households.
- Energy flow simulations showed applicability of the model for wide range of boundary conditions.
- Sol-ion system offers a promising way of optimizing the energy flow without affecting the consumption habits of the user.
- In a basic scenario, the additional income of a Sol-ion system overcompensates installation and maintenance costs if specific battery costs are below 350 €/kWh, a level which corresponds to the cost expectations of battery manufacturers.
- Further functionalities of the Sol-ion system:
  - Optimisation of energy flows in combination with time-variable electricity prices or supporting grid operation
  - Feed-in of the loads in case of grid failure, with lower costs compared to conventional stand-alone back-up solutions

Increasing self-consumption of PV energy

Rural Electrification with Hybrid Systems

Example: Darsilami in The Gambia (West Africa)

System Technology

6.

Hybrid Systems
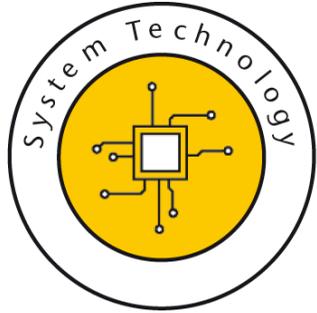
▶ **Initial Position**

Research

Results

Initial Position

The unelectrified village of Darsilami is located in The Gambia close to the border with Senegal.

The village has 3,000 inhabitants and does not have any existing grid (the nearest electrical grid is at 10 km).

PV-Generator of power supply plant in Darsilam

Rural Electrification with Hybrid Systems

Example: Darsilami in the Gambia (West Africa)

System Technology

6.

Hybrid Systems
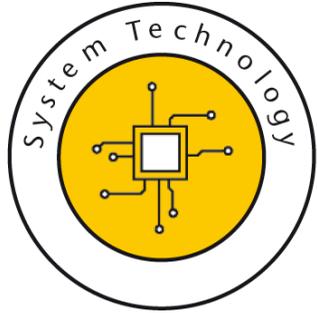
Initial Position

▶ **Research**

Results

Research

Currently, Darsilami has a small 3 kW PV-diesel hybrid system, installed by IWES that delivers electricity to the local hospital since 11th December 2004.

The hybrid system has the possibility to upgrading in a mini-grid, the capacity of the extension will depend on the consumer profile, their electricity needs, and the potential for productive use of electricity.
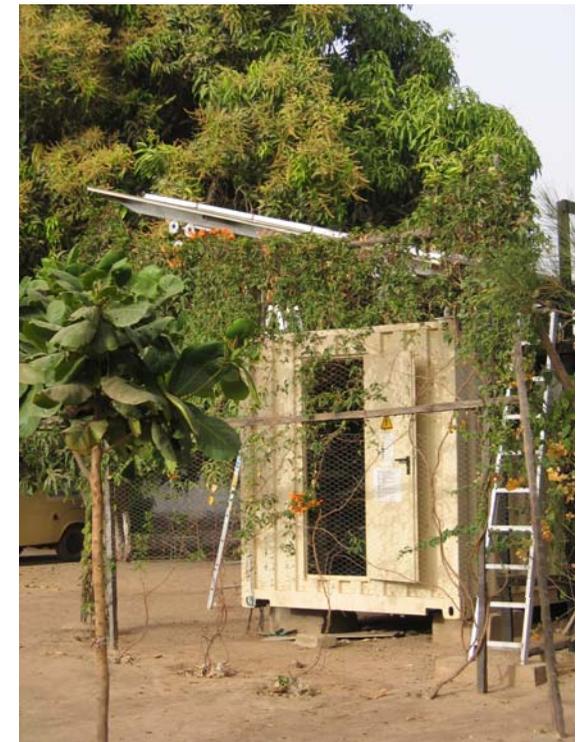
Hybrid system Gambia, integration and overshadowing of the container with creeping plants

Rural Electrification with Hybrid Systems

Example: Darsilami in the Gambia (West Africa)

System Technology

6.

Hybrid Systems

Initial Position

Research

▶ **Results**

Results

This project proposes a self-organized solar community where the members vote for a board of directors and the board makes the management decisions. The solar community would be a non-profit organization bringing electricity to their members.

The proposed innovative financing scheme is the Renewable Energy Regulated Purchase Tariff (RPT), developed by the European PV platform WG4 to make renewable energy projects attractive to policy-makers.

Villagers discuss power supply system in Darsilami (Gambia)

Partners: REMIS, University of Kassel, Ferdedsi, EU PV platform

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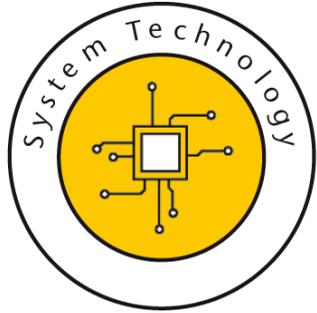
Hybrid Power Plant

System Technology

7.

DLR Hybrid Power Plant

▶ Initial Position

Research

Results

Initial Position

• Hybrid Power Plants offer high electrical efficiencies even at small sizes.

• The interest in the technology is high especially since Siemens tested their pressurized hybrid system in 2000 with an efficiency > 53%

• They consist of a solid oxide fuel cell and a gas turbine cycle responsible for the pressurization of the fuel cell system.

Schematic of the hybrid system cycle configuration
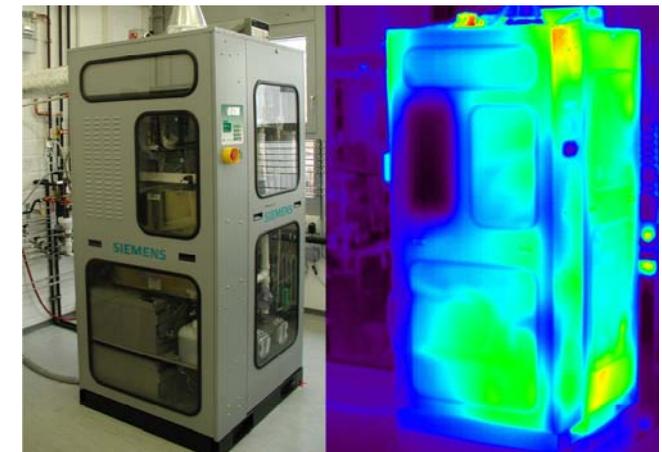
Hybrid Power Plant

Research

In the Hybrid Power Plant project research is based on modeling as well as on experiments

Modeling:

• Building of a model library for fuel cell systems

• Analysis of dynamic behavior of large fuel cell systems

• Detailed fuel cell modeling based on elementary kinetics approach

• Helps understanding the effects of pressurization on SOFC

Experiments:

• System operation experience based on a Siemens SFC-5 alpha

• Electrochemical behavior of SOFC at higher pressures

• Examination of operational boundaries of SOFC in dynamic systems

• Validation data for simulation

Siemens SFC-5 system in the laboratory
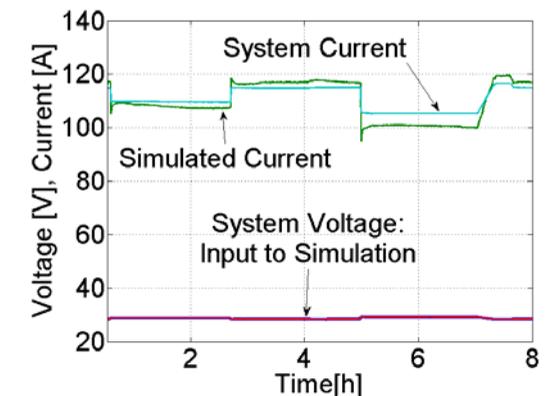
Validation experiments on SFC-5 system

Hybrid Power Plant

Results

• Model library has been developed and validated on Siemens SFC-5 Alpha system

• Simulation shows SOFC systems load following capability

• The designed control system is able to keep the modelled system in safe operating conditions

• Experiments show promising first results

• The framework for building a real Hybrid Power Plant is ready to use.

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DLR-Institute for Technical Thermodynamics
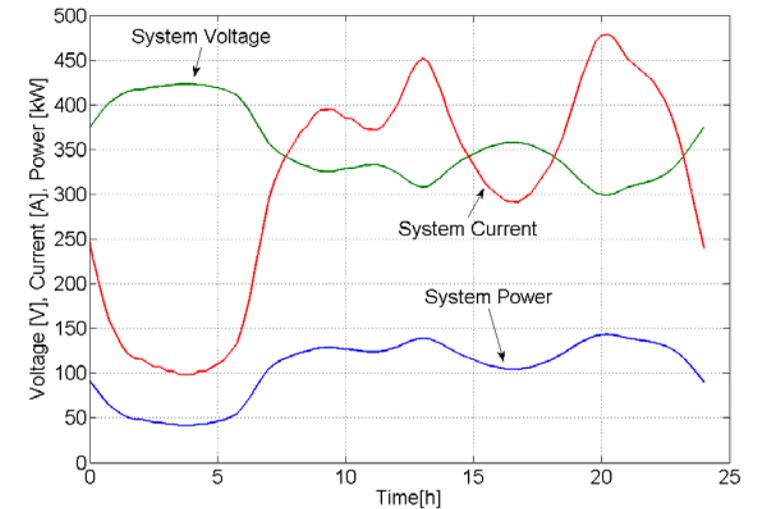
Load following characteristics for a 100kW (atm) system at 4 bar during a 24h load cycle