

Market Access for Smaller Size Intelligent Electricity Generation (MASSIG)

**Examples for:
Adjustment of Generation Properties by Clustering**

**= Project Work Report =
Task 3.3**

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Abstract:

To enter “big markets” by “small DG” it is necessary for the power producers to fulfil a number of technical and other pre-conditions required by the market platforms or the trading parties. Examples of such pre-conditions are the generation patterns, required minimum power and energy levels or the kind of transient behaviour during load change transitions. Because of such requirements, it is quite difficult especially for fluctuating generation from RES to contribute to energy market products and be integrated into the general system of electricity supply.

Considering the pre-conditions identified in Task 3.1 and the contradictions between demand and generation from RES and DG as discussed in Task 3.2, the present working document presents representative results from previous and current projects demonstrating the ability of clusters integrating generators of various technologies to achieve new properties for electricity generation and new options for contributions to energy market products.

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1 Introduction

The present study is part of the investigations in Work Package 3: Pre-conditions for entering “big markets” by “small DG”. The intention of this work package is to identify and analyse technical and non-technical requirements for DG power producers to generate products, which can be sold at the electricity markets or might be offered to market parties. Quite often there are contradictions between the required delivery profiles and the options for actual generation because of the technical properties inherent to the individual generation technologies. The most obvious case for this are fluctuating renewable generation technologies (RES), which normally feed-in electricity when wind or solar irradiation are available and which (by themselves only) can not adjust to the momentary grid load.

By combining a number of different generators either of the same or of different technology types it is possible to create a larger “virtual generator” with new technical properties, which can be influenced by intelligent management of the individual generation units (including energy storage). Even though this is a very complex field depending much on the concrete individual generator types, in the current report some known approaches for clustering a number of systems are presented and their concepts are evaluated with respect of applicability for new marketing options. For this evaluation, results of previous and ongoing projects of project partners and other show cases were collected. It is important to note, that task 3.3 describes existing general approaches only, while innovative new technical solutions are to be worked out in WP4.

2 Local and regional systems including co-generation

Besides RES generation systems, generators with combined heat and electrical power production (CHP) are the most important technology class to be installed in a high number and with a high total power volume in electricity distribution grids in future. Reasons for this are the high overall efficiency for energy conversion (especially compared to electricity production from large conventional central power plants) and the option for burning bio fuels that might be produced locally near the CHP installation. The European Union expects a large potential for the further installation of new CHP systems – so it has been analysed in the SET-plan [SET 2007], that starting from about 95 GW_e of today installed capacity figures could go up to 185 GW_e in 2020 and 235 GW_e in 2030.

In Germany, CHP electricity generation reached a market share of 11% with some cities like Flensburg or Schwäbisch Hall having already even more than 50%.

Today most CHP are heat operated, which means, that the units are running during times of high heat demand regardless of the momentary electricity demand in the grids. The produced electricity is just fed into the grids and (in countries with feed-in tariffs) remunerated by flat rates.

There are, however, some options to overcome this problem and shift the CHP operation to times with high electricity need. Such options are intelligent thermal energy management including alternative thermal generation units, the use of thermal storage systems or the adjustment of thermal loads. This way the electric output of CHP becomes (within certain limits) controllable and might help to compensate fluctuations from RES technologies like wind or PV. With a larger ensemble of fluctuating generation, controllable CHP and additional thermal and electrical storage systems it becomes possible to create a “Virtual Power Plant” that actually can deliver certain energy market products.

First field test for this approach haven been implemented during the last years and some operation results are available. A number of such examples will be presented in the following chapters.

2.1 Solar Settlement „Am Steinweg“, Stutensee

2.1.1 Technical description

As part of the European research project DISPOWER – Distributed Generation with high penetration of renewable energy sources [DISPOWER 2006] a number of test sites have been implemented, where different aspects of the integration of DG/RES technologies into distribution grids could be studied and the operation of a decentralised energy management system developed by Fraunhofer ISE was tested [Erge 2005]. One of these test sites is the Solar Settlement “Am Steinweg”, Stutensee.

The settlement is located near Karlsruhe, Germany. It was built as a pioneer ecological settlement with decentralised combined heat and power generation by the architect Heinz Maier in co-operation with MVV Energie. About 400 persons live in the settlement “Am Steinweg” in 101 apartments. Electrical power consumption is mainly caused by residential loads for cooking, washing, TV etc. Approximately 125 kW maximum load has been measured at the transformer.

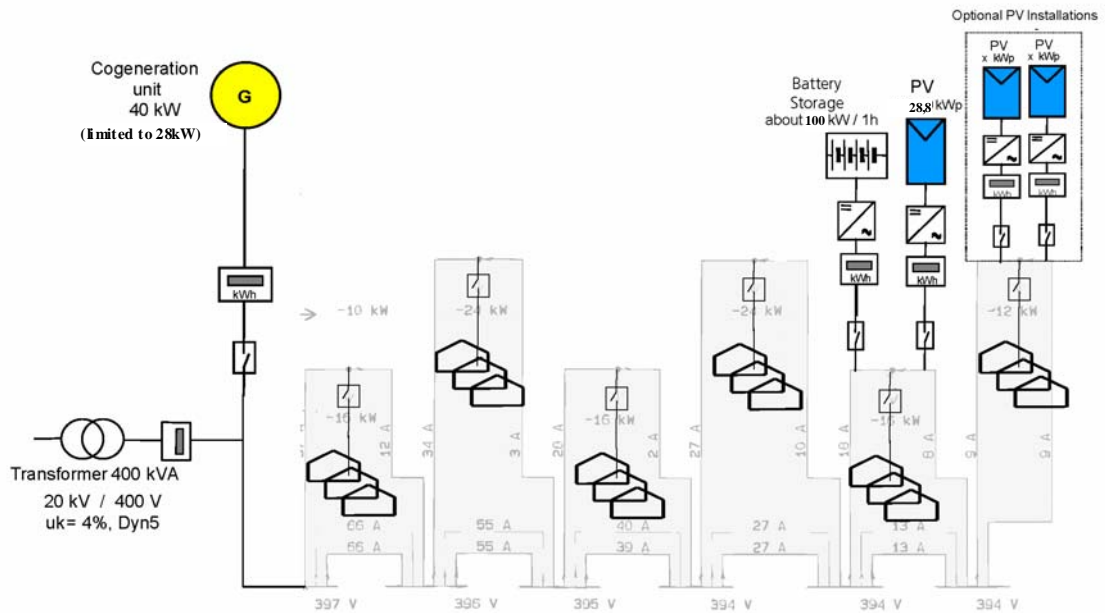


Figure 1: Ecological settlement “Am Steinweg”, Stutensee: the grid is connected to one transformer and is operated in closed ring configuration.

The LV network at the location “Am Steinweg” (Figure 1) is a common three-phase network with distributed neutral. The LV voltage is 230 V (phase to neutral voltage) / 400 V (phase to phase voltage). The LV network is connected to the MV level by using a MV/LV transformer with a rated power of 400 kVA.

During the project period there were three main distributed generators connected to the LV grid:

- a **combined heat and power plant** (GTK 40, Kuntschar & Schlüter) with a nominal electrical generation power of 40 kW. The unit had to be operated with a reduced electric output power of about 28 kW because of noise protection requirements. In addition to the CHP, a thermal store with 4000 l volume and two additional boilers (345 kW_{th} each) driven by natural gas are installed as well.
- a **lead acid battery** system with a total battery capacity of 880 Ah and inverter rated 100 kW in both directions (4 quadrant operation), 3 phases. After the end of the DISPOWER project the battery storage had to be removed.

- a **PV installation** with 28.8 kWp nominal power, feeding in a point of delivery using five one-phase inverters. The PV installations consist of 10 rows with 18 PV modules. Four more 2 kWp PV installations are installed on private houses and further small individual PV systems are expected.

By using the so called “POMS” (Power Flow and Power Quality Management System) developed by Fraunhofer ISE, the operation of the controllable generators and storage systems had been managed in a way to balance local loads and generation, to integrate fluctuating generation and to improve power quality in the local distribution grid. Day-ahead forecasts for load and generation involving the evaluation of detailed historic data from the settlement are the main basis for this optimisation process.

Even though the battery system has been removed after the end of the MASSIG project, the POMS system until today optimises the CHP operation with the intent to lower the peak load in the grid.

2.1.2 Operation results

Within the project DISPOWER, the following investigations and experiments were done in the LV grid at the settlement:

- investigation of the current situation regarding power quality and energy flows, including the dependence on the operation of the distributed components and the varying electricity demand of the households,
- implementation of energy algorithms to cut peak-loads and decrease or level-out, respectively, the energy demand via the LV-MV transformer.
- experiments to realise some “virtual” islanding mode for the whole grid segment, where momentary generation equals momentary consumption.

Main results from the experiments have been:

- The PV energy yield could be maximised, because the voltage band is not exceeded even in extreme situations. Depending on the limited transport capacity of the grid cabling, the voltage level during excess times of fed-in energy might rise, leading to a switch-off of distributed generators like PV. By intelligent energy management this situation can be avoided and a maximum of renewable energy might be delivered to the grid.
- The energy flow is optimised: use of high tariff electricity is minimised and the energy flow at the transformer can be driven to zero for a certain period of time. This means that from the energy flow perspective an islanding operation is feasible, even in winter time with low solar electricity input.

- Components operation is optimised, leading to less maintenance and longer lifetime.

As an example, Figure 2 shows the effect that intelligent energy management of the distributed energy resources might have. It can be seen, that the peak power demand from the MV grid (measured at the transformer) could be reduced significantly. Besides technical advantages this also lowers the costs for the operator of the distribution grid regarding the fees to be paid for using the MV grid.

It should be noticed, that also the electricity production by the PV system has been considered for the overall energy management, since the PV output power significantly influences the energy flow within the entire distribution grid. By means of day-ahead prognoses it became possible to estimate the PV generation schedule for the next day and adjust CHP operation accordingly to compensate low PV production by increased CHP generation.

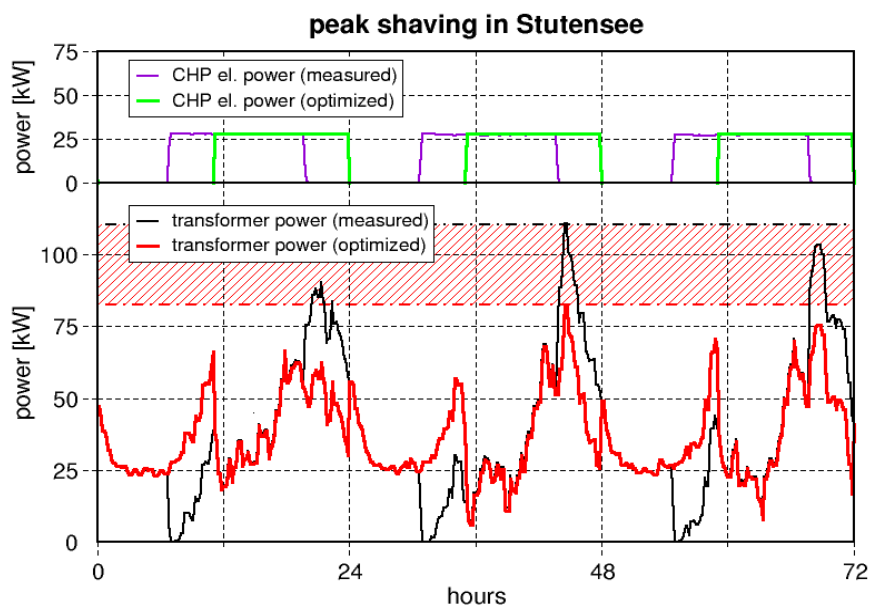


Figure 2: Peak shaving effects can be achieved at the pilot installation “Am Steinweg” Stutensee by adjusting CHP and battery operation. The figure shows simulation results for improving MV transformer energy balance.

2.1.3 Conclusions with relevance for the MASSIG project

In this pilot installation the following combination of different technologies was investigated:

CHP generation + heat storage + boiler + electrical storage (battery) + Photovoltaics

The main new features resulting directly from the combination of different technologies are:

- a higher degree of freedom for CHP operation by using intelligent heat management integrating boiler and storage systems,
- some potential to compensate generation fluctuations from the PV system by adjusting CHP operation schedules according to solar irradiation prognoses,
- a modification of the energy flow in the electrical distribution grid by intelligent energy management of the different generation resources,
- a higher percentage of electricity produced and consumed locally.

Table 1 shows a summary of technical solutions that could be achieved by the combination of systems and the potential relevance of those solutions for market options that have been identified in the MASSIG project in WP2.

Technical solution	Marketing option
Combination CHP + storage + boiler allows power driven operation of CHP	Contributions to: electricity trade, balancing trade, tertiary reserve, avoided grid utilisation, self balancing, local peak shaving =if combined with other generators to reach minimum power levels=
Combination of CHP + PV + electrical storage allows “upgrading” of of the fluctuating PV electricity to a tradable and controllable electricity product	electricity trade, balancing trade, tertiary reserve, avoided grid utilisation, self balancing, local peak shaving =if combined with other generators to reach minimum power levels=
Even <u>without electrical storage</u> the combination of CHP + PV allows a certain fraction of PV electricity to be traded, if reliable generation prognoses are available	limited relevance for electricity trade, some relevance for (mostly negative) balancing power, relevance for avoided grid utilisation, self balancing and local peak shaving
CHP schedules optimized with respect to PV generation forecasts and expected grid load profiles might prevent grid congestion	Local congestion management
Energy management of different generators and storages improves power quality	Ancillary services

Table 1: Solutions for the adjustment of technical properties by combining different generation technologies and the relevance for MASSIG marketing options

Restrictions and problems:

- The generators at the pilot installation add up to a relatively small total power volume, which does not reach the lower limits for contributions to the power exchanges or other market products.
- Especially in the winter season under normal operation mode conditions the CHP runs continuously during the whole day. Any intelligent energy management would infringe this operation mode and lower the number of full-load hours of the CHP during the year, which normally is not the intention of the CHP operator.
- Integration of PV generation requires reliable predictions, which need to be sophisticated and which always will have a certain level of uncertainty. Taking into account the situation, that the output level of the CHP can not be adjusted freely, the compensation of PV fluctuations is very limited, if no additional battery is available.

2.2 Virtual Power Plant “badenova” Freiburg

2.2.1 Technical description

In a project finished recently, the German utility “badenova” together with the Fraunhofer Institute for Solar Energy Systems ISE investigated options to optimise the operation of an ensemble of distributed generators in the regional distribution grid with respect to required technical or economic targets [badenova virtplant]. Such targets were e.g. the compensation of fluctuating wind power generation or the lowering of peak loads in the grid. Approaches for an economic optimisation targeted at the adjustment of local electricity generation according to varying prices for electricity sales, e.g. orientated at the price level at the German Power exchange EEX. One special feature of the project was the discussion of the role of the different market parties in the liberalised and unbundled energy supply system and the (prospective) conflict of interest between the owners of the generators, the operators of the distribution grid and the energy traders regarding the optimisation goals for the energy management system.

The distribution grid of badenova supplies a region with about 260.000 thousand people and is spreading on an area of about 60 km². It includes low voltage and medium voltage grid segments with 15 transformers to the high voltage level. The profile of the grid load is typical for German distribution grids and shows higher demands during winter time and during noon at working days (Figure 3).

Gesamtnetzlast 2. Halbjahr 2007

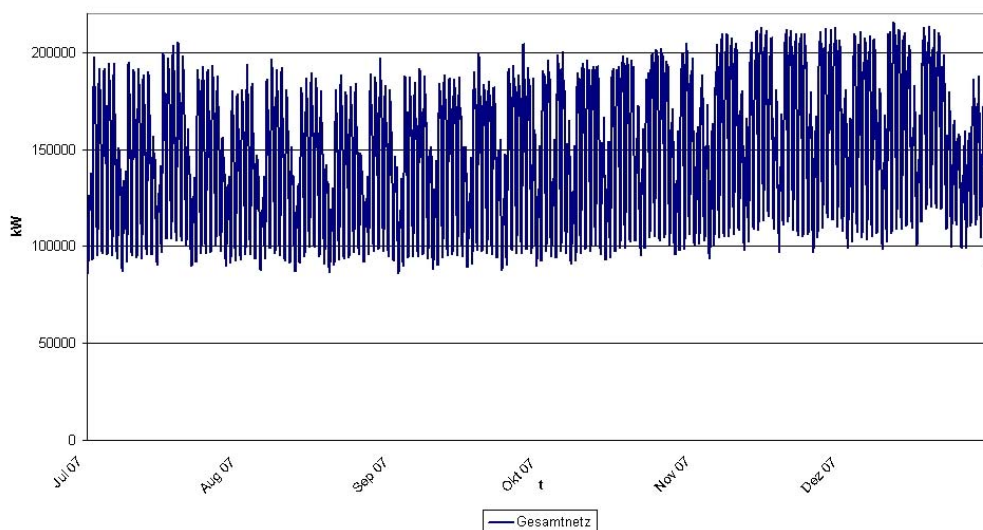


Figure 3: Total grid load for the badenova distribution grid during 2nd half of 2007 [badenova grid]

There is a significant percentage of distributed generation in the badenova grid, 37% of total demand is covered by the technologies shown in Figure 4. So there are more than 6 MW_p photovoltaic systems in the grid and about 11 MW wind turbines.

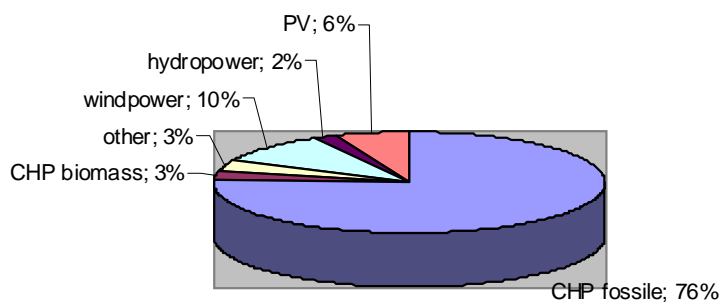


Figure 4: Generation technologies installed in the badenova electricity grid. Generation in the badenova grid covers 37% of the total energy demand. (2004)

For the research project the following controllable generators were available (Figure 5):

- CHP system with two units (2760 kW_{el} each) driven by natural gas
- CHP system with five units (678 kW_{el} each) driven either by natural gas or landfill gas
- Several motor generators driven by diesel fuel with a total power of about 3900 kW, mainly used for peak load supply.

The combination of CHP plus motor generators plus wind power system plus photovoltaic systems has been called “Regional Virtual Power Plant” to point out the aspect, that also the properties of the local distribution grid are considered when operating the VPP.

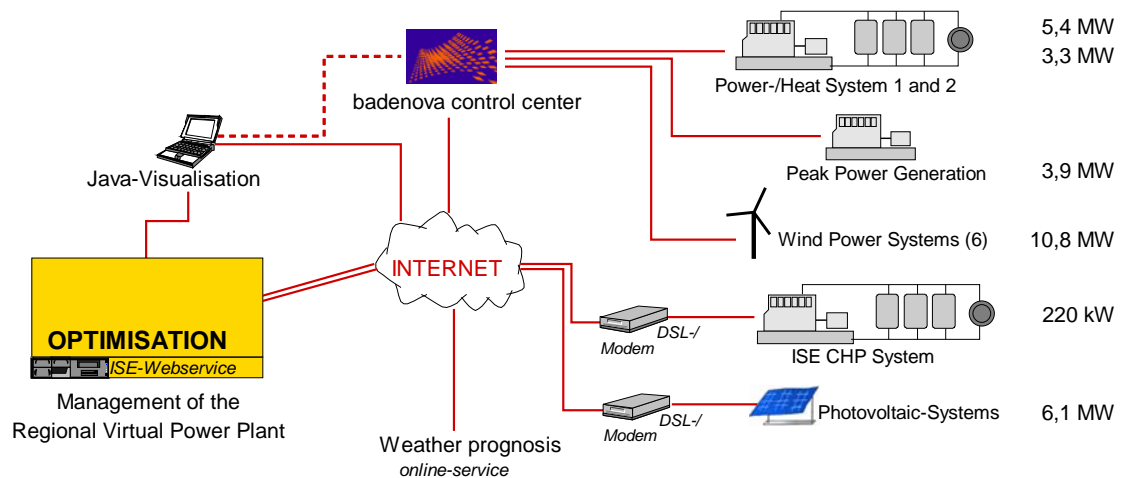


Figure 5: Scheme for the “local virtual power plant” of badenova

2.2.2 Operation results

The following investigations and experiments were part of the badenova project:

- compensation of fluctuating generation of wind turbines by adjustment of CHP operation,
- limitation of the peak grid load and the power flow via the transformers to the TSO grid,
- adjustment of distributed generation to variable electricity prices at the power exchange.

Main results from the experiments have been:

- A model of the badenova grid with the main generators, consumers and interfaces to other grids has been created and a flexible energy management system was designed to optimize the grid operation according to technical and economic targets set.

- It turned out, that a (even partly) compensation of fluctuating wind power produced by a small number of localised wind turbines is extremely difficult because of fast and unpredictable fluctuations in wind generation.
- Day-ahead predictions for electrical and thermal grid loads were quite reliable and allowed to implement an automated mechanism adjusting the CHP operation according to the optimization targets (peak-load shaving, adaptation to EEX price level).
- It was found, that the optimisation according to EEX prices might bring at the same time benefits both to the owner of the CHP (in case of energy sales at the power exchange!) and the grid operator, who is motivated to lower peak loads.

As an example, Figure 6 shows for one day in August a comparison between standard operation of the distributed generators and a situation, where the controllable loads have been adjusted in a way to operate especially during times of high demand and lower wind power production. It can be seen, that a significant adaptation to the load curve could be achieved by shifting the operation times of the CHP units accordingly.

One specific advantage for the project was the available monitoring and communication infrastructure for all distributed generators, which are linked on-line with the control centre of the grid operator badenova. Schedules for optimised operation of the CHP have been generated automatically and were submitted to the personnel of the badenova control centre for optional integration into the overall grid management.

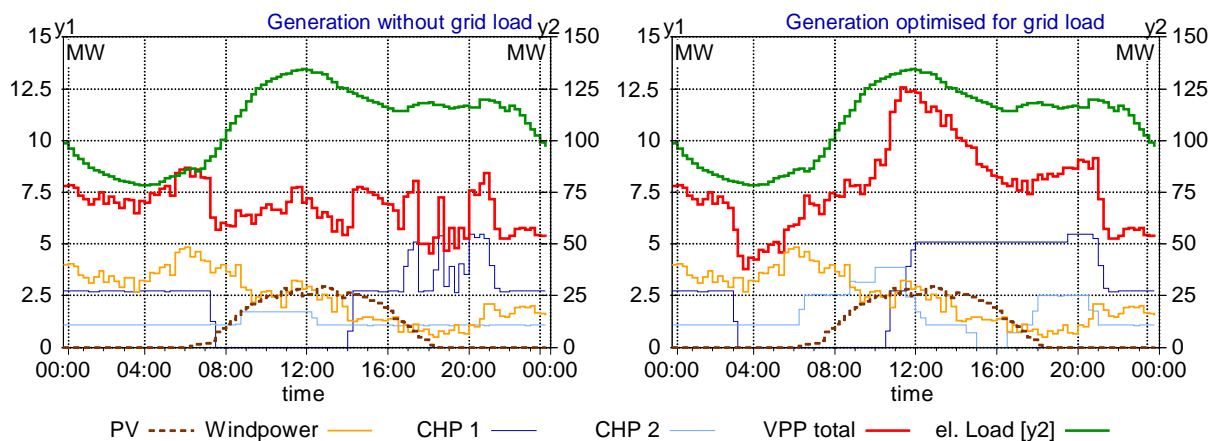


Figure 6: Comparison between standard operation of the distributed generators and a situation, where the controllable loads have been adjusted in a way to operate especially during times of high demand and lower wind power production (one day in August).

2.2.3 Conclusions with relevance for the MASSIG project

In this pilot installation the following combination of different technologies was investigated:

CHP generation of different technologies (including local heat management) + motor generator + photovoltaics + wind power

The main new features resulting directly from the combination of different technologies are:

- CHP systems could be operated in a way to lower the peak load of the grid and the energy flows via the HV-MV transformers.
- By predicting local loads and fluctuating generation it was possible to adjust the CHP operation to the momentary local grid load, thus increasing the share of local generation in total consumption.
- The whole “regional virtual power plant” could be operated in a way adjusted to (predicted) electricity prices at the power exchange EEX. Adjusting to EEX prices mostly turned out to be advantageous for the grid operator at the same time.

Table 2 shows a summary of technical solutions that could be achieved by the combination of the systems and the potential relevance of those solutions for market options that have been identified in the MASSIG project in WP2.

Technical solution	Marketing option
Combination of various generation units of medium size leads to a total generation capacity in the range of several MW. Thus critical limits for electricity and reserve markets can be met.	electricity trade, balancing trade, tertiary reserve, avoided grid utilisation, self balancing, peak shaving
By proper combination of local heat management with the electrical grid management it was possible to shift operation times for the CHP according to need from the electricity grid or power exchange.	electricity trade, balancing trade, tertiary reserve, avoided grid utilisation, self balancing, peak shaving
By adjusting CHP schedules to predicted wind and PV generation and prognoses for the local loads it became possible to adjust total energy balance of the whole load + generation ensemble to external parameters (e.g. EEX price level)	electricity trade, balancing trade, tertiary reserve, avoided grid utilisation, self balancing, peak shaving

Table 2: Solutions for the adjustment of technical properties by combining different generation technologies and the relevance for MASSIG marketing options

Restrictions and problems:

- Integration of PV and wind generation requires reliable predictions, which need to be sophisticated and which always will have a certain level of uncertainty. Especially short-term fluctuations for local wind turbines could not be predicted at all, if only few turbines on single locations are involved.

2.3 Virtual Power Plant KONWERL

2.3.1 Technical description

KONWERL was one of the first German VPP projects combining generation units and loads installed in an energy park. The project was implemented in 2002 and combines generation from photovoltaics, wind energy, biomass CHP and boilers. Table 3 shows the components and technical data integrated in the KONWERL project.

Component	Power	Notice
Photovoltaics	16 kW _p	Feeds public electricity grid
Windpower	1800 kW _{el}	Feeds public electricity grid
Biomass CHP	488 kW _{el} , 4500 kW _{th}	Feeds public electricity grid and local heat grid
Boiler	4500 kW _{th}	Feeds local heat grid
Electrical peak load	850 kW _{el}	80 living houses, industries, research centre, hotel, own consumption CHP
Thermal peak load	5250 kW _{th}	
Fraction of controllable load	160 kW _{el}	

Table 3: Technical data for the VPP KONWERL [Buchholz 2006]

As can be seen from Table 3, the VPP has a considerable high fraction of fluctuating generation (1,816 kW out of 2,304 kW maximum generation capacity) and a relatively small fraction of controllable loads (160 kW).

It was the intention of the project to integration RES and conventional generation by using an elaborate energy management systems from Siemens – DEMS. Using system data and prognoses for generation and thermal and electrical loads the DEMS produced optimized schedules for the operation of the individual systems.

2.3.2 Operation results

By using the DEMS system, schedules of fluctuating generation, changing demands and controllable generators and loads could be matched to each other in order to increase the share of locally used renewable energy and to achieve more predictability regarding the load demand from the public electricity grid. Figure 7 shows load and generation schedules for one day.

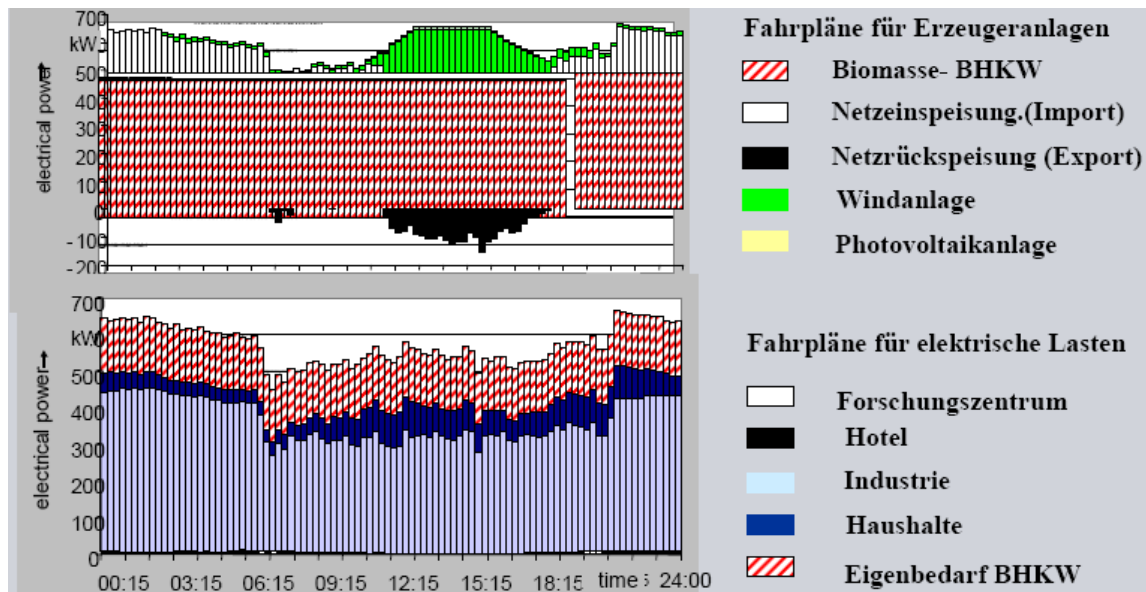


Figure 7: Load and generation schedules for the VPP KONWERL [Buchholz 2006]

Upper graphic: schedules for generation – biomass CHP / grid import / grid export / wind turbine / photovoltaics

Lower graphic: schedules for electrical loads – research centre, hotel, industry, living houses, own consumption CHP

2.3.3 Conclusions with relevance for the MASSIG project

In the KONWERL project an intelligent energy management system was used to combine different technologies of RES and conventional generation by means of operation schedules in order to serve local load profiles by the ensemble. Primary target for this had been the intention to increase the share of electricity generation by RES; market aspects (like in MASSIG) have not been in the focus in the project.

Nevertheless this early VPP project shows, that by combining fluctuating and conventional generation and using elaborate prediction mechanisms it become possible to create generation schedules, which include a considerable fraction of RES generation. In the project it was found, that the average error for load prognoses was in the range of 6 – 14% and the error in the wind power forecast was about 40%. Average deviations from the grid schedule (import and export) are reported to be smaller than 12 %.

Table 4 shows a summary of technical solutions that could be achieved by the combination of systems and the potential relevance of those solutions for market options that have been identified in the MASSIG project in WP2.

Technical solution	Marketing option
By adjusting the schedules of CHP, boiler and controllable loads to predicted wind and PV generation, and by combining this with prognoses for the general load schedules it became possible to adjust total energy balance of the whole load + generation ensemble to given targets	Contributions to: electricity trade, balancing trade, tertiary reserve, avoided grid utilisation, self balancing, peak shaving

Table 4: Solutions for the adjustment of technical properties by combining different generation technologies and the relevance for MASSIG marketing options

2.4 Virtual Power Plant Unna

2.4.1 Technical description

Subject of the Virtual Power Plant Unna (Stadt Unna, Germany) was to combine distributed generation capacities installed within the electrical distribution grid of the utility Stadtwerke Unna (Figure 8). The VPP was officially started in December 2004 and initially consisted of 5 CHP units, which were extended during the following years. Table 5 shows a summary of the involved controllable generation units.

Location / Generator	Power	Notice
CHP I (Gartenvorstadt)	600 kW _{el} 13.050 kW _{th}	3 gas motors, 2 boilers, 2 heat stores (50 m ³ each)
CHP II (Königsborn)	940 kW _{el} 18.100 kW _{th}	3 gas motors, 3 boilers, 2 heat stores (50 m ³ each)
CHP III (Eissporthalle)	105 kW _{el} 1.180 kW _{th}	1 gas motor, 1 boiler, 1 heat store (7 m ³)
CHP IV (Freizeitbad)	105 kW _{el} 1.280 kW _{th}	2 gas motors, 1 boiler, 1 heat store (7 m ³)
CHP V (Zechenstraße)	181 kW _{el} 752 kW _{th}	1 micro-gas turbine, 1 boiler, 1 decompression turbine, 1 PV system (6 kW _p), 1 heat store (4 m ³).
Total	5.116 kW_{el} 39.242 kW_{th}	

Table 5: Technical data for the controllable loads of the VPP Stadtwerke Unna [Hennig 2006]

In addition to the controllable generation units, also one hydropower system, two windparks and some PV installations have been considered in the context of the VPP, leading to a total electrical generation capacity of 16 MW_{el} [Auer 2006].

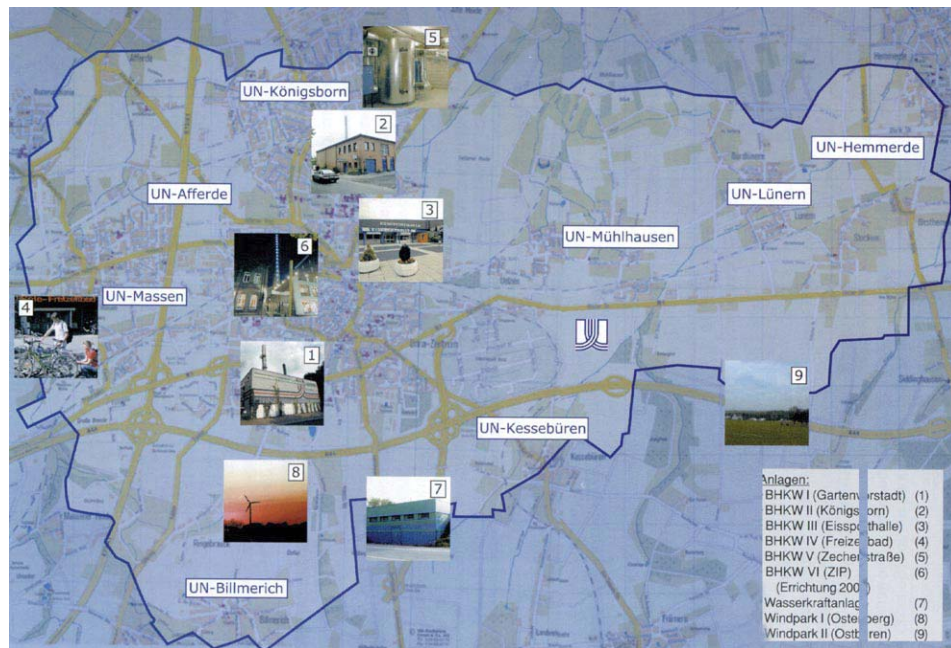


Figure 8: Distributed generation systems of Stadtwerke Unna [Henning 2005]

2.4.2 Operation results

One major target for the operation of the VPP had been the limitation of electrical peak loads by elaborate generation and load prognoses and performing energy management involving all controllable generators and the heat stores. It was found, that peak loads of the Stadtwerke Unna could be reduced up to 5,1 MW_{el}. Using the gas motors electrical and thermal energy could be produced during times of high energy prices.

The VPP could contribute to the reduction of deviations from the scheduled energy flows in the balancing area. This led to a decrease of necessary balancing energy. It was also possible to increase the share of local generation by adjusting CHP operation (which also led to a reduction of CO₂ emissions), and to decrease the grid losses.

2.4.3 Conclusions with relevance for the MASSIG project

With the Virtual Power Plant Unna it was demonstrated, how a combined ensemble of medium size DG generators can significantly influence the energy flow in the electricity grid, how it can limit the peak load demand from external suppliers and how it can increase the self balancing capability of the corresponding distribution grid.

Table 6 summarises the new technical solutions and compares them with the MASSIG market options.

Technical solution	Marketing option
Combination of various generation units of medium size leads to a total generation capacity in the range of several MW. Thus critical limits for electricity and reserve markets can be met.	electricity trade, balancing trade, tertiary reserve, avoided grid utilisation, self balancing, peak shaving
By proper combination of local heat management with the electrical grid management it was possible to shift operation times for the CHP according to need from the electricity grid or power exchange.	electricity trade, balancing trade, tertiary reserve, avoided grid utilisation, self balancing, peak shaving
By adjusting CHP schedules to predicted wind and PV generation and prognoses for the local loads it became possible to adjust total energy balance of the whole load + generation ensemble to external parameters (e.g. peak load in the grid)	electricity trade, balancing trade, tertiary reserve, avoided grid utilisation, self balancing, peak shaving

Table 6: Solutions for the adjustment of technical properties by combining different generation technologies and the relevance for MASSIG marketing options

2.5 Other projects

A number of other projects demonstrate solutions to couple local or regional generation and storage systems including CHP thus adjusting the generation properties of the whole ensemble.

“Virtuelles Kraftwerk Harz”

- Integration of up to 1.000 micro CHP systems (Senertec “Dachs”) in the VPP.
- Most systems are installed in private houses and have powers of 5 .. 5,5 kW_{el} and 10,3 .. 12,5 kW_{th}.
- In addition, another 2 MW of larger generation systems will be included in the VPP as well.
- Target for operation: lowering of peak power demand in the regional grid, lowering of costs for grid use and electricity purchase.
- The start of regular operation was announced for June 2007.
- References: [BEF 2006], [Clausthal 2006]

- Relevance for MASSIG:
integration of a large number of very small generation units to generate actual impact for electricity supply, combination of small size units with larger generators.

“Energiepark Clausthal”

- Energy supply of one large commercial building was to be realised by an ensemble of distributed RES generation technologies.
- Figure 9 shows the technical concept for the Energy Park’s power stations and their output details.
- Technologies used: wind turbine (80 kW), hydro power plant (30 kW), PV system (18,5 kW_p), Biogas plant with gas motor (30 kW_{el}, 60 kW_{th}), wood chip combustion with integrated Stirling engine and waste heat boiler (CHP up to 40 kW_{el} and 160 kW_{th}).

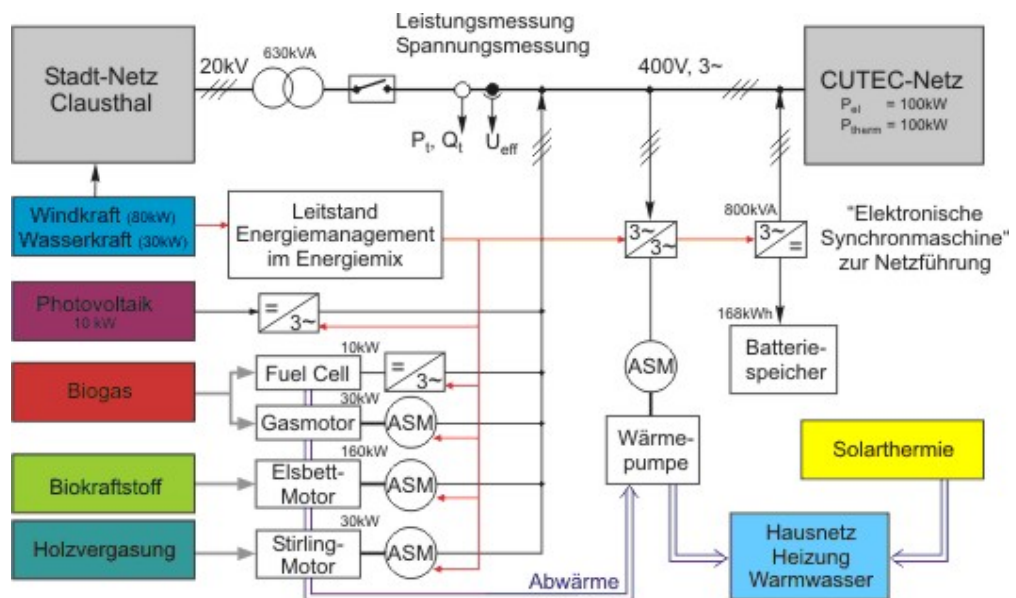


Figure 9: Technical concept of the demonstration system “Energiepark Clausthal” [DRESY 2008]

- Special feature of the project: the electricity supply system is design for changing to islanding operation and separation from the public electricity grid.
- References: [DRESY], [FEN], [Beck 2001]
- Relevance for MASSIG: combination of different technologies and integration in a self-sufficient supply system, one of the few attempts of local supply grids, that could be run grid-connected or in islanding mode (which requires, that the ensemble of generators is able to provide all kinds of supply and ancillary services). Integration of fluctuation generation.

“European Virtual Fuel Cell Power Plant”

- The aim of “The Virtual Fuel Cell Power Plant” [EUVPP 2005] was to develop, to install, to test and to demonstrate a virtual power plant consisting of 31 decentralized stand-alone residential fuel cell systems. The project was funded by the 5th Framework Programme of the European Commission and ran between November 2001 and February 2005.
- 31 field test systems were successfully installed and operated (Figure 10). The low temperature (LT) PEM microCHP fuel cell systems were installed in apartments, houses and small businesses across Europe. The consortium has successfully demonstrated the operation of the decentralized microCHP fuel cells as a Virtual Power Plant as well of fuel efficiencies of up to 90% and electrical efficiencies of greater than 30%.
- Technical data of fuel cells: 4.6 kW_{el}, 9 kW_{th} (Vaillant)
- Results of a test week in the end of 2004, where selected systems received a load profile, showed, that if the technical systems don't have any technical problems they can follow the requested demand very good.

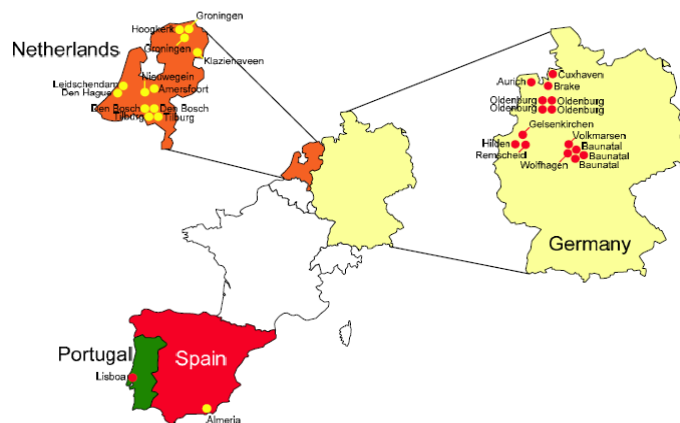


Figure 10: Map of field test locations of the project “European Virtual Fuel Cell Power Plant” [EUVPP 2005]

- References: [EUVPP 2005], [ProEcoPolyNet 2007]
- Relevance for MASSIG: Clustering of a larger number of distributed small size fuel cell systems and adjustment of electrical output to a pre-defined load profile.

“PowerMatcher Application – Imbalance Reduction System IRS”

- ECN (NL) is performing a field test for the Imbalance Reduction System IRS. Essentially, IRS is a flexible framework for implementing and checking the results of operating a number of strategies for reducing DG-RES caused imbalance in the context of external markets. IRS is developed in the CRISP-project [CRISP 2006]
- The problem tackled by IRS is the minimisation of the difference of predicted power and the real-time realised power of a portfolio of installations as operated by a program responsible party. The 'heart' of the portfolio consists of two wind turbine parks that operate on the market based on power predictions one day ahead. Deviations from these predictions closer to real-time (a time-ahead of 5 - 15 minutes) are countered by a number of flexible installations which are added to the wind park portfolio. Thus a reduction in the imbalance (preferably zero imbalance) is established, which results in a reduction of imbalance cost, that is imposed on the portfolio by the network operator. Figure 11 shows an overview of the technical infrastructure and communication network in the field test.

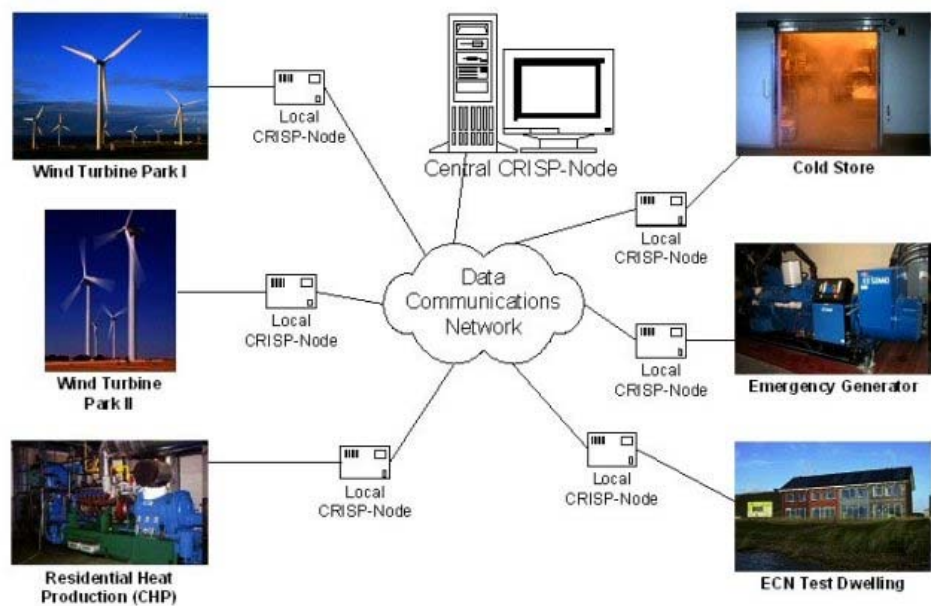


Figure 11: Overview of the technical infrastructure and communication network in the field test for the Imbalance Reduction System IRS [Warmer 2006]

- One special feature of the “PowerMatcher IRS” approach is, that it is a market-based control concept for supply and demand matching in electricity networks with a high share of distributed generation. In the PowerMatcher model each device is represented by a control agent, which tries to operate the process associated with the device

in an economical optimal way. The electricity consumed or produced by the device is mediated by the device agents on electronic exchange markets.

- Application areas (from the viewpoint of ECN) are local voltage cell control, imbalance management and contribution to Virtual Power Plants (VPP). For VPP, the PowerMatcher IRS might be used for managing a number of distributed generators to offer contributions for the day-ahead power market (e.g. the APX), the imbalance or spinning reserve market or giving support to the local distribution system operator (e.g. reduce local peak demand or defer reinforcement in grid infrastructure).
- References: [PowerMatcher 2007], [Warmer 2006]
- Relevance for MASSIG:
With the application of the PowerMatcher – System the ECN project team could show, that different distributed generation technologies can be combined in operation and that way can produce an electricity output profile, which can serve needs of the power markets or the grid operators. The approach of integrating market-based control concepts might make it easier to interconnect the system to larger market platforms and make market driven operation decisions for the individual generation units.

3 Larger Virtual Power Plants

Virtual power plants are clusters of distributed generation installations which are collectively run by a central control entity. In contrast to the showcases and projects in Chapter 2, examples to be presented in this part of the report show the following features:

- Objectives for the energy management do not target or consider the physical grid operation
- The projects do not necessarily involve a combined energy management of heat and electricity
- In most projects, larger generation units (MW range) are involved
- Systems are primarily run to generate products for power markets.

3.1 The Virtual Power Plant of Evonik Industries / steag Saar Energie

3.1.1 Technical description

Evonik Industries / steag Saar Energie is the first operator of a large Virtual Power Plant (VPP), which is specially designed to deliver reserve power. The VPP is realised by pooling of a larger number of distributed generation capacities located all over Germany. Figure 12 shows the locations taking part in this pooling. The operation of the VPP started in September 2003. Table 7 shows the specific data for the VPP.

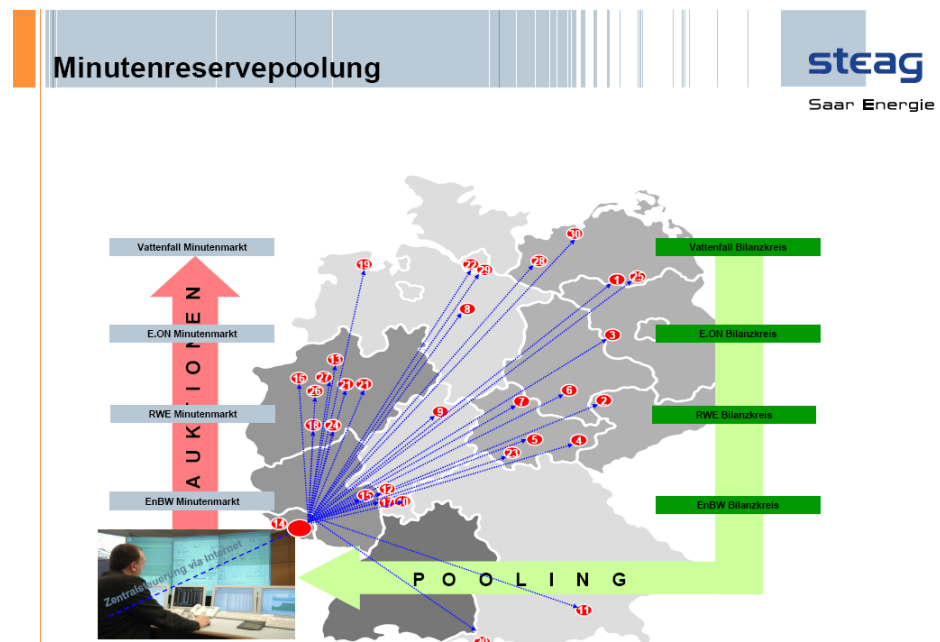


Figure 12: Pooling of distributed resources to a Virtual Power Plant by Evonik Industries / steag Saar Energie [Schweißthal 2007]

	Positive	Negative
Market volume	3.370 MW	2.450 MW
Market share	10 %	2,5 %
Pre-qualified power	1.019 MW	341 MW
Participants	41	4

Table 7: Data for the Virtual Power Plant operated by Evonik Industries / steag Saar Energie (product: tertiary reserve) [Schweißthal 2007]¹

There is a comprehensive set of technical prescriptions that must be met by the participating power generators, which are mostly in line with the pre-qualification requirements for the tertiary reserve markets. Generators that want to participate in the Virtual Power Plant need to be able to deliver at least 1 MW for at least 4 hours. Details can be found in [steag 2008].

3.1.2 Conclusions with relevance to the MASSIG project

The Virtual Power Plant of Evonik Industries / steag Saar Energie demonstrates in practice, how an independent company can combine and bundle a number of distributed generators and generate a marketing product that can be sold at the power exchange. It proves that such a solution can be economically beneficial and technically feasible. Unfortunately no detailed public information is available about the operation details and the individual customers bundled by Evonik Industries / steag.

It should be pointed out, that participation in the Virtual Reserve Power Plant most probably is only a secondary function of the individual generation units, which this way can produce extra income if the operation schemes of the VPP do not unacceptably interrupt normal operation!

Table 8 assesses the relevance to marketing options of MASSIG.

Technical solution	Marketing option
Combination of controllable loads and generators to reach critical power volumes for participating the reserve market.	Participation in market for tertiary reserve Potentially it might also be possible to generate other market products, like secondary reserve.
Addition of the option to provide reserve power to the regular operation scheme with only minor interruption of the main function of the generation units.	Creating (tertiary) reserve as secondary and additional marketing option to the main generation tasks (option for <u>additional</u> income)

Table 8: Technical solution and relevance for MASSIG marketing options

¹ Note: different figures have been published by other authors.

3.2 The German “Combined Power Plant” project

3.2.1 Technical description

The “Combined Power Plant” project (Figure 13) links and controls 36 wind, solar, biomass and hydropower installations spread throughout Germany. It shows how, through joint control of small and decentralised plants, it is possible to provide reliable electricity in accordance with needs. The power plants are selected to meet one ten-thousandth of Germany’s electricity needs – roughly equal to the electricity requirements of a town with 12,000 households (such as Schwäbisch Hall in Germany). The Combined Power Plant optimally combines the advantages of various renewable energy sources. Wind turbines and solar modules help generate electricity in accordance with how much wind and sun is available. Biogas and hydropower are used to make up the difference: they are converted into electricity as needed in order to balance out short-term fluctuations, or are temporarily stored.

The Combined Power Plant is an initiative of the companies Enercon GmbH, Schmack Biogas AG and SolarWorld AG, and is supported by many partners from the renewable energy sector. Operation of the “Combined Power Plant “ started in May 2007.

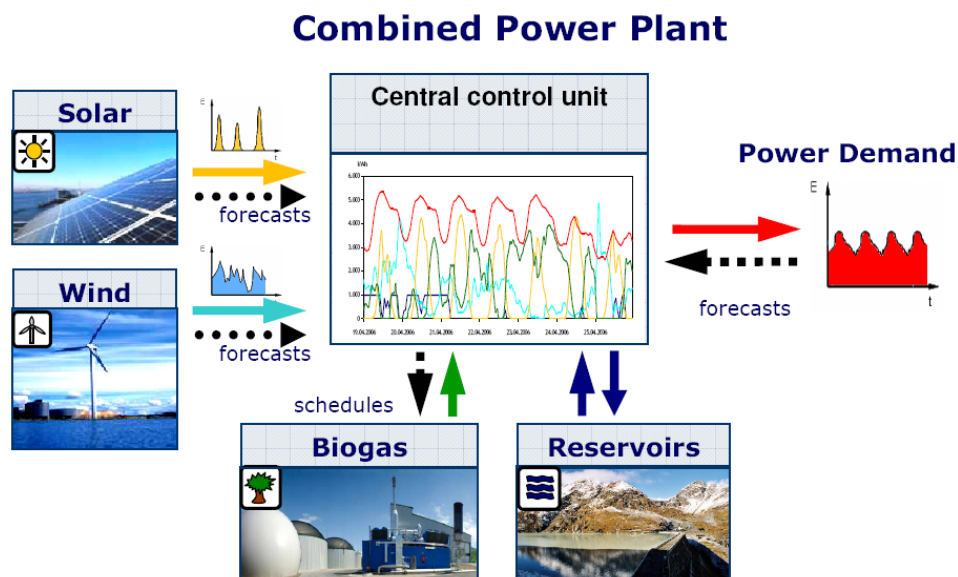


Figure 13: The “Combined Power Plant” targets to replace conventional energy supply by the use of RES including Biogas and storage systems [CPP 2008-1]

Table 9 shows the energy generation portfolio for the “Combined Power Plant”.

	Wind	Solar	Biogas	Reservoirs	Import/Export	Total
Installed Capacity [MW]	12.6	5.5	4.0	1.06	-1.0	-
Electrical energy [GWh/a]	26.5	6.2	10.8	-0.6	0.02/1.8	41.1 (43.5)
% of Total	60.9	14.3	24.8	-	-	100.0

Table 9: Generation portfolio for the “Combined Power Plant” [CPP2008-1]

The range of nominal power for the individual generation units is quite broad and reaches from relatively small generators, like a 30 kW gas turbine up to larger installations like a 3 x 2.000 kW wind park.

3.2.2 Conclusions with relevance for the MASSIG project

The “Combined Power Plant” project is a somewhat untypical project, since it is in between an “academic simulation” and a “real field test”. During the testing period, schedules for the operation of the controllable generators have been created and operation actually has been adjusted according to the needs of the “virtual customers”. Thus it was proven, that this ensemble of fluctuating and controllable generation units actually would have been able to supply the load profile, which has been chosen for this field experiment.

Regarding the MASSIG project this experiment clearly shows, that a proper combination of different RES generation technologies (including CHP) together with heat and electricity storage would be able to generate just the power profile needed by real consumers (and thus would also be able to adjust the generation to the needs of power exchange or ancillary service products). So the project verifies the approach of adjusting generation properties by clustering similar and different technology types of distributed generators.

Table 10 assesses the relevance of this solution to marketing options of the MASSIG project.

Technical solution	Marketing option
Combination of various generation units of small and medium size leads to a total generation capacity in the range of several MW. Thus critical limits for electricity and reserve markets can be met.	electricity trade, balancing trade, tertiary reserve, avoided grid utilisation, self balancing,
By proper combination of different DG / RES technologies combined with storage for heat and electricity a self sufficient supply of certain customer groups becomes possible. This also opens the option to generate flexible energy market products.	electricity trade, balancing trade, tertiary reserve, avoided grid utilisation, self balancing,

Table 10: Technical solution and relevance for MASSIG marketing options

3.3 Other Projects

“Virtuelles Kraftwerk Rheinland-Pfalz”

- The target for the VPP Rheinland-Pfalz was to combine existing CHP and emergency power supply units to a Virtual Power Plant offering especially tertiary reserve energy.
- Generation systems involved add up to about 52.4 MW peak power (December 2006).
- Marketing of the reserve energy is realised via STEAG Saarenergie (see 3.1).
- References: [Simon 2007]
- Relevance for MASSIG: The VPP Rheinland-Pfalz is another example for producing reserve power as a market product by clustering a number of distributed smaller generation units. The relevance for MASSIG is alike to the STEAG application explained in detail in Chapter 3.1.

Virtual Green Power Plant (Virtuelles Ökostrom Kraftwerk)

- The target of this VPP project was to enhance the competitiveness of distributed power generation from renewable energy sources under current market rules in Austria through a centrally coordinated dispatch of flexible power plants and loads.

- The analysed generation portfolio includes wind farms (up to 85 MW), small scale hydro (7 MW), biogas plants (0.4 MW) and PV installations.
- Different operation strategies have been simulated based on historical data including self-balancing, scheduling of flexible units based on power price forecasts and scheduling of flexible units based on the actual control area imbalance.
- References: [Obersteiner et al., 2008]
- Relevance for MASSIG: The project illustrates operation strategies for VPPs and assesses their profitability in the Austrian power market. Results may provide an orientation for further analysis of VPP concepts within WP4 of the MASSIG project.

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