Title **Concept and Practical Implementation of Integrated Flexible Biogas-Intermittent RE-Battery Storage for Reliable and Secure Power Supply to Meet Actual Load Demand At Optimal Costs**

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Summary

A practical implementation of flexible biogas with an intermittent renewable energy source and an energy storage in a virtual power plant (VPP) is shown. It provides reliable and secure power supply, and covers different load schemes regarding varying electricity prices. Methods applied were building a VPP, and developing a power management system (PMS) for the VPP. PMS is based on an agent-concept, the optimization algorithms are based on linear programming. Sensitivity analysis of different load schemes is done for different market integration approaches.
The results show that electricity from RES combined in a VPP delivers a secure power supply on low costs, when optimally integrated to energy markets e.g. futures market. It is also shown that the average optimized costs are influenced depending on the share of adjustable components (biogas, battery), e.g. in winter costs are higher due to less PV power.
The logical backbone of the PMS-the agent concept- is able to maintain the power supply stable and reliable. The applied Multi Agent Based Optimization Algorithm (MABOA) is working with high reliability; its plug-and-play structure allows the implementation of new components and adoptions of the algorithms in the operating system (hot plug), which helps to quickly react to changing requirements (legal, economic, technical) on the system without harming the system stability.

Purpose of the work

The challenges of RES-integration to the grid are network stability and matchmaking mechanism between supply and load demand [1;2]. Accurate forecasting, demand response and flexible generations are solutions addressing these issues [3]. Another method is to apply a control unit and automation to the integrated RES, as well as the deployment of a VPP [4;5]. An implemented VPP delivers technical and economic advantages of RES- and Distributed Generators (DG)-integration [6;7;8]. On the other hand, flexible energy from CHP and storage is taking an important role as balancing power supply [9;10].
The current state-of-the-art of biogas power plants enables biogas to provide flexible energy [11]. In practical implementation, flexible biogas for demand-oriented operation by flexible feeding and gas storage management is able to increase the income from electricity [12]. The optimization approaches on combined RE power plants to grid applications is currently booming [13].
However, the current concepts and implementations of integrated RES do not answer the question of how to overcome the problem of RES market integration (simultaneity effect). The purpose of this work is to develop a VPP based on RES with a PMS, which will supply secure electricity on minimum costs.
The flexible biogas is projected to answer residual load from intermittent RE. The reliability issue is addressed by an intelligent mix of flexible biogas, PV and battery. The communication within the VPP is addressed by implementing an agent concept. Furthermore, this integration enables the active participation of stakeholders in the markets.

Approaches

The research combines flexible biogas, PV and battery storage through a VPP using a multi-agent (MA) concept. Multi-agent concept is a system, which determines each of the combined power plant components as an entity that cooperates within the system based on common goals [14]. Models of the physical components, weather-, load- and price-predictions are generated and implemented as separate entities in a VPP to answer a certain load scheme under price and weather constraints. The conducted approaches are:

1. Developing hardware and intelligent system

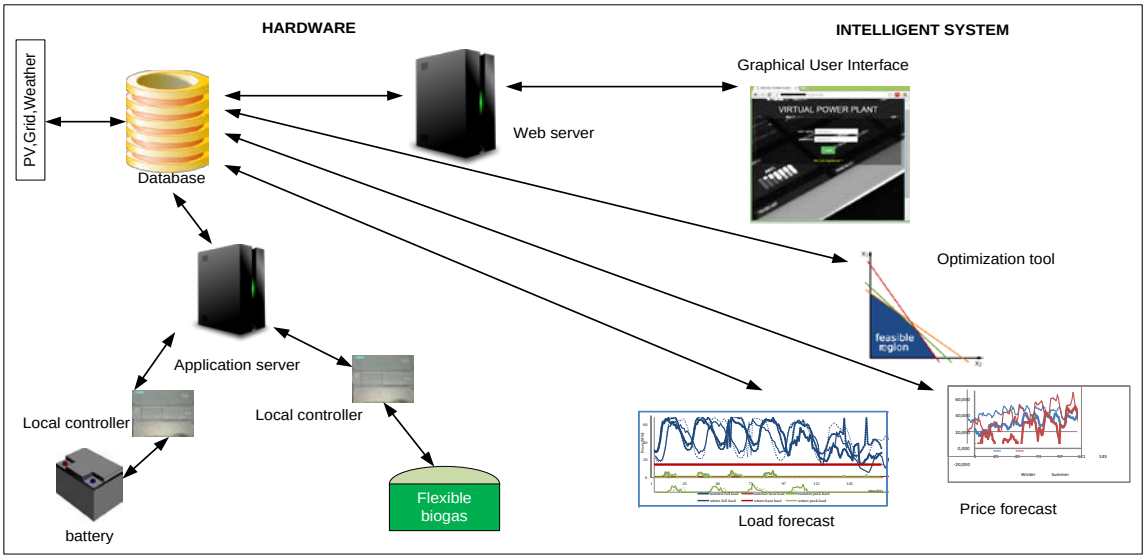

Figure 1. Hardware and intelligent system of integrated flexible biogas-PV-battery.

The hardware components provide actual information about the availability of power supply, its quantity, load and weather conditions to the optimization. PV, grid, and weather data are provided continuously by third party and integrated to the database. The VPP represents the operator's input/output data of the power plant. The intelligent system predicts load demand and electricity price and optimizes the dispatch of the power plants to answer the given load scheme. Power matcher generates the amount and time of each power plant to deliver power in regards of actual load at optimal costs.

2. Performing sensitivity analysis of different load scenarios

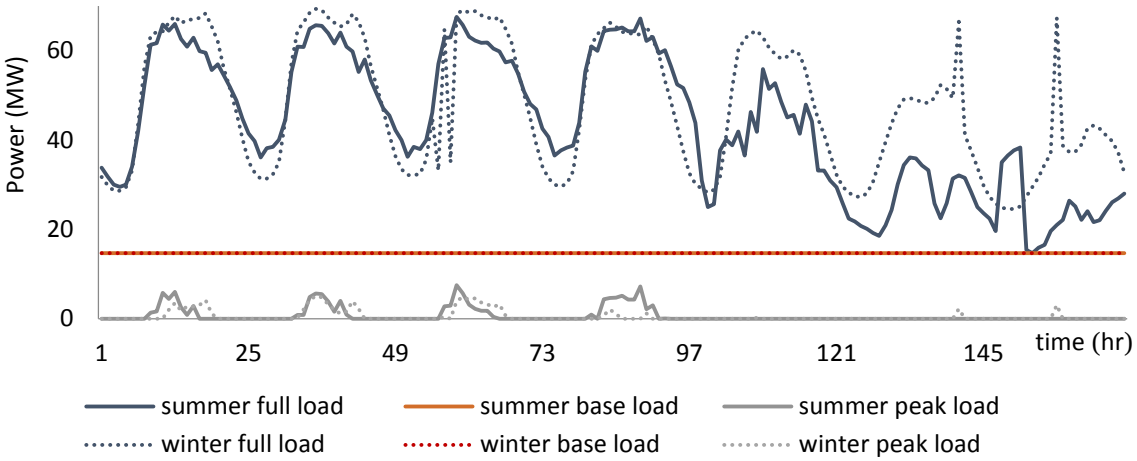

Figure 2. Different load scenario for sensitivity analysis.

The scenarios are classified into peak load, base load, and full load. Herein base and peak load are percentage shares of the full load profile. All scenarios are analysed in a winter and a summer profile. Analyse is done in steps of one hour for a period of seven days.

Scientific innovation and relevance

There are three main innovations realized in this research project.

1) The implementation of flexible biogas-PV-battery to provide secure and reliable power supply. The biogas plant is based on the ReBi-concept [15], operating a biogas plant at the stability limit in a real virtual power plant with short reaction times. With this kind of biogas implementation in a VPP the electricity from biogas gets more useful and more valuable in the concert of RES. Thereby electricity from biogas gets a new importance for the RES integration in the energy market.
2) The implementation of the MABOA system for the integration of several databases, optimization algorithms, process models in a common VPP. The MABOA allows quick reaction to changes in all connected agents and the hot-plug implementation of these changes.

3) A VPP application for integrated flexible biogas and intermittent RE with real data from stakeholders (load, price, weather). This combination shows the proximity of the RES-VPP concept to the market.

The applied integration approach has several advantages to the current development of power supply.

1) In regards to network reliability and stability; in the future there will be more installed RES on the grid, so that the grid needs more maintenance for its network stability. The modular concept is more adaptive to grid infrastructure changes since the agents are not rigid and can be reused for different cases [16]. By introducing the full knowledge of the characteristic of the system [17], the agents provide better optimization results than centralized systems. Agent concepts balance multiple stakeholder interests [18].Implementing an agent concept brings economic viability, profit of the VPP, and power plants emissions reduction [19;20;21]. Furthermore, the agent concept supports decision-making based on different situations such as dispatch strategy [22].The agents match the power supply and load based on available data.
2) The implementation of flexible biogas in real applications gives added value to RE developments for instance to get more information about flexible biogas boundaries. In combination with base load products on the futures market this is a new economy for biogas plants and bioenergy in general.
3) The VPP development is independent from the optimization algorithms as they are different entities in the agent-based system. So, the risk of failures between both of them is minimized.

The research is also relevant to the current RE development situation. The research integrates different stakeholders: grid operators, meteorological services, energy exchanges. A flexible biogas plant and a battery storage were implemented to test the integration concept using real data from stakeholders. The theoretical concept is tested in areal implementation. This research is answering the needs of reliable and secure power supply from flexible biogas and intermittent RE. Furthermore, this research shows the possibilities of selling RES electricity on the futures market. With this step the spot market gets relieved from excess supply, in the consequence prices could stabilize again; this price stabilization will affect also the futures market. Using the futures market for selling RES electricity brings more stability in the whole energy system, i.e. less back-up power is needed for grid stabilisation.

Preliminary results and conclusions

The optimized costs of the analyzed VPP depend on its power availability and the generation cost per unit [kWh]. Figure 3 shows the different average optimized costs calculated from marginal cost for different load schemes. The size of power plants in each case is set to be equal. Generally, the costs in winter are higher compared to costs in summer. The load demand requires more energy from flexible biogas in winter than in summer time. The most expensive operation is peak load since the load demand is small but the power plants generate energy with high energy dumping. The base load operation is the cheapest operation because less energy from flexible biogas and battery is required. The full load is more expensive than base load operation because the total energy demand in full load is higher and more fluctuating than in base load operation. As a consequence, in full load operation the use of flexible biogas and battery is higher than in base load operation.

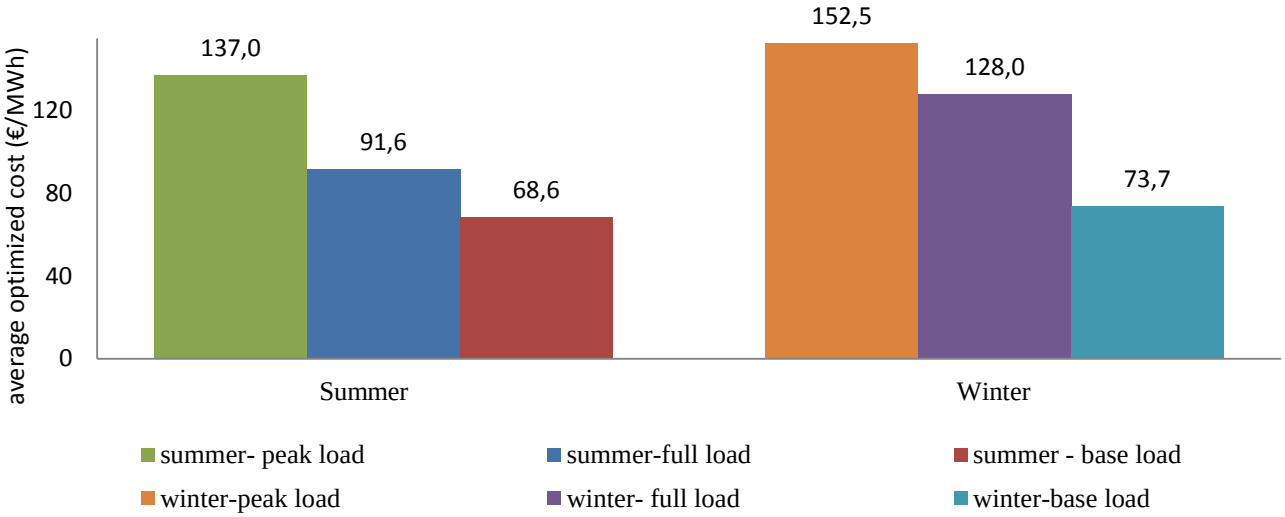

Figure 3. Average optimized costs for different load operation scheme.

Another finding is that the concept of plug-n-play MABOA matches the load and power supply requirements. The concept can be developed continuously; the reason is that the additional functions can be directly added to the core of MABOA algorithm.

It is possible to provide reliable and secure power supply from a VPP integrating flexible biogas-PV-battery. The flexible biogas works to cover the residual load as has been expected. However, more research in the future will be necessary to gain more information related to flexible biogas boundaries. On the other hand, MABOA optimizes the integrated power plants and maintains its stability. The results show the new economy for flexible biogas and MABOA concept applications in the future power supply structure.

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