VIRTUAL POWER PLANTS OF MICRO CHP UNITS COMBINED WITH ACTIVE COMPONENTS REDUCING PEAK LOADS AND LOAD FLUCTUATIONS

Phillip GRONSTEDT
TU Braunschweig - Germany
p.gronstedt@tu-bs.de

Arne DAMMASCH
TU Braunschweig - Germany
a.dammasch@tu-bs.de

Magnus PIELKE
TU Braunschweig - Germany
m.pielke@tu-bs.de

Martin TRÖSCHEL
OFFIS e. V. - Germany
martin.troeschel@offis.de

Michael KURRAT
TU Braunschweig – Germany
m.kurrat@tu-bs.de

Hans-Jürgen APPELRATH
OFFIS e. V. - Germany
appelrath@offis.de

ABSTRACT

The Energy Research Alliance of Lower Saxony, FEN, is focusing on active distributed energy systems with advanced energy informatics to minimize the grid losses and increase the energy conversion efficiency by using a grid-orientated operation mode.
The use of virtual power plants (VPP) of micro CHP units in a composite plan could contribute to the reduction of load flow fluctuations in the low voltage grid. A developed energy management system, based on a standard communication (IEC 61850), coordinates the use of a grid-oriented virtual power plant of micro CHP units. In this study the virtual power plant is enhanced by PV generation. A flexible demand side and electrical storage units are also implemented in order to shift and balance power consumption load peaks and reduce the overall load fluctuation on the low voltage level more effectively. In this manner the future feasibility for large scale integration of renewable energy resources will be improved.

INTRODUCTION

The German power supply relies more and more on distributed systems which are often based on renewable energy resources (RES). The current share of RES in the covering of the electric power consumption is about 16 % and is expected to increase significantly in the next years [1]. For 2020, Germany aims for RES having a share of at least 30 % in the energy consumption. Beside this aim, the share of combined heat and power (CHP) units is intended to be increased to 25 % [2]. These goals will change the structure of the power supply dramatically. In the past, the main power supply relied on centralized large-scale power plants which delivered the energy top down. This structure lead to a well-defined power flow from high to low voltage network levels. The extra-high voltage network was a pure backbone for power plant outages. High and medium voltage networks were designed for energy delivery from centralized power plants to local network stations.
The integration of high shares of distributed and renewable energy resources (DER) will lead to changes in the directions of the load flow. In light load periods, reversal load flows in medium and low voltage networks will occur due to feed-in of photovoltaic systems (PV) that is depending on the availability of solar radiation. Furthermore, the predominant operation of CHP micro units in domestic buildings is heat supply: both the thermal and electrical power production depends on the thermal load profile, which does not correlate strongly with the electrical demand [3]. This often results in times of CHP-operation during light load periods of electricity.

FEN-SCENARIOS

Due to the stochastic availability of solar radiation and wind power an optimization in the operation of energy systems dominated by renewable energy systems as well as decentralized power units is often only feasible with additional equipment or by curtailing the feed-in. Up to now, DER are connected to the main power supply without any super ordinate energy management. This scenario is called "connect & forget". To overcome the challenges of decentralized power generation the FEN designed a so called grid-oriented operation mode to further integration of the mentioned power units into the existing grid.

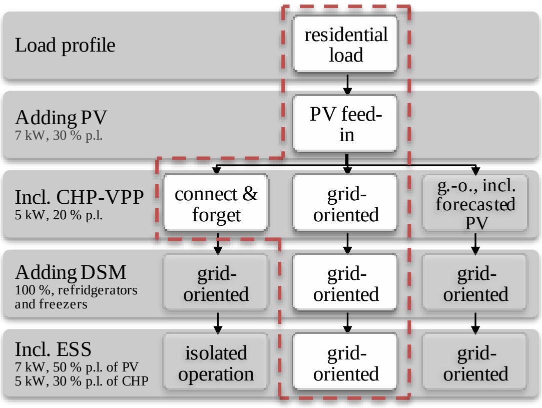

Fig. 1: FEN- Scenarios for residential areas

This approach is based on a VPP consisting of CHP micro units. This VPP is combined with other energy components like smart applications, here freezers and refrigerators, and energy storages for large scale integration in the low voltage grid.
In this context several different scenarios for future energy supply are investigated for selected rural and residential areas. For each of these districts two scenarios are

implemented, a “Green business-scenario” that considers a high increase of decentralization within the energy sector. In contrast the “Business as usual-scenario” includes more conservative assumptions.

In this paper we will present our grid-oriented research approach for a residential area under consideration of a “Green business-scenario”. Fig. 1 gives a brief overview of all relevant scenarios for residential areas. The selected one is framed in red colour.

In the first phase of the analysis, a residential area with around 300 residences is simulated for the year 2030. 30 % of the house connections are assumed to be equipped with PV systems of 7 kW rated power each. In case of VPP, the scenarios distinguish between two VPP applications, the first VPP predict only the expected load flow where the second VPP take the expected feed-in of PV systems into account. In consideration of the “Green business scenario” feed-in of the PV units is included in the calculation without any degree of prognosis. Furthermore, 20 % of the households are equipped with a CHP micro unit of 5 kW electric rated power each. The scenario also implies that all refrigerators and freezers can be used for demand side management purposes. In the last step of the approach electric storage capacity is added equal to the nominal load of every second PV and almost every third CHP unit. The load flow of the residential area is determined by single load flow simulations of each residential unit.

In the following sections we will present the performed analysis in details by explaining the sub-approaches and indicating the grid impact for each step of the selected FEN-scenario.

Impact of PV generation on the load of a residential area

The feed-in of the PV systems is generated by a physical model for solar radiation and a stochastic component for clouding and shadowing effects. Based on the scenario mentioned above the residential area’s level of PV penetration is increased by 30 % (210 kW).

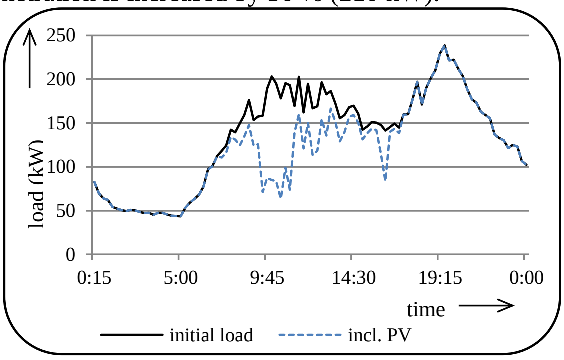

Fig. 2: Initial load profile with and without PV generation

Fig. 2 shows the initial 24h-load curve of the residential area and the photovoltaic generation on a working day in October. Due to the feed-in of PV the load level decreases over the hours with solar radiation. Moreover, the resulting load profile is more fluctuating, but the spread of the minimum to the maximum load is still the same.

The graph illustrates that the dramatic changes in the traditional electricity distribution systems require innovative concepts to integrate renewable generation at the LV and MV levels.

Virtual power plant of combined heat and power micro units

CHP micro units - which are commonly installed with thermal storage systems - are in a special focus because they offer the potential for a grid-oriented schedule management. By using the thermal storage system in an anticipatory way, the operation times can be partially decoupled from the thermal demand.

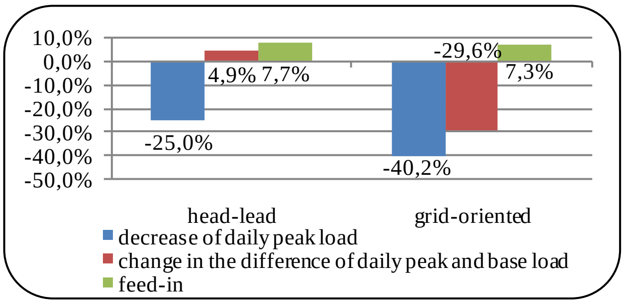

Fig. 3: Exemplary results of the head-lead and grid-oriented CHP scenarios without PV prediction

This schedule management enables a shift of electrical feed-in into peak-load periods. For this reason the FEN has developed a simulation tool which generates grid-oriented day-ahead schedules for a VPP based on CHP micro units. An optimization of the overall load flow in low voltage networks can be achieved with a schedule management set up centrally by network operators [4]. By implementing a CHP-VPP in the previous mentioned working day a reduction in the peak-load at 19:15 h from 240 kW to 130 kW, which represents approximately 46 %.

The added value of VPP is determined by comparison with the currently predominant heat lead operation mode (see Fig. 3).A schedule management using the potential of CHP micro units requires information about the predicted load flow in the low voltage network district.

The decrease of the daily peak-load, the feed-in and the change of difference between peak and minimum load are illustrated in Fig. 3 to describe the main benefits which can be achieved from implementing CHP-VPP. The change of the difference between peak and minimum load describes a dimension for the load flow fluctuation in the low voltage network. The results show, that concerning the grid-oriented operation mode, the decrease of the daily peak load is approximately 15%more than that of the head-lead operation mode. Moreover, the daily load flow fluctuation is reduced using the CHP-VPP by approximately 30 % using the grid-oriented operation mode. In contrast the head-lead mode leads to an increase of the fluctuation of almost 5 %. Concerning the amount of electrical feed-in, the grid-oriented mode is only 0.4 % better than the head-lead operation mode. This is due to the fact that the schedule management is not considering the predicted feed-in of PV.

To verify the simulation results we have started a field test by building up a CHP-VPP in Braunschweig (Germany). A communication module which is required for the connection between the CHP's control-interfaces and the central schedule management has been designed by FEN [5]. In addition the heating system of the residences has been equipped with specific hardware for measuring the heat profiles.

The central schedule management generates a thermal load-prediction based on the historical measured thermal load information which has been submitted by the communication system as can be seen in Fig. 4. On the basis of the thermal load-prediction and a forecasted domestic electrical load profile, schedules for every CHP micro units are generated and then sent back to the CHP via the communication module. All the information transfer is based on UMTS standard. Regarding the entire FEN-scenario model the CHP-VPP is the first active component for stabilizing a low voltage network and reducing load flow fluctuations, followed by DSM devices and electric storage systems.

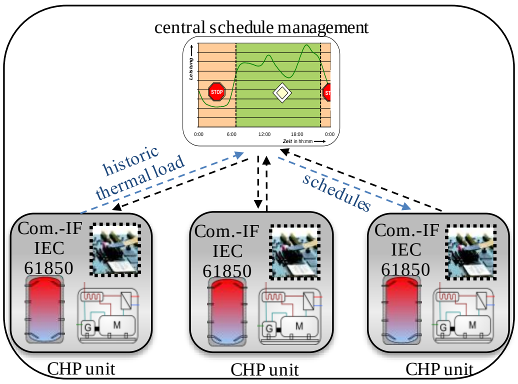

Fig. 4: Communication scheme of the Virtual power plant

Using virtual devices for DSM

The basic idea in the field of demand side management is to aggregate appliances with similar load shift properties in a pool, a so called virtual device [6]. This virtual device allows certain statistic assertions. Instead of controlling each appliance individually load shift measures are only scheduled for virtual devices. As household appliances account for a large fraction of the overall load and are the major contributor to daily load peaks, we are investigating how a pool of household appliances can be used for load shifting. In contrast to many competing projects the approach at hand is not limited to appliances with thermal storages (like for example refrigerators) and allows direct scheduling of basically any type of (household) appliance as long as it is possible to influence its operation. The effect of pooling smart cooling devices is marginal for the analyzed grid with around 300 residencies as shown in Fig. 5. The number of pooled refrigerators has a load shifting potential of about 2.7kWh in a period of about 3 hours.

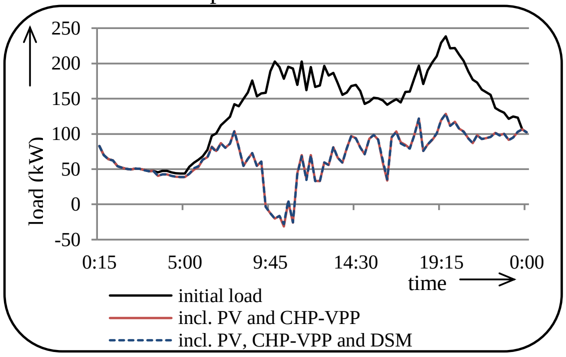

Fig. 5: Initial load profile including PV, CHP-VPP and smart devices

Nevertheless, the effort of using the demand side to further increase the level of efficiency on the low voltage level is successful and this DSM approach can be used more effectively on a large scale basis.

Therefore, demand side management measures like these are nearly instantly available and may be operated e. g. to compensate regenerative feed-in prognosis errors or to smooth startup-ramps from conventional power plants.

Electric storage systems within an active distribution network

To ensure a stable and reliable power supply within a network dominated by distributed generation and fluctuated renewable energy generation, power supply and demand need to be balanced.

Energy storage systems have the potential to avoid load peaks or react to unforeseen fluctuations in the energy generation process. By taking grid characteristics as well as other constraints into account the FEN research activities on energy storage systems are mainly focusing on electro-chemical storages, such as lithium-ion batteries, to further integrate distributed energy conversion within the existing low and medium voltage networks.

The energy storage study is not just an assessment of the grid and economic options of electrical storages. We are also evaluating different kind of concepts for the placement, dimensioning of storage capacities within distribution networks in order to implement them in most effective way.

Therefore, we set up a simulation tool which allows a comparison between storage systems that are operating directly in combination with PV and CHP-units on the household level (close to demand) and those storage capacities that are installed centrally e.g. next to a transformer station (far off demand). In the case of "close to demand" storage concepts, the storage systems are operating basically for economic purposes [7]. The study implies "far off demand" storages are going to be installed in first instance for grid purposes regarding today`s market mechanisms.

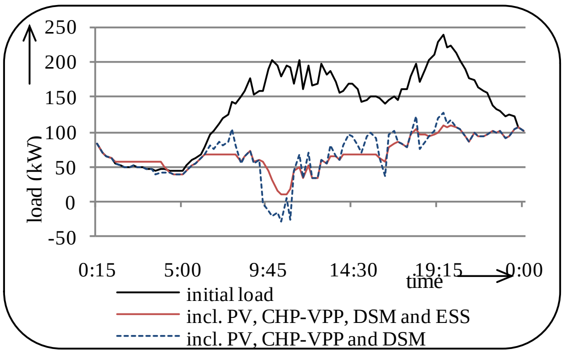

Fig. 6: Initial load profile including PV, CHP-VPP, smart devices and electric storage systems

The implemented simulation for the electric storage performance considers all relevant battery parameters based on measurements taken at the Institute of High Voltage Engineering and Electric Power Systems at the TU Braunschweig. The dimensioning of storage performances (capacities) were also defined by analyzing measurements, grid specifications as well as current market trends. Following the "Green business scenario" with focus on the grid-oriented operation mode the considered electric storage capacities of around 230 kW lead to significantly more stable load profile of the residential area in spite of high portions of decentralized energy generation (see Fig.6).

PRELIMINARY RESULTS AND DISCUSSION

FEN`s research objective is integrate decentralised power in the existing low voltage network most efficiently. In order to evaluate the preliminary results of the overall simulation we are using three indicators:

- share of feed-in by distributed energy generation
- change in daily peak load
- change in the difference of daily peak and base load

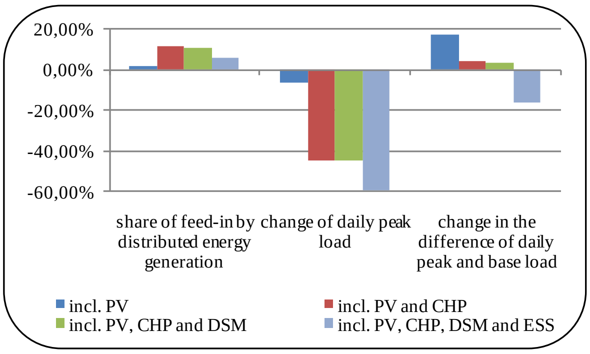

Fig. 7: Exemplary results of the grid-oriented scenarios

In the case of the share of feed-in by distributed power units, the electrical storage can minimize the increased share due to the feed-in by PV and CHP from 11% to 7% (Fig. 7). It is interesting that the feed-in of the same power units would be much higher without any energy management (almost 17.4%). This indicates for a positive effect of the grid-oriented FEN-approach.

The diagram also illustrates grid advantages of the FEN-approach for the changes in daily peak loads. By adding PV and especially the CHP-VPP to the initial residential area's load profile, the peak load decreases by more than 40 % despite the share of decentralized power generation increases rapidly.

The third indicator, the change in the difference of daily peak and base load, shows again the importance of electrical storages for the further integration of renewable energy resources. The storages not just balance the changes in the difference of daily peak and base load, they also reduce it by around 17%.

SUMMARY AND OUTLOOK

The preliminary results of the simulation as well as the ongoing field test in Braunschweig present that the FEN-concepts are feasible and improve the further trend of decentralization in the energy sector.

In the near future the presented study as well as other analyzed will be enhanced by a comprehensive network model for the medium and low voltage level.

For further information regarding our research please visit our website (www.fven.de) and be part of the FEN symposium, March 2011 in Hannover/ Germany.

Acknowledgments

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