DECENTRALIZED ENERGY MANAGEMENT SYSTEM FOR EFFICIENCY IMPROVEMENTS OF DISTRIBUTED ENERGY RESOURCES

Thomas WERNER
Siemens AG – Germany
thomas.werner@siemens.com

Erich FUCHS
Siemens AG - Austria
erich.fuchs@siemens.com

ABSTRACT

One of the major challenges for the future electric networks will be the integration of renewable energy and distributed energy resources. Due to their fluctuating infeed or heat-operated applications, they make special demands for the electrical power grids. In order to provide a reliable, economical and environmental-friendly energy supply furthermore, our power grids have to be evolved to Smart Grids which are more flexible and more efficient.
Distributed energy resources are per-se efficient and environmental-friendly. Nevertheless, a coordinated operation can create synergies and support the networks. Furthermore, the bundling of decentralized generators opens new markets for their owners, which they cannot address by themselves individually. This bundling can be realized by setting up virtual power plants. Virtual power plants are combinations of a number of decentralized generators, storages and controllable loads which are supervised and optimized by a decentralized energy management system.

This paper discusses an approach for implementing virtual power plants in smart grids to increase the efficiency of distributed energy resources.

TRENDS IN THE ENERGY MARKET TOWARDS DECENTRALIZED ENERGY GENERATION

Distributed energy generation has become a well-established and mature technology in the last two decades. Different types of distributed energy resources (DER) are available for the use in public or private power systems:

- Biomass power plants
- Photovoltaic
- Fuel cells
- Cogeneration of heating or cooling energy and electrical power in block-type power plants or micro-turbines
- Wind power plants
- Geothermal power plants
- Small hydro power plants

Due to the fact that thermal energy has a major share in the effective energy, combined heat and power production is of particular interest for setting up distributed energy systems. In the past, the power output of decentralized generation like block-type power plants was in the range of some hundreds kW to one MW electrical output and some hundred kW thermal. In the meantime, we see a trend towards small block-type power plants which are designed for supplying smaller buildings. They use gas engines, Stirling engines or micro turbines. Currently, field tests are performed with small fuel cells for supplying one-family houses. These types of micro block-type units are mainly designed for generating heating or cooling energy. The generation of electrical energy is a welcome secondary effect. The thermal output of the units is between 10 and 20 kW and the electrical output is up to 5 kW. All of these generating units have one big advantage: The total efficiency factor can exceed 80 % if heating and cooling energy is produced simultaneously with electrical power. This helps to reduce the cost for energy supply and to reach environmental targets, e.g. the reduction of carbon dioxide emissions.

On the one hand, generation technologies using renewable energies are getting more attractive. They depend on the use of wind, water, solar radiation, geothermal energy or biomass. Due to the massive promotion given by the governments in several countries, the installed capacities and the produced energy have highly increased. For example, renewable energies have grown very strongly in Germany. The installed capacity based on renewable energies is about 30 GW compared to an electrical yearly peak load of 75 GW. Motivated by the IPPC report, the amount of renewable energies will be increased.

On the other hand, the decentralized generators as wind turbines and photovoltaic units depend completely on the unsteady wind or solar radiation. Therefore, the electrical networks have to manage the resulting fluctuating infeed of electrical energy. Already today, the large amount of wind turbines causes sometimes bottlenecks in some transmission networks. They force the responsible network operator to switch off some wind turbines in order to secure or stabilize the network.

Furthermore, the network operator has to organize the regulating energy, which is normally provided by conventional power plants. The result is an operation of these power plants, which is not optimal and causes higher operational costs. Therefore it would be an advantage, if decentralized generators coordinate their operation in order to reduce the regulating energy.

In addition, the current electrical network infrastructures are not designed for a large amount of decentralized generators. The networks are based on the assumption that powerful generators provide the electrical energy to the consumers via the transmission and distribution networks. For this reason, the generation and consumption cause a “top-down-orientated” load flow. In general, the current concepts for network operation, e.g. protection schemes, often suppose this direction. With the expansion of the decentralized generation, this unique power flow direction will no longer exist. A fast and adequate modification of the electrical networks, e.g. by building new lines, is often uneconomic or not possible due to the required expenditure of time. That also motivates a coordinated operation of decentralized generators in order to avoid or minimize problems in the electrical networks.

The coordinated operation of decentralized generators can be achieved by setting up so-called Virtual Power Plants (see figure 1). A Virtual Power Plant (VPP) is a collection of small and very small decentralized generation units, which communicates with a decentralized energy management system. This system plans and monitors the operation of the decentralized generators. Furthermore, it optimizes the operation in terms of several criteria, like operation costs, participation at energy markets or supporting the network operation.

The core elements of a VPP are the information and communication systems. The following sections describe them in more detail.

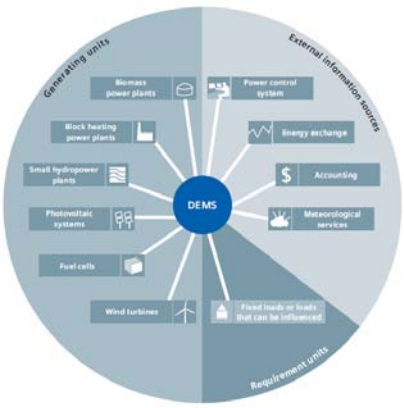

Figure 1: Virtual power plant

DECENTRALIZED ENERGY MANAGEMENT SYSTEMS

A successful operation of a VPP requires the following technical equipments:

1. An energy management system that monitors, plans and optimizes the operation of the decentralized power units.
2. A forecasting system for the loads that is able to calculate very short-term forecast (1 hour) and short-term forecasts (up to 7 days).
3. A forecasting system for the generation of renewable energy units. This forecast must be able to use weather forecasts in order to predict the generation of wind power plants and photovoltaic.
4. An energy data management system that collects and keeps the data which is required for the optimization and the forecasts, e.g. profiles of generation and loads as well as contractual data for customer supply.
5. A powerful front-end for the communication of the energy management system with the decentralized power units.

First of all, a VPP needs a bidirectional communication between the decentralized power units and the control centre. For large units, conventional telemetry systems based on protocols like IEC 60870-5-101 or 60870-5-104 can be used. In the future, the communication channels and protocols will play a more important role with an increasing number of small decentralized power units. It is likely, that the costly conventional telemetry technique will be substituted by other techniques base on simple TCP/IP adapters, power line carrier techniques or GSM/GPRS.

All operation planning and scheduling applications require forecast with a sufficient accuracy. For the characterization of the forecasts, several operating figures are used, like the average forecast error per day or the absolute error per day or per forecasting time period. Depending on the main purpose of the VPP, the requirements for the forecast methods may change. If the primary purpose is to reduce the peak load or the balance energy, the forecast has to be very exact in the peak load time or times with the high prices for balance energy. Furthermore, the forecast algorithms must be able to adapt rapidly to new situations. For example, a VPP operated by an energy service company must be able to consider changes in the customer structure.

Based on the results of the forecast algorithms and the actual situation of the VPP, the load to be covered can be dispatched by using the decentralized power units and the existing energy contracts and market options. This is a complex and recurrent task. Therefore, computer based methods of operation research are used. This is the most important component in a VPP, since it realizes and uses the optimization leeway.

The special structure of a VPP makes high demands on the mathematical models for the optimization. It must be very precise since rough models could yield to optimization results which cannot be realized by the power system. Since the VPP must provide an automatic mode for on-line control of the decentralized power units, e.g. for compensating the imbalance, no operator can check and correct the results. Furthermore, the optimization leeway can only be used, if the optimization package is able to determine the solution cyclically within the settlement period.

Based on the requirements mentioned above, a software package for decentralized energy management was developed, called DEMS®. The DEMS system is not a substitute for automation equipments necessary for operating the components of a VPP. There must be at least local automation equipments available to allow the basic operation of the decentralized power units to ensure the component and personal safety in the absence of the DEMS system.

The components/units of a VPP and their energy flow topology are modeled in DEMS by certain classes of model elements, e.g. converter units, contracts, storage units, renewable units and flexible loads.

The DEMS planning applications models all cost / revenue and constraint relevant energy and media flows, regardless of their types (electricity, hot water, steam, cooling, emissions, hydrogen, etc.). The DEMS control applications provide control and supervision capability of all generation units, storage units and flexible demands as well as their control capability to maintain an agreed electrical interchange or energy production / consumption profile.

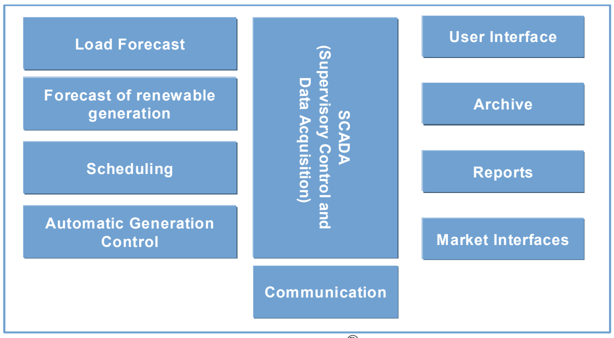

Figure 2: DEMS® modules

As presented in figure 2, DEMS provides on the one hand all the modules which are typical for power control systems, like the SCADA system, the communication front-end, user interface and archive and report means. On the other hand, DEMS encompasses advanced applications like load forecasts, the forecast of renewable generation, scheduling and automatic generation control.

The DEMS *Load Forecast* provides a forecast calculation for a multiple number of load classes. The basic data needed is the continuous historical measured load data in the time resolution of the planning functions. A piecewise linear model is being set up explaining for modeling the demand behavior as a function of influencing variables like day types, weather variables or production schedules from industrial loads. The model equation coefficients are estimated cyclically each day after new measurements are available.

The mathematical method for calculating the model coefficients is a Kalman Filter. By using the Kalman Filter, the definition of fully dynamic, partial static and fully static forecast models is possible.

The DEMS *generation forecast* module calculates the expected output of renewable energy sources dependent on the forecasted weather conditions. The forecast algorithm is a piecewise linear transformation of two weather variables to the expected power output according to a given transformation matrix (e.g. wind speed and direction for wind power units, light intensity and ambient temperature for photovoltaic systems). The transformation matrix is determined from historical measurements.

The DEMS *scheduling* module calculates the optimized dispatch schedules (including the commitment) for all flexible units like contracts, generation units, storages and flexible loads. The objective function is the difference of revenue minus costs, the profit. The scheduling considers the parameters of the model elements and their topological connection, which defines the financial information, as well as the technical, environmental and contractual parameters and constraints of the VPP. The unit commitment uses Mixed Integer Linear Programming to calculate the results of the optimization problem.

The DEMS *automatic generation control* module allows the control and supervision of all generation and storage units of the VPP. This module determines the updated states (startup, online, remote controllable, disturbed) and the set points for all DER. It considers the control mode of the respective units (independent, manual, scheduled or regulating) and the unit parameters (e.g. maximal/minimal power, power gradients, energy contents). The calculated commands and set points are transmitted via the communication frontend. Furthermore, the command response and the set point following status of the units are supervised and signaled. In case of a unit disturbance, the automatic generation control module starts a spontaneous unit commitment calculation to force a rescheduling of the remaining units under the changed circumstances considering all integral constraints too.

Additionally, the automatic generation control provides functions allowing the control and supervision of all flexible loads in the VPP. These loads are grouped in so-called load classes which receive the updated switching states and demand measurements via the communication frontend. The module considers the control mode of the load class (independent, scheduled or regulating), the current switching state, the current consumption and the control delay time of the load groups. It applies a rotational load shedding of all the load groups belonging to one load class. The optimized load class schedules calculated by the scheduling module are the basis for load class control in the operation modes "schedule" and "regulating".

As a part of the automatic generation control, an exchange monitor calculates the expected deviation of the agreed electrical interchange schedule of the current accounting period (15 or 30 or 60 minutes) and the necessary power correction value to keep the interchange on schedule. The total power correction needed is distributed to all DERs being in "regulating" control mode and according set points are sent to the field via the communication front end.

INCREASING THE EFFICIENCY OF DER

As stated before, VPPs use often small CHP units with high efficiency factors. On the one hand, this reduces the cost for the generation of energy. On the other hand, the energy generation becomes more environment-friendly. For example, bio mass fuels are neutral for the carbon dioxide balance. Already these two advantages motivate VPPs. But there are also some other benefits possible: the reduction of expensive peak power and regulating energy, the reduction of network use fees and the reduction of maintenance and expansion costs for the electrical grid.

A vertical integrated utility supplying the customers with energy and operating the electrical grid can use a VPP to generate the electrical power in peak load periods: In general, the thermal and the electrical output of CHP units are coupled. The actual thermal output limits the electrical output and vice versa. With an optimized operation of the CHP units, the production of heating or cooling energy can be shifted to off-peak times. The thermal energy can be stored in the thermal system, e.g. by increasing the supply temperature or by using a dedicated hot water or ice storage. Thus, the CHP can use more of its capacity to produce electrical energy in the peak-time. Since the peak time energy is very expensive, the utility can reduce its costs for buying energy from other companies significantly. In Germany, savings of 23.000 € / a per avoided MW peak load electricity are possible [1].

The DER based on renewable generation are completely dependent on the weather factors like solar radiation, wind etc. Therefore, the power provided by these DERs is volatile and requires regulating energy provided by larger conventional power plants. By compensating the fluctuating infeeds on a local level, the conventional power plants are discharged from keep the regulating capacity and can be operated in a more optimal way.

In the German market model, all network customers have to pay for the network use with a power tariff and an energy tariff. In this context, the distribution grid companies are network customers of the transmission grid companies. With the use of a VPP, the distribution company can reduce the peak power. In doing so, they reduce their network fees.

Beside the benefits in operating a power system together with a VPP, there are also benefits for the maintenance and the expansion of the electrical grids. With the consideration of VPPs in the network expansion planning process, investment in the electrical network can be reduced, avoided or postponed. For example, establishing a new residential area requires often an enhancement of the medium-voltage grid that will supply the area. If the decentralized generation will also be installed in new area, the enhancement of the medium-voltage grid could be avoided.

The participation in the regulation market requires a minimum reserve power value per offer that can be provided, e.g. some Megawatts. In general, individual decentralized generation units are too small to participate. But VPPs can be used to aggregate the reserve of a number of small units in order to fulfill this requirement. Furthermore, many decentralized generators can also provide reactive power flexibility (when not running on nominal active power) – which can be used e.g. for network voltage stabilization purpose [2].

CONCLUSION

Decentralized energy generation has become a major trend in many countries. Wind converters, fuel cells, bio mass units, micro turbines and combined heat and power units belong to these new and innovative generation technologies. In this context, the interest is directed in so-called Virtual Power Plants. A Virtual Power Plant is a collection of small and very small decentralized generation units, which are monitored and controlled by an energy management system.

The concept of VPPs increases the efficiency of a power system in different ways. By pooling the generation, a VPP can reduce expansive peak power, regulating energy and network fees and does provide access to energy markets which are normally closed for small DER.

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