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Virtual Power Plants: Basic Requirements and Experience in Practice

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Summary

The aim of the European Community is to increase the quota of the renewables energy sources from 14% to 22% as well as doubling the share of heat and power cogeneration (CHP) on the total energy production from 9 to 18% by 2010 to achieve environmental protection and resource saving. However, the output of most renewable energy sources depends on meteorological conditions; the electrical output of CHP is driven by the heat demand, which also depends on the weather. To cover 40% of the yearly energy production the installed power of dispersed and renewable energy resources (DER) will exceed 60% of the peak load. Their daily contribution to the actual power coverage will vary from small shares up to 120% (in low load and heavy wind situations). Such a significant impact requests a sustainable restructuring of the operation practice in distribution systems.

For economical reasons reserve power centrally provided to compensate intermittent DER output has to be minimised. Therefore, dedicated distribution areas with a significant mix of different DER, storage units and demand control facilities have to provide the features of "virtual power plants" that show similar behaviour like larger central units. Power exchange profiles of these balanced supply areas with higher level networks are planned in advance and the adherence to the schedules is supervised on-line by operational means. The basic functionality for it is provided by a decentralised energy management system (DEMS).

Innovative information, communication and automation technologies have to be established for monitoring and control of a large number of units on generation and on demand side. The basic requirements for this enhancement are considered in this paper. Experiences in practice gained so far with this concept in a German demonstration project are demonstrated in detail.

Challenges to Integrate Increased Dispersed and Renewable Generation

The aim of the European Community is to increase the quota of the renewables energy sources from 14% to 22% as well as doubling the share of CHP units on the total energy production from 9 to 18% by 2010 to achieve environmental protection and resource saving. Consequently the share of dispersed and renewable energy resources (DER) will cover 40% of the total electricity production. Due to dependency on the weather the installed power of the DER must achieve 60% of the peak load to achieve this goal.

At present in Europe DER systems are operated without further control mechanisms, feeding in a maximum possible generation corresponding to current political and regulatory framework conditions. Depending on load and meteorological conditions the power flow from transmission to distribution networks may change the direction (Figure 1).

With the traditional generation concept the import from transmission to distribution is planable in advance according to seasonal and daily load profiles. With the new concept there is no stable import/ export profile available; e.g. in 2010 for low load and heavy wind situations the contribution of DER in the power balance of the European Community may achieve up to 120% [1]. The transmission system operator is responsible for the power balance providing positive and negative reserve power to cover the changing conditions and fluctuations of the intermittent electrical generation of DER. This leads to considerably higher costs (up to Billion of Euros per year only for Germany [2]) for reserve power compared to traditional energy generation in big central power stations.

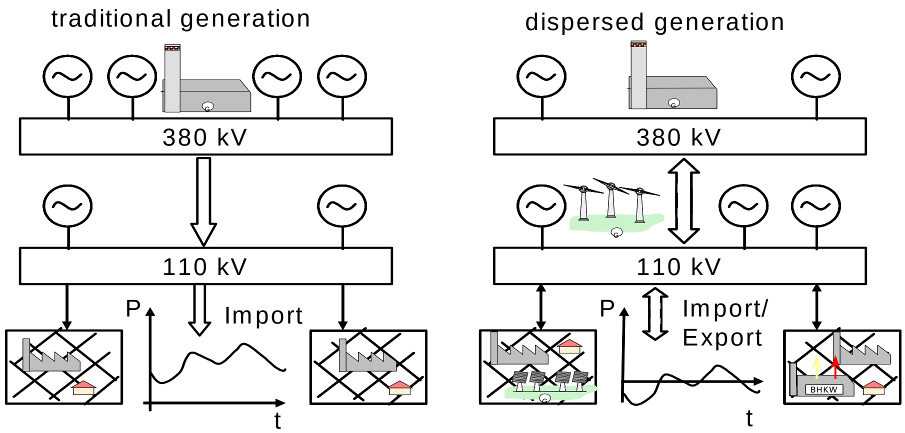


Figure 1 - Traditional and Dispersed Generation Concepts

Therefore, a future economic and stable grid operation with such a high penetration of DER necessitates a new approach. The power balance in particular supply areas has to be established by a decentralised energy management system (DEMS) based on offline planned and online supervised schedules for dispersed and renewable generation, storage units, demand management capabilities and power exchange by contracts.

Furthermore, static and dynamic simulations with planning software have to confirm system conformity of the grid integration of DER. Constraints for voltage control, power quality, maximum power flows or fault management corresponding to specific interconnection rules must be achieved. Additionally, a high availability, remote controllability and a specific “fault ride through behaviour” of DER units is required to keep the reliability of supply on the actual high level [2].

Virtual Power Plants

Virtual power plants (VPP) are formed by a mix of decentralised generation, storage and load units in particular supply areas that show similar reliable, planable, and controllable behaviour as larger central generators or loads. This is – in spite of different profiles of the units that form these balanced supply areas – the adherence to schedules (import and export of energy) that have been communicated in advance to higher-level management systems.

There are different possibilities for vertical and horizontal integration of these VPP. Thus one VPP can be included into an overlaying VPP. It is also possible to connect several different VPP to existing distribution management systems.

The basic functionality of a VPP is provided by DEMS. This system performs generation, storage, and load management. Including demand side management strategies normally requires incentives for the customers providing a win - win situation for all participants. Communication facilities are required for online monitoring and control of the participating units.

Basic Requirements for Virtual Power Plants

Function of DEMS

Renewable generation and electrical and thermal demand within the supply area is forecasted for each 15 minutes billing period by the offline modules of DEMS. Based on this, quarter-hourly schedules for controllable generation units, storage units, and loads (if manageable) are calculated within a time horizon of 1-3 days in advance (Figure 2). For this, only units with a certain share on the maximum power of the VPP are considered. Units with smaller sizes (i.e. small fuel cells with rated power of 1 kW) or non-controllable ones such as PV plants are only forecasted.

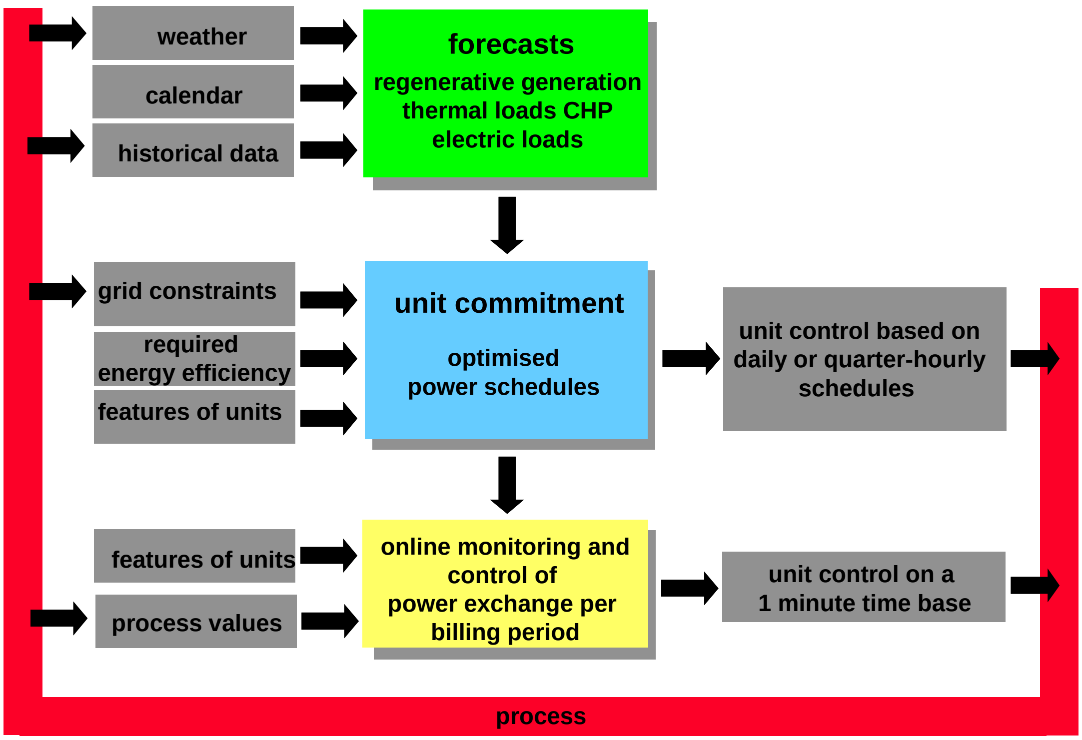


Figure 2 - Functional Groups of DEMS

Different optimization criteria for the unit commitment can be parameterized, such as cost minimization, management of export contracts, maximization of a renewable power generation, or minimization of CO2-emissions. Optimising both, heat and power production of CHP units increases energy efficiency. It may also be reasonable to include other energy forms like gas supply or, for example in industrial applications, also water and compressed air.

The adherence to the schedules has to be guaranteed online in operation to enable an exactly defined contractual power exchange of the balanced supply area. Unplanned power fluctuations and deviations from the schedules require a fast adjustment of the real power flow within the individual period by dispatching controllable generation, storage units and demand in a one-minute time interval. To cope with unavoidable prediction errors of generation and demand the system provides already with the unit commitment sufficient reserve strategies to cover the reserve power locally, yet meeting all technical constraints. Thus central power reserves can be reduced [3].

The management has to be done decentralized as with an increasing number of DER possible restrictions of the network (overload, voltage control) have to be considered for optimisation. Small loads and many different generation units with small rated power operated with different energy media have to be integrated. Renewable energy sources show a high intermittency. Unexpected events don't have to disturb system functionality. Additionally the system must be simple to use and to install and be available at low costs.

Communicational requirements

Data to be transmitted for online monitoring and control of the participating units are in particular metering and measuring values, schedules, status information, commands as well as network topology constraints. The technological progress in information, communication and automation technologies allows this integration at acceptable costs. Generally, the costs for operation and installation of communication must not be higher than possible savings by the management.

Communication is done via LAN or WAN, buses of telecommunication links possibly by using already existing communication links. Future standardisation defining suitable interfaces - probably based on the station automation standard IEC 61850 - is still necessary.

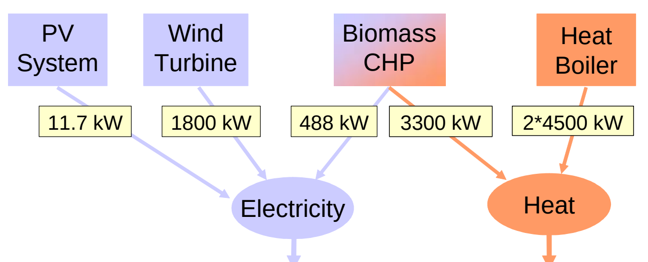
German Demonstration Project KonWerl 2010

Project description

The project "KonWerl 2010" provided the opportunity to test, demonstrate, and optimize DEMS and its peripheral installations using latest information, communication and automation technologies [4].

In order to analyse different optimisation criteria of the energy management and to overcome the restrictions given by the current legal framework in Germany, different systems with individual focus were set up. In this paper the energy park system is considered, where biomass CHP, wind, solar power and conventional heat plants supply different types of thermal and electrical loads: industry, households, an office building, and a hotel (Figure 3). Contrary to the district heating system the electrical system does not form an autonomous local grid. The sum of all generation and demand within the virtual supply area determines the energy exchange with the interconnected network. Online control of the energy flow is mainly done influencing loads. For the first operation period a load level of 200 kW was selected.

Profile meters acquire electrical demand and generation. A commercial software system manages the meters and archives the data. Thermal profiles are calculated every quarter of an hour by the difference between the meter readings, because appropriate profile meters have not been available. In addition a completely independent automation system acquires one-minute mean values of the electrical power to provide a basis for online monitoring and control. To demonstrate different technical possibilities both systems use a wide variety of interconnection techniques and transmission paths.



P_{Load} [kW]	Public Grid				District Heating		
	min	max	mean		min	max	mean
Households	31	211	78		0	895	99
Industry	71	2162	709		0	2500	290
Office	0	45	7.7		0	112	17
Hotel	0,6	18	3.1		0	103	17

Figure 3 - Components of the KonWerl Energy Park System

Operational experiences

Forecasting accuracy

The generation forecast of wind and PV plants is calculated via a set of characteristic generator curves (look up table) based on weather forecasts, which are imported from a national service provider on a daily basis. The accuracy achievable is therefore limited by the uncertainty of the weather forecast and the insufficiency of the generator model. At present the forecast errors amount up to a mean absolute deviation (MAD) of about 40% referred to the average generation per month while already the weather forecast imported shows a 30% MAD.

A Kalman filter is used to predict electrical and thermal loads. The algorithm optimizes itself adjusting its parameters after analysing historical results. External factors e.g. temperature or global radiation are considered as well as information about special events like holidays. Depending on the type of load the MAD varies between 6% - 14% (Table 1).

	Households	Industry	Office Building	Hotel
MAD	10%	6%	10%	14%

Table 1 - Forecasting Accuracy Referred to the Average Monthly Load

Compared to the low overall load level with small coincidence factors these results are quiet good. Every single event, for example a new tenant in the office building or the installation of new equipment in the logistics centre, results in a relative high temporary forecast error until the filter adapts to the new situation and the accuracy improves. Best results are achieved for the main load, the industry, due to persistent production profiles and a higher coincidence factor due to higher load.

The forecast of thermal loads is in general more difficult, e.g. due to the delayed reaction of the supply system. A MAD of 20% - 35% for the single types of loads and of 8% - 17% (depending on the month) for the total load is achieved during the heating period.

Unit commitment

Actual cost structures are parameterised in DEMS reflecting the situation given by the present legislation in Germany. Therefore the CHP plant is usually scheduled and operated at maximum electrical output. Surplus thermal power in summer is dumped as waste heat through the emergency cooling. With this the overall energy efficiency of the CHP plant is clearly reduced.

Fixed feed-in tariffs support to increase the share of renewable energy sources but not the rational use of energy and the special benefits provided by decentralised systems. In addition the holistic view to optimize all energy forms as a whole is contrary to the unbundling of energy supply companies. To achieve a real benefit from decentralized supply structures rational use of energy must yield a profit for any partner involved. Therefore legislation must be adapted accordingly.

Online monitoring and control

Due to a higher inertia of the thermal network, that allows also unbalanced periods, online supervision is only required for electricity. As mentioned above online control is done in the KonWerl project by demand side management with a 200 kW maximum load. Compared to the forecast error that is dominated by a MAD of 40% for a maximum 1.8 MW renewable generation 200 kW controllable power turned out to be too less to enable a sufficient adherence to the schedules in spite of reserve strategies implemented.

In case of a good and unbiased prediction system the forecasting errors are normally distributed. Probability calculations showed that for the KonWerl project with a peak load of 2436 kW and an installed DER power of 2300 kW the planned power profiles can be met with a probability of 99% in the bandwidth of +/- 1% if controllable load or generation sums up to 35% of the peak load. Building these 850 kW by influenceable loads is quite difficult while realizing it with DER units would be quite easy. But further legislative actions also allowing control of DER are still required in Germany.

In general the controllable share required to meet the exchange profiles has to rise with increasing renewable generation. Other ways to reduce the controllable share are to improve forecasting accuracy by using shorter forecast and optimisation horizons.

Additionally a high availability of DER units is required to integrate them reliably into existing supply structures. In the course of the project outages of the biomass CHP unit occurred for several days. Also in this case reserve power must be available to meet the demand continually. Only then generation near demand increases reliability of supply in case of faults in higher level networks.

Generally, limitations of the electricity energy balance result from external constraints, such as financial support induced by the present legislation, the limited complexity of the managed cell and the composition of the operational equipment (power level, the number of elements and the degrees of freedom for optimisation). Thus, even with "intelligent" management software, it is essential to design the managed cell in a technical and economical sensible way.

Communicational experiences

Different communication technologies offered today for data transmission such as PSTN, ISDN, Profibus, GSM and radio transmission were tested for data transmission. While load profiles and schedules are transmitted as daily time rows, status information as well as metered values in a one to 15 minute cycle. Although mature technologies are available a lot of unexpected problems such as high installation efforts due to missing interoperability, transmission errors, missing data and immense transmission costs occurred during the demonstration. To enable a widespread use of the VPP concept costs for communication must be reduced, i.e. by using existing communication lines, and reliability of data transmission must be increased.

Conclusions

In the environment of an increasing share of DER an economic and reliable grid operation requires the extensive introduction of the virtual power plant concept: The power exchange between particular distribution areas with a large share of DER and the higher level networks must be planned in advance and the adherence to the schedules planned must be ensured online by means of supervision and control. The traditional central energy management has to be supplemented by a decentralized energy management on distribution level.

The realization of this concept is based on daily forecasts for load and generation. It requires the installation of measurement facilities, communication channels and remote control for a big number of DER units and customers. The cost efficiency of such an approach necessitates the use of existing infrastructure for telecommunication and a careful selection of participating units. Only components with a significant contribution to the power balance and with time varying power profiles can be concerned.

The practical experience demonstrates the possible prediction accuracy in the range between 6% and 14% for different types of load and 40% for renewable generation. Reserve strategies have to compensate the prediction errors inside the virtual power plant. For this a part of the DER units and of the customer demand must be controllable. The controllable share has to be enlarged with increasing prediction errors and with increasing requirements for the adherence of the exchange schedules. Prerequisite of the virtual power plant concept is the availability of controllable load and generation. For this the actual legal framework in Germany has to be adapted also allowing the control of DER units. Incentives for demand side measures have to be offered.

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