PLANNING AND DESIGN OF SMART GRIDS WITH VIRTUAL POWER PLANTS

Khalil EL BAKARI
Alliander/Eindhoven University of Technology – Netherlands
k.el.bakari@tue.nl

Wil L. KLING
Eindhoven University of Technology – Netherlands
w.l.kling@tue.nl

ABSTRACT

While traditional planning and design of the distribution network is mainly based on developments of power demand and connection requests, nowadays the contribution of distributed energy resources (DER), including storage devices and controllable loads, as well as the deployment of electrical vehicles should be taken into account. To embed these newcomers in the power system and to give them an active role the concept of the virtual power plant (VPP) is selected. While the combination of VPP systems with active distribution network management leads to smart grids operation, this paper discusses the planning and design of smart grids in which the VPP concept is fully employed. First the developments of DER, controllable loads, storage devices and electrical vehicles are considered. This is followed by an assessment of the planning methodology of the passive and active distribution network in order to discuss the needed optimization.

INTRODUCTION

As technological developments have led to the introduction of distributed energy resources (DER), controllable loads, storage devices and electrical vehicles (EV) connected to the distribution networks around the world, expansion of these newcomers depends significantly on the energy policy of countries [1]. These policies can encourage further development of these technologies as well as energy consumers to become prosumers, see Fig. 1.

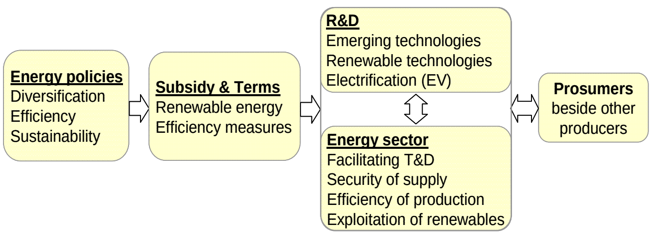

Fig. 1 Impact of energy policy

In countries where the increase of prosumers and producers of DER is expected, the intermittent characteristics of high penetration level of DER will lead to operational problems in the distribution network in question [2]. To cope with these problems the implementation of active control on distribution network as well as DER units is required [2-4]. Considering the regulatory framework in some unbundled energy markets, like in the Netherlands, the operation of distribution network is issued to the distribution network operator (DNO) while the control operation of large number of DER units must be performed by a different operator (producer or supplier). This stimulates the introduction of the Virtual Power Plant (VPP) concept to control and manage DER, controllable loads and storage devices next to the control system of the active distribution network, see Fig. 2.

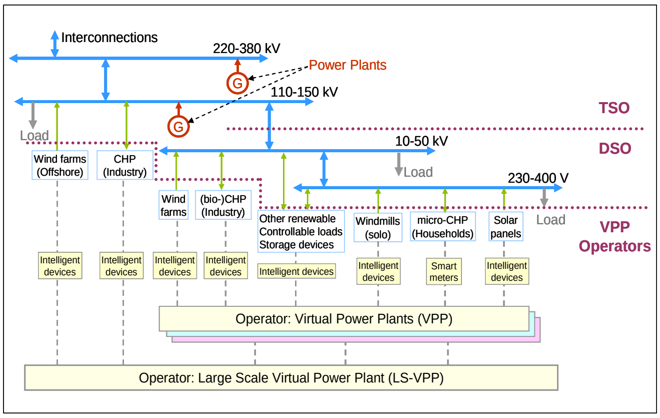

Fig. 2 Operators of network and VPP alongside

However actively controlled congestion management in distribution networks might be necessary in case of large contribution of DER. This implicates the necessity of VPP control system. In the following subchapters the planning and design of active distribution network is discussed including the implications of newcomers and solutions offered by the VPP concept.

PLANNING PROCESS

The aim of the planning process is to ensure the stability, reliability and quality of the power transmission and supply to the end-users. Fig. 3 demonstrates the phases of the planning process which ends by initiating the design process of planned activities.

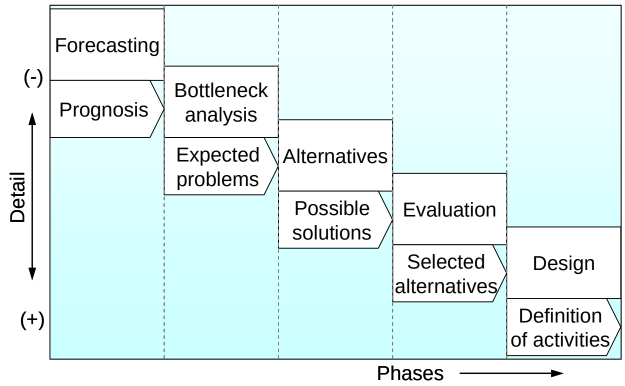

Fig. 3 Phases of planning process

As most DNOs perform this planning process for their passive distribution network, nowadays the shift towards smart grids will urge them to adapt their planning process in order to include the newcomers. In fact the steps followed by the planning process of an active distribution network are comparable to those in case of passive network. Differences can be found when executing the process phases starting by forecasting the future demand and generation, then performing a bottleneck analysis and generating alternatives for the bottlenecks to finally evaluate and select solutions. These process phases are discussed in the following subchapters focusing on the changes which have to be made in order to achieve active distribution network. In addition the planning and design of a VPP is added alongside the active distribution network in order to cope with the challenges might be caused by the increase of DER.

Forecast of demand and generation

Because of lack of information from the markets, effect of policies in the past, most forecasts were mainly based on historical demand growth. Those forecasts were occasionally adjusted with correction factors determined through statistical calculations or expectations based on experiences of specialists. During the last couple of decennia the forecasts have evolved to integrate information obtained from plans concerning new developments and expansions in the markets and society.
Currently most forecasts are based on both historical consumption as well as information on new developments. Occasionally trends and developments are translated into scenarios to clarify the expected developments in the future energy markets. Then these scenarios are projected on the forecasts in order to reflect the effect on the load growth.

As the above described forecasts are concerning the load growth, it is necessary to have forecast of the contribution of DER which might lead to inaccuracy. However, in liberalized energy markets DNOs are confronted with the fact that most of DER units within the distribution network are not visible to them. On the other hand, the VPP which includes the DER units can deliver historical generation data on individual or collective basis as illustrated in Fig. 4.

The VPP operator is able to forecast the generation growth based on the historical data and information from markets and environment. For the years ahead forecasting only the constant part of the generation profile which is shown in Fig. 4 provides an adequate forecast. The variable part can be used during the trade on the intraday and day-ahead markets.

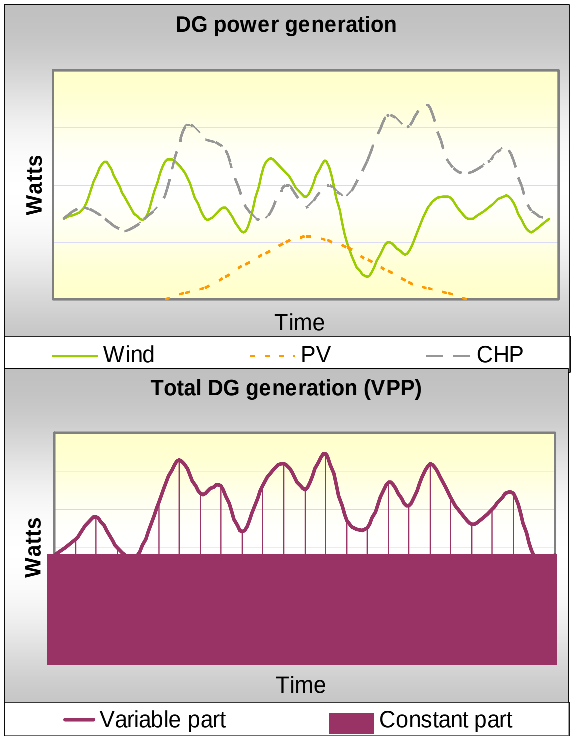

Fig. 4 DER power generation of a day

The impact of DER on the total load is time variable as demonstrated in Fig. 5 for a 50/10 kV substation. Combining the daily profiles of load and DER simultaneously will result in the total load and generation profile of the substation. This profile provides the maxima and minima which should be handled by the capacity of the substation, see Fig. 5.

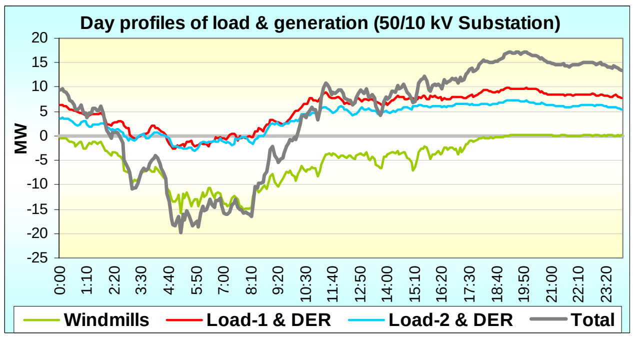

Fig. 5 DER power generation of a day

Bottleneck analysis

The second phase of the planning process is the so-called

'Bottleneck analysis' which results in an overview of expected problems in the distribution network in question. The analysis is performed for different scenarios which are processed in the forecasts of load and generation. Based on these forecasts and on information gathered during the forecasting phase as well as other relevant information, the DNO makes calculation of among other things the load flow, short-circuit currents, voltage and reactive power. For this purpose the DNO mostly possess models of the main infrastructure of the distribution network which are simulated in dedicated software tool.

In distribution networks with significant contribution of DER units, the calculation results might become inadequate when the DER contribution is not taken in consideration. In this case the calculated maximum energy flow, which indicates the required grid capacity, might be smaller than in reality. Also fault currents, voltage deviations and reactive power might be larger in practice as the effect of DER is neglected. For this reason the generation profile is needed alongside the load profile. In addition technical data of the DER units is required to perform short-circuit and reactive power calculations. As most DER units are invisible to the DNO in the liberalized energy markets, which hinders the collection of their data, it is upon the VPP operator to offer this information.

Bottleneck analysis in active distribution network is similar to that of passive network with the exception of the extra active functionalities which might reduce the number of bottlenecks. These solutions are discussed in the next subchapter.

Alternatives for bottlenecks

After determining the expected bottlenecks the DNO will generate alternatives to solve them in most efficient and inexpensive way taking the following aspects (if relevant and available!) in consideration:

- Company policy and objectives
- Regulatory restrictions, codes and standards
- Information from markets and environment
- Scenarios and forecasts
- Terms under which the bottleneck occurs
- State of the assets
- Maintenance and refurbishment plans
- Economical and financial implications

In general most alternatives presented in the past for technical bottlenecks in the passive distribution networks have led into network expansion and reinforcement. Nowadays with the introduction of risk and asset management other alternatives are taken into account, such as:

- Agree to certain risks of disconnecting a group of end-users
- Tolerate overload of specific assets for certain periods of time
- Accept penalties

With the implementation of active distribution network a wider range of alternatives is created for load and congestion management. In case of overload or congestion risks the DNO can in the active network choose to redirect the demand or in worst case to disconnect a group of end-users. However, the intermittent contribution of DER in the active networks will lead towards exceeding the tolerated limits of these alternatives if large concentrations of DER remain unseen by the DNO, as explained in the previous subchapter. As active control on the DER can be provided by the VPP, its operator is able to offer this service to the DNO.

Evaluation and selection of alternatives

A preferred solution is an alternative which most fulfill the requirements and consider the aspects stated in the previous phase. Different evaluation techniques can be used in order to select the preferred alternative as most DNOs apply an in company developed prioritization matrix.
A range of these matrices are based on economical and financial evaluation of the alternatives while company policy and objectives, regulatory restrictions, codes and standards and other relevant aspects are given as preconditions.
As the DNO is able to disconnect an end-user in order to prevent a blackout in a network section, this solution can be added to the active control of the distribution network. On the contrary, the DNO is prohibited to dispatch DER in order to prevent congestions in the distribution network. When this DER is belonging to the VPP, then the dispatch operation can be carried out by its operator. Also when compensation of voltage drop is required, the VPP is able to add power from available storage units as well as reduce the demand of contracted prosumers with controllable loads.

DESIGN OF SMART GRIDS WITH VPP

The design of smart grids concerns mainly the infrastructures of distribution network and the ICT system which is necessary for the active control functionalities. In unbundled energy markets, where the DNO is prohibited to operate DER, the ICT control systems of distribution network and DER might be separated.

During the design of the active distribution network it is crucial to identify on which components and locations the active control must be implemented. Also to determine whether remote or automated control must be implemented. For example it is convenient to add an automatic tap changer to the HV/MV transformers in substations for the voltage control while remote control might be designed for a selected group of switchgears to facilitate the redirection of energy flow.
Such considerations have led Liander, network operator in the Netherlands, to design an active 20 kV network to form

the backbone of the MV network as described in previous work [3-4]. Further implementation of active functionality depends on the increase of DER in the distribution network in question, see Fig. 6. Corresponding to this implementation strategy, in time solutions are implemented for bottlenecks which might occur because of scheduled increase of the intermittent contribution of DER. However, in order to anticipate the increase of DER a reliable forecast of generation growth is required, which might be provided by the VPP operator.

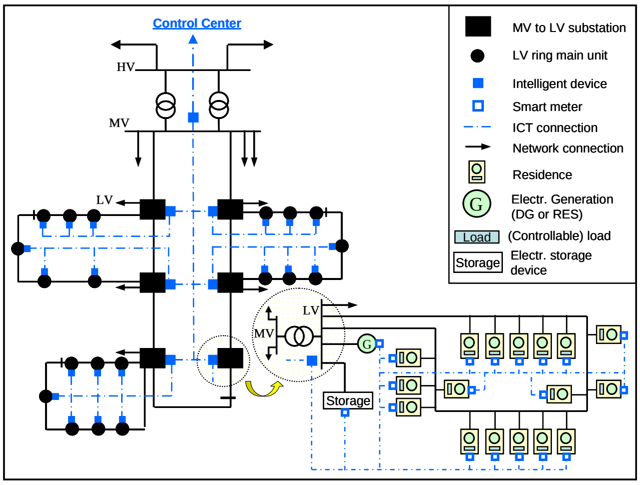

Fig. 6 implementation of active networks

The design of the ICT infrastructure for the VPP system focuses on determining the required components of the system in accordance with intended functions and services of the VPP. For example, if balancing services are required by the DNO, it is obvious to include fast communication connections in the VPP system. If DER are dispersed over a wide region, then this will lead to a decentralized control topology of the VPP system which will be able to provide system services in local networks as well as for the region. Beside system services the VPP concept offers the joined prosumers to profit from collective trading and the expertise of the VPP operator.
In addition, when prosumers place their controllable loads, storage devices or EVs at the disposal of the VPP, under certain conditions, the operator will be able perform demand side management and offer this service to the DNO.

CONCLUSIONS

In order to embed DER and other newcomers in the power system active control of both distribution network and DER is required. Such smart grid systems can be achieved through the planning, design and implementation of active networks and VPP systems. With VPP it is possible to control and manage the contribution of DER and other newcomers to increase stability, reliability and quality of the power supply.

In general the phases of planning process of passive and active networks are similar. As most DER, controllable loads, storage devices and EVs are invisible to the DNOs, forecasting the generation growth for coming years can be offered by the VPP operator.
The introduction of load and congestion management in active distribution network will reduce the number of bottlenecks. Further reduction can be offered by the VPP through active control on the contribution of DER and other newcomers. The combination of active networks and VPP systems, which leads to smart grids operation, provides a wide range for load and congestion management.

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