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Prospects of a Virtual Power Plant to control a cluster of Distributed Generation and Renewable Energy Sources

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***Abstract*– The integration of distributed generation (DG) and renewable energy sources (RES) in the passive controlled distribution networks leads in present situation to an expansion of the network capacity and thus to excessive investments. If no measures will be taken these expenditures will increase in proportion to the growth of DG&RES. The virtual power plant (VPP) anticipates these challenges and in addition facilitates better dispatching of power and energy from centralized generation to the DG&RES. The VPP offers a concept for the control and management system of DG&RES that responds to the regulatory and socio-economical constraints beside technical challenges. While most VPP concepts are based on active distribution networks, this work uses the VPP concept to transit the present passive distribution networks to the active networks in the future. For that purpose three transition stages are developed after laying of the foundations for a definition of the VPP with the Dutch situation as an example. To anticipate future developments in the electricity infrastructures, the capability of the VPP to combine with the common known control and management concepts is investigated.**

***Index Terms*– Distributed Generation, Power system operation and control, Virtual Power Plant.**

I. INTRODUCTION

Concerns about the lack of fossil energy, which lead to high energy prices, and their environmental effects like global warming have urged most of the industrialized countries to modify the focus of their energy policy towards diversification of energy supply and deployment of renewable energy. This development has accelerated the shift from centralised electricity generation with conventional energy towards distributed generation with better efficiency and use of renewable energy sources.

While a significant increase of DG&RES units in the past decades have taken place in most industrialized countries, the progress of the traditionally designed distribution networks to facilitate this development is lagging behind. In the Netherlands the distribution networks, which are designed to deliver electricity from centralized generation to the consumers, have not the facilities to control DG&RES units actively. That will lead in some cases to expand the capacity of the electricity infrastructure as will be demonstrated in the following paragraphs.

At first, this paper discusses the integration of DG&RES in combination with examples from the Dutch medium voltage (MV) networks to illustrate the necessity of capacity expansion in case of further growth of electricity contribution by DG&RES. The prospects of the VPP alternative are preceded by an initial definition of the VPP followed by identification of three stages for the development of a VPP that will facilitate a coordinated transition to the future electricity market. After considering the capability of the VPP to combine with the common known control and management concepts, policy issues are linked up to the prospects of the VPP.

II. INTEGRATION OF DG&RES IN THE ELECTRICITY INFRASTRUCTURE

Integration of DG&RES at high voltage level

As known, centralized large scale electricity generation was traditionally integrated in the high voltage (EHV and HV) networks in order to regulate and control the frequency, the voltage level and reactive power. A cluster of DG&RES with large generating capacity can be directly connected to the HV networks as well as shown in Fig. 1. According to Dutch regulatory rules and in contrast to centralized generation, the owners manage the dispatch of the individual units by themselves. Therefore, the transmission system operator (TSO) must take the utilization of the transmission network in consideration in the scenario of high electricity generation and low demand. Examples of this situation have already been occurred in the Netherlands at rural areas or close to sea where clusters of CHP's and windmill parks are situated.

Integration of DG&RES in MV distribution networks

In the Dutch distribution networks the high to medium voltage transformers will regulate the MV level through their

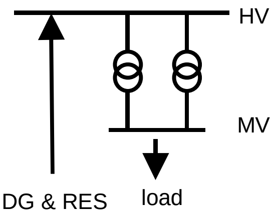

Fig. 1. DG&RES connected at HV level

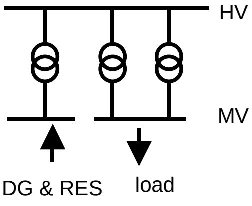

Fig. 2. DG & RES connected separately at MV level

automatic voltage regulators. Therefore, when a cluster of DG&RES is connected to the MV side of the transformer, as demonstrated in Fig. 2, their power contribution (S_{max}) must not exceed the capacity of the transformer according to (1):

$$\sum_{n=1}^{x}\left(S_{\max,\,DG\&RES(n)}\times g_{(n)}\right)\times g_{(x)}\le S_{\max,\,transformer} \qquad (1)$$

x = number of DG and RES categories
$g_{(n)}$ = simultaneous factor per DG or RES category
$g_{(x)}$ = simultaneous factor between DG and RES types ($g_{(x)}$=1 in case of one category)
In general g=1 if all DG&RES are simultaneously delivering their maximum capacity and the more variety in DG&RES categories the lower g becomes.

In Fig. 3 the energy consumption is combined with the generation of the DG&RES units. Excessive power, which is not consumed by the variable load, will flow through the transformer into the transmission network. The maximal generation power is then limited by the maximal transformer capacity and minimal load which can occur in low demand scenario. Therefore for the situation in Fig. 3, (1) can be transformed into (2).

$$\sum_{n=1}^{x}\left(S_{\max,DG\&RES(n)}\times g_{(n)}\right)\times g_{(x)}\le S_{\max,transformer}+L_{\min} \qquad (2)$$

L_{min} = minimal load in low demand scenario

The capacity of DG&RES is also limited by the tolerated short-circuit power (S_k) of the MV installation. To calculate the exact contribution of DG&RES to the short-circuit power the distribution system operator (DSO) must possess the characteristics of each DG or RES unit. When not available the characteristics of a sort of DG&RES units can be modulated using standards. Then the maximal contribution of DG&RES to the short-circuit power is limited as shown in (3):

$$\sum_{n=1}^{x}\left(S_{k,\,DG\ or\ RES(n)}\right)\le S_{k,\,MV\ installation}-S_{k,\,transformer} \qquad (3)$$

x = number of DG and RES categories

To maintain the reliability and security of distribution networks with DG&RES, the DSO must consider (1), (2) and (3) beside other usual network calculations. Exceeding the limitations in these equations caused by the growth of DG&RES in passive controlled MV networks will lead to larger capacity of transformers, installations and other components. Fig. 4 shows for a 50/10 kV substation with CHP units as illustrated in Fig. 3, the daily profile of the active and reactive power based on measurements in the field.

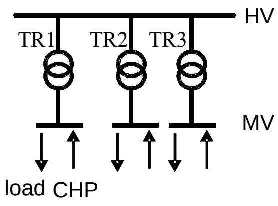

Fig. 3. DG & RES integrated at MV level

As demonstrated in Fig. 4 the generated electricity by the CHP's is exceeding the energy demand. While owners control the CHP's and manage their electricity contribution, the DSO must facilitate the energy transport. In this case an increase of the CHP units will lead to excessive investments to facilitate the transport of generated electricity. Similar cases have already occurred with windmill parks and clustered small CHP's at different places in the Netherlands.

Hence, these clusters of DG&RES units connected to distribution networks behave as centralised generation without the ability to control and manage their power and energy by the DSO.

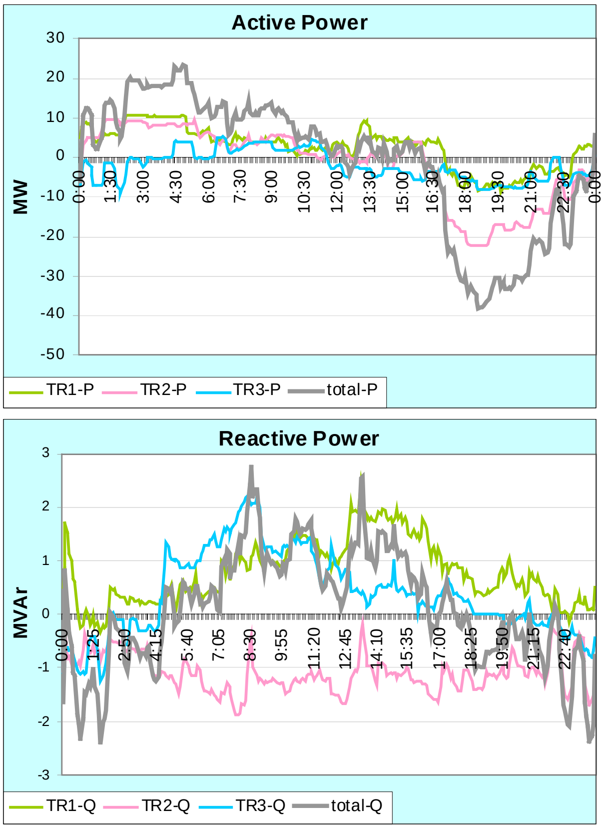

Fig. 4. daily profile of active and reactive power of 50/10 kV substation with CHP's

Integration of DG&RES at low voltage (LV) level

In the future a significant growth [1] of small DG&RES units is expected especially in the urban areas where they will be mostly connected to the LV networks. Large number of small DG&RES units in households, offices and others will be aggregated at LV level. On the contrary to the MV networks, an automatic voltage regulation in the LV networks is lacking. Therefore, the challenges mentioned for the MV networks will arise faster at LV level. If no measures are taken high penetration of DG&RES in LV networks will cause operational problems regarding voltage variations, power quality, system stability, protection and increase of short current.

Relevant regulatory and socio-economical developments

As most countries in the EU aim to liberalise their energy markets by unbundling the vertically integrated energy companies, the electricity generation is separated from transport and distribution. In the next step, the Dutch authorities have assigned the operation of the HV networks to the TSO. This has resulted in different network companies which operate the passive controlled distribution networks beside the TSO.

Thus the distribution network companies in the Netherlands are blocked by the technical possibilities and regulatory constraints to control and manage the power and energy of electricity generation. This explains the term distribution network company in place of distribution system operator, but as matter of convenience the term DSO will also be used. Despite the above mentioned regulatory rules the distribution network companies are still interested in the control and management of DG&RES to prevent excessive expenditures in the networks.

Therefore, with the present passive controlled distribution networks on one hand and the regulatory constraints on the other an increase of expenditures will occur in proportion to the growth of DG&RES. If congestion management is not an option, the distribution network companies are confronted with excessive expenses which finally have to be socialized. In addition, it is out of the question for them to act as a market operator. To anticipate this situation the VPP is considered as a concept to control and manage the power and energy of DG&RES. Regulatory and socio-economical conditions of a VPP are also subjected to this consideration.

III. DEFINITION OF VIRTUAL POWER PLANTS

A consistent definition of the VPP is useful for the benefit of communicating and implementing this concept. The absence of a VPP definition has lead to different specifications, such as described in [2] to [6]. In order to achieve uniformity a proposed definition of the VPP is presented followed by classification of its development stages.

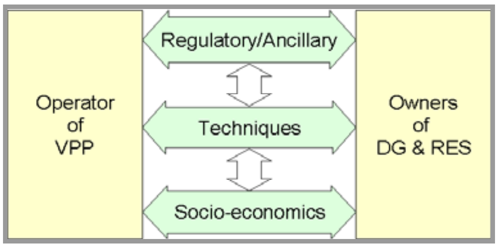

Fig. 5. Critical aspects of a Virtual Power Plant

Besides providing a control and management system for DG&RES the VPP must offer flexible solutions to the changing demands of energy market concerning critical regulatory, technical and socio-economical aspects. The VPP must also cope with issues and constraints concerning the operator of VPP and the owners of DG&RES. Thus in the present situation the development of VPP depends on the success of operator and owners in coping with interdependent critical aspects as illustrated in Fig. 5.

In the previous section the main function of a VPP was implicitly defined as the ability to control and manage the power and energy flow of a cluster of DG&RES. In addition, the VPP take advantage of controllable loads but their availability is not a must. Furthermore different important questions have to be answered regarding the critical regulatory, technical and socio-economical aspects. A summary of relevant questions and suggested answers for the proposed definition of the VPP is shown in table 1.

TABLE 1
Definition of a virtual power plant

Definition (questions)	*Suggestions (Dutch situation)*
Technical	
Scale of installed generation capacity by DG&RES	≥ 10 MW (contracts)
Minimal number of DG & RES units	≥ 2 (≥ 10 MW)
Control topology of VPP	Remote in & out of contracted capacity
Advanced control: power quality, energy flow, etc.	Minimum: as regulated in codes & standards
Regulatory & ancillary	
Operator	Commercial operator, TSO and DSO by contract
Relationship operator and owner	Bilateral contract
Operators' authorisation to control(dispatch) units	Permit from relevant authorities
Unit control limitations for owner	Manual in & out due to contract with operator
Responsible for trade contracts and ancillary services	Operator
Responsible for unit operation and maintenance	Owner (operator can offer services)
Socio-economical	
Financial administration of energy delivery contracts	By operator
Monitoring and metering of produced energy	DSO and TSO
Delivery versus demand tariffs, within regulated margins	Delivery: due to contract with operator Demand: due to contract with supplier
Life cycle costs of unit	Owner
Life cycle costs of control and management system	Operator
Responsible for trading financial risks	Operator

Various countries or regions can have different definitions due to situational regulatory, technical and economical constraints. A threshold of 10 MW for the minimal scale of electricity generation power by a VPP can vary from one to another country. Despite this difference a definition of the minimum power for the VPP is achieved on national basis.

The control topology can differ from one to another VPP depending on whether if producing electrical or thermal energy is the leading production type [2]. The technical specifications of control and management system to meet owners and trading requirements and regulatory constraints will also prescribe the control topology.

The initially defined VPP will not obstruct the development of more sophisticated VPP in the future; on the contrary it may enhance the growth of DG&RES units. The VPP-operators will relieve owners from difficult challenges and risks since participation in the wholesale energy markets require knowledge and skills. In present political and economical environment the VPP will primarily control and manage the power of a cluster of DG&RES units while in the future displacement of energy from transmission to distribution networks through the VPP will be possible. To meet future developments of the energy market, the VPP should evolve through three transition stages.

1. In the first stage many technical, regulatory and socio-economical challenges must be overcome mainly by the VPP-operator. The main objective of the VPP in this stage is to introduce a control and management system to dispatch power and energy and normalise the socio-economical and regulatory conditions.
2. The focus of this stage is the enhancement of technical possibilities of the VPP. The control and management system is improved to dispatch power and energy from centralised generation (through the program responsible parties). Regulatory and socio-economical aspects regarding the interaction between owners of DG&RES, VPP-operator and third parties are clarified.
3. The control and management system of the normal VPP will evolve in this stage further to lead to a sophisticated VPP with ability to offer among other things ancillary, system and power quality services.

IV. ANALYSIS OF FUTURE VIRTUAL POWER PLANTS

Future VPP has a sophisticated control and management system that facilitates anticipating the regulatory constraints and economical demands from operator and owners of DG&RES and possibly variable loads. Besides, this control and management system must take technical limitations of the networks in consideration.

The VPP could be operated by different parties as for instance the DSO's and authorised commercial operators. The TSO will have to aggregate all the input of the individual customers and VPP's into a so called large scale VPP (LS-VPP) in order to perform the required transmission system stability, security and other services. Fig. 6 illustrates such a situation where DG&RES are controlled through VPP's which are aggregated into the LS-VPP.

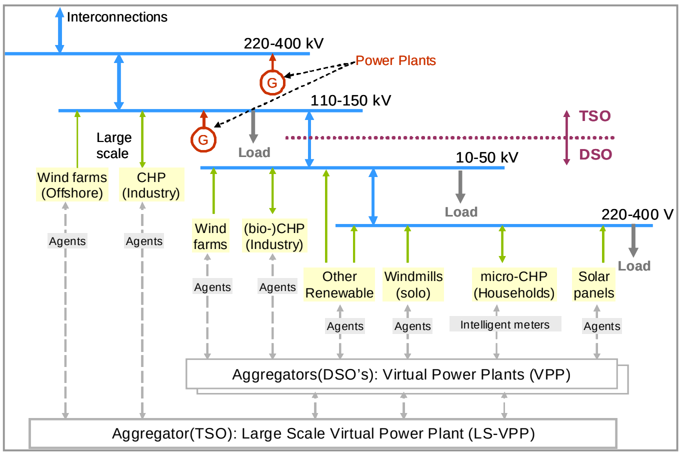

Fig. 6 DG&RES are aggregated into VPP

As already announced a new law is emerging in the Netherlands that will give priority to renewable above conventional energy for grid connection and transport. Hence, the operator must be able to control and manage the flow direction, quantity and quality of electricity in future networks. In order to achieve this future scenario promising control and management concepts [7] are explored and an evaluation of their technical appropriateness in the described VPP transition stages is summarized in table 2.

TABLE 2
Control and management concepts in VPP

Control & management concept	***Technical appropriateness in the VPP perspective***	***VPP development stage***
Micro Grid [8]	involves DG&RES units, storage devices and controllable loads to operate islanded as well as interconnected to the LV grid. Exchange of energy will flow through these interconnections. Thus a positive to negative variable load can represent a micro grid in the VPP.	I
Autonomous Network [9]	is similar to the micro grid concept, except performance optimization is added to this MV network. In addition, larger energy exchange at the MV level is expected.	I
FRIENDS [10]	controls the power quality and voltage level, beside network operation, through local quality control centre (QCC). This functionality can be offered by the VPP.	I & II
Active Network [11]	combines the advantages of micro grid concept into local control areas(cells) which are interconnected to other cells and FRIENDS through providing system services. This combination allows an enhanced control and management of the VPP.	I, II & III
Smart Grid [1]	facilitates the VPP concept in all its development stages through deployment of advanced techniques in control, communication, simulation and power electronics.	I, II & III

V. PROSPECTS OF VIRTUAL POWER PLANTS

In order to facilitate the growth of DG&RES units in the present passive distribution networks, plans handling the transition must be considered. The three transition stages of the VPP provide a coordinated transition and prevent further mitigation of DG&RES penetration. Collaboration between the present distribution network companies and the TSO with third parties will manage political and regulatory challenges and allow the creation of a solid socio-economical system that takes the situational constraints of the country in consideration.

However, to facilitate farther penetration of DG&RES units in distribution networks that is based on the transition stages of the VPP, policy issues are still to be resolved:

I. *Regulatory*: present distribution network companies should be allowed to operate and manage the dispatch of power and energy generated by DG&RES as well as authorised commercial parties.

II. *Technical*: engineering bidirectional distribution networks with high penetration level of DG&RES should be developed conform regulatory rules and international standards by the distribution network companies.

III. *Socio-economical*: funding or socialization the costs and investments of intelligent ICT infrastructure that accommodates the control and management system of the active distribution networks should be assured.

Although the transition stages of the VPP offer a transfer from present to future electricity market design, additional issues will mitigate this transition. Due to the Dutch situation, where ‘priority for renewable energy’-law is emerging, the development of VPP’s by the DSO’s, TSO and in the future by commercial parties is a condition rather than a choice.

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