ENERGY RESOURCES SCHEDULING IN COMPETITIVE ENVIRONMENT

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ABSTRACT

The increasing use of distributed generation units based on renewable energy sources, the consideration of demand-side management as a distributed resource, and the operation in the scope of competitive electricity markets have caused important changes in the way that power systems are operated. The new distributed resources require an entity (player) capable to make them able to participate in electricity markets. This entity has been known as Virtual Power Player (VPP). VPPs need to consider all the business opportunities available to their resources, considering all the relevant players, the market and/or other VPPs to accomplish their goals.

This paper presents a methodology that considers all these opportunities to minimize the operation costs of a VPP. The method is applied to a distribution network managed by four independent VPPs with intensive use of distributed resources.

INTRODUCTION

The development of the SmartGrid (SG) concept is extremely important for future Power Systems (PS), namely in the context of a sustainable society. Although the details involved in the SG are not consensual, it is widely accepted that PS require changes to improve power quality and to adequately integrate all the new players. In future PS each costumer can be a player with the ability to manage his consumption and, in many situations, to generate and storage energy. The advantages of using renewable resources is clear from the environment point of view, as most Renewable Energy Systems (RES) based electricity generation technologies have a null or low impact in what concerns greenhouse gas emissions [1-5]. This led to a significant increasing of electricity distributed generation (DG), most of it based on RES.

To improve energy resource management in the SG context it is necessary to adopt new management systems with different hierarchy control levels. Each level can involve several players acting in medium and low voltage management levels [6]. Players operating in such a complex environment of dynamic and competitive nature must have a competitive strategy in order to gain advantages over their competitors so that they can accomplish their individual goals.

SG requires means so that a wide range of diverse scale players can fairly act in the energy markets. In this context, producers from large to small and even micro scale should be able to operate in the competitive / collaborative environment. Diverse types of aggregators allowing putting together existing energy resources with common interests and aiming at maximizing their individual profits are likely to be very relevant players in the forthcoming scenarios [7].

The players acting in the SG have, on one hand, common goals, such as system security and reliability, for which accomplishment they cooperate. On the other hand, they also have antagonist goals as each player has specific individual goal, aiming namely at maximizing his profits what leads to a competitive behaviour.

Virtual Power Players (VPPs) are a type of aggregator that manages the resources of producers and costumers.

This paper deals with the intelligent management of distributed energy resources in the context of smart grids, and is proposed a methodology to undertake an intelligent management of distributed energy resources in the SG context, in which several players control different parts of distribution network.

The relationships among players (Producers/Consumers/ VPPs and between VPPs) are supported by contractual agreements, so contracts gain a much more relevant role than in present power system operation.

The second section addresses some important points concerning VPPs negotiation and the third section includes a case study. Finally, some conclusions are presented in the last section.

PLAYERS NEGOTIATION

The proposed approach considers a set of independent players acting in a competitive environment, cooperating to accomplish common goals and competing to attain their individual goals. Each VPP can control a part of consumption (contracted with consumers), and a set of DG and storage units. This methodology is based on realistic models, considering the network constraints (line thermal limits and bus voltage limits).

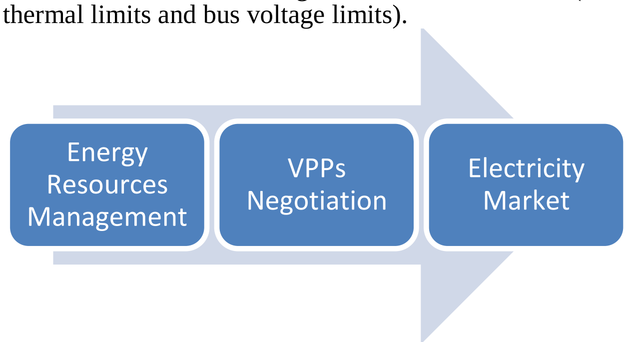

Figure 1. Energy Resources Scheduling Process

The proposed methodology considers players operation scheduling in three distinct levels (Figure 1). The first level considers all the energy resources the player manages, giving place to an operation schedule that can correspond to an energy shortage or surplus situation. The second level corresponds to negotiation processes that are undertaken among different players so they can agree on transactions that can fulfil their unsatisfied energy requirements, sell their surplus energy and/or reduce their operating costs. Finally, the third level corresponds to the participation of the players in the general electricity market mechanisms. The use of the proposed methodology in the scope of SG allows a more efficient resource management, which is especially important for the players with low installed capacity.

Energy Resources Players Management

In the developed methodology, each VPP can operate all the available resources in its network area. The management is based on an optimization tool able to consider the available resources (generation resources including DG, storage, demand response, and distribution network) and demand requirements in order to minimize operation costs. The presented tool considers all the relevant costs including losses costs, and uses AC power flow, providing, as a result, the energy resource scheduling along a multi-period time horizon defined by the user.

However, in the SG context, the VPP has to respect the contracts established with the producers and consumers. For example, some technologies like photovoltaic units have a generation price higher than the other technologies. In spite of this, to respect the established contract, VPPs that aggregate photovoltaic producers may have to buy all their generated energy. The solution to the energy resources players' management is obtained based on a mixed-integer non-linear programming problem [8]. The objective function represents the operation cost of each VPP and can be represented as in (1) in a simplified way.

$$Minimize\ \ f =$$

$$Min \sum_{t=1}^{T} \begin{bmatrix} \sum_{G=1}^{Ng} P_{Gen(G,t)} \times c_{Gen(G,t)} + \sum_{S=1}^{N_S} P_{St(S,t)} \times c_{St(S,t)} + \\ + \sum_{L=1}^{Nl} P_{DR(L,t)} \times c_{DR(L,t)} \end{bmatrix} \quad (1)$$

$$\forall t \in \{1,..,T\}$$

where G refers to the generation units, S to the storage systems, and L to the loads. P_{Gen}, P_{St} and P_{DR} are the power of each generator, storage and load demand response program, respectively. c_{Gen}, c_{St} and c_{DR} are the costs of each resource in period t. The problem was implemented in GAMS software [9].

VPPs Negotiation

The negotiation between VPPs is an important task in the future power systems. The easiest way to trade energy is to negotiate with neighbour VPPs, avoiding the use of third party's electric networks.

This paper proposes the use of Locational Marginal Prices (LMP) values in the interconnection buses to determine the price and quantity of energy to negotiate between neighbour VPPs.

LMPs reflect the impact of power flows on specific lines and provide individual nodal pricing, whereas the zonal representation does not involve the monitoring of individual lines, and assumes that all prices are the same within the each zone [10, 11].

The energy balance, the losses and the network congestion and technical limits (bus voltage limits) are considered to determine the LMP value in each bus [12]. The energy balance takes into account distributed generation, storage units and demand response programs.

Figure 2 shows the flowchart of the developed methodology. Each VPP indicates the LMP value in the interconnection buses. If the values of interconnection LMPs are very different, and if there are one or more VPPs with non-supplied energy, the method determines the price and the quantity of energy to be negotiated between VPPs. The method gives priority to the interconnection with the highest difference between interconnection LMPs. The quantity of negotiated energy is limited to a cap in each negotiation iteration in order to improve the competition between VPPs. Once this process is finished, the new values of LMPs considering the negotiated energy are evaluated. The stop criteria are the inexistence of non supplied energy or the inexistence of resources in all neighbour VPPs.

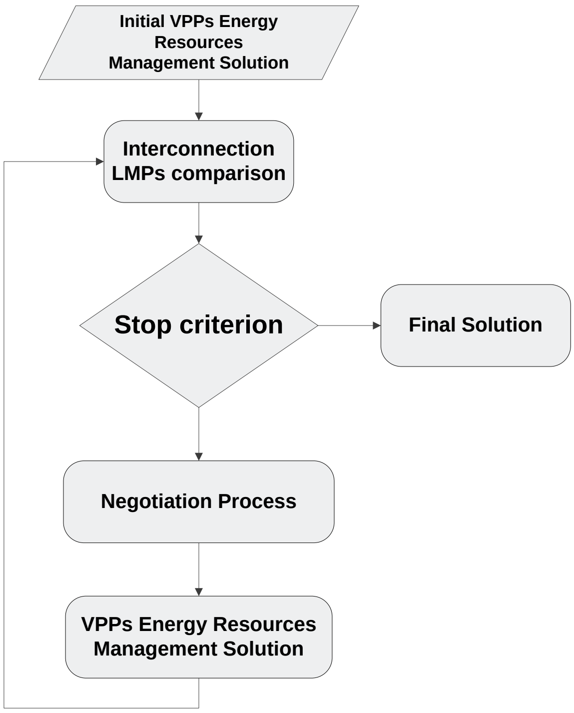

Figure 2. VPPs negotiation flowchart

Electricity Market

After the bilateral negotiation between the VPPs, it is possible to submit bids to the day-ahead market. The sell or buy bids can be based on the LMP values and on the forecasted energy price for the day-ahead market. Depending on the contracts established between the VPPs and their aggregated producers/consumers it is possible to include the forecasted market price in the initial energy resources management algorithm. However, the price of energy in the electricity market should be lower than the DG generation prices. In off-peak hours, this may not happen meaning that DG units should be disconnected.

CASE STUDY

This section presents a case study that illustrates the use of the developed methodology. Let us consider a distribution network with 114 buses, adapted from [13]. Figure 3 shows the distribution network and the DG units. Figure 4 shows the VPPs network areas. This distribution network has 84 loads, 97 DG units and 9 storage systems.

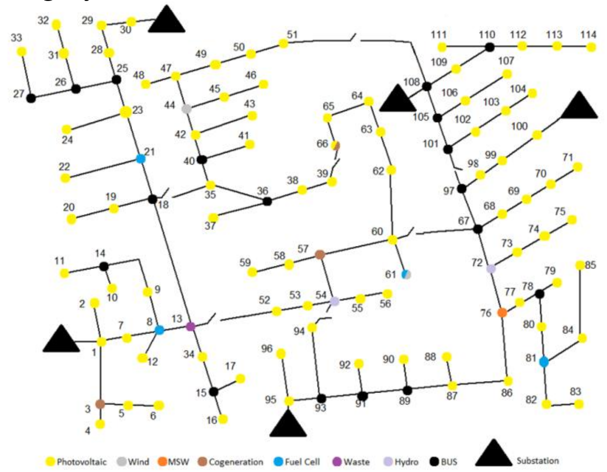

Figure 3. Distribution Network Test Case

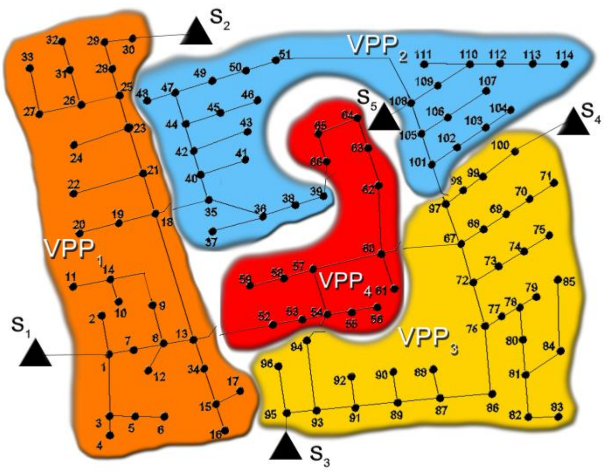

Figure 4. Distribution Network VPP Management

As can be seen in Figure 4, VPP1 and VPP3 have two points of interconnection with the AT network through substations S1 and S2 for VPP1 and substations S3 and S4 for VPP3. VPP4 is not connected to any substation acting normally in islanded mode. VPP2 is connected through AT network by substation S5. Table I shows a summary of the characteristics of each VPP.

Table I – VPPs Characteristics

	No. Load	No. DG	No. Stor.	No. Bus	Sub-stations	Inter-connections
VPP 1	23	27	2	34	S_1 e S_2	VPP2; VPP4
VPP 2	24	25	2	31	S_5	VPP1; VPP3; VPP4
VPP 3	25	28	1	34	S_3 e S_4	VPP2; VPP4
VPP 4	12	17	4	15	----	VPP1; VPP2; VPP3

The following figures show the obtained results for the VPPs generation from the initial energy resources management process (Figure 5) and after the VPPs negotiation process (Figure 6); load flows in the interconnections (Figure 7); and ΔLMP, after the energy initial resources management process (Figure 8) and after the VPPs negotiation process (Figure 9).

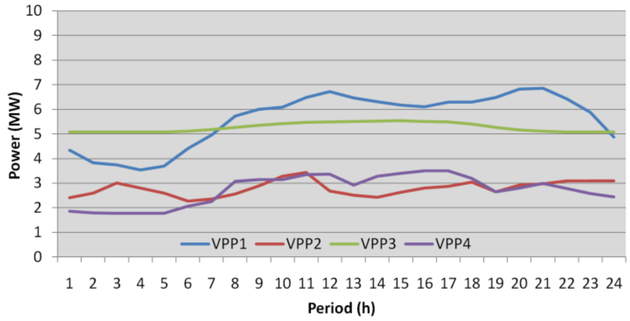

Figure 5. Initial VPPs generation resulting

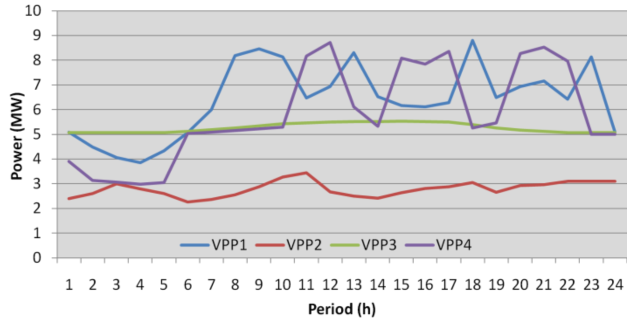

Figure 6. VPPs generation after VPPs negociation

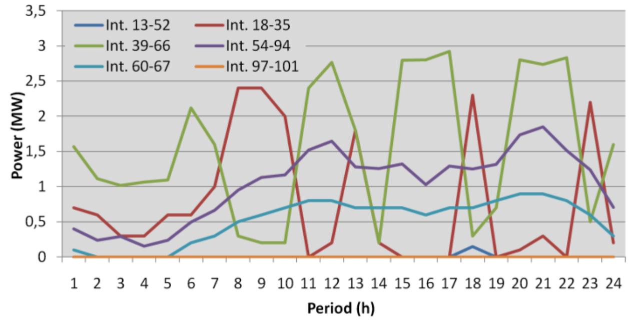

Figure 7. Interconnections load flows

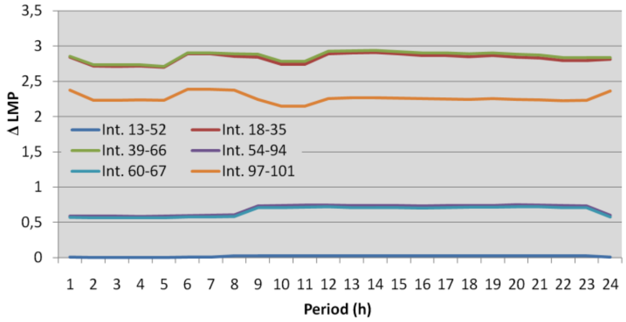

Figure 8. ΔLMP after energy resources management process

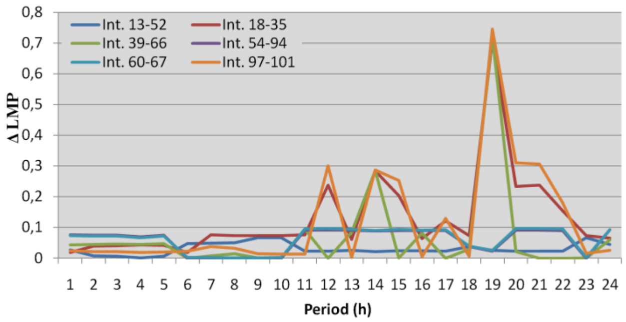

Figure 9. ΔLMP after VPPs negociation

Analyzing Figures 5, 6, and 7 it is possible to see that VPP2 and VPP3 have the same generation schedule after the first and the second processes. VPP1 and VPP4 increase their generation to export energy to VPP2 and to VPP3. VPP 4 sells energy to VPP 3 using interconnections 54-94 and 60-67. VPP2 buys energy from VPP1 and VPP4. In this case VPP1 and VPP4 compete for selling energy to VPP2 and the purchased power is divided by both VPP as seen in Figures 6 and 7.

In Figures 8 and 9 it is possible to see that there are significant differences between LMPs in the interconnections 39-66 and 18-35. These differences reflect the non-supplied energy in VPP2 and VPP3 areas. As the values of the penalties are high, the LMP value for VPPs with non-supplied energy is also high. After the negotiation process, the difference between LMPs is lower for the whole optimization period (T). Only the values for period 19 are relatively higher due to the VPP2 and VPP3 necessity of using demand response programs. In this case, VPP2 and VPP3 can buy energy in the day-ahead market.

CONCLUSIONS

The paper includes a case study with a 114 buses network adapted from IEEE 123 Node Test Feeder network with 4 players having the control of different network areas. Each player has different generation resources and different operation strategies. The results of individual operation with and without players' cooperation are presented and discussed. The obtained results are very interesting because they consider a complex and realistic environment of dynamic and competitive/collaborative nature. These results make new light on the ways in what the players can use the new opportunities in the context of future SG.

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