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Real-time Energy Resource Scheduling Considering a Real Portuguese Scenario

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Abstract: The development in power systems and the introduction of decentralized generation and Electric Vehicles (EVs), both connected to distribution networks, represents a major challenge in the planning and operation issues. This new paradigm requires a new energy resources management approach which considers not only the generation, but also the management of loads through demand response programs, energy storage units, EVs and other players in a liberalized electricity markets environment. This paper proposes a methodology to be used by Virtual Power Players (VPPs), concerning the energy resource scheduling in smart grids, considering day-ahead, hour-ahead and real-time scheduling. The case study considers a 33-bus distribution network with high penetration of distributed energy resources. The wind generation profile is based on a real Portuguese wind farm. Four scenarios are presented taking into account 0, 1, 2 and 5 periods (hours or minutes) ahead of the scheduling period in the hour-ahead and real-time scheduling.

1. INTRODUCTION

Future power systems have new challenges in this century due to the integration of several new concepts and paradigms. The new concepts results mainly from the integration of Distributed Energy Resources (DER), such as Distributed Generation (DG) based on renewable energy sources, Demand Response (DR), storage units, Electric Vehicles (EVs) and new players, such as Virtual Power Players (VPPs). VPPs can ensure a reliable, secure, and flexible operation in the context of smart grids (Fang*, et al.*, 2012).

The smart grids operation will allow a greater availability of functions in the power system, providing new services and the optimized management of the electric network. In the future power systems paradigm, consumers will have an active participation. The flexible demand assured by the loads control systems, by the integration of DG units and also by the EVs, allows the active participation of the consumers in several services like a the resources scheduling or in voltage control (Faria*, et al.*, 2011).

The planning and operation of the electric network became more complex with the introduction of DG units (Morais*, et al.*, 2010). VPPs can aggregate several distributed small-size resources in order to make them able to participate in electricity markets (Vale*, et al.*, 2013). The aggregation of DERs can be seen as an important strategy to improve the management of these resources. In the proposed methodology, it is considered that the VPP can manage a high number of DERs, such as DG units, storage systems, DR programs and EVs short-term Energy Resource Management (ERM) (Faria*, et al.*, 2011; Kieny*, et al.*, 2009; Pudjianto*, et al.*, 2007). One of the most important tasks of the VPP is the use of an efficient methodology to solve the short-term ERM problem (Borghetti*, et al.*, 2010; M. Silva*, et al.*, 2011).

In the proposed methodology, the VPP uses a deterministic optimization technique to solve the DERs optimal short-term management connected to the distribution network considering an intensive use of DERs. The proposed optimal short-term ERM method considers two distinct time horizons: the hour-ahead scheduling; and the real-time scheduling, all of them considering the main goal of maximizing the VPPs profits. In the first step, the hour-ahead scheduling obtains the resources dispatch for the next hour considering the influence of the day-ahead scheduling. In the second step, the real-time scheduling is conducted with 5 minutes of anticipation, taking into account the hour-ahead results and the most recent forecasts. In each scheduling process, it is necessary to update the generation and consumption operation, and the storage and EVs status.

The main contribution of the present paper is the evaluation of the impact of the inclusion of subsequent periods in the scheduling process. The main idea is to provide algorithms with a more robust process to manage DERs. Four different simulations were tested considering a different number of subsequent periods (0, 1, 2 and 5 ahead).

The paper is structured considering the following sections: Section 1 presents the introduction; Section 2 describes the proposed methodology and the mathematical formulation; Section 3 illustrates a case study involving the intensive use of wind generation, considering a real Portuguese scenario; and, finally, the last section presents the main conclusions of the paper.

2. ENERGY RESOURCES MANAGEMENT METHODOLOGY

The VPP aims to provide adequate support for medium and small players acting in the market, providing the best scheduling for the available DERs through the ERM. The short-term ERM is important to improve the management of the DERs by the VPP. The short-term methodology helps the VPP changing the hour-ahead scheduling according to the most recent forecast values (Venayagamoorthy, *et al.*, 2012).

2.1 Proposed Methodology

The main goal of the proposed methodology is solve the short-term ERM problem in order to maximize the VPP's profit in smart grid context. The ERM proposed methodology, shown in Fig. 1, is divided into two phases after the day-ahead optimal scheduling results: the Hour-ahead operation block and the Real-time operation block (Marco Silva*, et al.*, 2012; Marco Silva*, et al.*, 2013).

In the first phase, all the renewable resources and the consumption forecasts for each period are updated (one hour in this case) through the forecast hour-ahead, and then all the resources managed through the hour-ahead scheduling are adjusted taking into account the results of the day-ahead scheduling. The day-ahead scheduling for the specific period of intraday will come in as a constraint of the new scheduling problem.

In the second phase the resources are updated, as in the hour-ahead forecast, with the particularity of being optimized for the next five minutes. After the real-time forecast is run the optimal scheduling for the following 5 minutes takes into consideration the results of the first phase and the most updated forecasts of the resources. In this step, only the resources that have been scheduled in first phase of the hour-ahead optimal scheduling are considered. In this step, the dynamic constraints of generators, like ramps and inertia, are also considered preventing the resources schedule without mechanism to respond in a few minutes.

2.2 Mathematical Formulation

The VPP will maximize their own profits, which are determined by the income (*In*) minus the operation costs (*C*), as illustrated in (1). The optimization problem is formulated as a mixed-integer non-linear programming problem.

$$Maximize\ f = In - C \tag{1}$$

Equation (2) calculates the income that the VPP will receive from four sources: the revenue from supplying the demand power to the consumers; the selling energy to the electricity market; the revenue from the charging process of storage units; and the revenue from the charging of EVs. The operation cost of the resources managed by the VPP, shown in (3), considers the cost with DG units, external suppliers, the discharge of storage and EVs, DR programs, the penalization with non-supplied demand and the penalization with DG units' generation curtailment.

$$In = \sum_{t=1}^{T} \begin{bmatrix} \sum_{L=1}^{N_L} MP_{Load(L,t)} \times P_{Load(L,t)} + MP_{Sell(t)} \times P_{Sell(t)} + \\ \sum_{ST=1}^{N_{ST}} MP_{Ch(ST,t)} \times P_{Ch(ST,t)} + \sum_{V=1}^{N_V} MP_{Ch(V,t)} \times P_{Ch(V,t)} \end{bmatrix} \tag{2}$$

The MP_x terms refer to market prices, and P_x terms refer to the scheduled active power. The index *x* refers to the type of energy resources used in the income. In (2) it was used the load *L*, the selling energy to the market unit (*Sell*), the charge process of storage unit *ST* and the charge process of vehicle *V*, in period *t*. *Nx* refers to the number of resources *x*, and *T* is the total number of periods.

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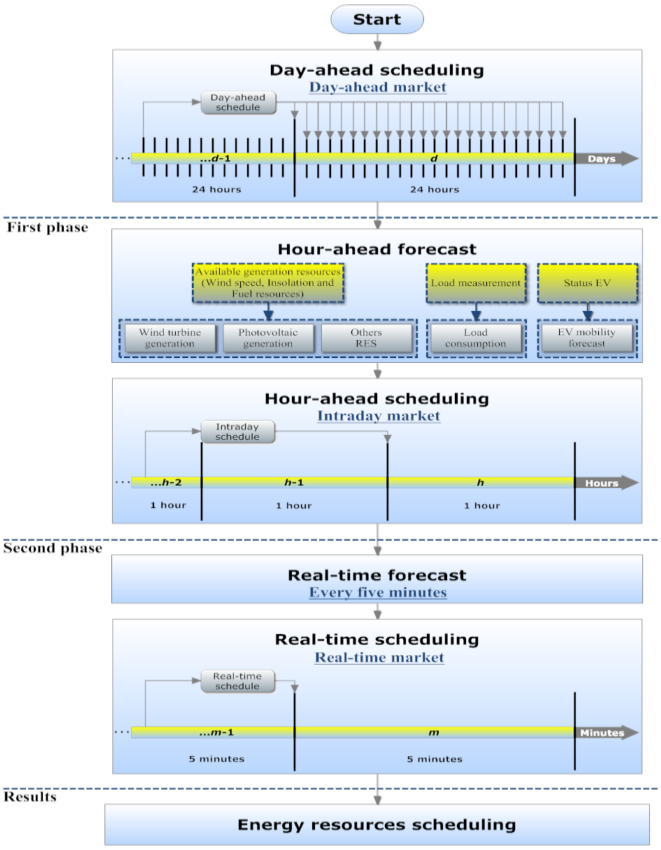

Fig. 1. ERM proposed methodology

$$C = \sum_{t=1}^{T} \begin{bmatrix} \sum_{DG=1}^{N_{DG}} c_{DG(DG,t)} \times P_{DG(DG,t)} + \sum_{SP=1}^{N_{SP}} c_{SP(SP,t)} \times P_{SP(SP,t)} + \\ \sum_{ST=1}^{N_{ST}} c_{Dch(ST,t)} \times P_{Dch(ST,t)} + \sum_{V=1}^{N_V} c_{Dch(V,t)} \times P_{Dch(V,t)} + \\ \sum_{L=1}^{N_L} c_{Cut(L,t)} \times P_{Cut(L,t)} + \sum_{L=1}^{N_L} c_{Red(L,t)} \times P_{Red(L,t)} + \\ \sum_{L=1}^{N_L} c_{NSD(L,t)} \times P_{NSD(L,t)} + \sum_{DG=1}^{N_{DG}} c_{GCP(DG,t)} \times P_{GCP(DG,t)} \end{bmatrix} \tag{3}$$

The C_y terms refer to the costs, and P_y terms refer to the scheduled active power. The index y refers to the type of energy resources considered in the operation costs. In (3) it was used the external supplier *SP*, the discharge process of storage unit *ST*, the discharge process of vehicle *V*, the DR reduction *Red*, the DR curtailment *Cut*, the non-supplied demand *NSD*, and the generation curtailment power *GCP*.

The constraints of the ERM problem must be considered, as presented in greater detail in (Marco Silva*, et al.*, 2013). These include the constraints concerning the first Kirchhoff Law, voltage limits, line capacity limits, the maximum capacity considering the available resources, storage and EVs resources, and DR power limits.

3. CASE STUDY

The case study presented in this section is implemented on the distribution network with 33 buses, with projection for the year 2040 regarding the penetration of DG units, as shown in Fig. 2. The case study considered comprises a single VPP with the ability of managing the distribution network and DERs connected to the network. The DERs considered are: a large wind farm, 66 DG units, 10 external suppliers, 7 storage units, 218 consumers (with demand response programs) and 2000 electric vehicles.

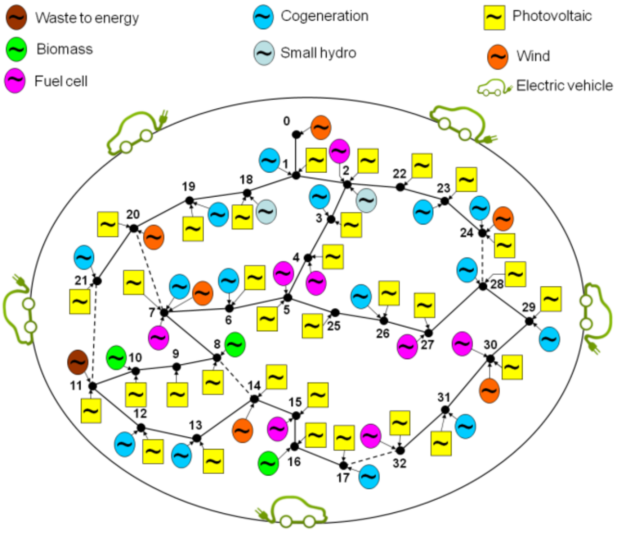

Fig. 2. Distribution network (adapted: M. Silva*, et al.*, 2012)

To evaluate the impact of a large wind farm in the short-term ERM problem, it has been included in bus 1 of the distribution network a large wind farm considering a real Portuguese scenario (see Fig. 3) concerning November 13, 2012. On this day, the generation rounds 1GW in the first hours of day representing about 20 to 25% of the total consumption in Portugal. After hour 10 the wind generation decreases around 90% to 100 MW in only 3 hours. After hour 18, the wind generation increases to more than 1 GW. By analysing the differences between the real and forecast wind generation curves it is possible to see a big gap (more than 500 MW) in several hours both in under and upper estimation errors. The forecast errors increased the need for real-time scheduling in order to avoid problems in power systems.

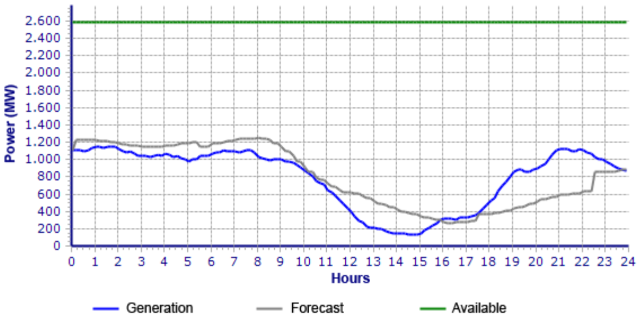

Fig. 3. Wind farm scenario based on a real Portuguese case (REN-Redes Energéticas Nacionais SA, 2013)

Table 1 shows the main characteristics of the considered DERs, namely the available power capacity and the energy prices established between the VPP and the owners of the resources. The external suppliers (last line of table 1) are not distributed energy resources, but they are a representation of energy contracts by the VPP to other VPPs, electricity market offers or bilateral contracts.

Table 1- Energy resources characteristics

Energy resources		Availability (kW)		Prices (m.u./kWh)
		min – max	Total	
Biomass		100 – 150	350	0.090
CHP		5 – 600	1150	0.060
Fuel Cell		10 – 50	235	0.150
Small Hydro		30 – 40	70	0.070
Photovoltaic		3 – 30	549	0.200
MSW		10	10	0.100
Wind		100 – 200	800	0.150
Large Wind		2600	2600	0.070
External Supplier		100 – 600	2400	0.600 – 0.150
Storage	Charge	150	–	0.086 – 0.158
	Discharge	100	–	0.106 – 0.178
Electric Vehicle	Charge	20 – 50	–	0.086 – 0.158
	Discharge	28 – 34	–	0.202
Demand Response	Red	2 – 172	3150	0.150 – 0.160
	Cut	0 – 206	2770	0.160
Load		–	–	0.086 – 0.158
External Suppliers		0 – 8000	–	0.100

The Generic Algebraic Modeling System software has been used to optimize the ERM problem (GAMS, 2011). The proposed methodology has been tested on a PC compatible with an Intel Xeon W5450 3.00 GHz processor, with 8 Cores, 12 GB of random-access-memory and Windows Server Enterprise.

3.1 VPP Profits Results

In Table 2 are presented the VPP incomes, costs and profits of each scenario, and also the average execution time of each scheduling process. Each scenario considers different time-schedules for the hour-ahead and for real-time scheduling. In the first scenario, it is only considered the optimization of the following hour in the hour-ahead scheduling, and the optimization of the next five minutes in the real-time scheduling. In scenarios 2, 3 and 4 are considered more periods than the following period in the scheduling process. In scenario 2, 3 and 4 are considered 1, 2 and 5 periods ahead for the hour-ahead and real-time scheduling processes.

As it is possible to see in Table 2, the use of more periods in hour-ahead scheduling process has not any advantage for the VPP. All the values for the costs and incomes, and consequently for the profits, are kept constant in all scenarios. In the real-time scheduling process one can verify some differences in the VPP profits, mainly when more than 5 minutes (1 period) after the following 5 minutes are considered. When comparing with the first scenario, the difference is the increase in 40 m.u. in the VPP's profits (more 0.71%). This value can represent an increase of around 14 000 m.u. in the VPP profits in one year, with any investment in new technology for the VPP. Other important aspect is that the use of the proposed algorithm does not bring problems in terms of execution time.

3.2 VPP Scheduling Results

Other important aspect is the analysis of the scheduling results in each scheduling process. The wind generation forecast (based on real data) is represented in Fig 4 and, the VPP's day-ahead scheduling is represented in Fig. 5 and 6. Fig. 7 to 10 show the hour-ahead and the real-time scheduling results for scenarios 1 and 4.

By analysing Fig. 5 and 6, and regarding the results of day-ahead scheduling process, it is possible to see the EVs charge during all day, yet with high values during the off-peak periods. In hour 8 (period 425), the consumption increases because of the increase of load demand and also the EVs charge requirements. The result is a flat load diagram with short differences in the load diagram during all the optimization periods.

In Fig. 7 and 8 it is possible to see the hour-ahead and the real-time scheduling considering only the following period in the scheduling processes. The result is a more unstable diagram from high variations in wind and consumption forecast and also to guarantee the established contracts in the previous scheduling processes.

Comparing Fig. 7 and 8 with graphics related to the scheduling processes, regarding 5 periods after the following one (Fig. 9 and 10), it is possible see very small differences. The most visible is the use of storage systems in the last periods of the day.

Table 2- Obtained Results

Periods ahead	Performa	Day-ahead scheduling	Hour-ahead scheduling	Real-time scheduling	%
0	Income (m.u.)	21670	21396	21412	0
	Cost (m.u.)	15878	15733	15772	0
	Profit (m.u.)	5792	5663	5640	0
	Time (s)	1254	0.9198	0.9568	
1	Income (m.u.)		21396	21431	0.09
	Cost (m.u.)		15733	15759	-0.08
	Profit (m.u.)		5663	5672	0.57
	Time (s)		2.4593	0.7951	
2	Income (m.u.)		21396	21398	-0.07
	Cost (m.u.)		15733	15722	-0.32
	Profit (m.u.)		5663	5676	0.64
	Time (s)		4.2724	6.4551	
5	Income (m.u.)		21397	21368	-0.21
	Cost (m.u.)		15734	15688	-0.53
	Profit (m.u.)		5663	5680	0.71
	Time (s)		8.8176	12.8845	

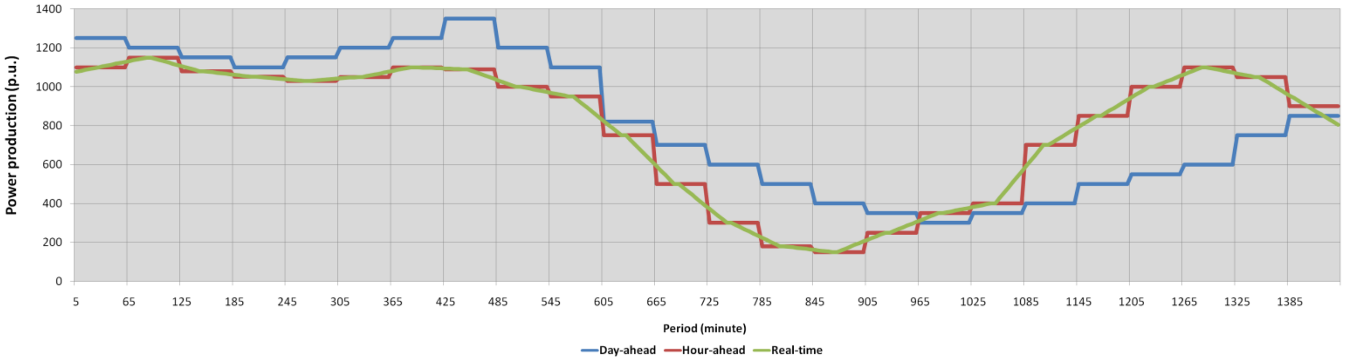

Fig. 4. Day-ahead, hour-ahead and 5-minutes ahead (real-time) forecast

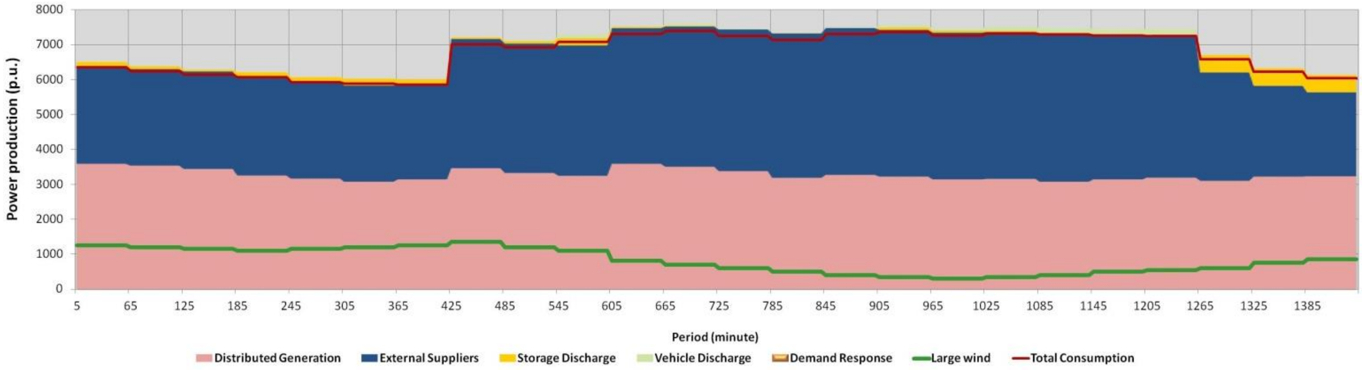

Fig. 5. Day-ahead generators scheduling

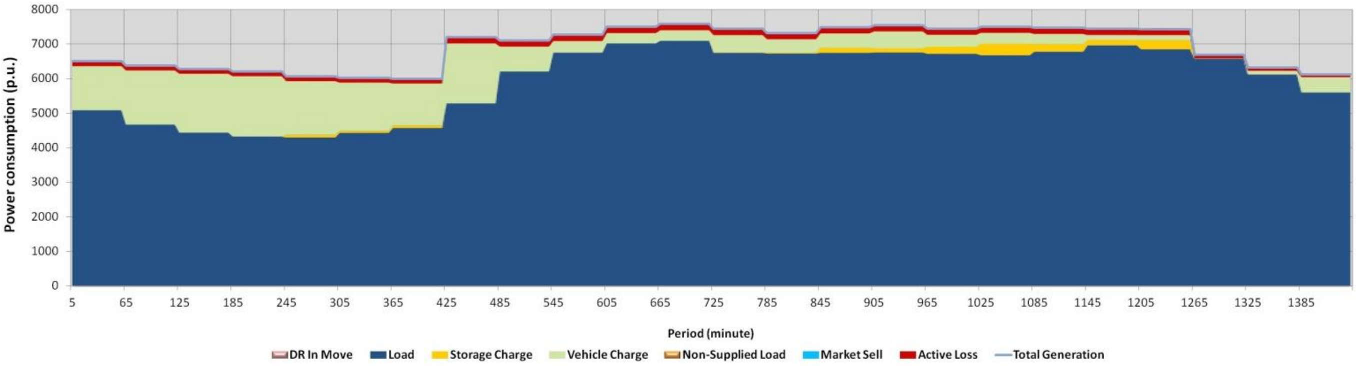

Fig. 6. Day-ahead load demand forecast and EVs charge scheduling

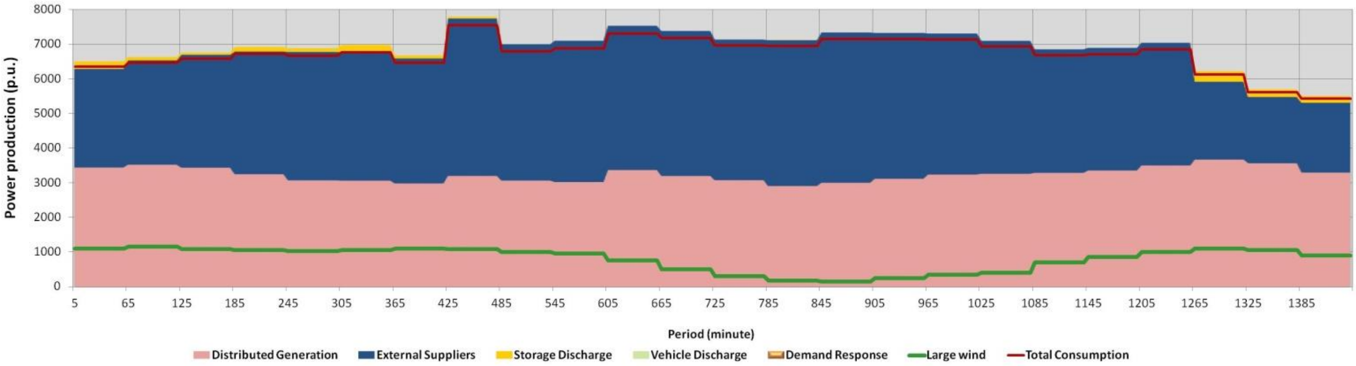

Fig. 7. Hour-ahead scheduling (0 periods ahead)

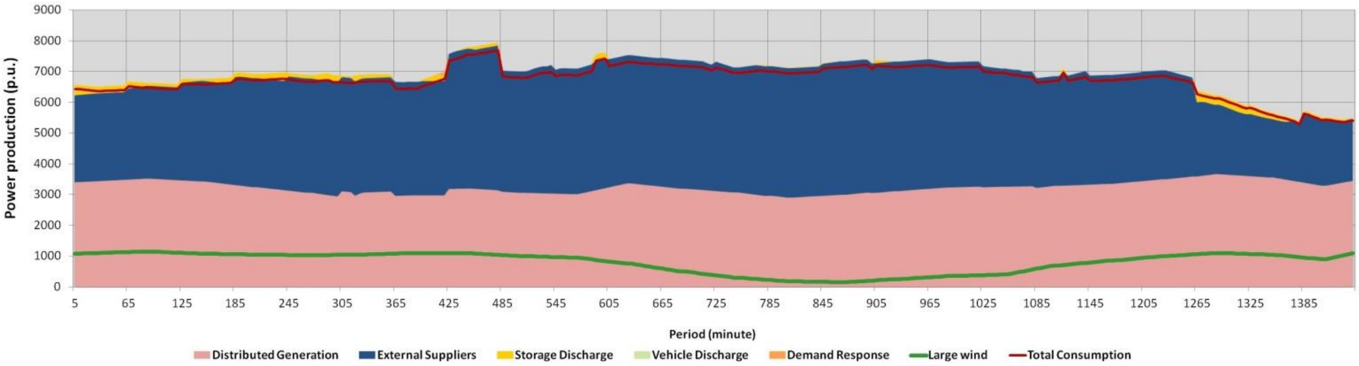

Fig. 8. Real-time scheduling (0 periods ahead)

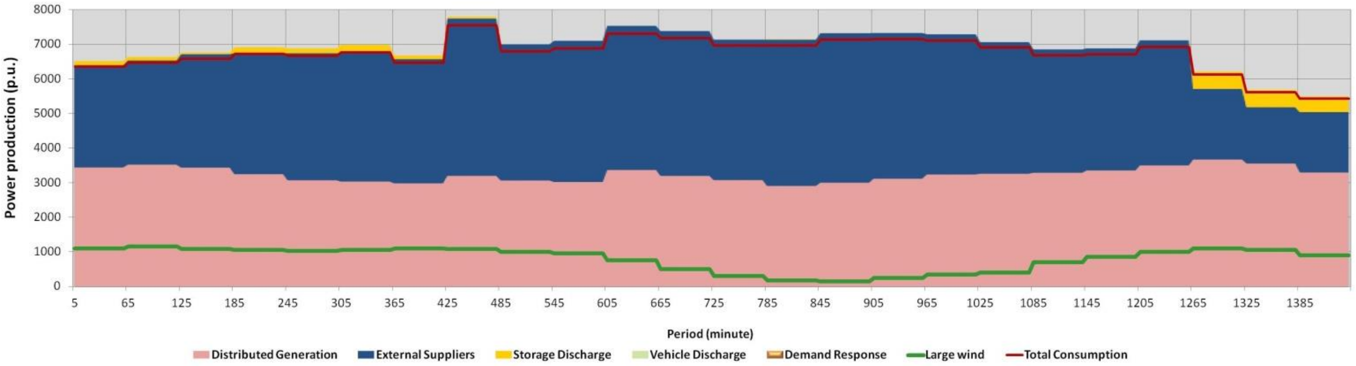

Fig. 9. Hour-ahead scheduling (5 periods ahead)

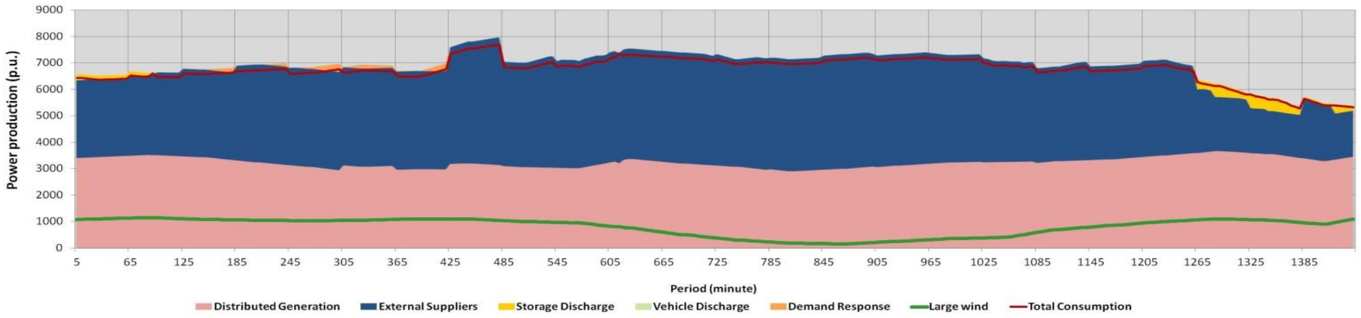

Fig. 10. Real-time scheduling (5 periods ahead)

4. CONCLUSIONS

The proposed methodology proved to be able to provide VPPs with significant profit increasing. With this methodology, the VPP can manage his resources in a very short period of time, improving his profits and fulfilling the established contracts. The use of periods after the following scheduling period in proposed methodology increased the VPP's profits in around 14000 m.u during one year in the simulated case study considering a small distribution network with 33 buses. This value can be improved in large systems. Other interesting aspect is the few influence in the execution time keeping times acceptable.

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