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# Intelligent Energy Resources Management in the Context of Smart Grids

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Abstract: Smart grids are envisaged as infrastructures able to accommodate all centralized and distributed energy resources (DER), including intensive use of renewable and distributed generation (DG), storage, demand response (DR), and also electric vehicles (EV), from which plug-in vehicles, i.e. gridable vehicles, are especially relevant. Moreover, smart grids must accommodate a large number of diverse types or players in the context of a competitive business environment.

Smart grids should also provide the required means to efficiently manage all these resources what is especially important in order to make the better possible use of renewable based power generation, namely to minimize wind curtailment. An integrated approach, considering all the available energy resources, including demand response and storage, is crucial to attain these goals.

This paper proposes a methodology for energy resource management that considers several Virtual Power Players (VPPs) managing a network with high penetration of distributed generation, demand response, storage units and network reconfiguration. The resources are controlled through a flexible SCADA (Supervisory Control And Data Acquisition) system that can be accessed by the evolved entities (VPPs) under contracted use conditions.

A case study evidences the advantages of the proposed methodology to support a Virtual Power Player (VPP) managing the energy resources that it can access in an incident situation.

## 1. INTRODUCTION

Energy resource management should not only consider the available energy resources but also their use permission, according to regulations, ownership, bi-lateral contracts and auctions. This paper presents an energy resource management methodology, based on an intelligent and flexible SCADA that supports these concepts.

Present SCADA systems are intended for the monitoring and supervision of equipments owned, or at least operated, by a very limited number of entities, only one in most cases. It is generally assumed that there is a fixed entity to operate each piece of equipment (ARC, 2007). In the scope of future smart grids, SCADA systems have to consider both the physical part of each power system component and its cyber dimension, which requires a SCADA based on a cyber-physical model of the power system (Ilic *et al.*, 2008).

Each component can always be operated by its owner, as long as the required technical constraints are respected. Some components can also be operated by some other players if this is contracted between the involved players. In these cases, both technical and contractual constraints apply. Contractual clauses must be verified, according to the involved players and to the context situation as the use of a specific component may depend on the context. This is done at the SCADA level, using the information about the contracts established among the involved players that allow determining each equipment operation permissions, according to the context.

These concepts are especially relevant in the context of smartgrids for which a large set of distributed energy resources (DER) must be adequately managed. These resources are owned by a diversity of players acting in different parts of the smartgrid. An adequate management of smartgrid resources requires the use of these resources to be done in a flexible and decentralized way.

Future smartgrids should be able to provide the means so that the involved players' decisions can have the required technologic support as to become effective.

Smartgrid resource management involves decentralized decisions undertaken by a diversity of players. Each one of these players should be able to have access to a SCADA system that allows it to use the relevant operation data. Moreover, each player will use its SCADA to control and command the relevant equipment in order to undertake the actions corresponding to its decisions.

The required type of SCADA characteristics and use presents significant changes when compared to the present situation:

a) A relatively small area corresponds to a multiplicity of SCADA systems, of diverse sizes, that depend on each player dimension;

b) Each player should obviously have access to the information and control of its own equipment;

c) Additionally, each player should have access to the relevant information about the whole smartgrid so that it can adequately base its decisions;

d) In what concerns the control and command actions, each player's permissions should be considered by the SCADA so that these permissions are dynamically updated.

A SCADA simulator implementing the concepts presented in (Vale *et al.*, 2009) is used in the scope of the present paper to simulate energy resource management in the context of smartgrids.

Decentralized control of smartgrids is modelled considering that each player takes decisions concerning the network area under its control. These decisions are taken according to this player's goals, using adequate decision-support tools. Most of these involve an optimization approach aiming at achieving the player's goals (e.g. minimizing operation costs, load curtailment, and greenhouse gas emissions).

Optimization considers the resources and devices:

a) Owned by the player;

b) Owned by other players with which this player has celebrated contracts that allow him to use these devices, under a priori defined conditions.

Decisions involving resources and/or devices in the conditions of b) require the existence of a flexible SCADA with the characteristics described in (Vale *et al.*,2009).

Figure 1 shows the schematic representation of the proposed SCADA, which determines operation permissions. In this figure lines in blue represent interactions among system players to negotiate contracts and lines in red represent SCADA actions (Vale *et al.*,2009).

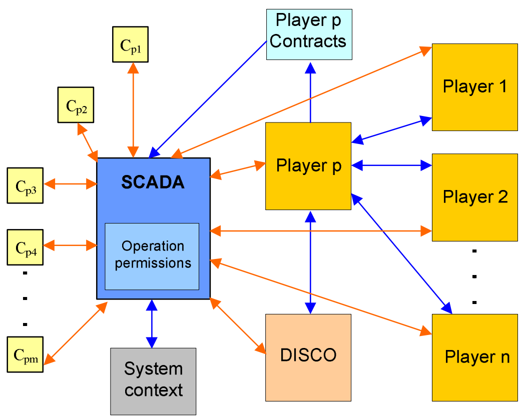


Figure 1- Proposed SCADA (Vale et al.,2009)

## 2. ENERGY RESOURCE MANAGEMENT

In the SmartGrids (SG) context, the future electrical networks should be an infrastructure able to accommodate all centralized and distributed energy resources (DER), including intensive use of renewable and Distributed Generation (DG), storage units, Demand Response (DR) (Faria *et al.*, 2010) (USDE, 2006), and also electric vehicles (EV), in the context of a competitive business environment (European Commission, 2007) (EAC, 2008) (Vale *et al.*, 2010.1) (Tai, 2009). SG should be adequate to put together all these energy resources guaranteeing the most adequate energy resources management, resulting in a complex environment (Vale *et al.*, 2010.1) (Vale *et al.*, 2010.2).

Optimization should not only consider the available energy resources but also their use permission, according to regulations, ownership, bi-lateral contracts and auctions.

For a more adequate management of the available energy resources, it is proposed to aggregate several players with different characteristics and with different resources. Virtual Power Players (VPPs) (Morais *et al.*, 2009) can bring this concept to practice aggregating several players and managing parts of the distribution network in coordination with the independent system operator (ISO).

Considering a specific VPP that wants to optimally manage the available resources, it can make use of its own resources (i.e. of the resources owned by its aggregated players) and also of the resources that other players can make available to its use. In order to operate in an efficient way, VPPs should have adequate decision-support tools. These must be based on the availability and processing of the required information and knowledge concerning producers, costumers, and network and market operation.

### 2.1 Resource Management Model

In order to optimize the management of energy resources, VPPs need to have access to all the information about the installations and contracts with their aggregated agents. This includes information about:

- the distribution network characteristics (line thermal limits;
- bus voltage limits;
- reconfiguration possibilities;
- generation units' characteristics (minimum and maximum generation capacity, generation costs, incentives, gas emissions);
- storage units characteristics (maximum storage capacity, maximum charge and discharge, efficiency, and discharge cost);
- demand response contracts (curtailment capacity, reduce capacity, cost of curtailment, cost of reduction, cost of non supplied energy);
- VPP and players contracts (minimum of remuneration, minimum of energy supply, difference of generation between periods, number of operation periods).

This information remains the same day to day. However, some information is different for each day, namely:

- generation forecast (wind, photovoltaic, and hydro);
- load forecast;
- market price forecast;
- initial storage units status.

With this information, the VPP undertakes the optimization process. In our proposed approach the problem was formulated in mixed-integer nonlinear programming and the objective function corresponds to the minimization of the operation cost, considering all available resources.

VPPs can run the optimization process many times, considering different scenarios of generation, load and market price because of the uncertainty of these values. With the obtained scheduling solutions the VPP can choose the solution that is the most adequate to its strategies.

The adopted scheduling solution is communicated to all aggregated players to the operation of next day.

Figure 2 represents a schematic diagram of the proposed VPP energy resources management process.

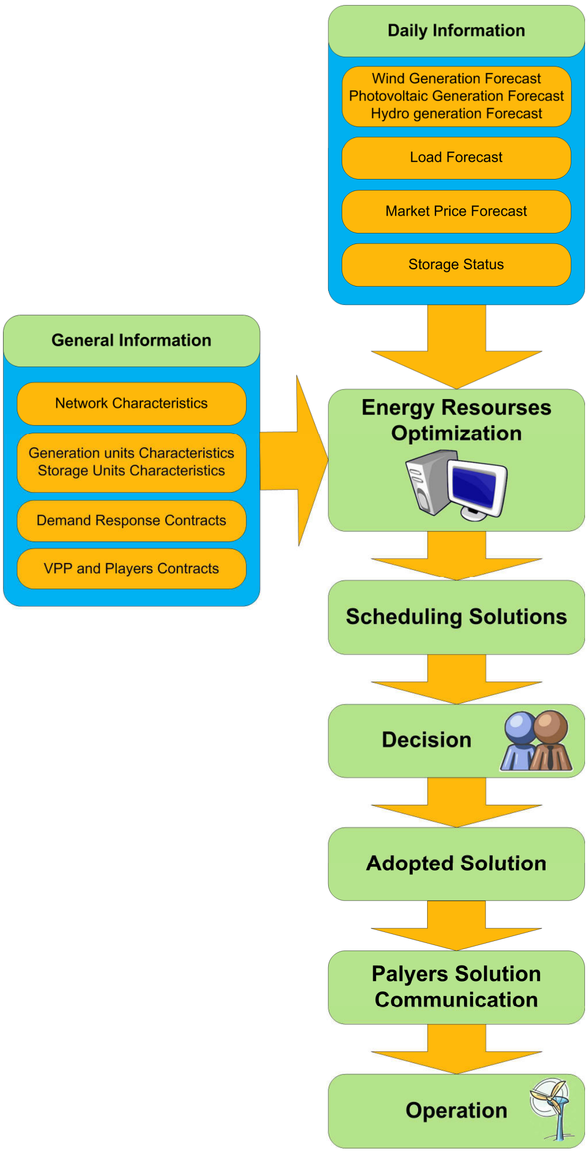


Fig. 2. Energy Resource Management schematic diagram

### 2.2 *Problem Formulation*

This sub-section presents the mathematical formulation used, based on a mixed-integer non-linear approach implemented in GAMS (GAMS, 2007).

The objective function (1) of the mixed-integer non-linear model is formulated with the aim of finding the total minimal cost of supplying the demand by a VPP. This formulation is inspired in the one proposed in (Vale *et al.*, 2011). The necessary energy can be obtained in the VPP own area resources (distributed generation, storage, and demand response), in a substation connected to the managed network, or in a near area operated by other VPP. The remuneration of use the energy of a near VPP is contractually defined and not considered in the optimization model since it is considered a fixed tariff not depending on the energy acquired.

The used demand response contracts include two types of load management, *DRR* and *DRC*. The first corresponds to the reduction of consumption in some loads technically able to this control, and the second is considered as the curtailment of some loads or circuits supply.

$$Minimize\ f =$$

$$Min \sum_{t=1}^{T} \left( \begin{array}{l} P_{Sub(t)} \times c_{Sub(t)} + \sum_{g=1}^{ng} (P_{Gen(g,t)} \times c_{Gen(g,t)}) \\ -\sum_{s=1}^{ns} \left( P_{StorageCharge(s,t)} \times c_{StorageCharge(s,t)} \right) \\ +\sum_{s=1}^{ns} \left( P_{StorageDischarge(s,t)} \times c_{StorageDischarge(s,t)} \right) \\ +\sum_{l=1}^{nl} \left( P_{NSE(l,t)} \times c_{NSE(l,t)} \right) \\ +\sum_{g=1}^{ng} \left( E_{xcessGeneratedEnergy(g,t)} \times c_{ExcessGeneratedEnergy(g,t)} \right) \\ +\sum_{l=1}^{nl} \left( P_{DRR(l,t)} \times c_{DRR(l,t)} + P_{DRC(l,t)} \times c_{DRC(l,t)} \right) \end{array} \right) \tag{1}$$

where,

| | |
|---|---|
| $c_{DRR(l,t)}$ | *DRR* program cost, for load *l* in period *t* |
| $c_{DRC(l,t)}$ | *DRC* program cost, for load *l* in period *t* |
| $c_{ExcessGeneratedEnergy(g,t)}$ | Unit *g* excess generated energy cost in period *t* |
| $c_{Gen(g,t)}$ | Generation cost of generation unit *g* (or a near VPP) in period *t* |
| $c_{NSE(l,t)}$ | Non-supplied energy cost, for load *l* in period *t* |
| $c_{StorageCharge(s,t)}$ | Storage unit *s* charge cost in period *t* |
| $c_{StorageDischarge(s,t)}$ | Storage unit *s* discharge cost in period *t* |
| $c_{Sub}$ | Substation supplied energy cost |
| $E_{xcessGeneratedEnergy(g,t)}$ | Excess generated energy, by unit *g* in period *t* |
| $ng$ | Total number of generators (including near VPPs) |
| $nl$ | Total number of loads |
| $ns$ | Total number of storage units |
| $P_{DRR(l,t)}$ | *DRR* program power reduction, for load *l* in period *t* |
| $P_{DRC(l,t)}$ | *DRC* program load curtailment, for load *l* in period *t* |

| | |
|---|---|
| $P_{Gen(g,t)}$ | Generation power of generator $g$ (or a near VPP) in period $t$ |
| $P_{NSE(l,t)}$ | Non-supplied energy, for load $l$ in period $t$ |
| $P_{Sub}$ | Power flow from the substations to the considered network |
| $P_{StorageCharge(s,t)}$ | Storage charge power, for unit $s$ in period $t$ |
| $P_{StorageDischarge(s,t)}$ | Storage discharge power, for unit $s$ in period $t$ |
| $t$ | Period |
| $T$ | Total time |

The equation (2) refers to the first Kirchhoff Law or power balance constraint.

$$\begin{aligned}
&P_{Sub(t)} + \sum_{g=1}^{ng} P_{Gen(g,t)} + \sum_{s=1}^{ns} P_{StorageDischarge(s,t)} \\
&+\sum_{l=1}^{nl} P_{NSE(l,t)} + \sum_{l=1}^{nl}\left(P_{DRR(l,t)} + P_{DRC(l,t)}\right) \\
&= P_{Load(t)} + P_{Losses(t)} + \sum_{s=1}^{ns} P_{StorageCharge(s,t)} \\
&+\sum_{g=1}^{ng} E_{xcessGeneratedEnergy(g,t)}
\end{aligned} \tag{2}$$

where,

| | |
|---|---|
| $P_{Load(t)}$ | Load demand power in period $t$ |
| $P_{Losses(t)}$ | Active power losses in period $t$ |

Other constraints must be considered, as presented in (Vale *et al.*, 2011). These include the constraints concerning the maximum capacity considering the available resources, and storage resources, which require a special treatment due to specific operation constraints.

## 3. CASE-STUDY

This section presents a case study that illustrates the use of the proposed methodology, considering several VPPs operating in the context of a smartgrid.

### 3.1 Network

Let us consider a distribution network with 114 buses, adapted from IEEE 123 Node Test Feeder network (IEEE, 2004). The main changes to the original network are the introduction of DG and storage units and that all lines and buses are tree-phase. Figure 2 shows the considered distribution network. This network includes 102 distributed generation units (84 photovoltaic plants; 2 wind farms; 1 MSW; 3 Cogeneration; 4 Fuel Cell; 1 Waste; 2 Mini Hydro), 9 storage units that are connected to the high voltage network in 5 different buses (1; 30; 95; 100 and 108) and supplies energy to 84 costumers,

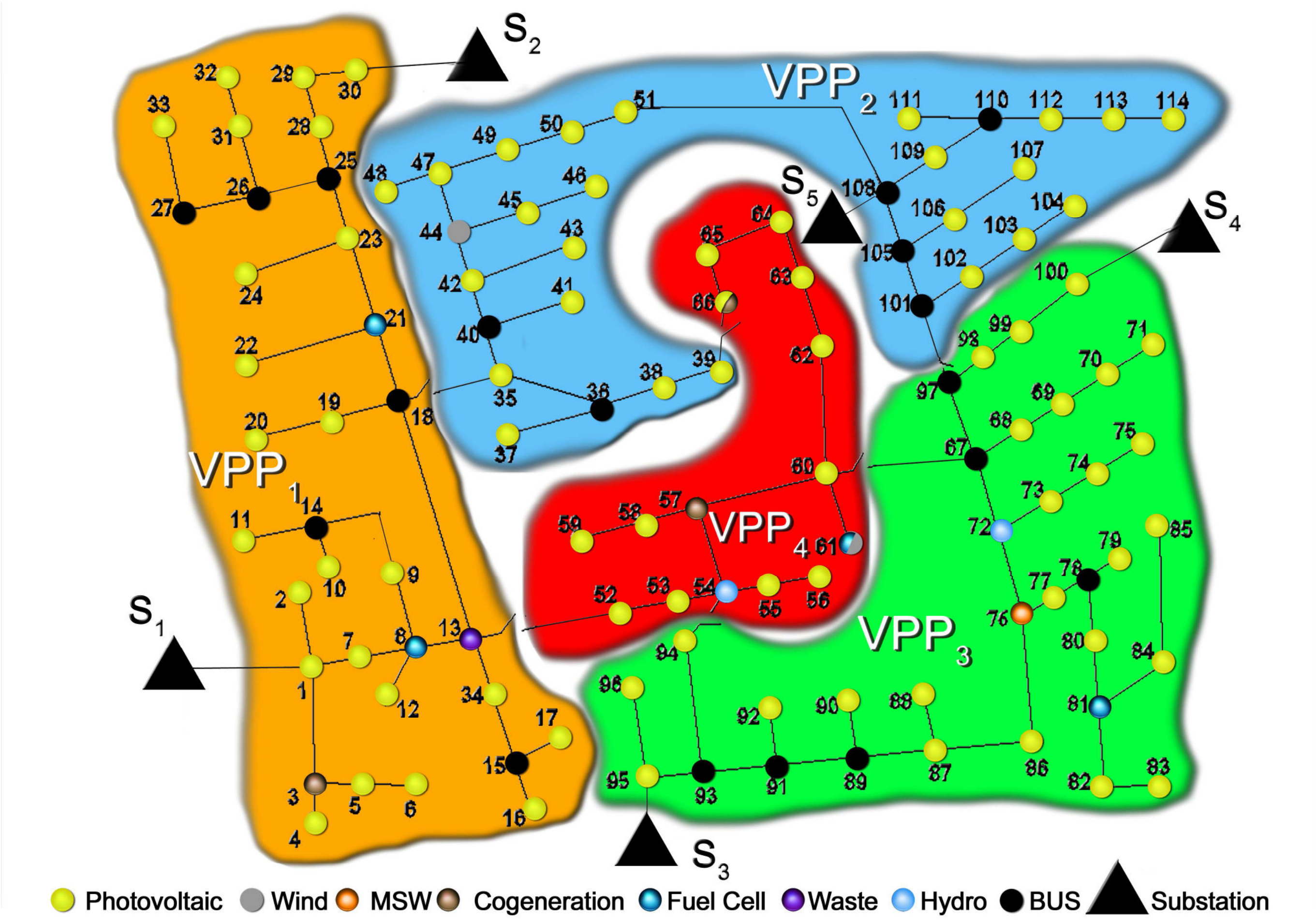


Fig. 3. 114 Bus Distribution Network

Considering a contingence in a substation and comparing the results of a situation when VVP2 (considered for this example) can only manage the resources of its own network area (section 3.2), and when VPP2 can obtain energy from VPP3 reducing the impacts of incident situation (section 3.3).

### *3.2 VPP2 managing only its own network area resources*

The simulated incident occurs in VPP2 area, in substation $S_5$ (Bus 108). VPP 2 has two types of small DG units (24 photovoltaic plants and 1 wind farm) which make this incident have a large impact on VPP 2 network. In Figure 4 can be seen, for VPP2, the load demand diagram and the resources used to supply the required energy. This energy was supplied by wind and PV (photovoltaic) generation, and trough the consideration of demand response contracts (DRR and DRC). The non-supplied energy (NSE) is also presented, as the load that was not possibly to satisfy. As it is an incident situation that considers the lack of supply from the substation, this source was not included.

Considering all these aspects, it is necessary to know the impact of each resource in the operation cost. These costs are presented in Figure 5. The total cost for the 24 hours considered in this case study is 90300 Euros. The main contribution is the value of penalties due to the Non-Supplied Energy (NSE).

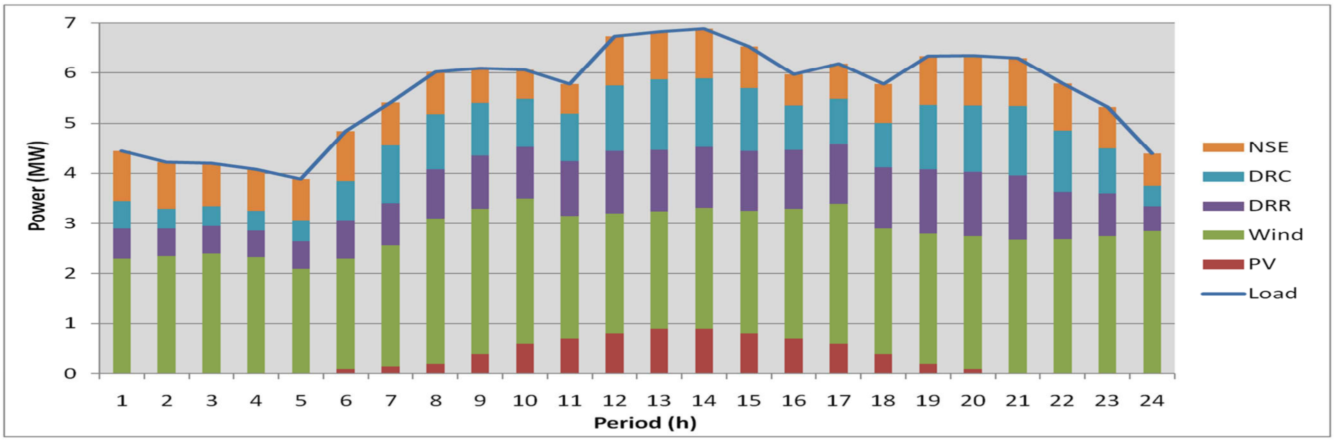


Fig.4. Resources and load power use, when VPP2 is not connected to VPP3

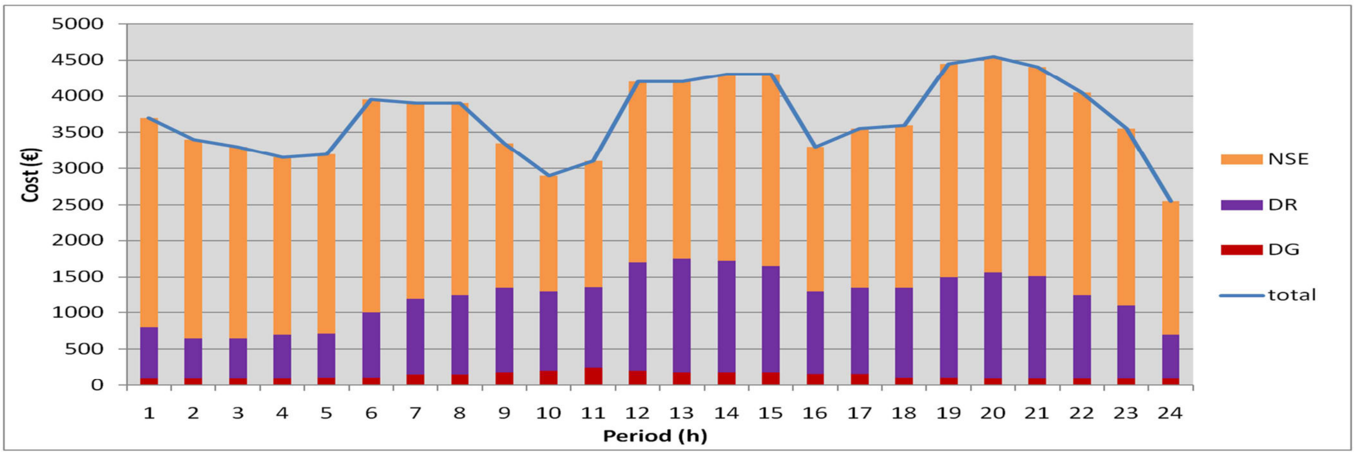


Fig.5. Operation costs, when VPP2 is not connected to VPP3

### *3.3 VPP2 managing its own resources and the ones of VPP3*

In order to reduce the impact of this incident, VPP2 can connect its network with the network of others VPP operating in the same smartgrid (VPP1, VPP3 or VPP4). However, third part SCADA equipment only can be used if this is allowed in the contract between VPP2 and the other player. A SCADA, with the characteristics presented in section 1 is modelled and considered in the optimization process that will determine the optimal energy resource management.

As a result of this optimization, VPP2 area will be connected with VPP3 by the line between bus 97 and bus 101. This is possible because the contract between VPP2 and VPP3 allows the connection of the two networks in this incident context. As a result of using some VPP 3 resources, the final operation cost, during the incident period, is significantly reduced.

Figure 6 shows the generation in VPP2 area and the energy bought to VPP3 by line 97-101. Figure 7 presents the operation cost in this situation.

The total cost is 6720 Euros. This cost has been evaluated considering that VPP2 buys energy from VPP3 at a price equal to the locational marginal price (LMP) in bus 97. The use of the connection trough bus number 97 is contractually defined as a fixed rate independent of the energy quantity acquired. However, several alternative methods can be considered to determine the price at what this energy is acquired (e.g. price resulting from a negotiation process, contracted for this kind of situation).

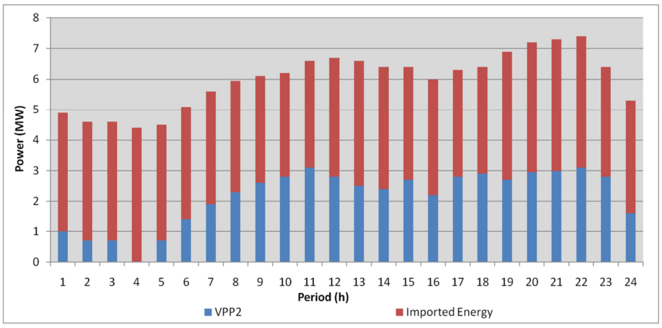


Fig.6. Resources and load power use, when VPP2 is not connected to VPP3

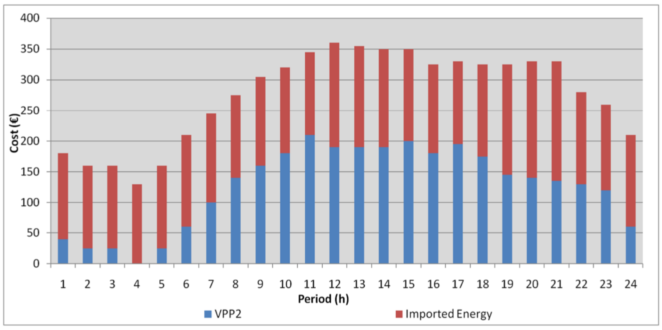


Fig.7. Operation costs, when VPP2 is connected to VPP3

## 4. CONCLUSIONS

This paper addressed the operation of Virtual Power Players (VPPs) in the scope of a smartgrid. Although each aggregator has its own energy resources, these can be insufficient, namely in peak periods and in incident situations, and lead to huge costs, caused by load shedding.

A flexible SCADA, able to support dynamic players' permissions, can give technologic support to aggregators operation, namely in the use of other players' resources. This paper proposed a resource management methodology that uses mixed-integer nonlinear programming to optimize resource scheduling, by a VPP, considering the ability given by a SCADA system to consider energy provided by other VPP.

A case study, considering four VPPs operating in a 114 bus network, illustrates the adequacy of the proposed methodology. The results of the simulated incident scenario show that incident costs can be drastically reduced if contracted third party resources use is enabled by a flexible SCADA with the proposed characteristics.

## 5. REFERENCES

ARC Advisory Group (2007). *SCADA Systems for Electric Power Industry – Five year market analysis and technology forecast through 2011*. 2007

Electricity Advisory Committee (2008). *Smart Grid: Enabler of the New Energy Economy*. December 2008

European Commission - Directorate for Research Co-operation Energy (2007). *European Technology Platform SmartGrids - Strategic Research Agenda for Europe's Electricity Networks of the Future*. 2007.

Faria P.; Vale Z.; Ferreira J. (2010). *DemSi – A Demand Response Simulator in the context of intensive use of Distributed Generation*. 2010 IEEE International Conference on Systems, Man, and Cybernetics (SMC 2010), Istanbul, October 2010.

IEEE Power System Analysis, Computing and Economics Committee - Distribution System Analysis Subcommittee (2004). *IEEE 123 Node Test Feeder*. IEEE Power Engineering Society.

Ilic, M.; Xie, L.; Khan, U.; Moura, J. (2008). *Modeling Future Cyber-Physical Energy Systems*. IEEE PES General Meeting, Pittsburgh, USA, July 20-24, 2008.

Morais, H.; Ramos, S.; Vale, Z.; Khodr, H. (2009). *MV Producers and Consumers Agents Characterization with DSM Techniques*. 2009 IEEE Bucharest Power Tech

Tai, H.; Hogain, E. (2009). *Behind The Buzz - Light Smart-Grid Trends Shaping The Industry*. IEEE Power & Energy, vol. 7, no. 2, March/April 2009, pp. 96 and 88-92

US Department of Energy (2006). *Benefits of Demand Response in Electricity Markets and Recommendations for achieving them*. Report to the United States Congress. February 2006. Available from: http://eetd.lbl.gov.

Vale, Z.A.; Morais, H.; Silva, M.; Ramos, C. (2009). *Towards a future SCADA*. Power & Energy Society General Meeting, 2009. PES '09. IEEE , vol., no., pp.1-7, 26-30 July 2009

Vale, Z. A.; Morais, H.; Khodr, H. (2010). *Intelligent multi-player smart grid management considering distributed energy resources and demand response*. Power and Energy Society General Meeting, 2010 IEEE , vol., no., pp.1-7, 25-29 July 2010

Vale, Z. A.; Morais, H.; Khodr, H.; Canizes, B.; Soares, J. (2010). *Technical and economic resources management in smart grids using heuristic optimization methods*. Power and Energy Society General Meeting, 2010 IEEE, vol., no., pp.1-7, 25-29 July 2010

Vale, Z. A.; Morais, H.; Ramos, S.; Soares, J.; Faria, P. (2011). *Using Data Mining Techniques to Support DR Programs Definition in Smart Grids*, Power and Energy Society General Meeting, 2011 IEEE, vol., no., 24 – 29 Jul 2011