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Plug-in Electric Vehicles as storage devices within an Autonomous Power System. Optimization issue

P. Lombardi[*], *Student Member IEEE,* P. Vasquez[*], *Student Member IEEE,* Z.A. Styczynski[*] *Senior Member IEEE*

***Abstract*— In modern Power Electric Systems (PES) consisting of diverse sources of energy supply, uncertainty regarding the availability of some renewable sources-based generation plants is one of the major issues affecting the task of sizing the capacity of conventional generation plants. Energy storage devices are able to mitigate the intermittence of the availability of renewable resources and, consequently, successfully reduce the aforementioned uncertainty. Along these lines, electric drive vehicles equipped with sophisticated storage, control and communication systems are being developed and improved in order to allow their connection to the distribution networks at the final consumers' level.**

This paper discusses the possibilities of taking advantage of plug-in electric vehicles while they are parked provided that their energy storage system installed on board is able to consume from or rapidly supply energy into the electric grid.

The impact of incorporating plug-in electric vehicles within an Autonomous PES (APS) is evaluated by modeling the dynamic decisions executed for the EMS and by formulating an optimization problem where the type and size of the diverse generation plants –conventional and renewable– are known and the penetration level of plug-in electric vehicles is determined. Solutions found involve maximizing the performance (expressed in monetary terms) of the tested APS.

***Index Terms*— Autonomous power system, combined heat and power plant, electric vehicles, energy storage, optimization, PV, stochastic, uncertainties, wind.**

I. INTRODUCTION

THE great complexity that currently involves satisfactorily upgrading Power Electric Systems (PES) in order to efficiently drive their evolution and operation while at the same time fulfilling exigent standards calls for updating the classic planning and operation procedures. Otherwise, PES soon will become outdated and fragile. One of the major concerns regarding this topic stems from the unavoidable presence of short and long-term uncertainties in the availability of renewable resources. In fact, during both periods of a lack of renewable energy sources and during circumstances of capacity surplus, there are risks of having insecure or inefficient operative conditions, and especially in those PES which should be able to autonomously cope with such risks (APS).

For an APS, designing the supply system with an adequate "over-capacity" of firm generation based on non-renewable resources (base load generation) could allow the System Operator (SO) to compensate the uncertain lacks of power and energy caused by the intermittence of the renewable resources and hence fulfill demanded security standards. However, under this traditional risk management technique, the "green energy" produced by wind farms or solar is not efficiently exploited. According to [1], PES with a high penetration of renewable energy sources -in this analysis wind and photovoltaic plants (PV)-, could lose up to 30-40 % of their potential production even with the support of a Net Security Management system (NSM). Moreover, the non-renewable-resources-based power plants operate not only under regimens of lower use factors but also under low efficiency points in their incremental costs curves.

By contrast, although Energy Storage Systems (ESS) [2] and [3] are much less efficient than non-renewable energy sources for providing firm capacity (base-load power), they exhibit advantageous technical and economical features when providing power during short periods. In addition, the ESS installed close to the final consumers are expected to increase their opportunities in the face of looming smart-grid schemes incorporated with innovations in customer interface (e.g. time-of-day, smart meters and communication systems), novel advanced load control and demand-side management [4].

In this paper, one of the most promising ESS, known as Vehicles to Grid technology (V2G) [5], has been chosen for analyzing its impact in the global performance of an APS. In fact, incorporating V2G in distribution grids could be favorably exploited for successfully carrying out the task of compensating the lack of renewable resources and furthermore storing their surplus for reasonable periods of time [6]. In Section II, the V2G technology concept and a set of beneficial characteristics that such a technology exhibits are described. In Section III a case study is proposed in order to numerically formulate an optimization problem where efficient combinations of V2G and renewable sources (wind and photovoltaic) are the decision variables. Section IV shows a general description of the methodology applied for solving the problem. The most important obtained results are detailed in Section V. Final conclusions close this paper in Section VI.

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[*] P.Lombardi, P Vásquez, and Z. A Styczynki are with Otto-von-Guericke Universität Magdeburg. (e-mail: pio.lombardi@ovgu.de)

II. VEHICLES TO GRID TECHNOLOGY (V2G)

Electric-drive vehicles can be categorized as hybrid (HEV) -internal combustion engine combined with electrical motor- and full electric (EV) [7]. At present, there are several mass-produced EV and HEV [8] and some of them include on board battery management systems (BMS) which allow their connection to the public electric grid [9]. EV with this characteristic are known as plug-in electric vehicles (PEV) [8]. The basic concept of "vehicle-to-grid" technology (V2G) is that the PEV exchange energy with the grid while parked. To successfully accomplish this task, in addition, a connection module to the grid (for electrical energy flow) and a module for communication with the grid operator are necessary [10].

In this paper, in order to evaluate the impact of fleets of PEV in the performance of an APS, it is assumed that the two above mentioned issues are overcome and that the acquisition of commercial PEV has been encouraged. Thus, fleets of PEV can operate either as energy sources, when they are required for the SO, or as loads, during strategic hours of the day when PEV batteries need to be charged [11].

Modelling the impact of a fleet of PEV within an APS entails previously defining a set of parameters. In this work, it is assumed that the fleet of PEV is composed of a number of N PEV (storage capacity 9.2 kWh) [8]. This currently commercial type of PEV can travel a distance of 80 km without recharge. Additional parameters are as follows:

Storage capacity: A lithium-ion-mangan battery pack composed by 16 modules and each module with 12 cells is installed in each PEV for obtaining a total storage capacity of 9.2 kWh at a DC voltage average of 346 V [8].

Transfer Limit: The electrical power capacity that a PEV can deliver to the grid is mostly determined by two factors: the maximal flow of the connection to the grid during the batteries' discharge, which is assumed to be 16 A (residential connection, 230 V AC), and the stored energy divided by the time used (see Fig. 1 and Fig. 2). It is also important to consider the converter efficiency, which in this work is assumed to be 95 %. The flow from the grid into the PEV during the batteries' charging periods generally depends on the type of the batteries and is controlled by the BMS (1).

Cycles of charge and discharge: In order to extend the life time of the batteries and thus to make a long-term efficient usage of the PEV's storage system, the range of discharge and charge are set between $E_{\text{low}} = 30$ %, and $E_{\text{up}} = 90$ %. Under this work cycle, the life time of the battery-based storage system is set to 10 years.

Charge and Discharge times: The charge time of the batteries, t_{charge}, is assumed as a linear function of the incremental energy stored. In fact, this parameter can be assessed by considering that a fully discharged PEV needs a time $t_{\text{full}} = 5$ *hours* to be completely charged (from 0 to 100 %) with a reduced current flow controlled by the BMS and a voltage of 230 V (1). Discharge time, $t_{discharge}$, depends either on the power injected to the grid or on the power delivered to the electrical motor, as well as on the converter efficiency and on the storage capacity, see (2). This parameter can be determined by using the continuous line plotted in Fig. 1 and Fig. 2.

$$t_{charge} = \frac{\left(E_{up} - E_0\right)}{E_{\max}} \cdot t_{full} \qquad (1)$$

where,

t_{charge} : time required to charge the PHEV's ESS until E_{up} (h)
E_{up} : upper charge limit of the PHEV's ESS (Ah, %)
E_0 : current level of charge of the PHEV's ESS (Ah, %)
$E_{\max}$: maximal level of charge of the PHEV's ESS (Ah, %)
t_{full} : time to completely charge the PHEV's ESS (h)

$$t_{discharge} = \frac{E_0 - E_{low}}{P_{inj}} \eta_{\text{conv}} \qquad (2)$$

where,

$t_{discharge}$: time to discharge the PHEV's ESS until E_{low} (h)
E_{low} : lower charge limit of the PHEV's ESS (kWh)
E_0 : current level of charge of the PHEV's ESS (kWh)
P_{inj} : Power injected to the gid (kW)
η_{conv} : converter efficiency (%)

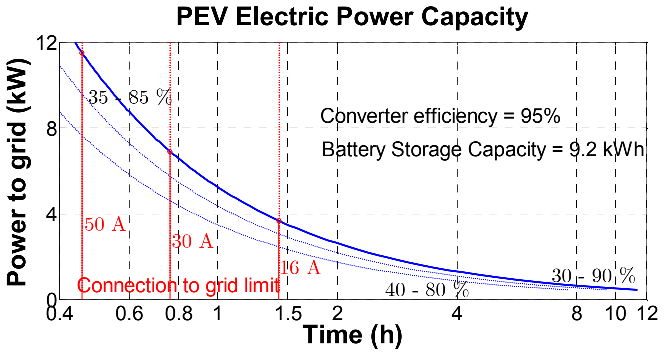

Fig. 1. Supply times for different discharge cycles of a 9.2 kWh PEV

Fig. 1 shows the behaviour of the chosen PEV as a source of energy provided that the batteries have an initial charge level of 80, 85 or 90 %. Energy that can be delivered to the grid depends on the final level of discharge of the batteries (40, 35 or 30 % respectively). For instance, by assuming that the PEV has a current charge of 90%, a complete discharge, i.e. PEV at the end has a 30 % storage capacity, entails a power capacity of 3.7 kW to be injected to the grid during 1.43 h.

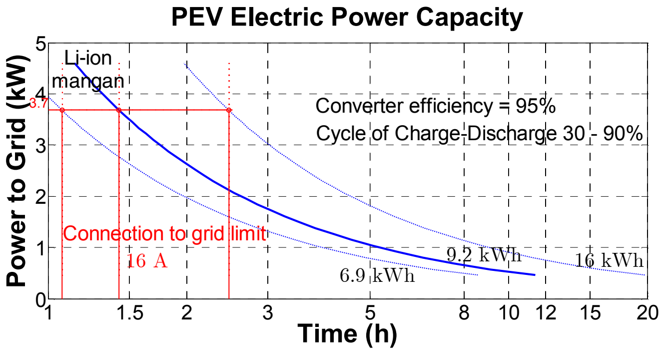

Fig. 2. PEV's discharge time for different storage capacities

The continuous improvement of the ESS looks promising since over the next two years a noticeable increase of the PEV's storage capacity is expected. Fig. 2 shows how the storage capacity of the PEV (in Fig. 2 for three chosen types of PEV: $6.9\ \mathrm{kWh}$, $9.2\ \mathrm{kWh}$ and $16\ \mathrm{kWh}$ [8]), enhances the time that a PEV can inject power to the grid. However, in order to increase the power capacity that a PEV is able to inject into the grid, the connection limit necessarily should be upgraded. Fig. 2 illustrates this situation; although the storage capacity of the three analyzed PEV is different, the connection limit sets their maximal transfer capacity to $3.68\ \mathrm{kW}$.

Additional important information about the PEV, which is plugged within the control of the SO, is combined with the distance that PEV travels every day as well as the periods during the day that they are not parked. These parameters depend on the uncertain and diverse diary requirements of each PEV's owner. However, since PEV used with residential or private purposes could exhibit, as fleets, an expectable behavior and extended periods plugged to the grid, in this paper it is assumed that, along one day, three equivalent firm fleets operate within the APS. They exhibit the following behavior:

Fleet a: $30\ \%$ of the N PEVs do not stay parked from $7\ \mathrm{am}$ to $8\ \mathrm{am}$ and from $5\ \mathrm{pm}$ to $6\ \mathrm{pm}$

Fleet b: $40\ \%$ of the N PEVs do not stay parked from $8\ \mathrm{am}$ to $9\ \mathrm{am}$ and from $6\ \mathrm{pm}$ to $7\ \mathrm{pm}$, and

Fleet c: $30\ \%$ of the N PEVs do not stay parked from $9\ \mathrm{am}$ to $10\ \mathrm{am}$ and from $7\ \mathrm{pm}$ to $8\ \mathrm{pm}$.

PEVs travel every day an average distance of $35\ \mathrm{km}$, $40\ \mathrm{km}$ and $30\ \mathrm{km}$, for the fleets a, b and c, respectively. To travel a distance of $20\ \mathrm{km}$ entails an energy consumption of $2.3\ \mathrm{kWh}$.

Finally, based on information found in the reviewed literature, the cost of one PEV including connection and communication modules is set to € 30,000 [8] and [9].

III. PROBLEM DEFINITION

In this work the behavior of an APS is analyzed, which is basically composed of a conventional equivalent power plant - more specifically a combined heat and power plant (CHP)-, and renewable energy sources-based generators -more specifically a wind farm and a PV equivalent plant. See Fig. 3.

The prime mover of the CHP plant is a Gas Turbine (GT) and the CHP plant is heat driven.

Energy suppliers should meet the thermal and electrical requirements of the industrial consumers as well as the electrical requirements of the residential consumers (a city with 20,000 habitants), see Table I.

TABLE I. ELECTRICAL AND THERMAL POWER DEMANDED BY THE CONSUMERS

TOTAL Demand	Electrical (MW)	Thermal (MW)
City	20	0
Industry zone	15	25

In the analyzed power system the electricity generated by renewable sources plays a key role. In fact, in order to decrease the dependence on fossil sources and to be as environmental friendly as possible, it was assumed that $20\ \%$ of annual electricity consumption has to be generated by wind and photovoltaic plants. For accomplishing this aim, an intelligent Energy Management System (EMS) coordinates in an efficient way, the power flow coming from different generators. Under the aforementioned assumption, the EMS gives the priority for dispatching energy to the generators based on renewable energy sources. In case of power surplus, the EMS is able to control the power flow in order to charge the batteries of the parked vehicles. If by means of such an operating procedure it would be not possible to dispatch the entire surplus, then the EMS reduces first the electrical power of the CHP and if necessary, it reduces the power coming from renewable sources. Since the CHP plant is heat driven, an external boiler is necessary in order to manage the power surplus and cover the heat demand.

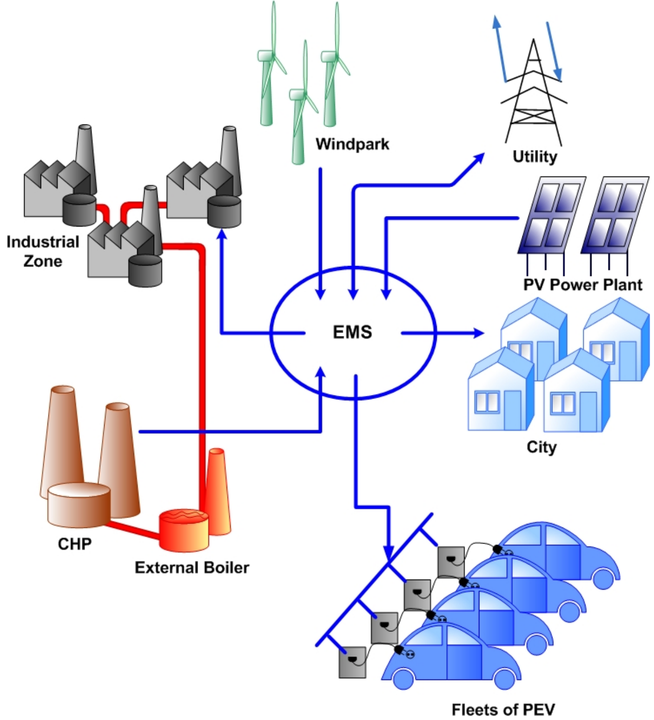

Fig. 3: Scheme of the analyzed energy suppliers. Electrical vehicles are charged with the electrical surplus produced by generators based on renewable sources.

On the other hand, in case of electricity deficit, the energy stored by the parked fleet of PEV can be injected to the grid. If the stored electricity can not cover the entire deficit, the EMS will increase the capacity of CHP. If such a operating procedure is not enough the EMS sheds the load according to a previous power purchase agreement with industrial consumers. Through such a procedure, the demand is suitably managed during the deficit conditions and consequently, the value of the $VOLL$, which has been previously agreed, is notably reduced.

In order to evaluate the impact of PEV as storage devices, two main scenarios are studied. In the first scenario the behavior of the network without PEVs is analyzed, while in the second one, PEVs are incorporated as ESS.

Besides modeling the EMS in a proper way, the aim of this study is to determine the capacities of the power plants and the penetration level of electric vehicles, which minimizes the total costs incurred by the PES during one year.

Related to the objective function *OF*, the authors consider not only the electricity generation and storage costs, but also the costs due to the block of the industrial process (estimable through the *VOLL* parameter), the costs of not exploiting "green energy" resources (evaluated as external costs), and a negative component of driving costs which estimate the fuel costs that have been avoided if vehicles with a combustion engine were used instead of PEV. The optimization problem is formulated according to (3) and (4) as follows:

$$OF = min\sum_{t=1}^{8760}(\sum_{j} G_{j,t} + S_t + E_t - D_t + C_{VOLL,t}) \tag{3}$$

Subject to: active power balance constraint (4), thermal power balance constraint (5), conventional plant capacity limits (6), renewable plants capacity limits (7) and (8), and number of PEV limits (9).

$$\sum_{i} P_i - \sum_{j} P_j = 0 \tag{4}$$

$$\sum_{i,j}(Q_i - Q_j) = 0 \tag{5}$$

$$5 \text{ MW} \leq P_{\text{CHP}} \leq 30 \text{ MW} \tag{6}$$

$$2.4 \text{ MW} \leq P_{\text{wind}} \leq 22 \text{ MW} \tag{7}$$

$$0.3 \cdot \text{P}_{\text{wind}\,min} \leq P_{\text{PV}} \leq 0.3 \cdot \text{P}_{\text{wind}\,max} \tag{8}$$

$$1{,}000 \leq \text{N} \leq 3{,}000 \tag{9}$$

where,

G_{cj} : Electrical and thermal generation costs of the generator *j*
S_c : Storage costs (costs of the electrical vehicle)
E_c : Costs for not generating from renewable resources
VOLL : Value of Loss Load
P_i : Generated active power
P_j : Active power demand
D_j : Driving costs

The generation costs are estimated as Levelized Unit Energy Costs (LUEC). The costs for not generating from renewable energy sources are assessed as external costs. Such external costs, for a GT power plant have been estimated between 10 and 40 €/MWh [12]. In this study external costs are set to 21 €/MWh. The value of the *VOLL*, in this work is set to 8,000 €/MWh. In Table II additional costs to be considered are summarized.

In order to simulate the behavior of the network, limited input data obtained from two German network operators were used. From those measured data, synthetic profiles that describe both the generation of the wind park and of the PV, and the electrical load of the city, are obtained. Specifically, the wind profile was obtained evaluating the transition probability matrix –so called Markov matrix-, then two random numbers were generated for each time step. The first is for generating the transitions from one state to the other following the probabilities of the Markov matrix. The latter is to put an equally distributed noise with the width of ± 5 % of rated power to ensure that the 10 % interval is filled out with values.

For the profiles of the PV plant and the city, the measurement data were normalized to the measured peak load. Then the hourly average value was computed along with the standard deviation of generated (for the PV plant) and consumed (for the city) power for three periods of the year. Furthermore, workdays, weekends and holidays were distinguished. By means of this procedure six daily profiles for one year were obtained.

Due to the lack of information on industrial processes, the electrical and thermal profiles of the industrial zone were obtained from data found in literature [15].

TABLE II. LIST OF VARIOUS COSTS

Parameter	Value	Unit
Investment cost of the CHP[1]	1,117	(€/kW$_{el}$)
O&M fix cost of the CHP[1]	14,896	(€/year)
O&M variable cost of the CHP[1]	0.006	(€/kWh$_{el}$)
Life time of the CHP	25	(years)
Investment cost of the boiler[1]	141.51	(€/kW$_{th}$)
O&M fix cost of the boiler[1]	29,304	(€/year)
O&M variable cost of the boiler[1]	0.0075	(€/kWh$_{th}$)
Life time of the boiler	30	(years)
Fuel price (natural gas) [2]	17	(€/MWh)
Investment cost of the wind park[2]	1,000	(€/kW)
O&M cost of the wind farm[2]	38	(€/kW)
Life time	20	(years)
Investment cost of the PV[2]	2,500	(€/kW)[2]
O&M cost of the PV[2]	29.4	(€/kW)
Life time	20	(years)
Discount rate	6	(%)
Storage costs (costs of one electrical vehicle)	30,000	(€)
Driving costs	0.07	(€/km)
External costs	21	(€/MWh)
VOLL	8,000	(€/MWh)
[1][13] , [2][14]		

IV. METHODOLOGICAL GUIDELINES

A planning approach which considers a rigorous modeling of the behavior of the renewable resources would entail formulating a stochastic optimization problem. However, since the major aim of this work lies in evaluating the impact of incorporating PEV within an APS, the hourly availability of the renewable resources is modeled by means of expected values. Under this perspective, the volatility of the renewable resources is reasonably incorporated while at the same time, a deterministic formulation provides a valid approach for facing this problem.

A fundamental task considered in this work in order to suitably evaluate the performance of the APS is the dynamic modeling of the decisions which should be carried out hourly for the EMS. Indeed, such decisions depend, among others, on: the hourly-available capacity of renewable resources, the hourly state of the PEV (parked or not), the hourly power generated by the CHP, the current energy stored by the fleets of PEV, and the PEV's requirements for the up-coming hour (if PEVs will need to be driven, they can not be discharged). Provided these underlying assumptions, the hourly management of the surplus and deficit of energy can be suitably carried out.

Another key issue to be considered during the solution process entails efficiently handling the information. In this sense, the wide range of values that the diverse parameters involved in the problem could hourly acquire, is proposed to be managed by means of multi-dimensional matrixes. As a result, the complexity of determining the parameters' status and value every hour is reasonably reduced. In Fig. 4, for instance, sizable but valuable information relative to the diverse ranges of power and energy that a fleet of 1,000 PEV can inject to the grid, depending on the stored energy, is suitably managed by means of a 3-dimensional matrix.

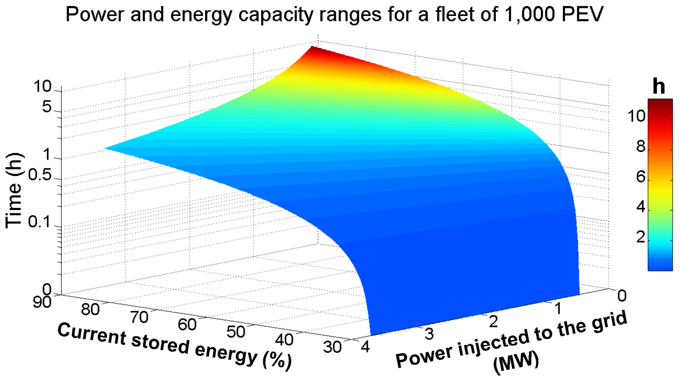

Fig. 4. Power and energy capacity ranges that a fleet of 1,000 and 10,000 PEV can provide depending on the stored capacity

In order to choose a suitable tool for solving the above formulated optimization problem, it is meaningful to consider that the OF is composed by a variable number of terms. In fact, the presence or not of some OF's components depends on the decisions that the SO makes every hour during one year, based on the EMS' procedure. This issue implies that applying a calculus-based optimization tool is not a suitable way to solve the problem, since OF hardly will be an analytical function and consequently, some major simplifications should be made. Nevertheless, provided that the heuristic-based methods do not consider the nature of the OF in this work, it is proposed to face the optimization task by using an evolutionary algorithm (EA) [16]. Under this perspective, it is mandatory that during the OF's evaluation stage, the developed algorithm is able to model the procedure executed by the EMS.

Every candidate solution is codified as a vector of integer numbers representing the decision variables (power capacity of the CHP and wind farm plants as well as number of PEV). Reproduction, mutation and movement based on memory are the three proposed search operations affecting the individuals. A selection mechanism based on replication and elimination of weak individuals is performed in order to control the size of the population in every offspring. The algorithm stops the search procedure once it is not possible to find improved solutions.

The solution process can be illustrated in 5 steps as follows:

1. Random generation of a set of candidate solutions (first offspring).
2. Thermal and electrical power hourly dispatch –based on the EMS procedure– along one year for every candidate solution. In the second scenario, the storage system management is included in the dispatch.
3. Costs assessment, OF's evaluation and ranking of candidates.
4. Performance of search operations and generation of new candidate solutions (new offspring).
5. Repeat steps 2, 3 and 4 until the stop criteria is achieved. The candidates evaluated and ranked during the last iteration belong to the set of solutions.

V. ANALYSIS OF THE RESULTS

A. Scenario 1. APS without fleets of PEV

Table III summarizes the main results obtained by analyzing the first scenario. In order to produce 20 % of the demanded electricity with renewable energy sources, the minimum capacity of wind power and PV are 19 MW and 8 MW, respectively. With a 25 MW capacity of the CHP plant, and by increasing the capacity of the renewable-based power plants, the OF's value decreases even if the amount of energy surplus increases with a higher rate compared to the decreasing rate of the deficit. The value of the $VOLL$ justifies this issue.

Since the CHP plant is heat driven, and renewable energy sources are volatile, the electricity generation does not follow the electricity demand, see Fig. 5. At this point it is important to mention that under surplus of renewable resources circumstances, the EMS can reduce the generation power of the CHP plant until 20 % of the nominal capacity. An external boiler is activated in order to cover the involved thermal deficit. If by means of such a procedure the electrical power is not totally balanced, the EMS decreases the power coming from generators based on renewable energy sources.

On the other hand, in case of deficit the EMS reduces the power flowing to the industrial zone. The deficit costs are evaluated by considering the $VOLL$ parameter.

Since the electrical efficiency of the CHP scales down to the generated electrical power, the costs due to the reduction of the power are driven by the higher amount of the fuel fired in the CHP and in the external boiler.

Finally, the costs for not exploiting renewable energy are estimated by the external costs occurring when energy is produced by firing burning natural gas.

Fig. 5 illustrates how the algorithm is able to model the smart procedure performed every hour for the EMS during one year. The major difficulties found during the development of this work have their origin in this stage of the evaluation process. For instance, since it is known that CHP electrical efficiency decreases considerably at partial load conditions, the EMS computes, step by step, the electrical efficiency of the CHP in order to evaluate the costs incurred when electrical power is reduced.

TABLE IIII. FIRST SCENARIO RELEVANT RESULTS

	Presence of renewable (%)	
	min	optimal
	20	22
P_{chp} (MW)	25	25
P_{wind} (MW)	19	22
P_{PV} (MW)	8	9
$Surplus_{renew}$ (MWh/year)	7,939	13,259
$Deficit_{renew}$ (MWh/year)	1,610	1,328
E_{Total} (GWh/year)	190.05	191.07
$C_{surplus}$ (M€/year)	0.17	0.28
$C_{deficit}$ (M€/year)	12.88	10.63
***OF* (M€/year)**	**26.19**	**24.70**

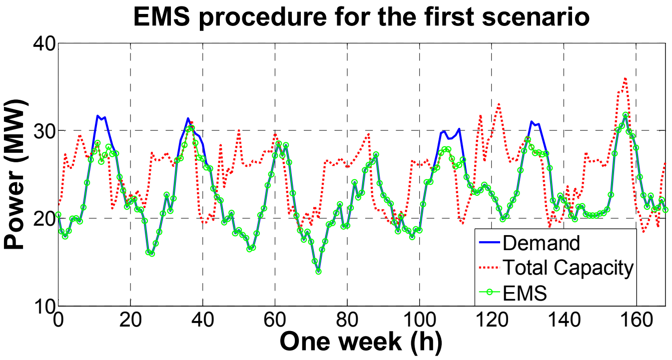

Fig. 5. Smart power balance executed by the EMS

B. *Scenario 2. APS with three fleets of PEV*

In this case, a new resource for managing the hourly power balance is incorporated in the EMS procedure. In fact, the EMS, in case of electrical surplus, stores the energy in the battery of the parked PEVs. The reduction of the CHP capacity happens only if the batteries of the PEVs are not able to be charged more. Even in this case an external boiler is active in order to manage the thermal power. A penalization cost of 100 €/MWh is incorporated in the *OF* in case of the PEV are not able to travel due to an insufficient stored energy.

In case of deficit, if the PEVs are parked and do not need to move during the next hour, the energy flows from the batteries to the grid. In order to preserve the lifetime of the batteries the EMS charges them up to 90 % of the nominal capacity and discharges them up to 30 %.

The results of the second scenario are shown in Table IV. The use of electrical vehicles also as energy storage systems has reduced the deficit by around 17 % in comparison with the first scenario. The optimal number of PEV which minimizes the *OF* is 1,200. According to Fig. 6, the PEV benefits are sensitive to their investment costs, if the investment costs of each PEV decrease the total costs of the *OF* decrease as well. Since the analyzed power system is characterized to be autonomous, the *VOLL* parameter largely determines the APS performance. For further analysis, it deserves mention that additional benefits coming from ancillary services, such as spinning reserve and frequency regulation, should be incorporated in the evaluation of the performance of the APS. Moreover, an environmental benefit from the reduction free gases could be also incorporated.

TABLE IV. SECOND SCENARIO RELEVANT RESULTS

	Presence of renewable (%)	
	19	22
P_{chp} (MW)	25	25
P_{wind} (MW)	19	22
P_{PV} (MW)	8	9
N	1,200	1,200
$Deficit_{renew}$ (MWh/year)	1,420	1,111
E_{Total} (MWh/year)	190.11	191.35
$C_{deficit}$ (M€/year)	11.36	8.88
***OF* (M€/year)**	**26.03**	**24.11**

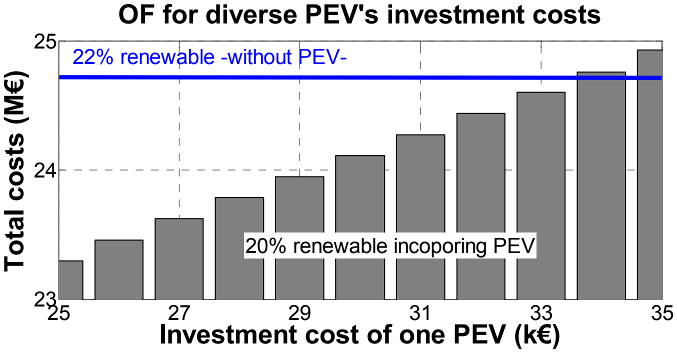

Fig. 6. Sensitivity analysis for diverse PEV investment costs

VI. CONCLUSIONS

A qualitative analysis of the impact of plug in PEV to the electric grids has been carried out in this paper by evaluating the performance of a test APS during one year. Efficient combinations of both renewable-based supply and PEV fleet-based storage capacities have been found by solving a multi-criteria optimization problem. In addition, suitable penetration levels have been obtained for renewable-based power plants as well as a fleet of PEV, which minimize the total costs incurred during one year under the perspective of an APS.

An algorithm able to efficiently model the procedure hourly executed by the EMS, has been developed and tested in a case study.

The obtained numerical results show that fleets of PEV's could be a plausible resource for increasing the autonomy of a power system, since the interconnection with other PES capacity can be reduced. This fact could soon be reinforced, since a noticeable increase in the PEV's storage capacity as well as a reduction in the prices for accessing to the V2G technology is expected.

The proposed algorithm could be upgraded in order to perform a further analysis for assessing the benefits of efficiently exploiting the stored energy in fleets of PEV for delivering ancillary services.

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VIII. BIOGRAPHIES

Pio Lombardi studied mechanical engineering at the Politecnico di Bari, Italy. He graduated in 2006 at the same university with the degree M.Sc. He joined the Chair of Electric Power Networks and Renewable Energy Sources at the Otto-von-Guericke University Magdeburg, Germany as a research engineer in 2006. His primary field of interest is the optimization of virtual power plants.

Paul Vasquez (M'04) obtained the Electrical Engineer degree from the "Escuela Politécnica Nacional," Ecuador in 2002. From 2001-2003 he worked as a private consultant in distribution systems. From 2003-2004 he was with Bellsouth Company at the Engineering Department. Currently he is working toward a Ph. D. degree at the Institute of Electrical Energy (IEE), National University of San Juan. His research interests are planning, optimization, and risk management techniques.

Zbigniew Antoni Styczynski (SM '01) received his PhD in EE at the Technical University of Wroclaw. He worked at the Technical University of Stuttgart, Germany and 1999 he became Chair of Electric Power Networks and Renewable Energy Sources of the Faculty of Electrical Engineering and Information Technology at the Otto-von-Guericke University, Magdeburg, Germany. Since 2006 he is also the president of the Centre of the Renewable Energy Saxonia- Anhalt, Germany. His special field of interest includes modeling and simulation of the electric power networks systems, renewables, and optimization problems. He is the author of more than 150 scientific papers, a senior member of IEEE PES, a member of CIGRE SC C6, VDE ETG und IBN and a fellow of the Conrad Adenauer Foundation.