Management of a Local Multi-Source Energy System in a Research Centre based on self-PV Generation and Electric Vehicles

Sandra Castano-Solis
ETSI Diseño Industrial
Universidad Politécnica de Madrid
Madrid, Spain
sp.castano@upm.es

Daniel Fernandez-Muñoz, Jesus Fraile Ardanuy, Alvaro Gutierrez
ETS Ingenieros de Telecomunicación
Universidad Politécnica de Madrid
Madrid, Spain
daniel.fernandezm@upm.es, jesus.fraile.ardanuy@upm.es, a.gutierrez@upm.es

Giussepe Conti, David Jimenez-Bermejo
GATV Research Group
Universidad Politécnica de Madrid
Madrid, Spain
gic@gatv.ssr.upm.es, djb@gatv.ssr.upm.es

Juan I. Perez Diaz
ETSI de Caminos, Canales y Puertos
Universidad Politécnica de Madrid
Madrid, Spain
ji.perez@upm.es

***Abstract*—This work proposes an energy management strategy of a local multi-source energy system that integrates photovoltaics (PV) generation and electric vehicles (as a dynamic battery system) in addition to the electrical grid to power a research building. The proposed strategy uses linear programming to coordinate the power of each energy source to reduce the building daily electricity costs. The optimization algorithm include data recorded of self-PV generation, the available storage capacity (that depends on the parked cars), the electrical energy demanded by the building and the retail energy prices. The simulation results indicate that the proposed model allows reducing the daily electricity costs in all cases analyzed.**

Keywords*—*local energy systems, dynamic battery system, electric vehicles, photovoltaic generation, energy management.

I. Introduction

Since the presentation of the 2030 Agenda for Sustainable Development in 2015, European countries are developing different strategies to change actual fossil-based energy systems into low-carbon ones. To accomplish this transformation EU climate and energy framework defined as goals by 2030: the reduction in greenhouse gas emissions at least 55% from 1990 levels [1], 32% share for renewable electricity and 32.5% improvement in energy efficiency [2].

The reduction costs of solar panels production [3] has motivated the installation of photovoltaic (PV) generation arrays in buildings (roofs and facades) as an effective way to reduce the energy supplied by the electrical grid, resulting in a reduction of the total electricity cost. However, PV generation is heavily dependent on weather conditions, presenting less power production during cloudy days [4]. To improve the reliability of this systems the best option is the integration of energy storage [5]. Batteries, specially Li-based batteries, are the most promising technologies to become a technical and feasible electricity storage systems in this self-consumption applications [6].

Li-ion batteries installation costs have dropped significantly in recent years [7]. However, this technology is still quite expensive and the installation of these systems increase the maintenance costs of the building. For this reason, in this case study electric vehicles are considered as a dynamic storage system instead of considering a stationary battery storage system installed in the building. Therefore, the available capacity of the aggregated storage system varies according to the parking occupation.

To coordinate the management of the local multi-source energy system that power the building an optimization algorithm based on linear programing is implemented. The model takes into account data recorded of self-PV generation, the available dynamic capacity (according to parking lot occupation), the power demanded by the building and the retail energy prices to minimize the daily electricity cost purchased from the utility grid by the building manager. This work is part of the first stage of the research's activities carried out within the eNeuron project [8]. These activities were focused on defining different study cases.

This paper is organized as follows. Section II presents the system configuration. Section III shows the energy management strategy. In Section IV, simulations results are shown. Finally, Section V presents conclusions.

II. System Configuration

The Solar Energy Institute (Instituto de Energía Solar-IES), is a research centre (belonging to Universidad Politecnica de Madrid) mainly focused on the fundamentals and practical application of photovoltaics (PV) systems. The main building is located at Escuela Técnica Superior de Ingenieros de Telecomunicación Universidad Politécnica de Madrid (ETSIT-UPM), in Madrid (Spain) and shares a common parking area composed by 29 parking lots, as it is shown in Fig. 1. Also, three PV arrays of 13 kWp are installed in the roof (Fig. 1). The PV panels tilt is θtilt=26° and the arrays are oriented directly to the South (θorientation=0°). This PV generation is monitored with an hour resolution, along with the total consumption of the building.

To carry out this analysis the average data of PV generation and building consumption during the months of March, April and May, before Covid-19 pandemic, were used (Figs. 2,3 and 4).

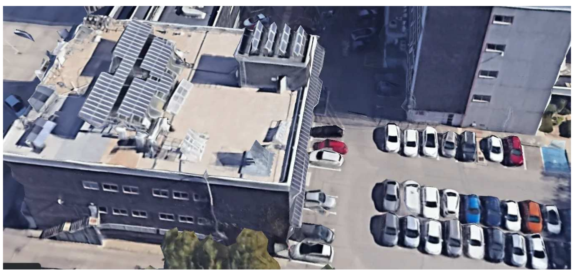

Fig. 1. IES location [9]

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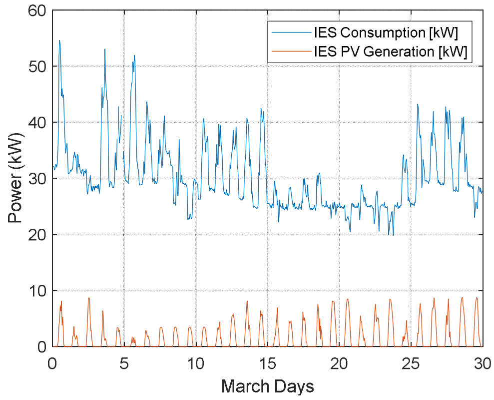

Fig. 2. PV generation and load consumption in March

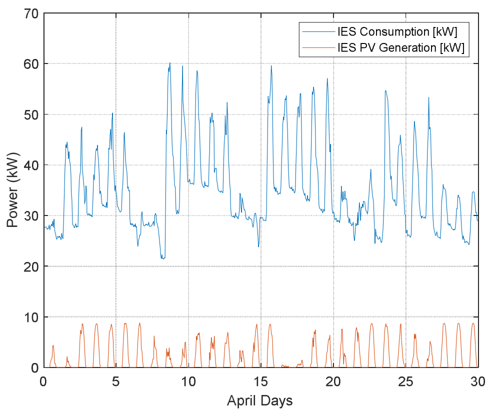

Fig. 3. PV generation and load consumption in April

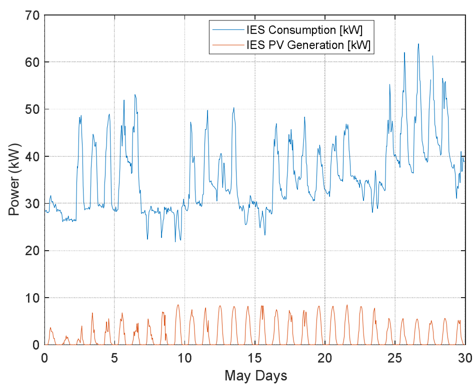

Fig. 4. PV generation and load consumption in May

Parking lot occupation was counted by means of an outdoor camera (installed in the parking) and an artificial-intelligence based algorithm trained to recognize the images of empty and full parking lots. In Fig. 5 is shown the number assigned to each parking spot. As an example, Fig. 6 shows the occupation of the parking in a specific moment. The average parking occupation during working days is presented in Fig. 7.

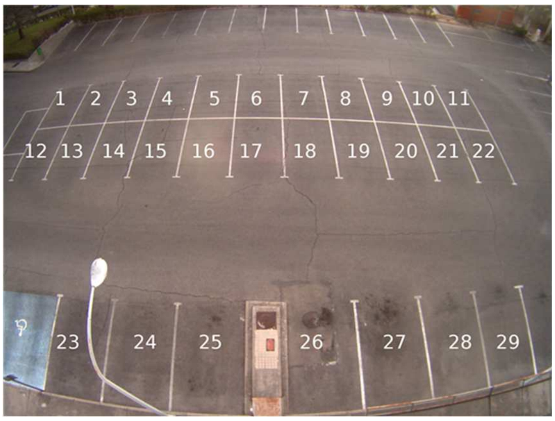

Fig. 5. Parking number assignation

Fig. 6. Example of parking occupation

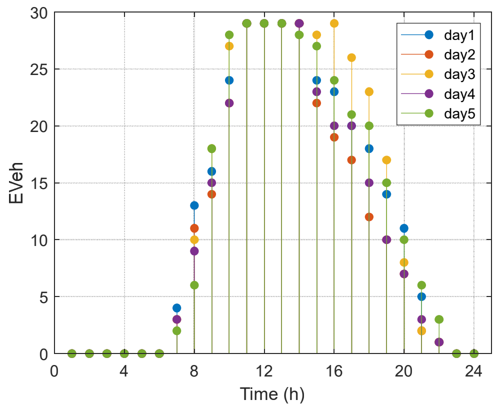

Fig. 7. Parking lot occupation on working days

III. LOCAL MULTI-SOURCE MANAGEMENT MODEL

Fig. 8 shows a schema of the local multi-source energy system. The electric grid and the PV generation power the IES building, while electric vehicles are considered as a dynamic storage system whose capacity depends on the parking occupation. This dynamic battery system can inject power to the building or consume power from the local electricity grid or PV generation. The parameters of the model are explained below.

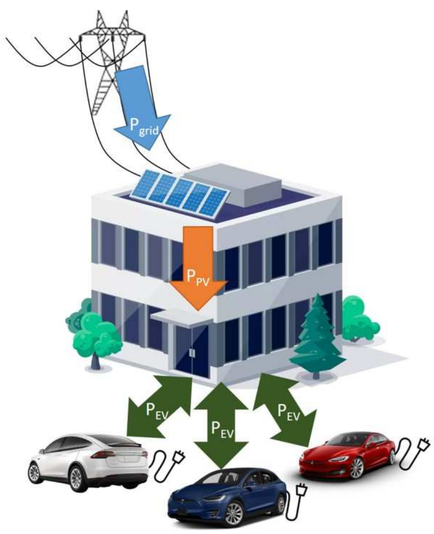

Fig. 8. Local multi-source energy system

A. *Load consumption and PV generation*

The analysis of PV generation and building load data shows that the average consumption is approx. 30 kW and the maximum value is over 70 kW, whereas the maximum value of PV generation is lower than 9 kW, this indicates that the PV generation does not supply the total electricity consumption of the research building. In order to evaluate the best and worst condition, in this model are chosen 6 days which correspond to the day with high load consumption and maximum PV generation and the day with high load consumption and minimum PV generation, in each of the considered months. Figs. 9 and 10, show the building load and the PV generation for these days.

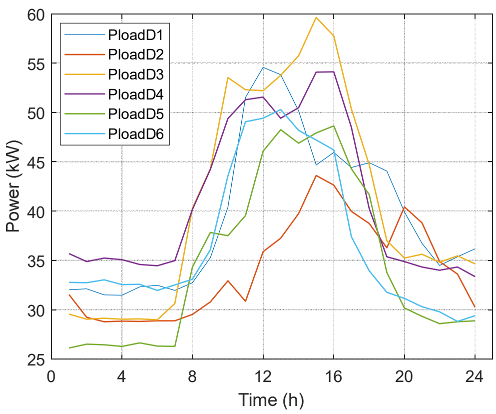

Fig. 9. IES load consumption of each day

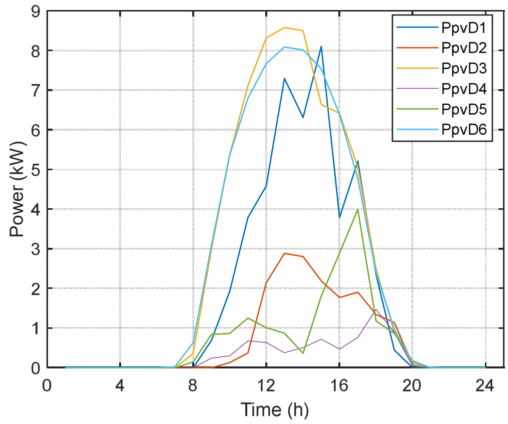

Fig. 10. IES PV generation of each day

B. *Dynamic battery system-EVs*

The available capacity of the dynamic battery system is estimated from the aggregated capacity of the electric vehicles parked at each hour of the day. In this model is assumed that all parked vehicles are five-passenger electric cars. Each car has assigned a total electric capacity of 60 kWh, that corresponds to the average capacity of the electric cars more sold in Spain in 2022 [10].

In order to ascertain IES employees' mobility habits an online survey was conducted involving over 30 survey returns. This survey reveals that most of the workers travel less than 30 km per day, resulting in an average distance of 27 km, and few workers travel more than 50 km. To determine an average electric consumption, data from drivers reported in [11] were used. For five-passenger electric cars were found a minimum value of 3.3 kWh/100 km, a maximum value of 22.9 kWh/100 km, and an average value of 16 kWh/100 km. For this model is assumed 10 kWh as the capacity used by the IES workers during a working day (to consider all the electric cars and different driver styles). This capacity corresponds to 16% of the total capacity of the electric car. The maximum available capacity of each vehicle in a working day is assumed as 18 kWh (30% of total capacity).

To exchange power with the local grid it is assumed that all vehicles use the conventional Type 2 socket with a typical onboard charger, whose maximum power is 3.7 kW. Therefore, each vehicle can exchange 3.7 kW each hour. As the parked cars vary during the day, the electricity that they can exchange with the building will also be variable, because it depends on the occupation of the parking lot. The maximum energy that can be exchange each hour is assumed as the maximum available capacity of the dynamic battery system. For example, when the parking lot is fully occupied, this maximum capacity is 29x3.7kWh= 107 kWh.

C. *Grid electricity prices*

Because the maximum power consumption of the research centre is higher than 15 kW, the hourly electricity prices are defined by the tariff 3.0TD. This tariff has six prices P_1=0.22 €/kWh, P_2=0.19 €/kWh, P_3=0.15 €/kWh, P_4=0.12 €/kWh, P_5=0.11 €/kWh y P_6=0.10€/kWh. Table I shows the distribution of these prices during the days of March, April and May.

TABLE I. 3.0TD HOURLY PRICES

Hour	March	April	May
0-8	P_6	P_6	P_6
8-9	P_3	P_5	P_5
9-14	P_2	P_4	P_4
14-18	P_3	P_5	P_5
18-22	P_2	P_4	P_4
22-0	P_3	P_5	P_5

To manage the local multi-source electricity system proposed, an optimization algorithm based on linear programing was used. The objective function is minimizing the total daily electricity cost as shown in (1).

$$Min\ [cost = \sum_{t=1}^{24} Pgrid(t) \cdot price(t)] \qquad (1)$$

Where P_{grid} is the power supplied by the electrical grid at time t in kW, *price* is the energy price applied by the utility at time t in €/kWh and the sampling time is defined as 1 hour. The planning horizon of the optimisation algorithm is 24 hours.

The power supplied by the electrical grid (P_{grid}) is given by (2):

$$P_{grid}(t) = P_{load}(t) - P_{pv}(t) - P_{bev}(t)\ \ \forall t \qquad (2)$$

Where P_{load} is the power demanded by the research centre, P_{pv} is the power generated by the photovoltaic arrays, and P_{bev} is the power injected or consumed by the aggregated battery system (composed by the electric cars) at time t. In this model is assumed that when the aggregated battery injects power into the building (discharge) $P_{bev}>0$, and when the aggregated battery is charging $P_{bev}<0$. This model must be subjected to the following constrains

$$C_{disp}(t) = P_{max} \cdot EV_{park}(t)\ \ \forall t \qquad (3)$$

$$|P_{bev}| \leq C_{disp}(t)\ \ \ \forall t \qquad (4)$$

Where (3) indicates that C_{disp} is the maximum hourly available capacity, defined as the product of the number of available EVs parked each hour, given by the variable EV_{park}, and the maximum charging power, which is limited to 3.7 kW by the EV's charger. Both limits are not constants and they depend on the parking lot occupation dynamics. Due to the recorded data of parking occupation of working days are similar, in this model the variable EV_{park} is created from occupation data of day 2 (see fig. 7). Moreover, in (4) it is indicated that the power that can be injected or extracted from the dynamic battery system, must be lower than C_{disp}.

IV. SIMULATIONS RESULTS

Figs. 11-16 show the power distribution of each energy source for the days analysed. The variable *CapEV* represents the capacity contributed by the dynamic storage system during each hour, and it is expressed as the percentage of the maximum available capacity. These simulations show that the aggregated storage system and the PV generation are able to supply the total power demanded by the IES building in some hours when the parking occupation is high. Even when the PV generation is low (figs. 12, 14 and 15), the battery system can effectively contribute to reducing the power consumed from the electrical grid.

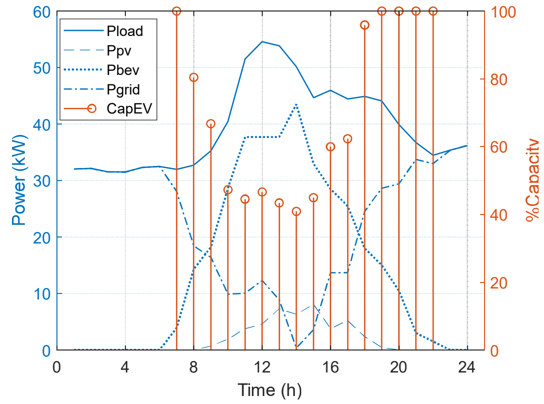

Fig. 11. Simulation results Day 1 March

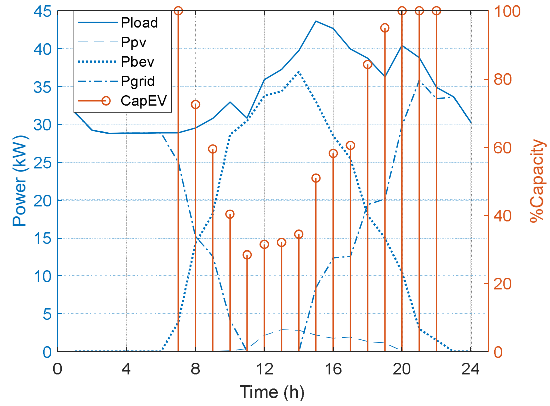

Fig. 12. Simulation results Day 2 March

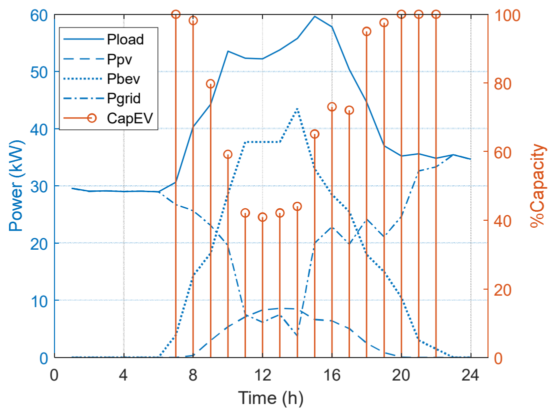

Fig. 13. Simulation results Day 1 April

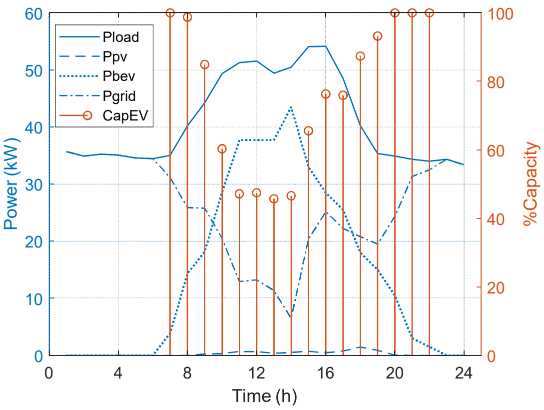

Fig. 14. Simulation results Day 2 April

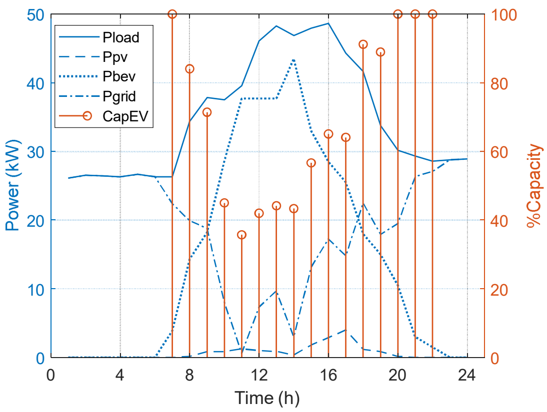

Fig. 15. Simulation results Day 1 May

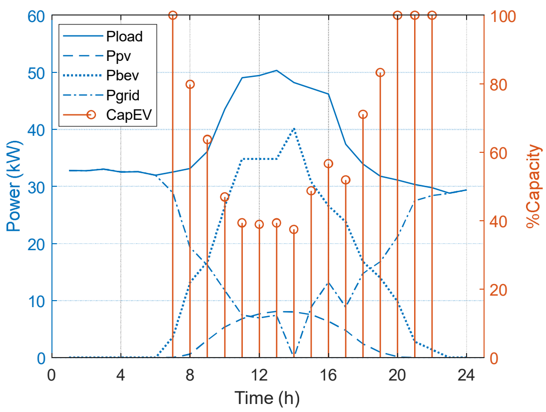

Fig. 16. Simulation results Day 2 May

Table II presents the daily electricity cost of each day simulated. Three cases are considered: Grid corresponds to the cost of electricity if all the energy demanded by the building is supplied by the electrical grid, PV presents the cost if the PV generation is included and in PV+EV the PV generation and the aggregated battery system formed by the electric cars are considered.

TABLE II. DAILY ELECTRICITY COST

Day	Grid (€)	PV (€)	PV+EV (€)
D1 March	134.48	127.92	85.45
D2 March	114.34	111.85	71.38
D1 April	109.20	101.89	65.76
D2 April	108.76	107.96	72.33
D1 May	92.77	90.96	58.48
D2 May	97.79	90.61	57.80

As it can be seen, the daily prices of March days are higher than April and May days because the energy prices P_3 and P_2 are higher than P_4 and P_5 prices. The average cost reduction due to the integration of PV generation is 3.96% (max: 7.34% and min: 0.74%). In the case of the multi-source system (PV +EV) the average cost reduction is 37.53% (max:40.90% and min:33.50%).

V. CONCLUSIONS

This paper proposes an energy management strategy of a local multi-source system to power a research building. This system integrates the PV generation and electric vehicles as a dynamic storage system (instead of a battery installation) with the aim of reducing daily electricity cost. The optimization model based on linear programming include data recorded of self-PV generation, the available storage capacity (that depends on the parked cars), the power demanded by the building and the retail energy prices.

Simulation results show that the proposed multi-source energy system presents a reduction on the daily energy consumption costs for all days analysed. Also, this reduction is not dependent of weather conditions as in the case of PV generation. These results will be used to define an innovative study case based on a university campus as part of the development of the eNeuron project.

ACKNOWLEDGMENT

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