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Ardavan Dargahi, Stéphane Ploix, Alireza Soroudi, Frédéric Wurtz

Institutions: Grenoble Institute of Technology, University of Tehran, University of Grenoble

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Ardavan Dargahi, Stéphane Ploix, Alireza Soroudi, Frédéric Wurtz

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Ardavan Dargahi
Grenoble Electrical Engineering laboratory (G2Elab), Grenoble Institute of Technology, Grenoble, France

Stephane Ploix
Laboratory of Grenoble for Sciences of Conception, Optimisation and Production(G-SCOP), Grenoble Institute of Technology, Grenoble, France

Alireza Soroudi
Faculty of New Sciences and Technologies, University of Tehran, Tehran, Iran

Frederic Wurtz
Grenoble Electrical Engineering laboratory (G2Elab), Grenoble Institute of Technology, Grenoble, France

Abstract.

Purpose –The use of energy storage devices helps the consumers to utilize the benefits and flexibilities brought by smart networks. One of the major energy storage solutions is using electric vehicle batteries. This paper develops an optimal energy management strategy for a consumer connected to the power grid equipped with V2H power supply and renewable power generation unit (PV).

Design/methodology/approach –The problem of energy flow management is formulated and solved as an optimization problem using a linear programming model. The total energy cost of the consumer is optimized. The optimal values of decision variables are found using CPLEX solver.

Finding – The simulation results demonstrated that if the optimal decisions are made regarding the V2H operation and managing the produced power by solar panels then the total energy payments are significantly reduced.

Originality/value – The gap that the proposed model is trying to fill is the holistic determination of an optimal energy procurement portfolio by using various embedded resources in an optimal way. The contributions of this paper are in threefold as:

- The introduction of mobile storage devices with a periodical availability depending on driving schedules.
- Offering a new business model for managing the generation of PV modules by considering the possibility of grid injection or self consumption.
- Considering Real Time Pricing (RTP) in the suggested formulation.

Keywords linear optimization, battery storage, vehicle-to-home (V2H), building power management, power system economics, solar power.

Paper type Research paper

1. Introduction

Car fleet electrification has been supported by a number of prior researches, e.g., (Lindly and Haskew, 2002) (Ford,1995) as a suitable alternative to push down the airborne pollutants in dense urban environments. Nevertheless, as concluded in (Karplus et al, 2010) the expected decreases in tailpipe emission would be outweighed by the additional CO_2 emission due to the increased electric power output necessary to support electric vehicles (EV). Hence, a widespread deployment of electric vehicles could also add a huge load to power generation and distribution infrastructures and also introduce line overloading and voltage stability problem.

Since the early 21st century, new concepts are born to change consumer's perception on EV as a transport only technology which becomes a huge energy consumer while charging its battery.

The Vehicle-to-Grid (V2G) technology moves from EVs common pattern of use and opens the opportunity to regard them as valuable resources. According to the new researches (Turton and Moura, 2008) personal vehicles are in average engaged only 4-7% of their lifetime for transportation purpose in a day and in the remaining time they are in rest on private or public parking lots. At this time each parked EV contains underutilized energy storage capacity which can also feed electricity to the grid when needed. For interested readers the principle of V2G power transmission can be found in (Kempton and Tomicé, 2005) with more details.

V2G could also extend to small private houses or residential and commercial buildings called respectively Vehicle-to-Home (V2H) or vehicle-to-building (V2B) (San Román et al., 2011) (Beer et al., 2012). In such case, instead of restoring the content of EV battery directly to the grid to serve a large number of the sites, one or several electric cars supply a single building. V2H concept would be regarded as the gateway toward a plausible convergence between transport and construction for a more flexible development. In this way, EVs can get charged during off-peak period at home or workplace from renewable energy resources located in buildings. The stored energy in the car battery can also supply the building at the high demand hours. This operation could relieve the electricity network at the peak hours and if properly performed can also create economic value for vehicle owners and building operators.

The integration of EVs storage and distributed energy resources to the building power supply, poses new technical and economical opportunities and challenges as follows:

- Opportunities
    - Avoiding high price values of electricity market in real time dynamic pricing paradigms
    - Reducing the risk of power outage and increasing the reliability of supply
    - Reducing the environmental risk by using clean energy resources instead of polluting conventional power plants
- Challenges
    - Probable increase of operating costs due to inappropriate energy management decisions
    - Uncertainty handling of renewable energy resources

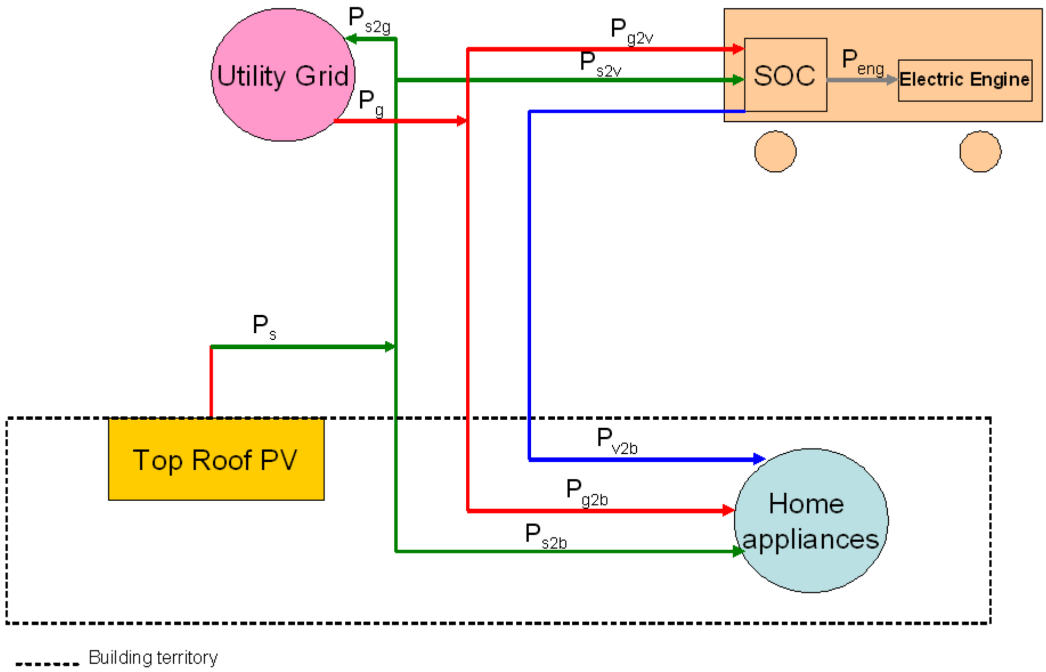

Figure 1. Schematic of V2H integration into building energy supply

    - Reducing the life time of the EV's battery due to multiple charging and discharging
    - Unavailability of energy storage capacity (EV) due to mobility of the vehicle

The gap that the proposed model is trying to fill is the holistic determination of an optimal energy procurement portfolio by using various embedded resources in an optimal way. The contributions of this paper are in threefold as:

- The introduction of mobile storage devices with a periodical availability depending on driving schedules.
- Offering a business model for managing the generation of PV modules by considering the possibility of grid injection or self consumption.
- Considering Real Time Pricing (RTP*)* in the suggested formulation.

The rest of this paper is organized as follows: the energy-system under study is described in section 2. Section 3 models the storage system of EV. The detailed formulation of the optimal management problem is explained in section 4, which is followed by section 5 with a description of examined system usage scenarios. Finally section 6 represents and discusses the results and the main conclusions are made in section 7.

2. Study case description and assumptions

The optimal power management proposed in this paper is illustrated by a theoretical example of small-scaled V2H power supply system consisting of a residential building with decentralized generation facility and a plug-in electric car. Figure 1 schematically illustrates the power architecture of the considered power system as well as the power flows direction trough the whole system. The notations used in this figure are explained as follows:

- P_g : Power flow from grid (kW);
- P_{g2b} : Power flow from grid to building (kW);
- P_{g2v} : Power flow from grid to electric car (kW);
- P_{s2v} : Power flow from PV plant to the electric car (kW);
- P_{s2b} : Power flow from PV plant to the building (kW);
- P_{s2g} : Solar surplus released on the grid (kW);
- P_{v2b} : Power flow from vehicle to building power (kW);
- P_{eng} : Power flow fed to the electric engine (kW);
- $b_{in/out}$: Net input/output power flow of the battery (kW);
- SOC : Stat of charge of the battery (kWh).

Table 1. Specification of the Nissan Leaf battery

Characteristic	Symbol	Value
Technology	-	lithium-ion
Nominal capacity	C_n	24 kWh
Charging rate	C_R	30 %
Discharging rate	D_R	30 %
Efficiency	η_b	95 %
Depth of discharge	DOD	90 %
Life cycle	-	160.000 kM

The building is supposed to be located in Grenoble, France. A rooftop installation consisting of 25 photovoltaic panels is disposed on the southern face of the roof. An electric driven Nissan Leaf is placed in disposal to ensure inhabitants daily commutes over short and medium distances. It is powered by a lithium-ion battery pack whose characteristics are given by Table 1. The operating mode of performed case study is defined based on the following assumptions:

- The excessive photovoltaic power can be injected into the electric grid for selling;
- Solar electricity used on the premises, either for recharging the car or to power the building, is also rewarded per unit. Self-consumption bonus (SCB) is one of the multiple schemes to accelerate the development of decentralized green power generation.
- The household appliance is assumed inelastic, i.e., appliances consume constant power within a considered time interval.
- The car is recharged only at home station and the refueling possibility in any other places is omitted.
- For the sake of simplicity, AC/DC and vice versa DC/AC conversion losses in different parts of the system are neglected.

3. Battery storage model

Unlike the stationary storage technologies commonly applied in housing applications, the EVs battery packs used in V2H and V2B systems are in constant motion when the car is driven from one point to another.

Although V2H technology relies on power supply ability of the electric cars, the primary task of a family car is to address the mobility needs of the users. During the driving period, car can neither refuel its battery nor deliver V2H or V2B power. So the amount of energy that the battery is able to absorb or release for V2H support in a time interval depends on the fraction of the time interval wherein the car is plugged-in.

Figure 2 depicts the position of a given trip performed by EV in the time. Let Ω be the set of journeys assigned to the electric car, ω= {1, …, N_Ω}, where ω is the journey (mission) index and N_Ω is the number of missions. We define the potential duration d (ω, t) which corresponds to the duration of journey ω within time interval [t,(t+t)[of length Δ as follow :

$$d'(\omega,t) = Min\big(Strt(\omega) + t + \tau(\omega), (t+1)\Delta\big) - Max\big(Strt(\omega), t\Delta\big) \quad (1)$$

Where Start (ω) represents the start time of the trip ω, τ the mission total time and d'(ω, t) is the potential duration of the trip in time period t. The duration is effective only if d' (ω, t) is positive. …..

$$d(\omega,t) = Max\left(d'(\omega,t),0\right) \tag{2}$$

Accordingly, the storage and V2B power flows should be limited with respect to the effective duration of the commutes scheduled for electric car as described in (2) and (3):

$$0 \le b_{in}(t) \le \left(1 - \sum_{\omega \in \Omega} d\left(\omega,t\right)\right) b_{in}^{max} \tag{3}$$

$$0 \le P_{v2b}(t) \le \left(1 - \sum_{\omega \in \Omega} d\left(\omega,t\right)\right) b_{out}^{max} \tag{4}$$

b_{in}^{max} and b_{out}^{max} stand for the maximum charge and discharge capacities of the battery in a given time interval respectively and are defined as :

$$b_{in}^{max} = \frac{C_n \, C_R}{\Delta t} \tag{5}$$

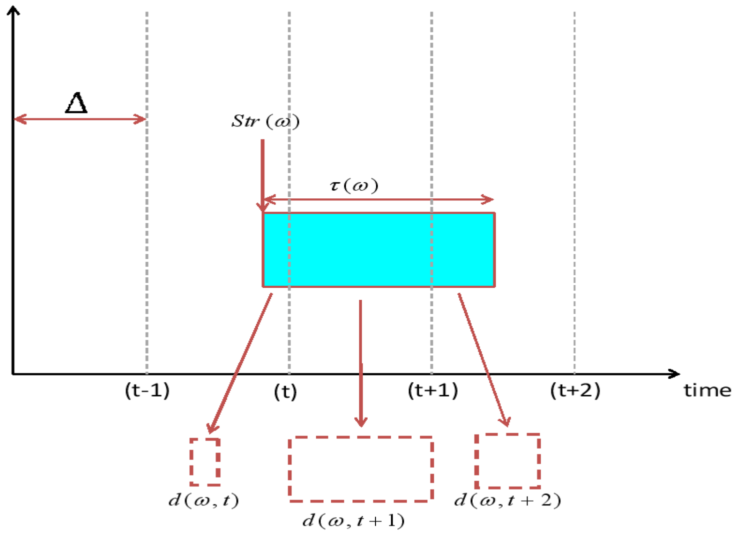

Figure 2. Position of a daily commute versus time periods.

$$b_{out}^{max} = \frac{C_n \, D_R}{\Delta t} \tag{6}$$

The respective value of the battery nominal capacity (C_n), charging (C_R) and discharging (D_R) rates can be found in Table 2.

As illustrated, the battery charging may occur in several ways: either via the photovoltaic power or via the grid. This is also valid for discharging which may be performed in the purpose of building supply or for driving. According to the Figure 1, the corresponding equations for the power flow in or out of the car storage are:

$$b_{in}(t) = P_{s2v}(t)\,\eta_b + P_{g2v}(t)\eta_b \tag{7}$$

$$b_{out}(t) = \frac{P_{v2b}(t)}{\eta_b} + \frac{P_{eng}(t)}{\eta_b} \tag{8}$$

On the other hand, when the car is driven, the energy accumulated in the battery is fed into the engine to propel the car forward and thus the available battery capacity drops. Discharge caused by vehicle use in each time period can be obtained from (6) considering a constant power drain.

$$P_{eng}(t) = \sum_{\omega \in \Omega} \frac{ED(\omega)\, d(\omega,t)}{\tau(\omega)} \qquad (9)$$

ED_ω represents the energy demand of the commute ω and can be calculated as the product of the vehicle fuel efficiency reported around 0.25 kWh/km in (Grosjean and Perrin, 2012) and the driving distance in km ….. D_ω; yielding equation (9).

$$ED(\omega) = \eta_{veh}\, D_\omega \qquad (10)$$

Monitoring the residual content of the battery also called State of Charge (SOC) is important for a good estimation on the available driving distance range with EV and the extent in which the latter can serve the building internal loads via V2H or V2B. A very simple and practical method is used for SOC assessment. The battery content at the end of a time period equals to its content in the previous time plus its transmitted power during the same period:

$$SOC(t) \;\; = SOC(t-1) \;\; + b_{in}(t) - b_{out}(t) \qquad (11)$$

4. Optimal energy flow management

4.1. Generic LP problem formulation

The problem of energy flow management can be formulated and solved as an optimization problem called "*multi-source energy dispatch*" which corresponds in its nature to some standard problems known in electrical engineering, such as "*economic dispatch(ED)*" and "*optimal power flow*" (Wood and Wollenberg, 1996) (Pardalos and Resende, 2002). A similar problem is suggested for a multi-source building in (Warkozek et al., 2012).

A particular formulation of the problem is tailored to our assumed V2H enabled building by using Linear programming (LP). The canonical form of linear optimization problem is given as:

$$\text{maximize} \;\; \text{or minimize} \qquad f(x) \qquad (12a)$$

$$\text{subject to} \qquad Ax \le b \qquad (12b)$$

$$\text{and} \qquad x \ge 0 \qquad (12c)$$

where

$x \in \Re^u$ is the $1 \times u$ vector of continuous optimization variables;

$f(x): \Re^u \mapsto \Re$ is a scalar-valued objective function;

A is the $m \times u$ coefficient matrix;

b is the $m \times 1$ vector of right-hand constants

4.2. Problem statement

The optimization is supposed to carry out the optimal energy procurement and scheduling for a 24 hour operating horizon. The decision variables, technical and economical constraints, as well as objective functions are defined as follows:

A) Decision variables

The decision variables are in fact available degrees of freedom in order to reach the optimal power flow configuration for considered V2H realization in each time period.

These variables can be categorized into three groups as:

- Solar generating units' decision variables (D_s):

  $$D_s(t) \in \{P_{s2b}(t), P_{s2g}(t), P_{s2v}(t)\}$$

- Grid related decision variables (D_g):

  $$D_g(t) \in \{P_g(t), P_{g2b}(t), P_{g2v}(t)\}$$

- EVs' decision variables (D_{ev})

$$D_{ev}(t) \in \left\{ P_{v2b}(t), b_{in}(t), b_{out}(t), SOC\ \ (t) \right\}$$

All these decision variables groups can be gathered into a unified whole:

$$D(t) = D_s(t) \bigcup D_g(t) \bigcup D_{ev}(t)$$

It should be noted that the decision making approach tries to find the optimal values for decision variables in a dynamic framework. It is not static and the decision variables are determined based on the time variant input parameters (price, solar production, load requirement, etc) as shown in Figure 3.

B) Input data parameters

The following data establishes the input parameters of the optimization model:

- $L_e(t)$: Electric load demand of the building (kW);
- $P_s\ (t)$: Power generated by the photovoltaic plant (kWc);
- $P_g^{\max}$:Maximum power import/export from/to grid (kW);
- $C_g(t)$: Grid electricity price (c€/kWh);
- C_s: PV overproduction purchasing price (c€/kWh);
- C_b :Bonus received for solar power consumed (c€/kWh).

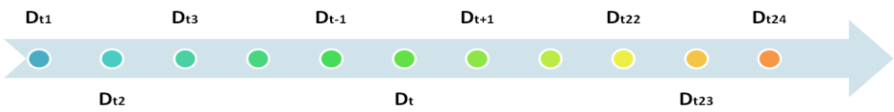

Figure 3. Dynamic decision variables versus time periods.

C) Objective function

The objective function of consumer as mentioned earlier is to minimize the total energy cost (TEC) during the day, which is defined as follows:

$$\min_{D^t} \quad TEC \tag{13}$$

$$TEC = \sum_{t=1}^{24} \Big(P_g(t) C_g(t) - P_{s2g}(t) C_s - \big[P_{s2v}(t) + P_{s2b}(t) \big] C_b \Big)$$

The first term indicates the payment for purchasing energy from electric grid. The second term corresponds to the income from selling the surplus PV power production and the last one describes the cash reward that the consumer receives for self-consumption supplied by renewable energy resource.

subject to:

D) Power balance constraints

Equality constraints (13-18) represent energy node balance for each time period under study which should be considered in the optimization model. According to Figure 1, the following balance equations can be derived:

The electric load can be supplied by three different resources namely: gird, PV and EV, as:

$$P_{g2b}(t) + P_{s2b}(t) + P_{v2b}(t) = L_e(t) \tag{14}$$

The power produced by PV is used to supply EV, household energy, sale to the grid

$$P_{s2v}(t) + P_{s2b}(t) + P_{s2g}(t) = P_s\ (t) \tag{15}$$

The electric power purchased fro, grid can be used to charge EV, household energy

$$P_{g2v}(t) + P_{g2b}(t) = P_g\ (t) \tag{16}$$

The net energy injected to the EV (supplied by solar panel and grid) depends on the value of charging efficiency

$$b_{in}(t) = \left[P_{s2v}(t) + P_{g2v}(t) \right] \eta_b \qquad (17)$$

The net energy released by EV (to supply V2b and electric motor propulsion) depends on the value of discharging efficiency.

$$b_{out}(t) = \frac{P_{v2b}(t)}{\eta_b} + \frac{P_{eng}(t)}{\eta_b} \qquad (18)$$

The state of the charge in each hour depends on the input/output net energy as well as the state of charge in the previous time period:

$$SOC(t) = SOC(t-1) + b_{in}(t) - b_{out}(t) \qquad (19)$$

Power limitation constraints

The power limitations of the system components are generally defined by inequality constraints. For instance the power drawn from or fed into the distribution network should never exceed a maximum subscribed level as shown in (19) and (20).

$$0 \le P_g(t) \le P_g^{max} \qquad (20)$$

$$0 \le P_{s2g}(t) \le P_g^{max} \qquad (21)$$

For the safety reasons and in order to extend the battery life time, constraint (21) insures that the stored energy level is always kept between recommended operating limits as :

$$SOC^{\min} \le SOC(t) \le SOC^{\max} \qquad (22)$$

Additionally, the charging and discharging rate of the battery should not exceed the safe limits as follows:

$$0 \le b_{in}(t) \le \left(1 - \sum_{\omega \in \Omega} d(\omega, t) \right) b_{in}^{max} \qquad (23)$$

$$0 \le P_{v2b}(t) \le \left(1 - \sum_{\omega \in \Omega} d(\omega, t) \right) b_{out}^{max} \qquad (24)$$

SOC^{max} is the highest admissible charge level the battery can reach. It is rated to be 0.9 of the stated nominal battery capacity in this consideration. SOC^{min} represents the minimum amount of power that the storage must always preserve and is defined as a proportion of the battery capacity according to permitted depth of discharge:

$$SOC^{min} = C_b \, (1 - DOD) \qquad (25)$$

4.3. Inputs data provision

This section describes how the optimization data have been collected for the date of February 13th 2012 as an example for the optimization day. Figure 3 shows the hourly grid electricity prices derived from EPEX energy Market [1]. EPEX is a European power exchange market which offers wholesale time varying prices for Day-Ahead and intraday transactions. This choice of dynamic pricing mechanism is particularly interesting because it would encourage the use of renewable power or energy stored in the car battery when electricity is expensive. Resale price for solar overproduction was considered to be 15 c€ and self -consumption is rewarded 12 c€.

A single household electrical demand is utilized to test the optimization model. The electricity load profile in Figure 4 was derived from the actual measurements conducted for one day in an office building.

The PV electricity generation of the building over the optimization day is given in Figure 5. To calculate the amount of solar output a mathematical model proposed in (Clastres et al., 2010) was used.

Finally, the power required for the electric vehicle usage was calculated using equation (8). The daily journeys demand profile can be seen in Figure 6.

5. Scenarios

In order to investigate the potential effects of using EV's storage capacity regarding household economy, the multi-source energy dispatch problem is analysed for a set of three scenarios summarized in Table 2.

- *Baseline* scenario considers the presented building without any interconnection with the electric car. This scenario is likely to serve as a reference for evaluating the financial savings for different system configurations.
- *Electric vehicle just as load(EVL)* scenario incorprates the electric vehicle in the energy system of the building as a pure electrical charge without providing any energy storage service for V2H supply.
- *Electric vehicle as load & storage(EVLS)* scenario takes into account energy storage capability for providing V2H service.

A 7kW power supply contract is settled with the grid supplier which is high enough to overcome evening peak. This limit is also applied to grid injection power from domestic solar facility.

6. Simulation results & discussion

The proposed model is coded in General Algebraic Modelling System (GAMS) environment (Brooke and Rosenthal, 2003) and solved by CPLEX solver (Guan and Jia, 2010) running on a Intel® Core ™ 2 Duo Processor T5300 (1.73 GHz) PC with 2 GB RAM. In order to demonstrate the strength of the proposed model, three scenarios (as defined in Table 3) are considered and analyzed in this section.

Graphical representations of the obtained results for all three scenarios are given in Figures 7, 8 and 9. Figure 7 depicts the energy purchased from electric grid. It can be seen that the energy purchase from grid is pushed toward the lower price hours.

Table 2. Summary of investigated scenarios

Scenarios	EV connexion	V2H power supply	Daily commute profile
Baseline	No	No	No trip
EVL	Available	No	12h15-14h45/ 30km 19h-19h30/5 km
EVLS	Available	Available	12h15-14h45/ 30km 19h-19h30/5 km

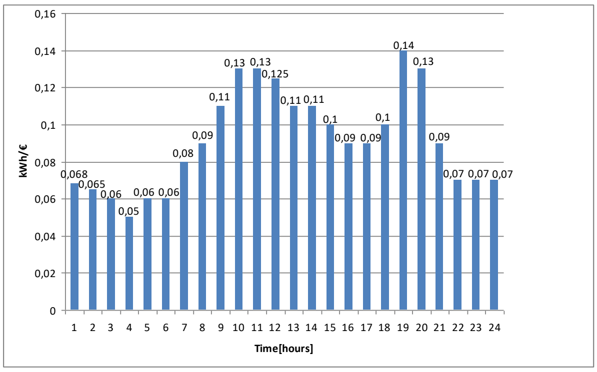

Figure 3. Evolution of electricity price on EPEX market on February 13th 2012

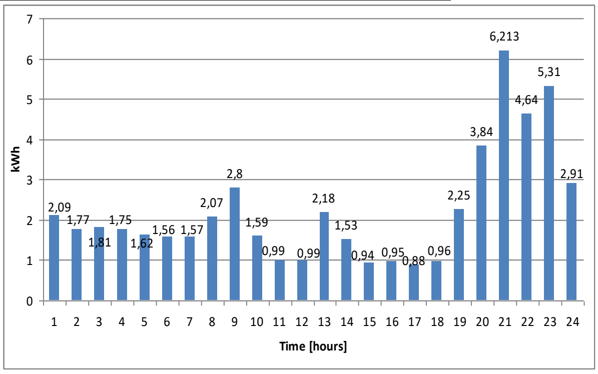

Figure 4. Load profile of the building over 24 hours (midnight to midnight)

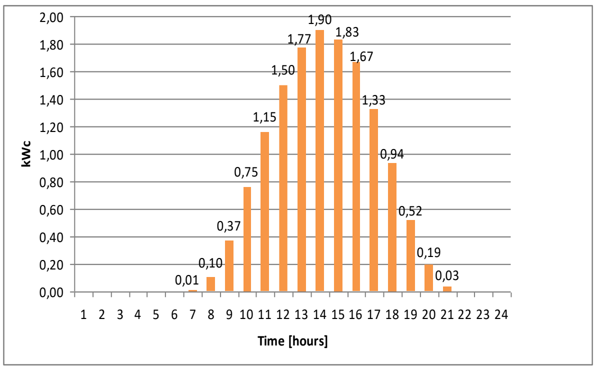

Figure 5. Photovoltaic generation during the day studied

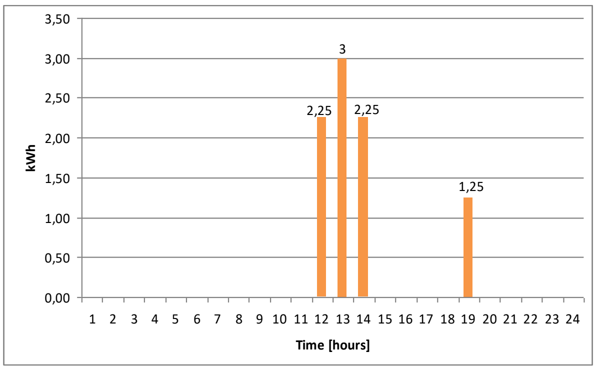

Figure 6. The energy demand profile of the electric car for the scheduled daily trips

In baseline scenario the consumer is forced to buy energy in the peak price periods since it has no EV to be used as energy storage device. On the other hand, due to the lack of solar radiation, it can not use its PV generation so it is obliged to buy energy from electric grid.

In EVL scenario the grid purchase pattern of the consumer is the same as the base line scenario except in hour 4 and 6 which shows an increase. The EV needs to be charged (for mission purposes) and this is shifted in the low price periods to reduce electricity payments.

In EVLS scenario the grid purchase pattern of the consumer is changed in most hours of the day. For example in peak price periods (t18 to t20) the energy procurement from grid is highly reduced. In contrast with two previous scenarios, the consumer is not forced to buy energy from grid in peak price hours since it can procure its energy from the stored energy in its vehicle. The aforementioned stored energy is purchased in low price periods (t3 to t6).

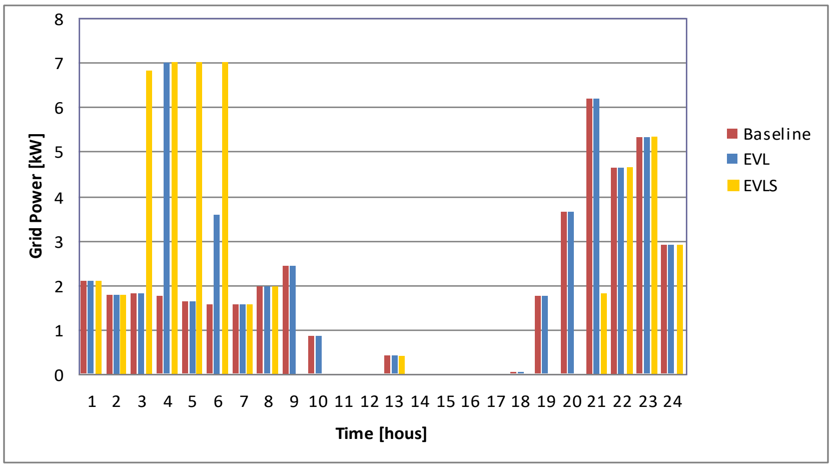

Figure 7. Procured hourly energy from Grid in three investigated scenarios.

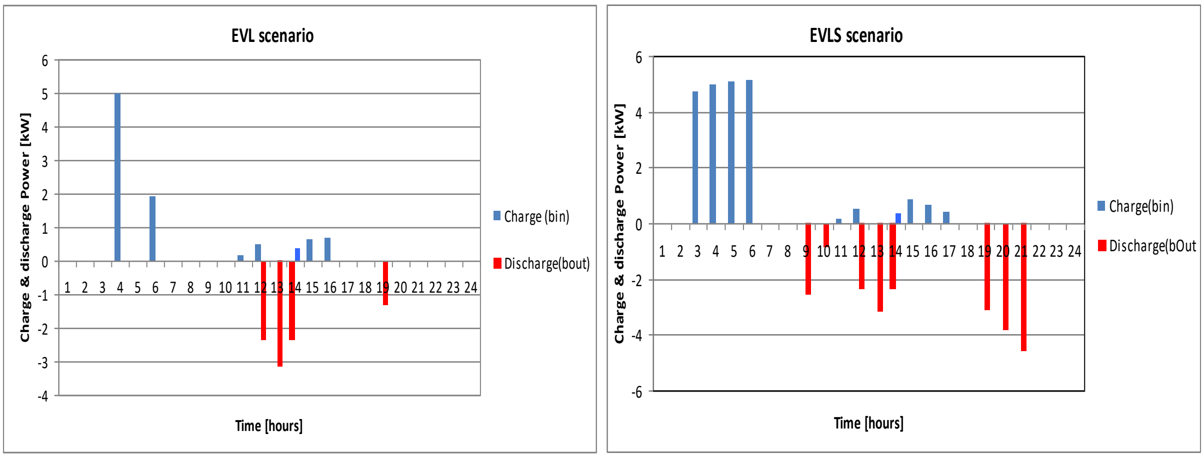

Figure 8. Charging and discharging pattern of EV in different scenarios.

The charging and discharging pattern of EV in two last scenarios are shown in Figure 9. The charging and discharging frequency in EVLS is more than EVL scenario because in EVLS the EV also can be used for V2H in addition to mobility applications . Consequently there is a bigger need to store energy and then the battery needs to be more charged which takes place rather in the early day.

In Table 3, the total energy purchased from grid is given. The numerical values show that the maximum energy procurement is occurred in EVLS scenario. This is evident due to the EV's energy requirement for mobility (the same as EVL scenario) and V2H supply. However, since it can use the EV as an accessory energy reserve to feed the domestic loads then it buys more energy compare to EVL case to use it in high price periods. The result of this scheduling is that although this scenario buys the maximum energy but it has the minimum grid electricity cost.

As it is mentioned before, there are two ways to earn income regarding the solar power namely: self consumption and selling solar power to the gird. The maximum solar consumption and SCB income are in EVLS scenario because it can store energy in EV and use it in other hours (for mobility or V2H). The power selling income is maximum in Baseline scenario since it can not save it is EV and it is forced to sell the excessive produced power to the grid. The trade-off between these two incomes and associated costs gives the best TEC in scenario EVLS.

Table 3. System operating performance and energy payments for the three considered scenarios.

	Baseline Scenario	**EVL Scenario**	**EVLS Scenario**
Electricity Grid			
-subscribed power	7 kW	7 kW	7 kW
-power used	42.27 kWh	49.53 kWh	50.27 kWh
-grid electricity cost	3.544 €	3.927 €	3.265 €
Solar facility			
- Self-consumed power	10.95 kWh	13.38 kWh	14.05 kWh
- SCB income	1.31 €	1.61 €	1.69 €
- power sold	3.10 kWh	0.67 kWh	0.00 kWh
- power selling income	0.47 €	0.10 €	0.00 €
Balance			
	3.544	3.927	3.265
	+ 0.4	+ 0.4	+ 0.4
	- 1.31	- 1.61	- 1.69
	- 0.47	- 0.1	
TEC	**1.76 €**	**2.22 €**	**1.58 €**

7. Conclusions remarks & Further work

The present work deals with the optimal operation of a typical building connected to electric vehicles. A set of three scenarios are examined to investigate the economic benefits that may arise from electric car storage utilized in building energy management system in different context of use.

The results show that the use of electric vehicles as normal loads for only transportation purpose could induce a negative value on electricity consumption cost. Nevertheless, alternating mobile storage employment in vehicles by an energy management application in housing proves to be economically beneficial. The electric vehicles may become valuable assets creating significant monetary value by reducing the dynamic cost of energy consumption if optimally operated.

Further work needs to be done to extend the optimization framework to larger scaled V2H applications with several sites and cars circulating between them. Another interesting way to explore would be the possibility to further improve the system profitability by relaxing certain constraints such as departure time of the trips or by shifting some electric appliances (cf. heating, washing machine…), the uncertainty modelling of renewable energies, electricity prices, forced outages of the facilities and etc.

Notes

1. EPEX SPOT. , "market data caution", available at: http://www.epexspot.com/en/market-data (accessed 20 June 2012).

References

(Beer et al., 2012) Beer, S., Gómez, T., Dallinger, D., Momber, I., Marnay, C., Stadler, M. and Lai, J. (2012), "An economic Analysis of used electric vehicle batteries integrated into commercial building microgrids", *IEEE transaction on smart grid*, Vol. 3 No. , pp. 517-525.

(Brooke and Rosenthal, 2003) Brooke, A., & Rosenthal, R. E. (2003). *GAMS,* GAMS Development Corporation, Washington DC.

(Clastres et al., 2010) Clastres, C., Ha Pham, T.T., Wurtz, F. and Bacha, S. (2010), "Ancillary services and optimal household energy management with photovoltaic production*", Energy*, Vol. 35 No. 1, pp. 55-64.

(Ford, 1995) Ford, A. (1995), "The impacts of large scale use of electric vehicles in southern California", *Energy and Buildings*, Vol. 22 No. 3, pp. 207-218.

(Grosjean and Perrin, 2012) Grosjean, C. and Perrin, M. (2012), "Le stockage d'électricité à la convergence des besoins de l'habitat et du transport. [Electricity storage at the convergence of housing and transportation requirements]", available at: http://www.u-cergy.fr/_attachments/club-eea actualite/JEEA2012_ppt_C-Grosjean.pdf?download=true (accessed 4 March 2012).

(Guan and Jia, 2010) Guan, X., Xu, Z., and Jia, Q. S. (2010), "Energy-efficient buildings facilitated by microgrid" , *IEEE Transactions on Smart Grid*, Vol.1 No.3, pp. 243-252.

(Karplus et al., 2010) Karplus, V.J., Paltsev, S. and Reilly, M. (2010)," Prospects for plug-in hybrid electric vehicles in the United States and Japan: A general equilibrium analysis", *Transportation Research Part A* , Vol. 44 No. 8, pp. 620–641.

(Kempton and Tomicé, 2005) Kempton, W. and Tomicé, J. (2005), "Vehicle-to-grid power fundamentals: Calculating capacity and net revenue", *Journal of Power Source*, Vol. 144 No.1, pp. 268-279.

(Lindly and Haskew, 2002) Lindly, J.K. and Haskew, T.A. (2002),"Impact of electric vehicles on electric power generation and global environmental change", *Advances in Environmental Research*, Vol. 6 No. 3, pp. 291-302.

(San Román et al., 2011) San Román, T.G., Momber, I., Abbad, M.R. and Sanchez Miralles, A. (2011), "Regulatory framework and business models for charging plug-in electric vehicles: Infrastructure, agents, and commercial relationships", *Energy Policy*, Vol. 39 No. 10, pp. 6360–6375.

(Turton and Moura, 2008) Turton, H. and Moura, F. (2008), "Vehicle-to-grid systems for sustainable development: An integrated energy analysis", *Technological Forecasting & Social Change*, Vol. 75 No. 8 , pp. 1091–1108.

(Warkozek et al., 2012) Warkozek, G., Ploix, S., Wurtz, F., Jacomino, M. and Delinchant, B.(2012), "Problem formulation and analysis for optimal energy management in multisources systems: W effect", *Compel: the International Journal for Computation and Mathematics in Electrical and Electronic Engineering*, Vol. 31 No. 3, pp. 904-919.

(Wood and Wollenberg, 1996) Wood, A.J. and Wollenberg, B.F. (1996), *Power Generation, Operation, and Control*, Wiley, New York.

(Pardalos and Resende, 2002) Pardalos, P.M. and Resende, M.G.C. (2002), *Handbook of Applied Optimization*, Oxford University Press, Oxford.