Investigation of Cost Reduction in Residential Electricity Bill using Electric Vehicle at Peak Times

Onur Elma and Ugur Savas Selamogullari

Abstract The use of electric vehicles (EVs) is becoming more common in the world. Since these vehicles are equipped with large battery capacity, they can be used as energy provider when they are parked and have enough charge level. This study investigates the possibility of Vehicle to Home (V2H) concept using EV as energy provider for a residential house in Istanbul, Turkey. High resolution residential electrical demand data is obtained to characterize the residential demand. Then, case studies are completed in MATLAB/Simulink to evaluate the cost reduction in residential electricity bill when the EV is used to supply the residential demand at peak times. It is assumed that the EV will be fully charged at off-peak hours when the energy cost is lower. Savings are calculated by finding the difference between residential electricity cost at peak times and EV charging cost at off-peak hours. Results will provide more realistic prediction of cost savings since residential demand dynamics are taken into account. In addition, the advantages of shifting peak demand to off-peak hours through the use of EV for existing grid infrastructure is discussed in terms of reduced losses and increased transmission capability.

Keywords: Vehicle to home (V2H) · Electric vehicle · Demand management · Cost analysis

1 Introduction

With the increased environmental concerns all around the globe, many countries have been offering incentives for EVs. Therefore, vehicle producers in many countries focus on this topic and have manufactured various prototypes of EVs [1].

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Since EVs are equipped with large energy backup capacity, they can be used to provide power to both grid and houses. These modes can be identified as Vehicle to Grid (V2G) and Vehicle to Home (V2H). The grid-connected electric vehicles can be used to meet the peak energy demand [2, 3]. It can be said that widespread use of EVs and the evolution of smart grid will lead to dramatic changes in existing electrical power systems in near future.

Overall, the residential electrical demand constitutes high percentage of total demand. This becomes important especially at peak hours when everybody is at home and using electricity. Thus, the effect of residential demand response (DR) on the peak loading has been investigated [4–7]. Several methods have been suggested in the literature for DR [8]. Most common method is shifting peak demand to off-peak hours by using smart control methods. Shifting load demand to off-peak hours offers benefit to both customer and to utility companies as well. In conventional grid structure, transmission and distribution losses contribute large percentage of total losses due to the distance between generation and customers. An optimization study for the cost of power loss and congestion of transmission services are given in [9].

If the residential demand can be reduced at peak hours or shifted to off-peak hours with proper control algorithms, then transmission losses can be minimized and optimal use of existing grid can be achieved. The EV will be an enabling technology to move towards such operation in the existing grid structure [10–13]. The feasibility of V2H technology is discussed in [10]. A simulation model is developed to investigate the peak demand reduction using the EV. Various case studies are completed and it is shown that the peak demand can be reduced with the use of EV battery. The use of plug-in hybrid electrical vehicles (PHEVs) together with renewable energy sources for energy and comfort management in large smart building is studied in [11]. Multi-agent control method with particle swarm optimization is used in control algorithm and it is shown that about 7 % savings can be achieved without affecting customer comfort. A general framework for analyzing Vehicle to Grid and Vehicle to Home applications of PHEVs is given in [12]. Daily load profiles for various house types and distribution transformer are obtained using probabilistic approach and national database on electricity consumption for various domestic electrical devices. Vehicle to building (V2B) operation of electrical vehicles are analyzed in [13]. It is stated that V2B mode of operation is much easier to implement within a 3–5 year time frame compared to Vehicle to Grid operation. Both demand side management under peak load and outage management under grid faults using EVs are analyzed. Case studies are used to demonstrate the feasibility of the demand side management and outage management strategies.

This study mainly focuses on the use of an EV to supply residential electrical demand at peak times and its effect on residential electricity bill for a house in Istanbul, Turkey. In order to obtain realistic saving estimates, high resolution residential demand characteristics are obtained through measurements, which is missing in the literature. Then, possible cost benefits of using EV for demand management in a residential house is investigated by considering daily energy tariffs in Turkey. A three level energy tariff is used in Turkey and the peak time pricing is about 2.5 times higher than off-peak time pricing. Thus, it would be highly economical to use the EV to supply the load demand at peak hours. In the demand management algorithm, the EV is used as much as possible to provide peak residential demand. It is assumed that the EV will be fully charged at off-peak hours when the energy cost is lower. This will result in savings in residential electricity bill since the EV will be charged at off-peak hours. Savings can be found by finding the difference between residential electricity cost at peak times and EV charging cost at off-peak hours where the cost is lower. Since the available energy from the EV depends on the driving conditions during the day, case studies are completed by considering different EV battery state of charge conditions. In addition, the advantages of shifting peak demand to off-peak hours through the use of EV as backup on for existing grid infrastructure is discussed in terms of reduced losses and increased transmission capability.

This paper is organized as follows: in Sect. 2, the measurement result of the residential electrical demand is given. In Sect. 3, details of energy tariffs in Turkey are given. In Sect. 4, basic information on EVs is given. In Sect. 5, case studies on the topic are completed and results are summarized. In Sect. 6, conclusions are given.

2 Residential Load Demand

Numerous parameters affect the energy use in a residential house. Mainly, user's habits, such as attitudes and opinions, determine the residential demand characteristics. In Maleviti [14], a theoretical model is given to analyze user's attitudes and opinions and to improve energy performance of a hotel building.

In this study, electrical power consumption data at a 4-person residential house in Istanbul, Turkey are measured with a sampling rate of seconds. Selected 4-person family structure represents large percent of family structure in Turkey.

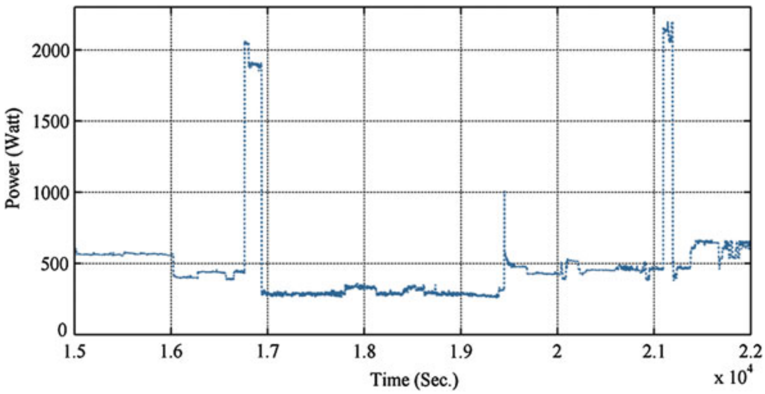

Fig. 1 A portion of measured residential load data

Table 1 Turkish electricity tariff for active power

	Day ($/kWh)	Peak ($/kWh)	Night ($/kWh)
Residential buildings	0.139	0.217	0.083
Commercial buildings	0.142	0.217	0.087
Industry	0.135	0.212	0.078

No demand management is applied during the data collection to obtain real electricity use of a typical Turkish family. The data is collected for a week [15]. During data collection, voltage and current measurements at the house main electrical panel are measured and stored with high resolution. A portion of the measured data is shown in Fig. 1 as an example. It is assumed that the residential demand has a periodic characteristic and weekly measurements can capture this periodicity.

3 Electricity Tariffs in Turkey

Since the cost of electricity depends on many parameters such as the type of source used, location, government policies, etc., each country has different tariffs for electricity. Mainly two tariffs are used for electricity pricing: fixed pricing and dynamic pricing. In fixed pricing, the electricity cost is fixed and does not depend on the time of use of electricity. In dynamic pricing, the electricity cost changes within a day based on the time of use of electricity [16].

In addition to fixed pricing, a 3-level tariff is employed in Turkey. In this tariff, a day is divided into three time frames (day-time, peak-time, and night-time) and each time frame priced differently:

- Hours between 06:00 and 17:00 are defined as day-time,
- Hours between 17:00 and 22:00 are defined as peak-time,
- Hours between 22:00 and 06:00 are defined as night-time.

Cost of electricity for each time frame, updated in April 2012, is given in Table 1 [17]. The values in Table 1 are raw prices which does not include costs such as tax, maintenance, transmission and distribution, meter reading, etc. When author's residential electricity bills are analyzed, it is found that final electricity cost per kWh is approximately 60 % more than the prices given in Table 1.

4 Electric Vehicles (EVs)

Although EVs were first developed in 1800s, they were not commercially available due to driving distance limitation and cost issues compared to internal-combustion engine powered vehicles. However, there has been growing interest in electrical vehicles in recent years due to mainly environmental concerns.

Table 2 A sample list of manufactured or planned to be manufactured EVs

Company	Model	Date of sale
Renault	Fluence ZE, Twizy, ZOE, Kongoo Express ZE	Fluence, Twizy, Kangoo: 2011 ZOE: 2012
Audi	E-tron, A1 E-tron	2012
BMW	MINI-E, Active-E, Megacity	2013
Chrysler-Fiat	Fiat 500	2012
Daimler	Smart ED For two	2012
Ford	Transit Connect Electric, Focus BEV	Transit Connect: 2011 FocusBEV: 2011
Honda	N/A	2012
Nissan	LEAF, NV200, Infiniti EV	LEAF: mass-production
Tesla	Roadster, Model S	Roadster: mass-production Model S: 2012
THINK	City EV	Mass-production
Toyota	Pirius PHEV	2012
Volkswagen	Golf Twin Drive	2013

EVs can broadly be divided into two groups: electric vehicles based on only battery power (BEV) and hybrid electrical vehicles (HEV) based on both internal combustion engine power and battery power. Recently, plug-in hybrid vehicles (PHEV) with the possibility of charging/discharging from an electrical outlet have been developed. A sample list of manufactured or planned to be manufactured EVs is given in Table 2 [18].

5 Case Studies

Since EVs are equipped with large battery capacity, they can be used as energy provider when they are parked and have enough charge level. This study investigates the possibility of V2H concept using EV as energy provider for a residential house in Istanbul, Turkey. V2H concept is also being studied by electrical vehicle manufacturers. Toyota City Low-carbon Verification project started in 2010 by Toyota and Leaf-to-Home project by Nissan are examples of such studies.[1,2]

First, high resolution residential electrical demand data is obtained to characterize the residential demand. Then, case studies are completed in MATLAB/Simulink to evaluate the cost reduction in residential electricity bill when the EV is used to supply the residential demand at peak times. The block diagram of the considered system is given in Fig. 2.

[1] http://www2.toyota.co.jp/en/news/11/06/0630.html

[2] http://www.nissan-global.com/EN/NEWS/2012/_STORY/121001-01-e.html

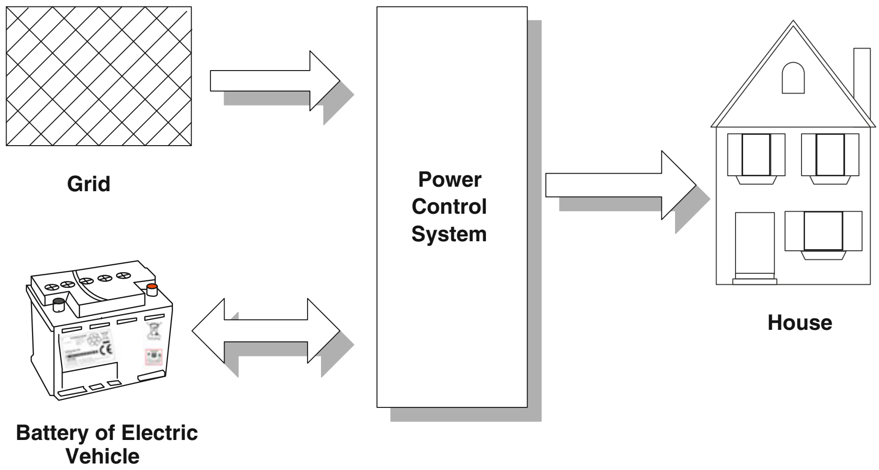

Fig. 2 Considered vehicle/grid hybrid power system

Renault Fluence ZE with battery capacity of 20 kWh is selected as the electrical vehicle for case studies since this vehicle is already on sale in Turkey. Renault Company owns the battery pack in its EVs and rent this battery pack to EV owner. This provides easy handling of recycling and battery maintenance.

A demand management algorithm is used to shift peak residential demand to off-peak hours by using the EV battery. It is assumed that the EV will be fully charged during off-peak hours when the energy cost is lower. The flowchart of the used algorithm is given in Fig. 3.

The algorithm uses the price of electricity and EV battery state of charge (SOC) as decision criteria. If the electricity price is high (between 17:00 and 22:00 h) and the EV is at home with enough battery capacity, then the demand is supplied by the EV until the predetermined minimum SOC level is reached. Here, minimum SOC level is chosen as 30 %. The EV is charged after peak hours with lower energy cost. If the required demand between at peak hours cannot be supplied with the EV at any instant, the demand is supplied through the grid. The proposed algorithm is implemented in MATLAB/Simulink as shown in Fig. 4.

Using the measured weekly residential demand data, minimum and maximum loaded days between 17:00 and 22:00 h within a week are found. The demand data for these two days are used as input to system simulations. Since the battery SOC level in the EV is depend on driving habits and the traffic during a day, available energy from the EV will vary. Thus, three different starting SOC levels (50, 75 and 100 %) are considered for the EV battery to consider daily driving effects on the battery SOC.

Simulation results are given in Fig. 5. As seen, when minimum loaded day is considered, the electrical vehicle can supply the demand at peak hours for each considered SOC level (Fig. 5a). When maximum loaded day is considered, the

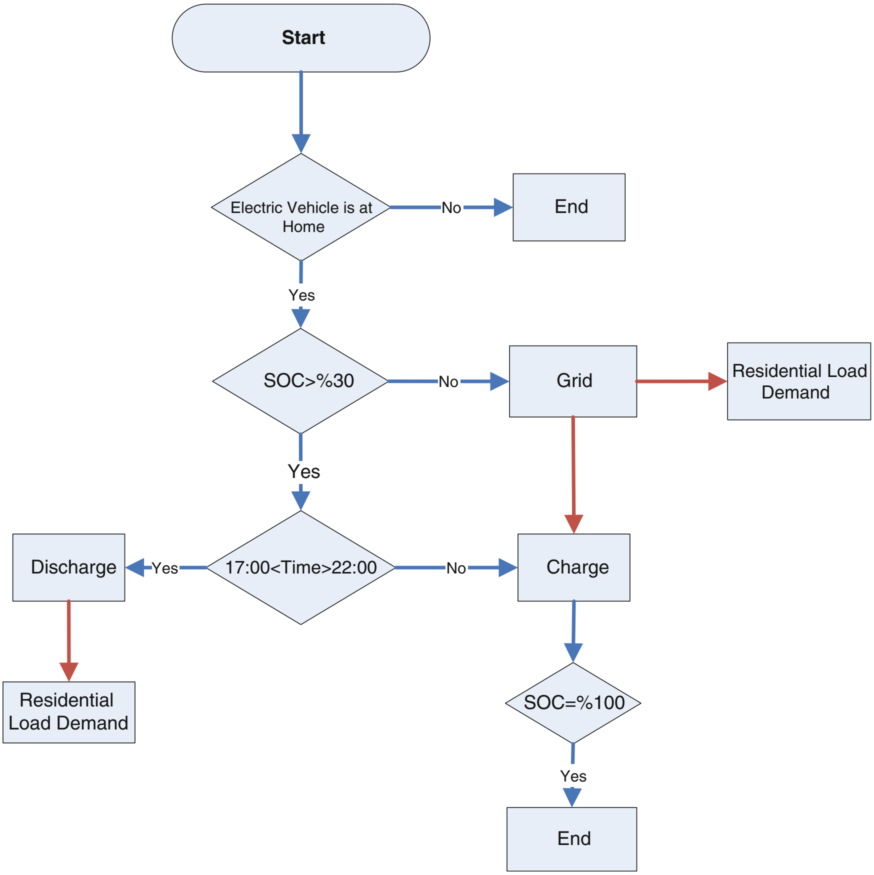

Fig. 3 Flowchart of EV use for demand management

demand between 17:00 and 22:00 h can be supplied by the EV for SOC levels of 75 and 100 %. However, when SOC level is 50 %, only a part of the demand can be supplied through the EV as SOC level goes below 30 % (Fig. 5b).

Economic savings can be found by finding the difference between residential electricity cost at peak times and EV charging cost at off-peak hours where the cost is lower. Savings for both minimum loaded day and maximum loaded day at peak times in a week are calculated. Then, using the calculated amounts as base values, monthly and yearly savings are calculated. Obtained results are summarized in Table 3. In these calculations, 60 % increased electricity price per kWh is used since in final billing the unit prices per kWh is about 60 % more than what is given in Table 1 due to addition of tax, maintenance, meter reading, transmission and distribution costs, etc.

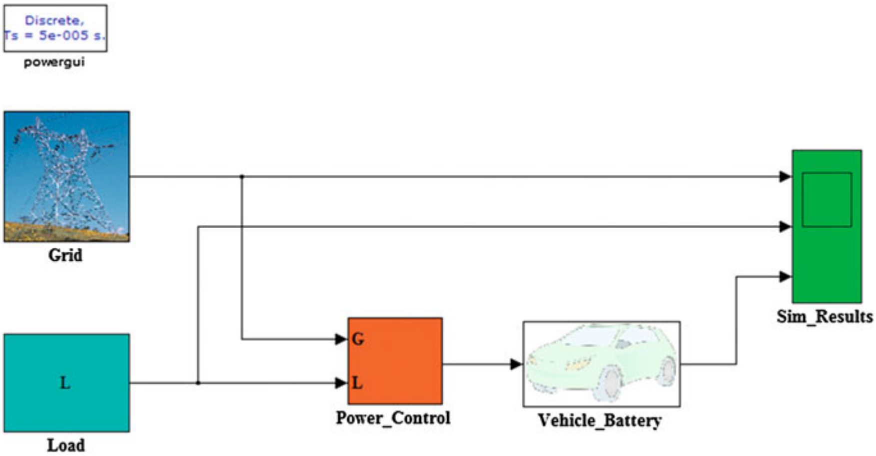

Fig. 4 System simulation block diagram

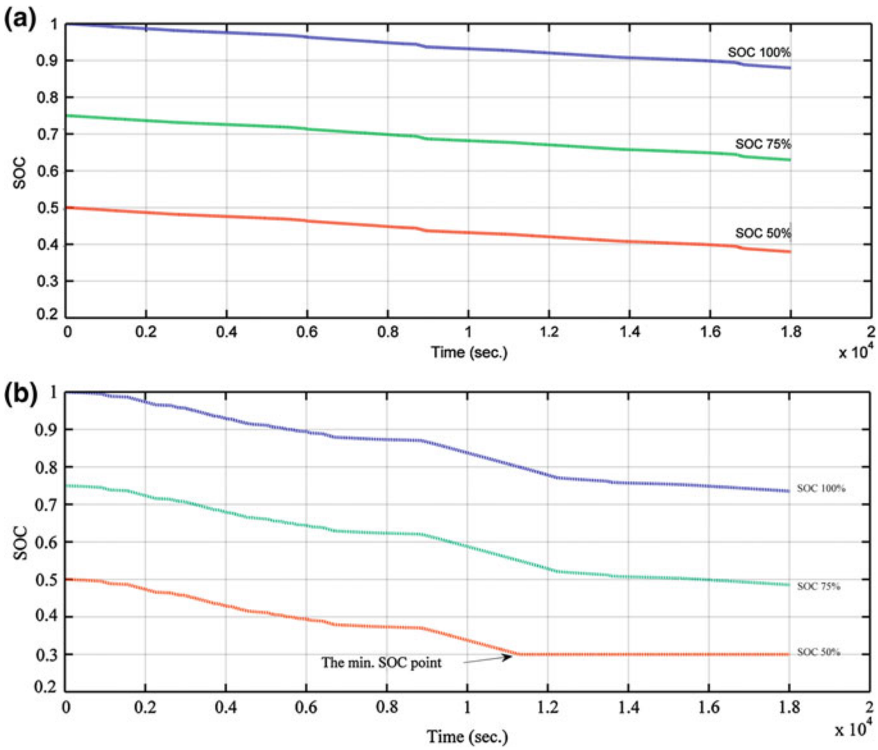

Fig. 5 Vehicle battery SOC values between 17:00 and 22:00 h for three different initial SOC levels. **a** Minimum loaded day between 17:00 and 22:00. **b** Maximum loaded day between 17:00 and 22:00

Table 3 Savings with the use of EVs at peak hours in a residential house

	Savings with the use of EV at peak hours ($) [minimum loaded day]		Savings with the use of EV at peak hours ($) [maximum loaded day]	
	Monthly	Yearly	Monthly	Yearly
Normal bill	25.1	305.1	55.33	673.3
Using EV at peak times	9.6	116.8	21.24	258.4
The price difference	15.5	188.3	34.1	414.9

6 Conclusions

In this study, the use of EV for demand management in a residential house is considered. Since EVs have large storage capacity, they can be used to supply residential demand at peak times when the vehicle is at home with enough battery capacity. The EV can be fully charged when the cost of electricity is lower.

Potential savings are assessed for a residential house by considering three different initial EV battery SOC levels, which emulate the driving conditions throughout the day. Based on minimum and maximum loaded days between 17:00 and 22:00 h within a week, it is found that between $15.5 and $34.1 can be saved in a month and $188.3 and $414.9 can be saved in a year.

In case studies, high resolution residential demand data is used. Since our focus in this study is to analyse the effect of the proposed demand management algorithm on residential electricity bill, analyses are completed based on required residential energy demand and available EV battery energy. This greatly simplifies analyses without going into details in component models such as battery model, control system model, etc. The results provides realistic upper limit on the savings with EV use for residential demand management. More detailed analyses will be completed in a future study.

The use of EVs in supplying residential peak demand provides benefits to utility as well. Although a single residential house is considered in this study, potential benefits to utility side will be more pronounced with increasing number of EVs. This is due to peak shaving offered by EV battery. The results can be summarized as less CO_2 emissions, reduced electricity unit cost, avoiding new installment of transmission and distribution lines, reduction in current ratings thus more efficient use of existing grid structure with lower losses, etc. However, careful planning of EV charging must be done in order to prevent another peak hour. Renewable energy integration together with charge/discharge scheduling of PHEVs will be subject of future research.

There are 2 million houses and 2.5 million cars in Istanbul, Turkey.[3] Using the measured data, the peak demand between 17:00 and 22:00 h can be approximated as 4.812 GWh for minimum loaded day and 10.596 GWh for maximum loaded

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[3] http://www.ibb.gov.tr/sites/ks/trTR/0IstanbulTanitim/konum/Pages/Sayilarla_Istanbul.aspx

day in a week. If 10 % of houses have EVs and use the proposed demand management algorithm, between 0.4812 and 1.059 GWh energy demand can be shifted to off-peak hours. This means that utility does not have to use additional gas turbine to supply these peak demands. Thus, considerable savings on CO_2 emissions could be achieved with the use of EVs for demand management. The saved CO_2 amount can be used in carbon trading between countries.

References

1. Masoum, A.S., Deilami, S., Moses, P.S., Masoum, M.A.S., Abu-Siada, A.: Smart load management of plug-in electric vehicles in distribution and residential networks with charging stations for peak shaving and loss minimization considering voltage regulation. IET Gener. Transm. Distrib. **5**, 877–888 (2011)
2. Saber, A.Y., Venayagamoorthy, G.K.: Intelligent unit commitment with vehicle-to-grid a cost emission optimization. J. Power Source **195**, 898–911 (2010)
3. Berthold, F., Blunier, B., Bouquain, D., Williamson, S., Miraoui, A.: PHEV control strategy including vehicle to home (V2H) and home to vehicle (H2V) functionalities. In: IEEE Vehicle Power and Propulsion Conference (VPPC), pp. 1–6 (2011)
4. Ghosh, S., Sun, X.A., Xiaoxuan Z.: Consumer profiling for demand response programs in smart grids. In: Innovative Smart Grid Technologies—Asia (ISGT Asia) (2012)
5. Fuller, J.C., Schneider, K.P., Chassin, D.: Analysis of residential demand response and double-auction markets. In: IEEE Power and Energy Society General Meeting (2011)
6. Saele, H., Grande, O.S.: Demand response from household customers: experiences from a pilot study in Norway. Smart Grid IEEE Trans. **2**(1), 102–109 (2011)
7. Shao, S., Pipattanasomporn, M., Rahman, S.: Grid integration of electric vehicles and demand response with customer choice. Smart Grid IEEE Trans. **3**(1), 543–550 (2012)
8. Albadi, M.H., El-Saadany, E.F.: A summary of demand response in electricity markets. Electr. Power Syst. Res. **78**(11), 1989–1996 (2008)
9. Shooshtari, A.T., Joorabian, M., Milani, A.E.: Transmission service cost calculation with power loss and congestion consideration. Int. J. Energy Optim. Eng. **1**(1), 39–58 (2012)
10. Haines, G., McGordon, A., Jennings, P.: The simulation of vehicle-to-home systems—using electric vehicle battery storage to smooth domestic electricity demand. In: Ecologic Vehicle and Renewable Energies International Conference and Exhibition, Monaco (2009)
11. Wang, Z., Wang, L., Dounis, A.I., Yang, R.: Integration of plug-in hybrid electric vehicles into energy and comfort management for smart building. Energy Buildings **47**, 260–266 (2012)
12. Turker, H., Bacha, S., Chatroux, D., Hably, A.: Modelling of system components for vehicle-to-grid (V2G) and vehicle-to-home (V2H) applications with plug-in hybrid electric vehicles (PHEVs). In: IEEE PES Innovative Smart Grid Technologies (ISGT), pp. 1–8 (2012)
13. Pang, C., Dutta, P., Kezunovic, M.: BEVs/PHEVs as Dispersed Energy storage for V2B uses in the smart grid. Smart Grid IEEE Trans. **3**(1), 473–482 (2012)
14. Maleviti, E.: The development of a theoretical model for optimizing energy consumption in buildings. Int. J. Energy Optim. Eng. **1**(4), 1–14 (2012)
15. Elma, O., Selamoğulları, U.S.: A comparative sizing analysis of a renewable energy supplied stand-alone house considering both demand side and source side dynamics. Appl. Energy **96**, 400–408 (2012)
16. Moholkar, A., Klinkhachorn, P. and Feliachi, A.: Effects of dynamic pricing on residential electricity bill. In: Power Systems Conference and Exposition, vol. 2, pp. 1030–1035. IEEE PES (2004)

17. http://www.epdk.org.tr/web/elektrik-piyasasi-dairesi/ulusal-tarifeler. Last accessed on 01.05.2012
18. Ugur, E.: Application of energy management on a prototype electric vehicle. MSc Thesis, Yıldız Technical University, Department of Electrical Engineering, Istanbul (2011)