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Electric Vehicle-to-Home Concept Including Home Energy Management

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Abstract—*In near future, Electric Vehicles (EVs) will replace conventional vehicles which provides both challenges and opportunities and this represents an important research area. Although EV increases the grid loading, it can also serve as the potential storage to facilitate the demand response. In this paper, a new energy control strategy has to be developed to consider the home-to-vehicle (H2V) and vehicle-to-home (V2H) capabilities including home energy management (HEM). The proposed algorithm is developed load management in residential sector which can automatically shift the operational time of the non-critical power intensive loads from peak demand periods to off-peak periods, while assuring the consumer comfort levels. The considered residential power intensive loads are air conditioner (AC), water heater (WH), clothes dryer (CD), and electric vehicle (EV). The main objectives of this work are to minimize the total cost and minimize the peak load considering a coordinated/uncoordinated charging for H2V and discharging for V2H. Simulation results show our proposed scheme can not only minimize the cost but also minimize the peak load and maximize the load factor of household daily load.*

Keywords—Electric Vehicles (EVs); home energy management (HEM); home-to-vehicle (H2V); vehicle-to-home (V2H)

1. INTRODUCTION

Vehicle-to-grid (V2G) creates a new capability for a plugin electric vehicle (PEV) where a PEV not only receives power from the grid but also provides power to grid. Another concept, Vehicle-to-Home (V2H) is a small version of V2G that allows a PEV to supply homes with power generated from its battery. V2H is one of three emerging concepts of grid-connected EV technologies [1]; Vehicle to Home (V2H); refers to the power exchange between the EV battery and home power network. In this case, EV battery can work as energy storage, which provides the backup energy to the home electric appliances and to the home renewable energy sources.

Indeed, many papers have studied the employment of the V2G concept. However, the research work carried out at the level of a housing (V2H concept) are uncommon. This justifies the present study. Previous researches in the area of V2H is found in [2], [3], [4], [5], [6], [7], and [8]. The work presented in [2] focuses on the application of Housing Peak Shaving Algorithm (HPSA) on 10000 studies where each is representative of the insertion of one EV per house. Tuttle et al. [3], [4] focused on the potential of V2H for providing backup power to home in emergency situations where the electric grid has failed. Tuttle et al. [4] emphasized that a smart control strategy is needed to avoid overspending gasoline on battery charging, which results in a large PV spillage. In [5], Authors optimize a V2H system in such a way that it provides the maximum "backup duration," meaning the time duration of V2H supporting residential load without experiencing a critical load curtailment in islanded mode. This is distinguished from the work in [4] in that the previous work only explored the potential of V2H as a backup power source by using a highly simple modeling and control but did not optimize the V2H system. In [6], a general control strategy is designed with the objective of to minimize the total energy cost, taking into account the overall system and the home power profile takes into account photovoltaic (PV) and wind production. Also in [7], Authors presents a novel controller based on fuzzy logic its objective is the minimum state-of-charge (SOC), which integrates an objective SOC for V2H application. D. Guo et al. propose in [8] an optimal and automatic scheduling scheme its objective is to minimize the total cost.

According to available researches in V2H, the main objectives are peak shaving to minimize the peak demand, and minimizing the total energy cost.

2. THE PROPOSED V2H METHODOLOGY

The main outlines of the proposed approach are presented in the following subsections.

2.1 Objectives

The main objective of proposed methodology in this work is to minimize the cost and the peak demand by a management of in non-critical power intensive loads through shifting their operational time from peak demand periods to off-peak periods, especially charging of EV. EV also can considered as a source of energy in discharging mode so, two main concepts are presented; a H2V in case of EV charging and V2H in EV discharging case.

In order to analyze demand response in the domestic sector, it is important to understand physical based power intensive load models with an emphasis on WH units, AC units, CD and EV.

2.2 Modelling of System Components for V2H

Electricity is used in household in many ways. Space heating/cooling is the major consumer of household electricity. Water heating also plays a major role in household electricity consumption. Lighting has the third largest percentage of the electricity usage. Other electric appliances such as freezers, refrigerators, clothes dryers, kitchen appliances and entertainment devices account for the rest of the power consumption.

A typical breakdown of electricity consumption in residential sector is shown in Fig. 1. Although power consumption of the electric vehicle has not been included in this figure, it is included in this study as it will become a widespread application in the near future.

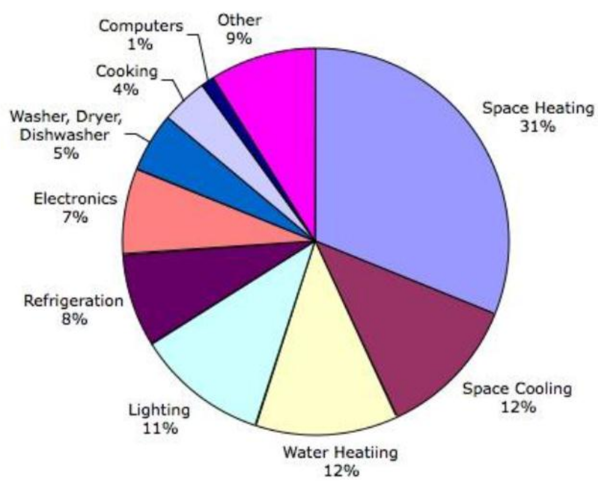

Fig. 1. *A typical electric energy usage in residential sector [9]*

In this paper, the household loads are divided in to two categories, non-critical (or controllable) loads and critical loads. Loads which are vital for the day to day activities of the consumers such as cooking, refrigeration and lighting fall under critical loads. Controllable or non-critical power intensive loads can be interfered without noticeable effect to the consumer's lifestyle. The air conditioning (AC) unit, water heater (WH), clothes dryer (CD), and the electric vehicle (EV) are the identified noncritical power intensive residential loads. Since these power intensive loads account for a significant percentage of the total household demand, controlling these loads during peak hours will help to reduce the peak demand in the house.

2.3 Study Cases and Assumptions

To implement the proposed algorithm in a home, different operational scenarios for home energy management (HEM) including H2V and V2H are studied in this work. A home without HEM or V2H is simulated in the first, next simulation is for a home with a HEM, and a home with both H2V and V2H is simulated in the final. All operational cases are developed considering real time pricing (**RTP)** extracted from Nord Pool website [10] as given in Fig. 2.

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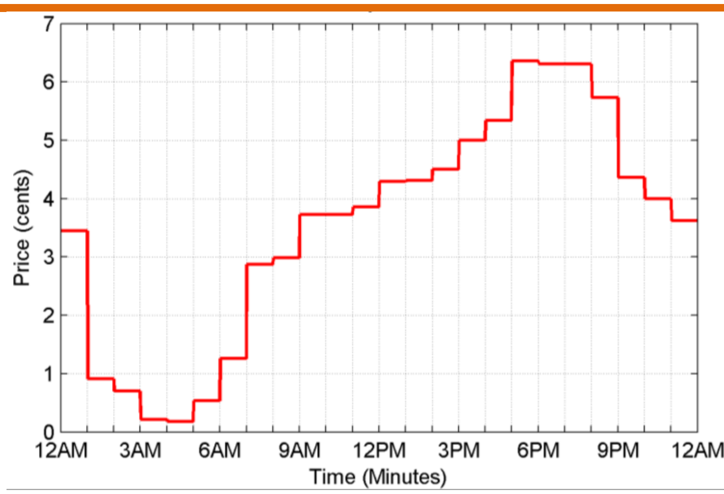

Fig. 2. *Real time pricing (RTP) [10]*

The critical loads of the household may include refrigeration, freezing, cooking, lighting and other electric appliances. A random profile (follow daily load in Egypt [11]) which has a maximum value of 3 kW and a minimum value of 0.3 kW is selected in the simulation program. A typical load profile for the critical loads considered in this work is given in Table 1, and the variation of the critical loads with time is shown graphically in Fig. 3.

Table 1: Hourly variation of the critical load demand

Time	Power demand (kW)	Time	Power demand (kW)
12 midnight.–1 a.m.	2.070	12 noon.– 1 p.m.	1.320
1 a.m. – 2 a.m.	1.980	1 p.m. – 2 p.m.	1.500
2 a.m. – 3 a.m.	1.830	2 p.m. – 3 p.m.	1.620
3 a.m. – 4 a.m.	1.320	3 p.m. – 4 p.m.	1.680
4 a.m. – 5 a.m.	0.300	4 p.m. – 5 p.m.	1.770
5 a.m. – 6 a.m.	0.300	5 p.m. – 6 p.m.	2.340
6 a.m. – 7 a.m.	0.300	6 p.m. – 7 p.m.	2.880
7 a.m. – 8 a.m.	0.300	7 p.m. – 8 p.m.	3.000
8 a.m. – 9 a.m.	0.600	8 p.m. – 9 p.m.	2.970
9 a.m. – 10 a.m.	0.930	9 p.m. – 10 p.m.	2.820
10 a.m. – 11 a.m.	1.080	10 p.m. – 11 p.m.	2.610
11 a.m. –12 noon	1.230	11p.m.–12midnight.	2.340

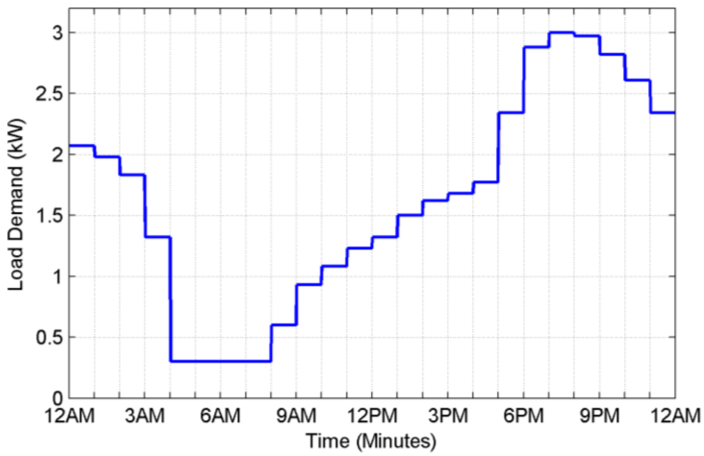

Fig. 3. *A typical variation of the critical loads during a day*

By referring the Fig. 3, it can be seen that for the selected critical load profile, the maximum value of the critical load demand has occurred at 7 PM – 8 PM where everybody return home and start their household work. During the night where everybody is in bed and in the day time where most of them are out, a low value is selected for the critical load demand.

3. Development of the Models

In order to develop an algorithm to control the household electricity demand, first the power intensive non critical loads have to be modeled. The next sections describe how the considered power intensive non-critical loads are developed in accordance with [12] using a MATLAB-m-file program.

3.1 AC Load Model

The 24 hours operation of the AC unit for the maximum and minimum limits of the temperature is considered and the typical operation of AC unit is given in Fig. 4.

For this AC unit, the set point of the room temperature is taken as 20°C and the upper limit of the room temperature is kept at 22°C whereas the lower limit of the desired temperature is kept at 18°C. These two limits of the room temperature has to be maintained during the operation of AC unit (shown in red lines in Fig. 4).The variation of the room temperature is shown in blue in the Fig. 4 and it can be seen that the room temperature is maintained within the preferred limits. In Fig. 4, it can be seen that as soon as the room temperature reaches to the upper temperature limit, the AC unit is switched on and then the room temperature drops. When the temperature drops below the lower temperature limit, the AC unit is switched off again. This cycle is repeated throughout the day to maintain the room temperature within the desired limits. The operational status of the AC unit is shown with green in Fig. 4.

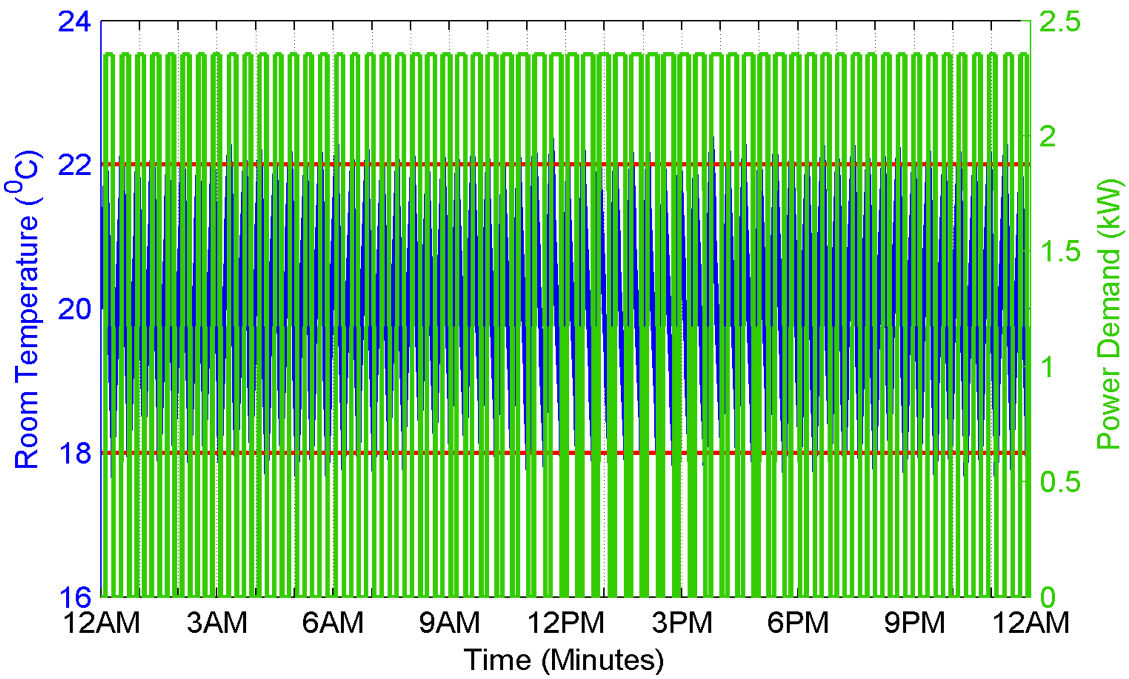

Fig. 4. *AC load model result*

3.2 WH Load Model

The 24 hours operation of the water heater unit for the defined minimum and maximum limits of the water temperature are considered and the typical operation of WH load model is given in Fig. 5.

In this work, it is assumed that a hot water draw event of 5 gpm occurs for a duration of 15 minutes at 7 p.m. and at 8 p.m. Around 9 p.m., 3 of hot water usage with 10 minutes duration occurs. When a water draw event occurs at 7 p.m., the outlet water temperature drops and reaches to its lower limit. As soon as the outlet water temperature reaches to the lower limit of the desired temperature range, the water heater is switched on to bring the outlet water temperature to the desired value. As a result, the outlet water temperature increases and when it reaches to the upper limit of the outlet water temperature (specified by the consumer), the WH is switched off. At 7 p.m. and 8 p.m., the outlet water temperature drops dramatically due to mentioned large water draw events as in Fig. 5. When the water temperature reaches to the lower limit of the preferred temperature, the water heater is switched on. But the water temperature drops further due to the high rate of water usage. At the end of the high water draw event the WH controller has been able to bring the water temperature to the desired temperature range. The water temperature profile for the selected case is shown in Fig. 5 in blue and the upper and lower limits of the customer specified water temperatures are shown in red. Also the power demand of the water heater is shown in green.

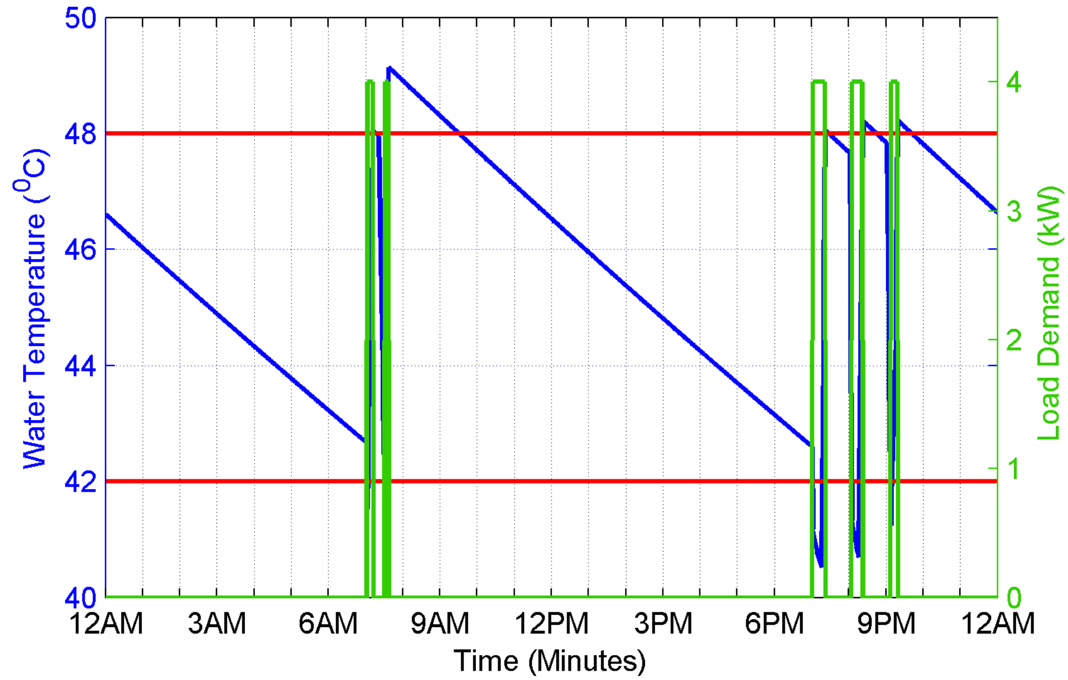

Fig. 5. *WH load model result*

3.3 CD Load Model

The load demand curve of the clothes dryer is shown in Fig. 6. In this work, it is assumed that the homeowner operates the clothes dryer at 6 p.m. in the evening and he specifies the duration of the drying job as 90 minutes. When the homeowner switches on the CD and specifies the required time, the CD operates until the job is completed. In this study case, the clothes dryer has started at 6 p.m. and has completed its job at 7.30 p.m. The power demand of the CD during this event is shown in blue and the status of the operation of CD is shown in green dotted line in Fig. 6.

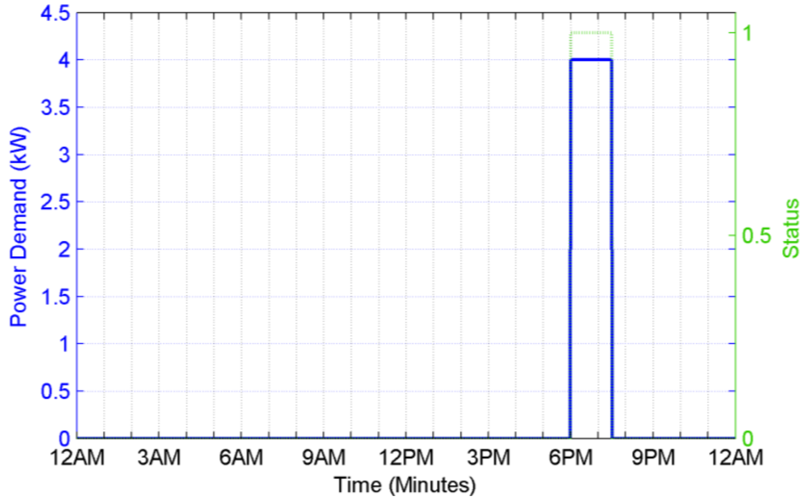

Fig. 6. *CD load model result*

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3.4 EV Load Model

The electric vehicle load curve with its charging profile is shown in Fig. 7. In this work, it is considered that the EV is plugged in at 6 in the evening by assuming that it has an initial state of charge of 50%. It can be seen from Fig. 7, that it has taken 3 hours and 20 minutes to fully charge the EV with 50% initial state of charge. In Fig. 7, the power demand of the EV at each time interval is indicated in blue and the state of charge is shown in green.

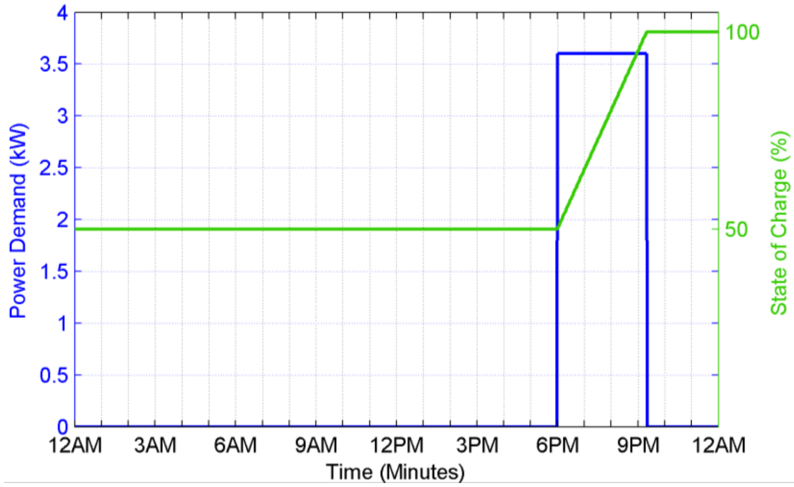

Fig. 7. *EV charging load model result*

4. Simulation Results

The total load curve for the household which includes the critical and non-critical loads without HEM or V2H is shown in Fig. 8. As shown in Fig. 8, the maximum power demand of the household is 16.952 kW and it occurs during 7:01 PM – 7:10 PM. The total energy consumption of the selected day which is obtained using the graph in Fig.8 is 90.2196 kWh. Typical average electricity energy consumption of the household in this case is 3.7591 kWh and the load factor is 22.18 %. The cost of energy of this day is 399.29 cents/day.

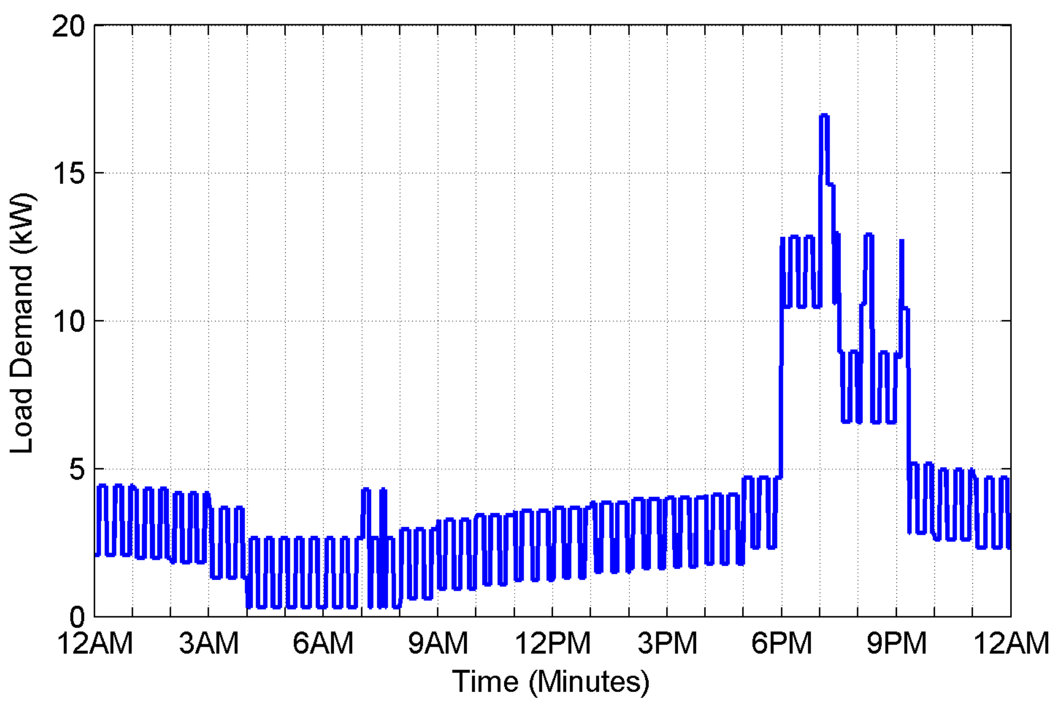

Fig. 8. *Total household load for 24 hours without HEM or V2H*

4.1 HEM Operational Scenario

In order to minimize the total household load, the HEM can force the controllable loads (AC, WH, CD, and EV) to shift their operating time. The peak demand occurs during 7:01 PM – 7:10 PM corresponding to working of all controllable loads. HEM system will shift the operating time of any of these loads according to customer predefined priority.

In this study, the proposed HEM system is assumed to shift the operating time of the load of charging EV from 6 PM to 1 AM as shown in Fig. 9. The total load curve for the household in this case is given in Fig. 10.

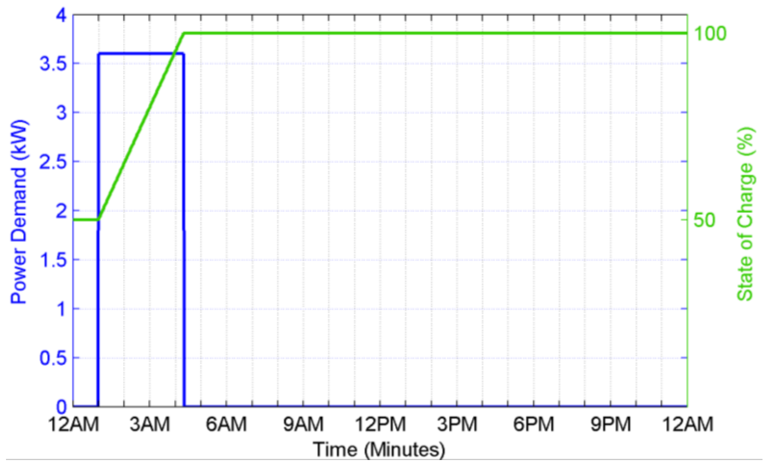

Fig. 9. *EV charging load with HEM*

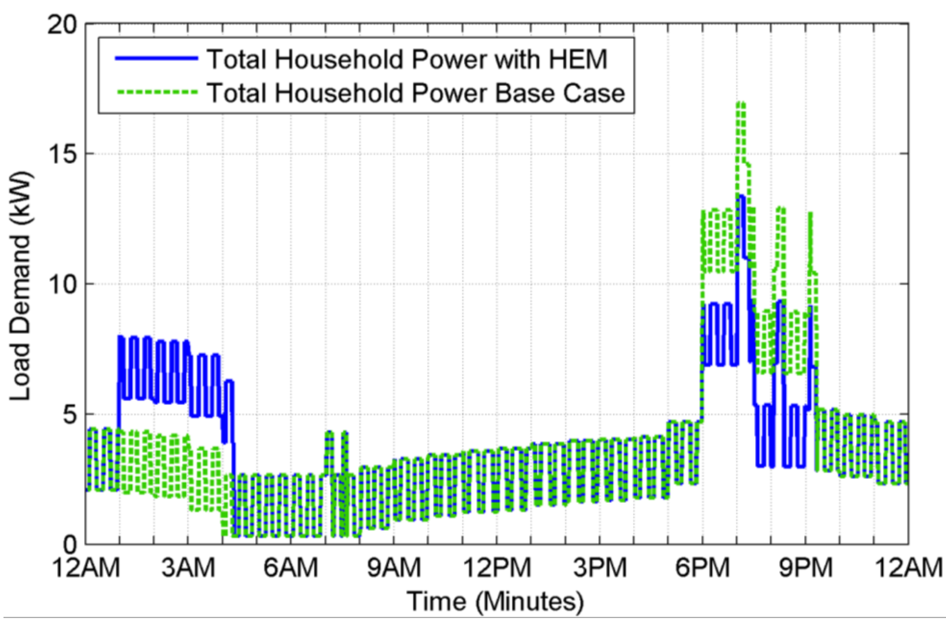

Fig. 10. *Total household load with HEM*

As seen from Fig. 10, the maximum power demand is reduced to 13.352 kW and the load factor is 28.15%. The cost of energy of this day is 334.88 cents/day (i.e. reduced by 16.13%).

4.2 V2H Operational Scenario

From EV load simulation given (see Fig. 7), it can be seen that a 50% SOC is left in the vehicle battery. The V2H study in this work is proposed to use this available energy in the peak time.

The discharging simulation of the EV is given in Fig. 11. The starting time of discharging is 6 PM. In a purpose of security, the lower limit SOC after discharging which defined by a customer is 10%. In this case, the initial SOC required for charging of EV is changed from 50% to 10%. So, a new EV charging simulation given in Fig. 12 with initial SOC of 10% and started at 1 AM.

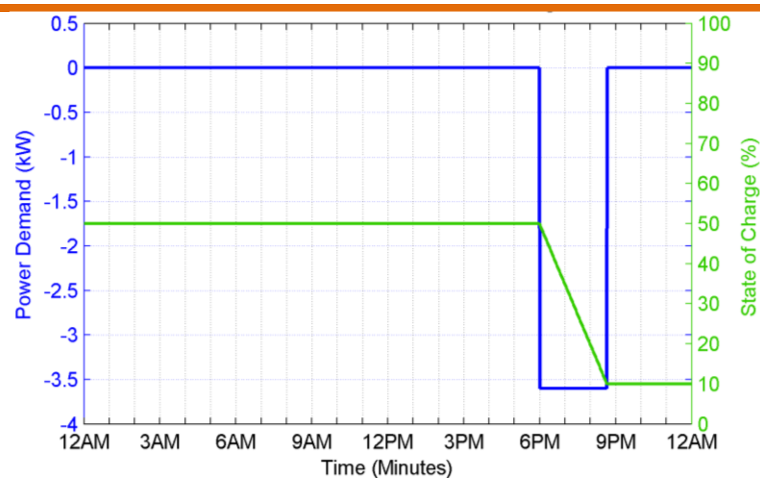

Fig. 11. *EV discharging load in case of V2H*

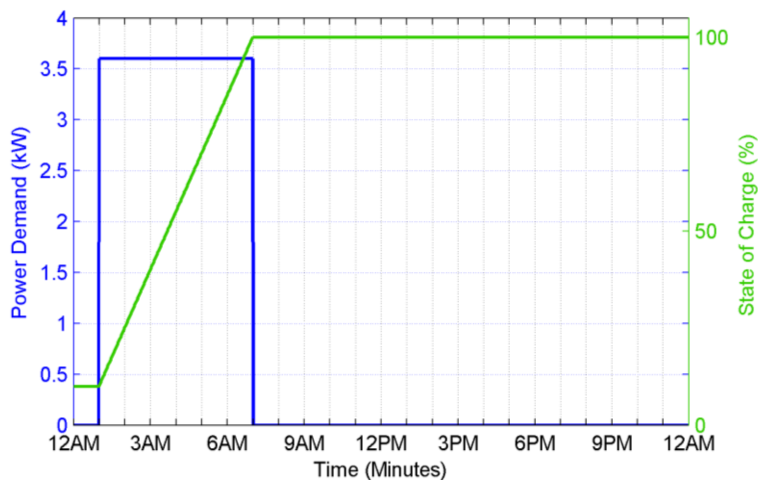

Fig. 12. *EV charging load with V2H*

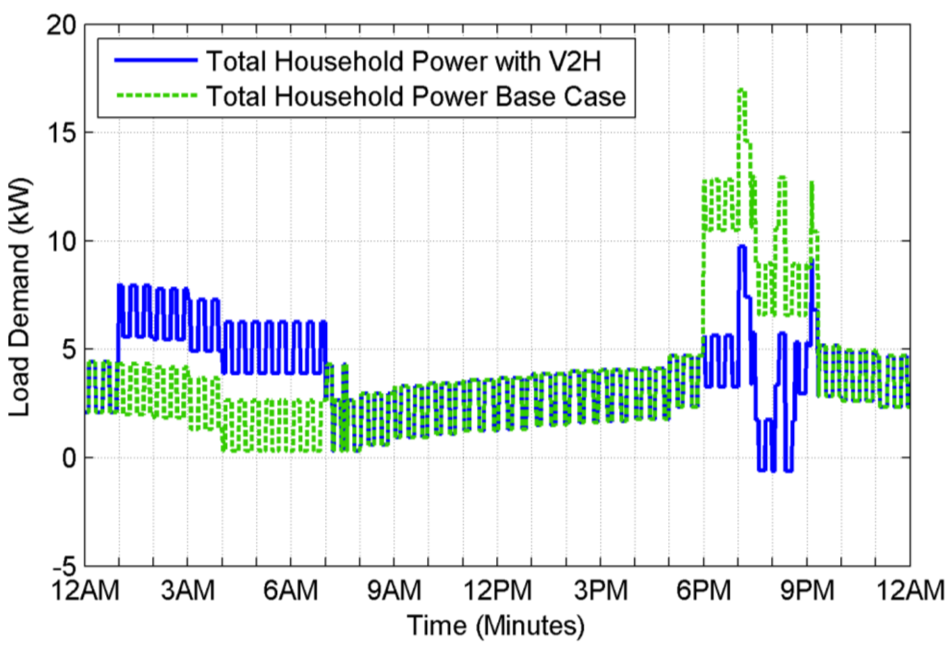

Fig. 13. *Total household load with V2H*

The corresponding total load curve for the household with V2H capability is given in Fig. 13. As seen from Fig. 13, the maximum power demand is reduced to 9.752 kW and the load factor is 38.55%. The cost of energy of this day is 282.53 cents/day (i.e. reduced by 29.24%).

5. Comparison between Operational scenarios

A comparison between scenarios of operation with and without HEM and V2H is given in Table 2. From this table, it is clear that the proposed HEM and V2H are enhanced the performance of household load as a maximum demand reduction and energy cost saving.

Table 2: Comparison between operational base case, HEM, and V2H operational scenarios

Case		Base Case	with HEM	with V2H
Max Demand	kW	16.952	13.352	9.752
	Time	19:01-19:10	19:01-19:10	19:01-19:10
Total Energy	kWH	90.2196	90.2196	90.2196
Average Energy	kWH	3.7591	3.7591	3.7591
Load Factor	%	22.18	28.15	38.55
Energy Cost	cetnts/day	399.29	334.88	282.53
	EUR/month	119.79	100.47	84.76
Cost Saving	EUR/month	--	19.32	35.03
	%	--	**16.13**	**29.24**

6. Conclusion

This paper investigates a new energy control strategy to consider the home-to-vehicle (H2V) and vehicle-to-home (V2H) capabilities including home energy management (HEM) to minimize the total cost and minimize the peak load. The developed load management algorithm can shift the operational time of the non-critical power intensive loads from peak demand periods to off-peak periods in residential sector while assuring the consumer comfort levels. This research considered residential power intensive loads as air conditioner (AC), water heater (WH), clothes dryer (CD), and electric vehicle (EV). A real time pricing profile and actual daily load curves are considered in this work. From the presented results it is clear that the proposed strategy can minimize the cost of energy, and minimize the peak load of household daily load and hence maximize its load factor.

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