

Spring 2017

Plug-in hybrid electric vehicle load profile estimation with opportunity charging

Reza Kazem Sharif Sharifi

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PLUG-IN HYBRID ELECTRIC VEHICLE LOAD PROFILE ESTIMATION WITH
OPPORTUNITY CHARGING

by

REZA KAZEM SHARIF SHARIFI

A THESIS

Presented to the Faculty of the Graduate School of the
MISSOURI UNIVERSITY OF SCIENCE AND TECHNOLOGY

In Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

2017

Approved by

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PUBLICATION THESIS OPTION

This thesis consists of the following article, formatted in the style used by the Missouri University of Science and Technology:

Paper I: Pages 2-27 is intended for submission.

ABSTRACT

This thesis focuses on the load profile analysis of the plug-in hybrid electric vehicles (PHEV), examining two different scenarios. In the first scenario, the battery of a PHEV is charged at the final arrival time, and the arrival time analysis has a minute accuracy. In the second scenario, opportunity charging, which refers to the stop-time between two trips, is used for charging the battery of the vehicle. However, if the stop-time between two trips is less than 30 minutes, the duration is not counted as an opportunity charging and it is filtered. The results of the two scenarios are compared, and through this comparison, it is revealed that the opportunity charging scenario has a more flat profile. The improvement not only shows the positive features of the opportunity charging in terms of using more electrical power instead of traditional petroleum-based fuel, but also creates more opportunity for the power grid to use renewable energy resources instead of traditional fossil fuels. These two significant features, present opportunity charging as a strong solution for the negative environmental effects of petroleum vehicles in urban areas, and even in a world-scale view. The data pool is collected from the national household travel survey (NHTS) database, which is a major reference for transportation studies. The analyses are done for the years 2001 and 2009, and the resulting data file includes the data of about 43000 different vehicles.

ACKNOWLEDGMENTS

I owe my deepest appreciation to my advisor, Dr. Mehdi Ferdowsi. He accepted me into his research group, and without him, I would not have been able to continue my pursuit of a master's degree in electrical engineering. With him, I have grown both academically and personally, learning about what it takes to not only be professional, but how to treat others with respect.

I would like to thank my committee members, Dr. Pourya Shamsi and Dr. Hamidreza Modares, who spent time to review my thesis and hinted me. Also, I would like to thank the friends I have made while working, Vignesh, Anand, Prashant, Rajesh, Ithar, Husam and many others. Finally, I have to thank my wife, Mojdeh Mansouri, for encouraging me to pursue my higher education.

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NOMENCLATURE

Symbol	Description
AER	All-Electric Range
EV	Electric Vehicle
HEV	Hybrid Electric Vehicles
ICE	Internal Combustion Engine
NHTS	National Household Travel Surveys
OC	Opportunity Charging
PCLP	Plug-in Charging Load Profile
PEN	Percentage Energy Need
PHEV	Plug-in Hybrid Electric Vehicles
PP	Peaker Plant
SOC	State Of Charge
w/	with
w/o	without

SECTION

1. INTRODUCTION

Although plug-in hybrid electrical vehicles can potentially be introduced as one of the most important solutions to overcome the negative environmental impact of the transportation sector, the load of PHEV charging on the power grid and its features, creates a challenge when it is looked at on a large scale. During the last decades, many research works have been done to reduce these negative effects.

This work models the load profile of plug-in hybrid electric vehicles (PHEV); using an opportunity charging scenario to examine PHEV and grid interaction. To do so, the national household travel surveys (NHTS) database, which provides reliable information about transportation in the United States, is used. In order to develop the model, some data from the years 2001 and 2009 are collected from NHTS. First, the plug-in charging load profile (PCLP) is modeled based on the arrival time during the year 2001. The results are examined and compared with previous works. Then, the opportunity charging method, which uses off-peak regions in order to decrease the maximum load of PHEV on the network, and at the same time increasing the efficiency of using PHEVs by increasing the electric power driving mode, is applied. Then, in a similar way, the opportunity charging scenario is used to develop the model with the data from the year 2009.

Although there is a long way to find an optimum solution for the negative impact of transportation on the environment, it seems that opportunity charging is a successful scenario to overcome the negative effects of plug-in hybrid electric vehicle features, and introduce them as a practical solution.

PAPER

I. PLUG-IN HYBRID ELECTRIC VEHICLE LOAD PROFILE ESTIMATION WITH OPPORTUNITY CHARGING

ABSTRACT

Air and acoustic pollution in mega cities, and dependence on hydrocarbon-containing energy resources are the most important weak point intimidating the defensible development of the automotive industry. To do so, vehicle electrification has been targeted as a solution, and followed by automobile manufacturers since decades ago. Plug-in hybrid electric vehicle (PHEV) technology, as one of the most significant innovations in automobile engineering, can play a key role to overcome many aspects of energy resources and environmental concerns. However, another side, where PHEVs reliance on electrical power is a considerable threat against the power grid stability, especially during peak hours, should be also measured. Instead, the possibility of using PHEVs as distributed energy storage system in the power generation is a strong advantage to PHEVs development, not only as a solution for the transportation section, but a functional resolution for improving power generation load profile. As a result, they are opening new windows for using wide varieties of different renewable power generation modes. With the intention of estimating the aggregated impact of PHEVs on the stability of pilot plant, it is necessary to be aware of the timing pattern during the charging process, and the amount of the power consumption. This work uses national household travel surveys (NHTS), as one of the most complete databases. The study focuses on the statistics of two different years. In order to obtain PHEV charging load profile (PCLPs), two distinctive charging scenarios, including charging procedure based on the arrival time and opportunity charging models, are

developed. Finally, the results of the models in two different years and approaches are discussed and compared.

Keywords- Load profile, plug-in hybrid electric vehicle (PHEV), opportunity charging, national household travel survey (NHTS), electric vehicles, vehicle-to-grid.

1. INTRODUCTION

Since decades ago, automotive industry has targeted electric vehicle, in order to improve automobile efficiency, and overcome to some serious eco-friendly concerns such as greenhouse gas emissions and air pollution. Petroleum-based vehicles are the main source of poisonous emissions, and acoustic noise in the cities, where living standards is the main issue from public apprehensions view point. Vehicle electrification not only provides healthier life in urban areas, but prepares opportunity for power grid through using varieties of sustainable energy resources for electrical power production. These double their positive role to increase environment standards.

1.1. A PLUG-IN HYBRID ELECTRIC VEHICLE (PHEV)

A plug-in hybrid electric vehicle (PHEV) is a model of hybrid electric vehicles, which has both an internal combustion engine (ICE), and an electric drive system. It has an electric motor and a large-capacity battery that can be charged by plugging it into an electrical outlet. PHEVs prepare more flexibility to drivers compare to previous styles, such as electric vehicles (EV) and standard hybrid electric vehicles (HEV). In comparison, PHEVs and EVs both have large-capacity batteries that can be charged from a power source. They increase the all-electric range AER, and as a result, increasing efficiency and reducing emissions. However, some other parameters should also be considered. Since, the battery is the only power source in an EV, the lengths of trips are limited by the rating of the battery and availability of charging stations. Consequently, EVs must be charged when the battery's state-of-charge (SOC) is depleted, otherwise it becomes inoperable. So, with its flexibility, the PHEV is able to operate efficiently and with lower emissions when

electric power is available. Also, when the battery is depleted and charging is not possible, a PHEV can continue to operate by using the ICE until charging is available.

Similar to HEVs, PHEVs have an internal combustion engine (ICE). They, therefore, have the capability of operating entirely from the ICE when recharging is not available. The HEV derives all energy from the ICE since external charging is not possible. This gives the HEV unlimited range potential but reduces efficiency and increases emissions. In comparison to HEV, a PHEV is more efficient, because in a PHEV the internal combustion engine works as a generator, then kicks in to supply power to the electric motor. While in a hybrid electric vehicle, ICE directly drives the vehicle. Therefore, a plug-in hybrid electric vehicle is essentially an electric vehicle that is able to call on gasoline in order to extend its range. As a result, the PHEV exhibits the strengths of both HEVs and EVs without their inherent weaknesses.

1.2. THE PHEV EFFECTS ON THE POWER GRID

In general, utilities prefer to have a constant load. In this case, it is possible to have optimum power generation scheduling. As a result, it reduces using costly peaker plant (PP). Moreover, grid components are generally chosen based on their peak not on average power transmission capability; so, if the peak load consistently exceeds component specifications, it is necessary to improve grid as well.

The grid should supply PHEV even when it is heavily loaded. This energy requirement creates a risk of grid overloading. However, the positive point is that the charging schedule of a PHEV is not so inflexible, because vehicle owners are able to choose charging time for maximum convenience, maximum efficiency or any variation between.

This point makes PHEV bulk power consumption adaptable, but at the same time unpredictable.

Furthermore, it should be also considered that PHEVs have two drive systems. They can operate independently; but sometimes, when a high amount of torque is required, both systems can operate simultaneously. This complicates the calculation of electrical power. Indeed, it makes some difficulty for determining the amount of energy that PHEVs requires in interacting with grid when it is going to be recharged. Apart from that, electric usage depend on the frequency that vehicle is recharged; the more recharging, the less fossil-fuel consumption, and the more grid demand.

When the load is unpredictable and fluctuating, it is difficult to schedule power generation, having reliable transmission, and efficient distribution parts. In addition, it is also difficult to plan necessary infrastructure improvement projects in order to supply power to the customers. When PHEV penetration increases, it becomes more critical to predict PHEV Load profiles [1], [2].

1.3. PREVIOUS WORK

Statistical distributions based on driving data from the 2001 national household travel survey (NHTS) was used, and modeled a plug-in charging load profile (PCLP) [1]. The approach was considering final arrival time and night-time charging. The database was about 40,000 vehicles, according to the driving habits in the survey. In this development, once the battery of the PHEV is depleted; the ICE is used for the remainder of the day. In terms of implementation, this is the simplest scenario for users and many drivers.

Previous studies about the impact of PHEVs on the power distribution system have been made using deterministic and stochastic scenarios [3]. When the number of charging stations increases, PHEV is able to have more interactions with the grid [4].

Furthermore, it has explored the possibility of more integration of PHEVs and the grid [5], where the feasibility of using PHEV batteries as the electrical storage device (ESD) is examined to smooth the erratic supply of power from renewable generation devices. When the vehicle is connected into the grid, batteries can absorb the surplus power and supply the power back to the grid when renewable generation decreases.

The advantages and disadvantages of integrating PHEVs are still largely unknown. More PCLPs are needed to estimate the possible impact on the grid. More data and further analysis are needed to determine optimization scenarios and the effects of high penetration of PHEV integration.

1.4. NATIONAL HOUSEHOLD TRAVEL SURVEY (NHTS)

In this work, the transportation data is from the National Household Travel Survey (NHTS), where in a telephone survey, randomly selected drivers are asked some information about their driving habits in a one-day period. Also, information for each individual trip during the day was recorded.

The attributes that are collected and used for this study are VEHTYPE, STARTTIME, ENDTIME, TRVLCMIN, TRPMILES, DWELTIME, HOUSEID, and VEHID, which refer to vehicle type, start time, end time, trip duration (minutes), trip distance (miles), length of rest before the next trip (minutes), and a unique identifier for each household and each vehicle of the household, respectively [3]. The data is in CSV file format. The following criteria and filtering are considered in using the NHTS data:

- Only vehicle types 1-4, Table 1.1, were used because they are available as PHEVs.
- The trip is removed if a value necessary to this model is missing.

The four types of considered vehicles are listed in the Table 1.1[1].

Table 1.1. Vehicle Types

VEHTYPE	Vehicle Name
1	Compact Sedan
2	Mid-Size Sedan
3	Mid-Size SUV
4	Full-Size SUV

1.5. PRIMARY ANALYSIS

The literature review shows that by delaying the evening charge of each vehicle by a couple of hours, load profile peak could be reduced considerably [1]. The time delay scenario spread the energy needed over a longer time by following the staggered arrival times of each vehicle. Some more complicated scheduling procedures could be used instead, but by adding a simple time delay, acceptable results would be achieved. It will not be discussed in detail because this is not the subject of this paper.

Load profile was modeled based on the night time charging profile of each vehicle [1]. In this research, all of the trips during the day were added together and only the total energy use for the day is considered [1], [2]. In fact, this is how most PHEVs currently operate. As more charging stations are installed, PHEV is given more options.

Opportunity charging (OC) is used for PHEVs load profile estimation, where the grid faces a more balanced demand. Opportunity charging (OC) is a kind of charging procedure in which the battery is recharged when the vehicle is stopped during the day. It is assumed that the electrical outlets are available when the vehicles is parked, while the driver is in shopping or at work. It is not a weak assumption, because more charging stations are installed nowadays, and drivers can take the advantage of opportunity charging during the day.

Therefore, opportunity charging can be done at home or any other charging station where the vehicle is parked. It has been proposed that OC can allow a PHEV to obtain fuel savings comparable to a PHEV with a battery 4-5 times its capacity [5], [6]. This estimate raises the importance of location and size of parking lots to charge PHEVs [7].

2. DATABASE STATISTICS

As it was mentioned under Section 1.4, the transportation data in this thesis is extracted from the national household travel survey (NHTS), which is sponsored by United States department of transportation. The objective of NHTS is to help those people who research and work of the transportation section, in order to make rules and regulations, and develop new plans and policies to improve the transportation functionality. In this thesis, all the data used for PHEV models over the years 2001 and 2009, are collected from NHTS database.

Although, this database is not principally arranged for electric vehicles study, it is possible to use NHTS for PHEV load profile calculation. To do so, some attributes of the data survey are collected, and a new database is constructed. In order to have a clear picture of database, this section presents some data analyses of driving habits and related information based on the NHTS data.

2.1. VEHICLE TYPE DISTRIBUTION

The study focuses on four different types of the vehicles, type 1, type 2, type 3, and type 4, which are listed in the Table 1.1. Indeed, in the Table 2.1 the percentages of each type of vehicles are listed. According to this table, the majority of the vehicles is belonged to types 1, which refers to the group of the automobile/car/station/wagon group. This group contains about 60% of the total vehicles used in the modeling.

In terms of AER, there are three common different groups of vehicles, PHEV-20, PHEV-30, and PHEV-40. For instant, PHEV-20 means that the vehicle can able to run 20 miles with electric power.

Table 2.1. Number and percentage of each type of vehicle in NHTS

Vehicle Type	1	2	3	4
Number	25,490	5,073	5,623	6,840
Percentage	59.24%	11.79%	13.07%	15.90%

2.2. TRIP ENDTIME ANALYSIS

ENDTIME, is the time that driver finishes his daily trips, parks the vehicle and does not use it until the next day. It is a logic assumption if it is assumed that battery is plugged into the outlet at ENDTIME. So, the arrival time can play a very critical role in the load profile calculation. ENDTIME attribute was analyzed and summarized it in a graph, where Figure 2.1 shows the arrival pattern for a 24-hour period [1].

Not surprisingly, the peak of ENDTIME is between 4 pm to 10 pm that indicates a tight relation between working hours during the week days and arrival time. It predicts that there would be a high demand of electric power for PHEV battery recharging in this period of time. It is one of the key points in the load profile analyses and vehicle grid interactions, which is named as the negative impact of PHEV on the power grid energy production. This period of time is in common with rush-hours, when generally is starting time for high electricity demand. In this case, the power generation as well as the transmission line is forced for peak power during these hours. This can create instability in electrical energy production section, which directly affects smooth services of the power grid.

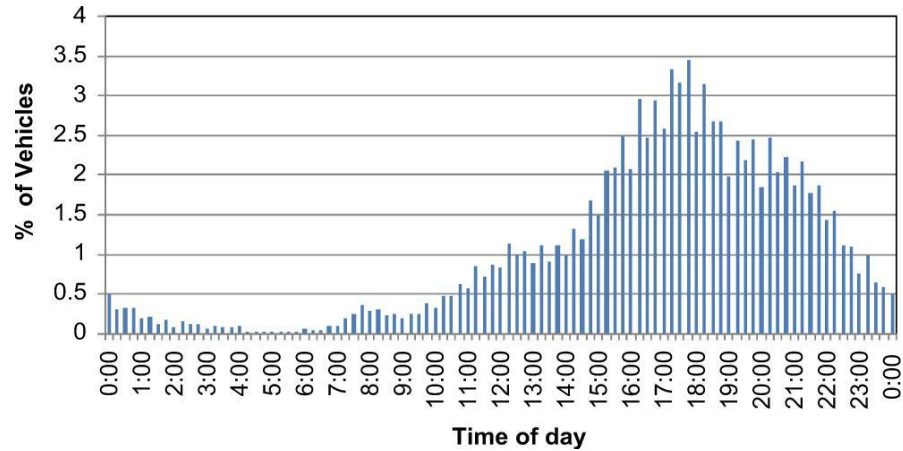


Figure 2.1. Percentage of vehicles versus their final arrival time.

2.3. DAILY MILEAGE

The number of miles that each driver runs the vehicle is another important parameter. In the ENDTIME-charging model, this parameter is more important in comparison with opportunity charging. Since the AER is constant for each particular model of PHEVs, more mileage results in more gas emission. It means that more mileage causes decreasing the PHEV efficiency. In this case, the vehicle uses more gas for remaining distance. This is another point that makes opportunity charging more functional and effective. Figure 2.2 shows the statics of the mileage distribution in the range from 0-5 miles to less than 100 miles. According to Figure 2.2, the majority of the car drivers used the vehicle for the total trip of 25 to 35 miles per day [1].

The red line shows the percentage of the plug-in hybrid electric vehicles that are driven less than a certain mileage during a day. The positive feature of the daily mileage data is that about 55% of the people drive less than 30 miles per day. The fact that the majority of drivers use the vehicle in this range sends a positive signal, showing that most of the cars can be used in electric power mode with only one or two times complete

charging per day. It means opportunity charging, which refers to charging the battery of a plug-in hybrid electric vehicle when it is parked between two trips, can significantly increases driving a vehicle electric mode.

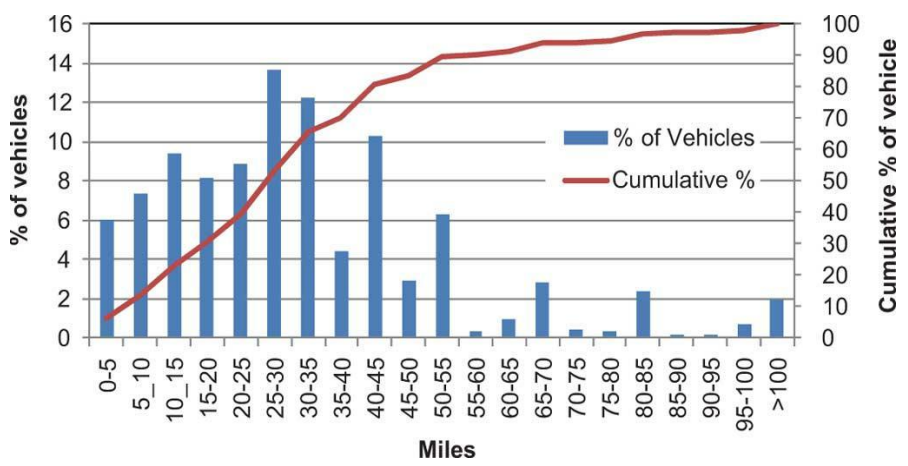


Figure 2.2. Percentage of vehicles versus daily miles driven.

In general, according to the NHTS, the majority of PHEVs have some stop times during their daily trips. For example, a large portion of personal cars are parked during the working hours. Therefore, this kind of charging can potentially decrease negative effects of transportation on environmental parameters, which is one of the basic reason for developing electric vehicles.

3. SOME OTHER IMPORTANT INFORMATION

In this section, charging level, which is one of most important subject related to plug-in hybrid electric vehicles is discussed. In general, there are four common charging level:

1. Standard outlet 110V/15A (normal charging level), 240V/30A (quick charging level)
2. Belgian standard outlets 230V/4 kW
3. EPRI from (Electric Power Research Institute)
4. SAEJ1772 (North America)

Through four charging level, EPRI and SAEJ1772 charging levels are used in the United States. Table 3.1 gives some more important information about these two charging levels [1].

Table 3.1. Charging Levels

level Standard	1	2	3
EPRI-NEC	120 VAC, 15 A (12 A), 1.44 kW	240VAC, 40 A, Single-Phase	480 VAC, Three- Phase, 60 to 150 kW
SAEJ1 772	120VAC, 12 A, Single-Phase, 1.44 kW	208-240 VAC 32 A, 6.66-7.68 kW	208-600 VAC, 400 A, Three-Phase, >7.68 kW

4. FINAL ARRIVAL TIME PCLP CURVES

In this section, the load profile of the plug-in hybrid electric vehicle is presented. The used database is of the year 2001, curves are developed for PHEV-20, PHEV-30, and PHEV-40, and time scaling scenario is used to develop curves for the car types 1, 2, 3 and 4, based on the arrival time.

The database include about 43,000 of four different types of the vehicles. The curves are developed for each type of vehicles separately, and at the end, they are added in order to develop the total curve. This scenario of PCLP calculation helps policy makers and professional planers to make more accurate plans, rules and regulations. Figure 4.1 shows the load profile of car type-1 with three different AERs.

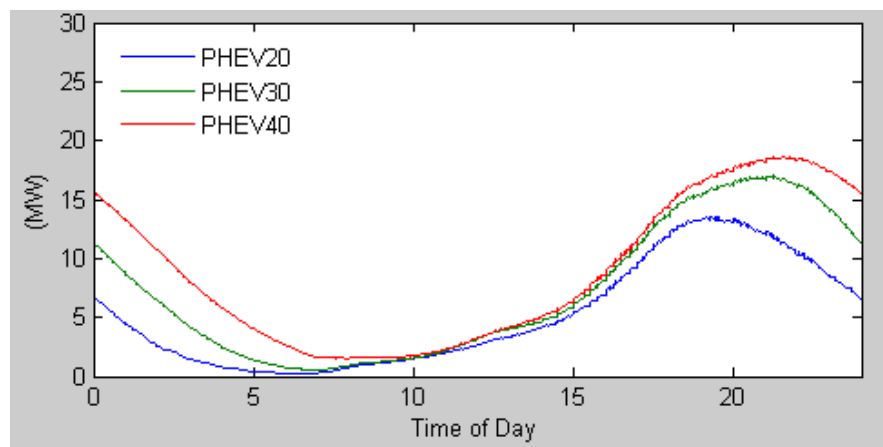


Figure 4.1. Load profile of PHEV- 20, 30, and 40; for car type-1.

The graph demonstrates a peak between 8 pm and 10 pm, which is in the rush-over, when there is a maximum load on the power grid. Apart from that, there is no significant load on the grid, especially during the 5am to 3pm time period.

Indeed, the order of the PHEV's curves, PHEV-40, PHEV-30, and PHEV-20 was expected to be in the existing form, because the battery of vehicle with higher AER need more time, and correspondingly more electrical power compare to the lower AER ones.

Moreover, a part of charging load from the late night continues to the next morning time period. Therefore, although logically no driver plugs the PHEV into the power outlet in the early mornings, there is still a relatively high demand of electric power in order to recharge the battery of vehicles. As is it is expected, this overload decreases, and then finishes between 6 am to 8 am, depending the AER of vehicle.

Figure 4.2 shows the PCLP curves of the vehicle type-2. The number of the vehicle type-2 is less than vehicle type-1; therefore, the level of power demand of this kind of vehicle is lower than the previous one.

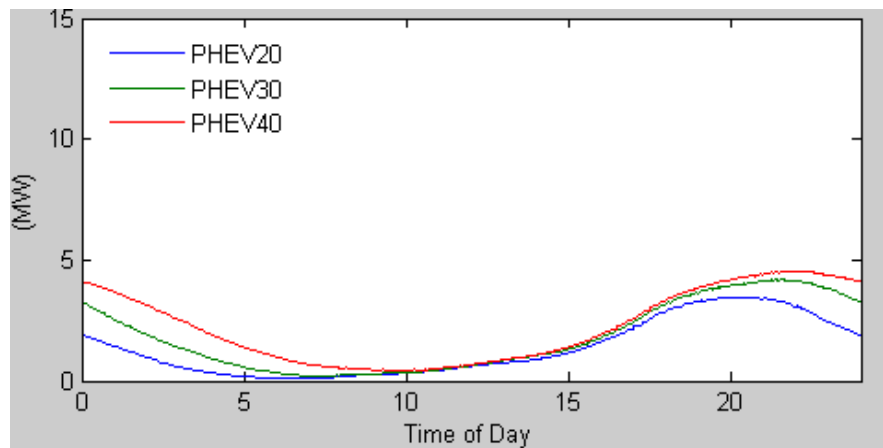


Figure 4.2. Load profile of PHEV- 20, 30, and 40; for car type-2.

Figure 4.3 shows the PCLP curves of the vehicle type-3. The number of the vehicle type-3 is almost as same as vehicle type-2; therefore, the level of power demand of this kind of vehicles is approximately the same.

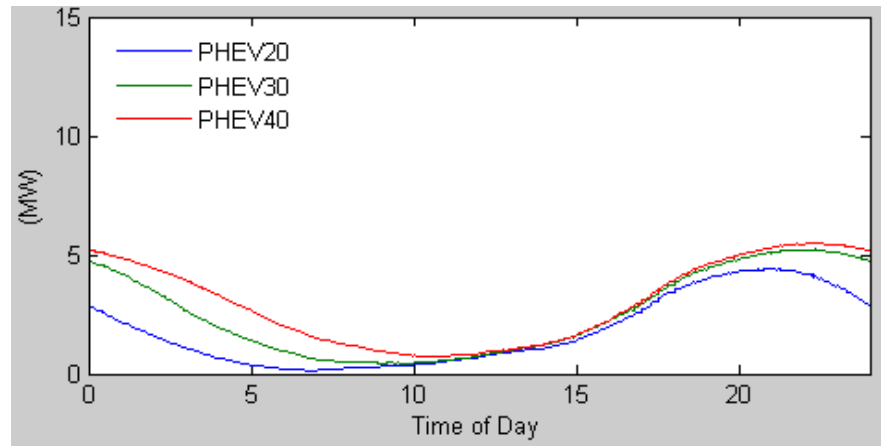


Figure 4.3. Load profile of PHEV- 20, 30, and 40; for car type-3.

The load profile of the vehicle type-4 is shown in the Figure 4.4. As it is expected, the load profile of this type of vehicles behave almost like other car types.

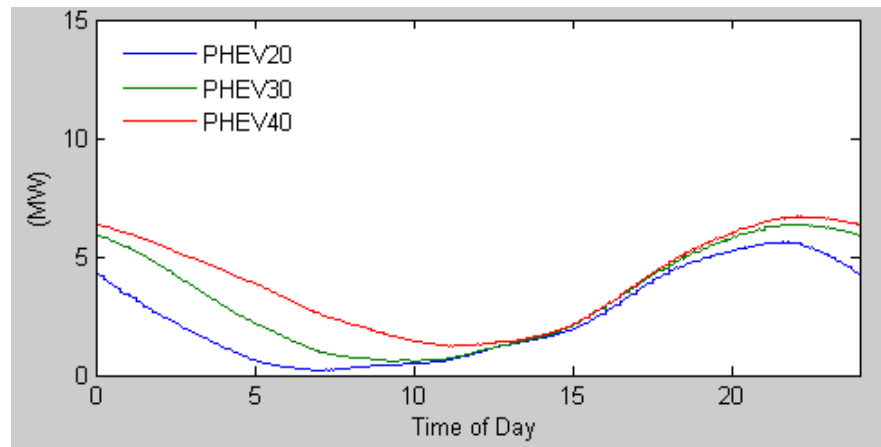


Figure 4.4. Load profile of PHEV- 20, 30, and 40; for car type-4.

There is a slight difference between 6am and 10am, especially for PHEV-40, where the power demand is a little more than other types of PHEVs. In general, all types of the vehicles have approximately the same pattern, in terms of the power demand, and the significant difference is the difference in the number of the vehicles. Figure 4.5 shows the

PCLP curves of all types of the vehicles, where there is a maximum load between 8pm and 11pm. In terms of power demand there are three different parts in the graph.

- a) Between 12am and 5am, where the curve is decreasing dramatically. A large amount of power demand in this region is because of recharging load which continues from the last day to the morning of the next day.
- b) The second part is between 10am to 7pm, where load profile is increasing with a moderate speed.
- c) The third part is between 7pm and 12pm that continues to the next day, where the load is in its maximum values. This is the most important soft point of the load profile model based on the arrival time.

From the power generation view point it is more critical, because a part of this time is in the rush over time, when there is basically a high demand for electricity because of other electric energy consumers.

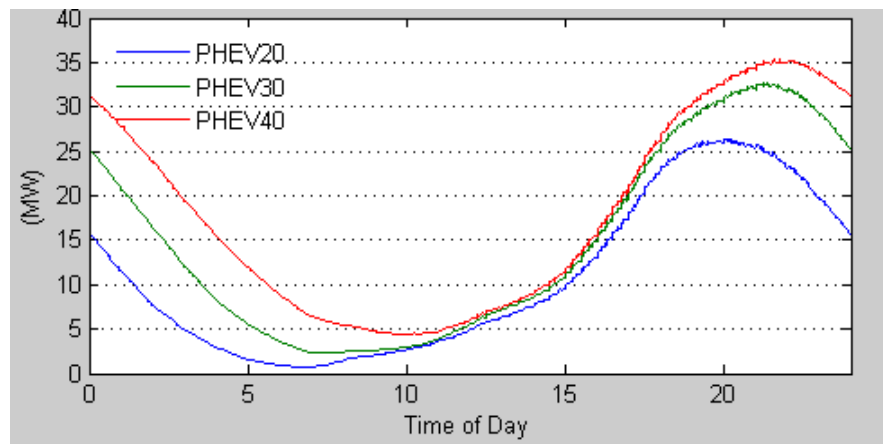


Figure 4.5. Load profile of PHEV- 20, 30, and 40; all types.

5. OPPORTUNITY CHARGING APPROACH

Opportunity charging refers to charging the battery of an electric vehicle once it is parked for any purposes. This scenario of charging can be useful; firstly, because it helps the vehicle drivers to run the car in electric power mode in larger distances compare to arrival time charging style. Secondly, the load on the grid can be decreased, because logically a part of load should be shifted to the peak-off region.

In this section, in order to present PHEV's load profile by using opportunity charging method, the database of the year 2001 from NHTS is used. The curves are developed for PHEV-20, PHEV-30, and PHEV-40. Then, at the end of Section 5.1, the results of arrival scenario (based on time scaling scenario in the last section) and opportunity charging style is compared. In the Section 5.2, the curves are developed for the data of the year 2009.

5.1. DATA OF THE YEAR 2001

Figure 5.1, Figure 5.2, Figure 5.3, and Figure 5.4, illustrate the PHEV's load profiles of four different types of vehicles. All curves have almost the same pattern; however, since the number of vehicles for each type is different, the electric power demand varies for different types of cars. There is a peak between 7pm and 9 pm, and also another one at about 9am, showing a three-hour shifting in the maximum power demand. All curves show almost a flat load profile during the 9am to 9pm time period. Figure 5.5 compares the curve of different types of vehicles, and finally Figure 5.6 shows the load profile of whole cars by using opportunity charging method.

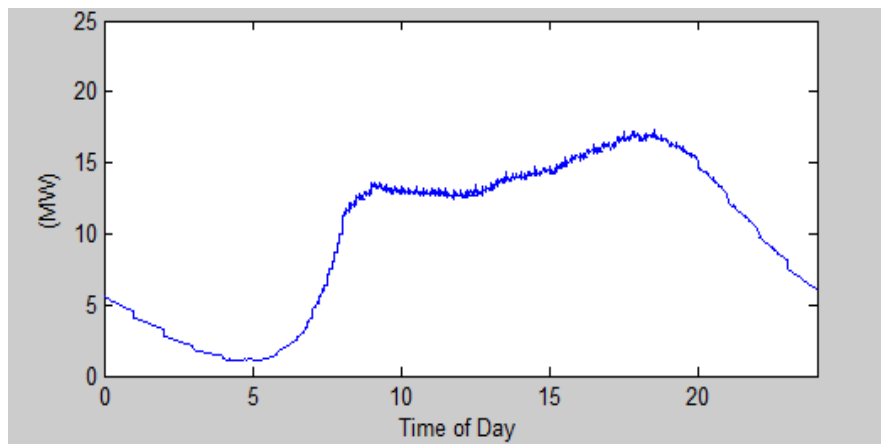


Figure 5.1. Load profile of PHEV- 20; car type-1.

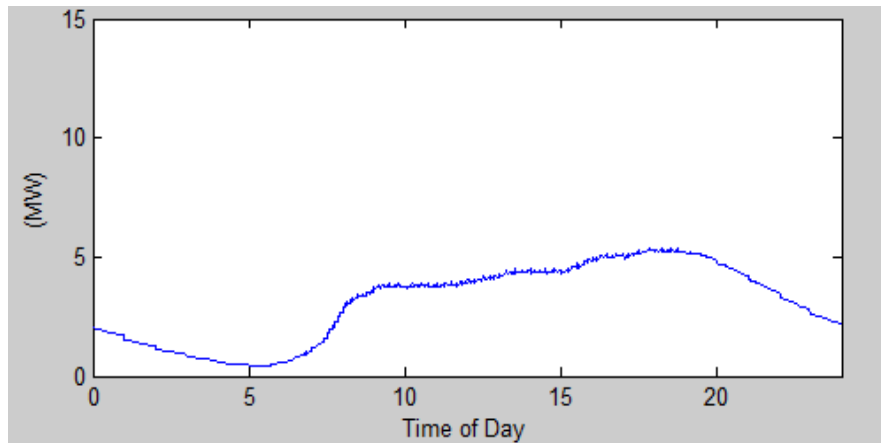


Figure 5.2. Load profile of PHEV- 20, and 40; car type-2.

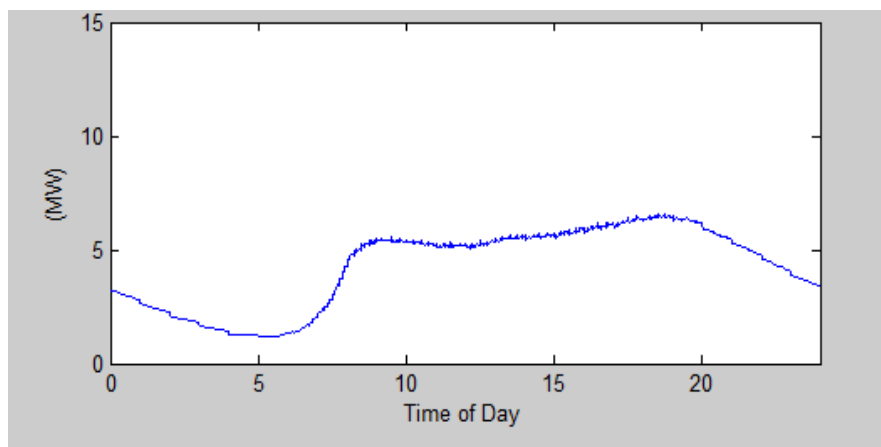


Figure 5.3. Load profile of PHEV- 20; car type-3.

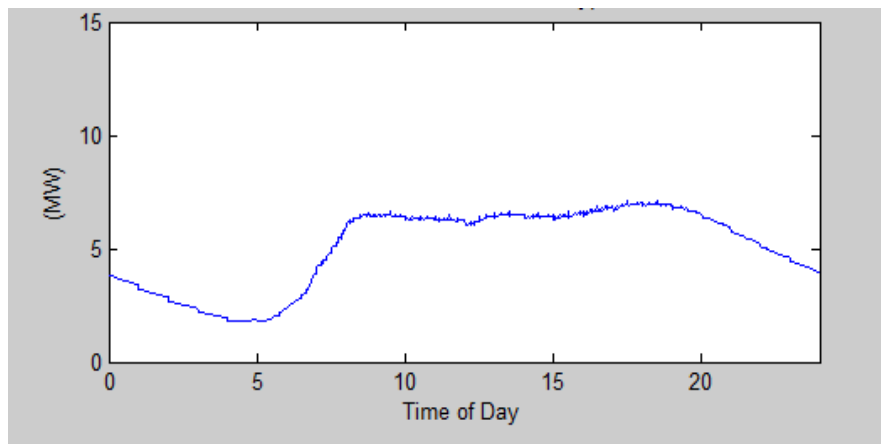


Figure 5.4. Load profile of PHEV- 20; car type-4.

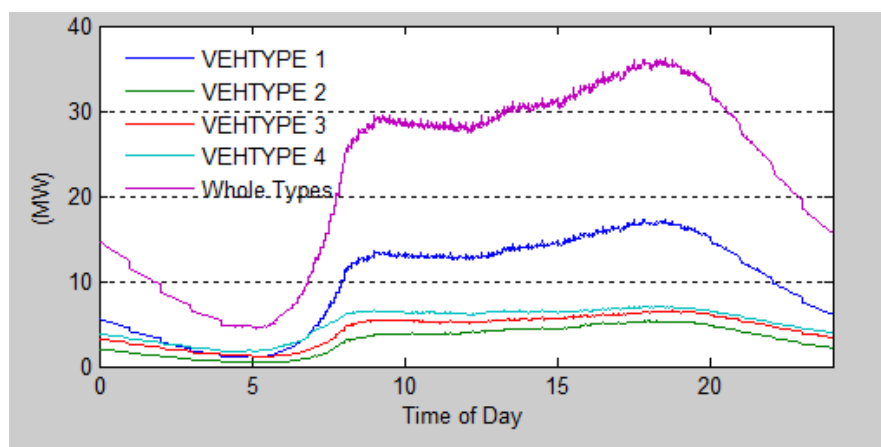


Figure 5.5. Load profile of PHEV- 20; all car types.

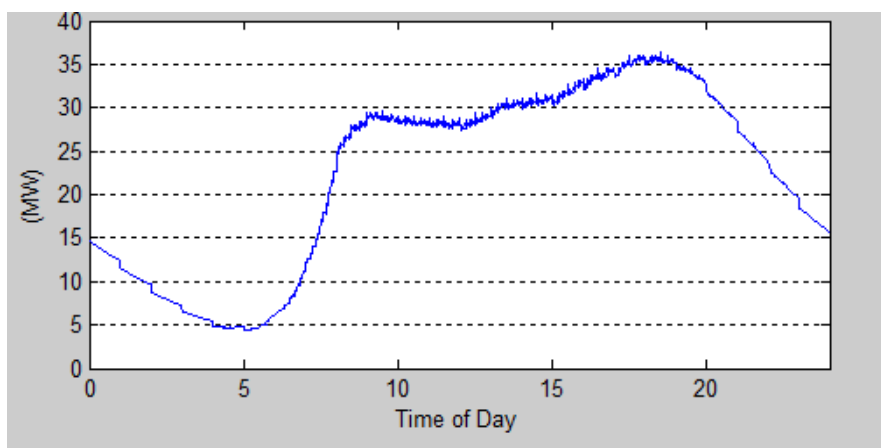


Figure 5.6. Load profile of PHEV- 20; all car types.

5.2. COMPARING THE RESULTS OF THE TWO SCENARIOS

In this section, the results of the arrival time load profile calculation method, based on time scaling and opportunity charging styles, for the data of the year 2001 are compared. Figure 5.7, Figure 5.8, Figure 5.9, and Figure 5.10 compare the PHEV's load profiles of four different types of vehicles, using opportunity and arrival time scenarios. Generally, these comparisons show that the opportunity charging model is a more efficient way in order to charge the battery of the electric vehicles. The figures clearly show, in opportunity model, vehicle is able to use more electric power compare to the arrival time load profile calculation method.

Figure 5.11 illustrates the total curve for all types of vehicles, but with different AERs. Not surprisingly, cars with larger AER use more eclectic power compare to the lower AER ones. In the following figures TO and ECH represents opportunity charging and arrival time scenarios, respectively.

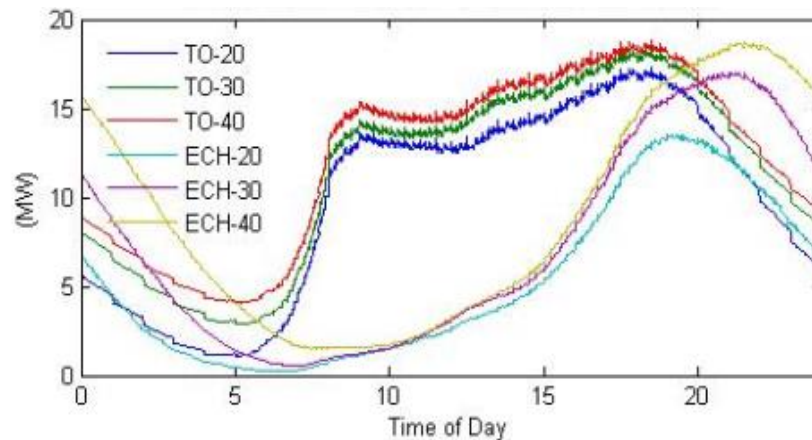


Figure 5.7. Comparing load profile of PHEV-20, 30, 40; w/ and w/o OC; car type-1.

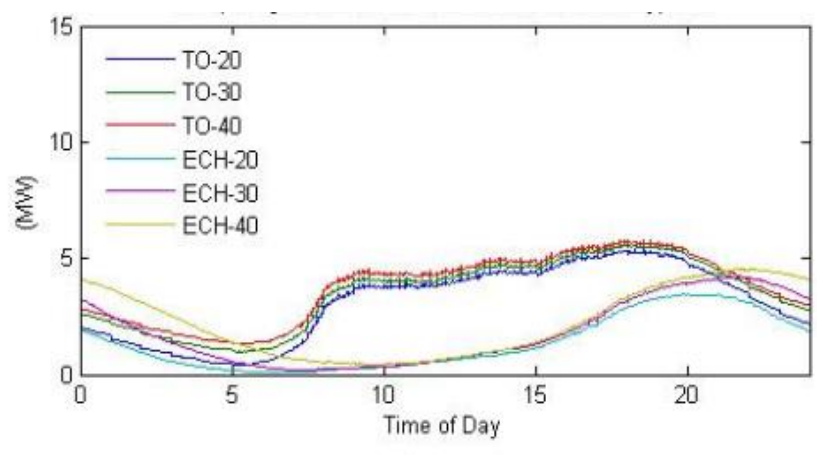


Figure 5.8. Comparing load profile of PHEV-20, 30, 40; w/ and w/o OC; car type-2.

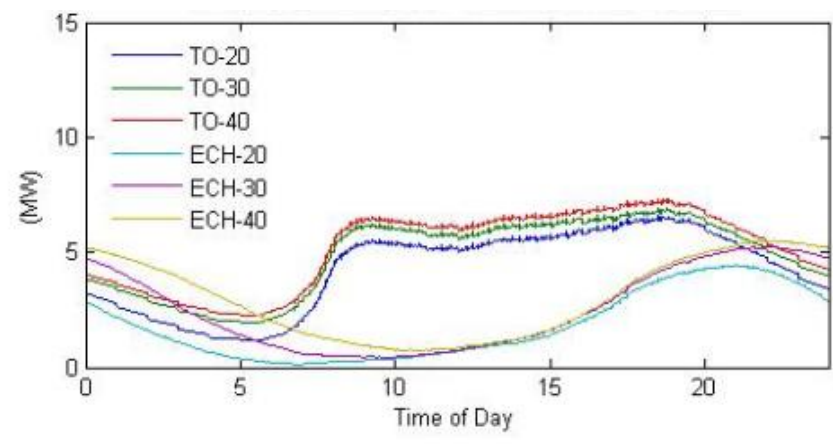


Figure 5.9. Comparing load profile of PHEV-20, 30, 40; w/ and w/o OC; car type-3.

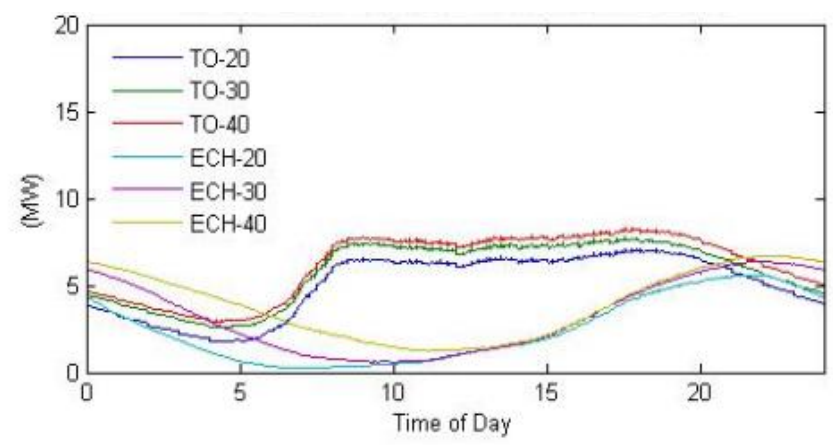


Figure 5.10. Comparing load profile of PHEV-20, 30, 40; w/ and w/o OC; car type-4.

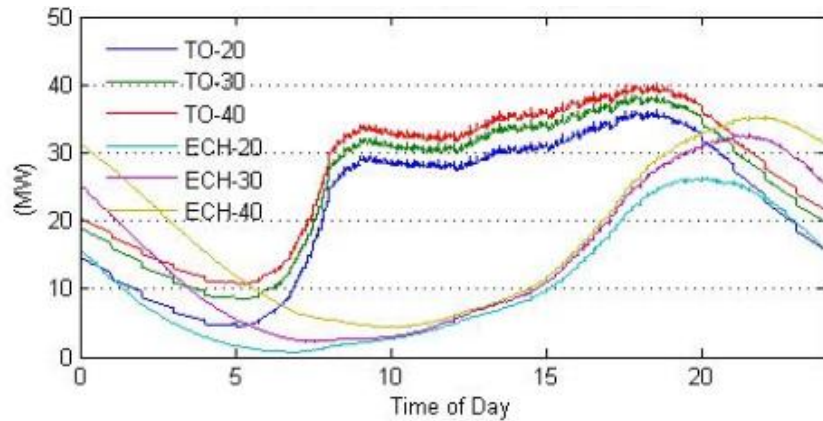


Figure 5.11. PHEV-20, 30, 40 load profile comparing; w/ and w/o OC, all car types.

5.3. PHEV LOAD PROFILES OF THE YEAR 2009

In this section, opportunity scenario is used for data of the year 2009. Figure 5.12, Figure 5.13, Figure 5.14., and Figure 5.15, show the load curves for different types of vehicles, and Figure 5.16 illustrate the total curve, representing the total power demand of all types of cars. Also, Figure 5.17 compares the load profiles of electric vehicles between the years 2001 and 2009. The comparison shows that in the year 2009, vehicles averagely use more electrical power compare to the year 2001.

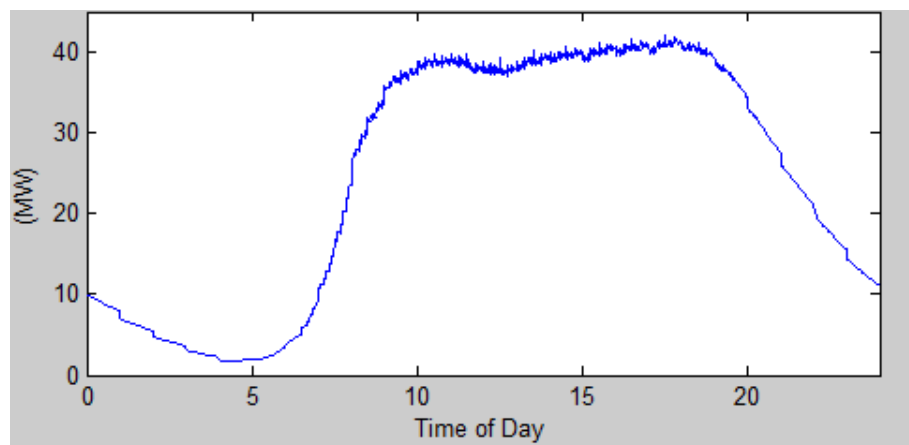


Figure 5.12. Load profile of PHEV-20; car type-1, year 2009.

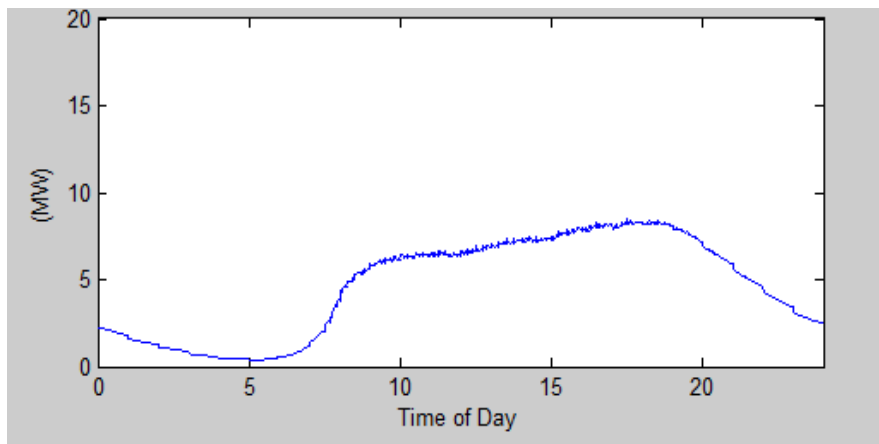


Figure 5.13. Load profile of PHEV-20; car type-2, year 2009.

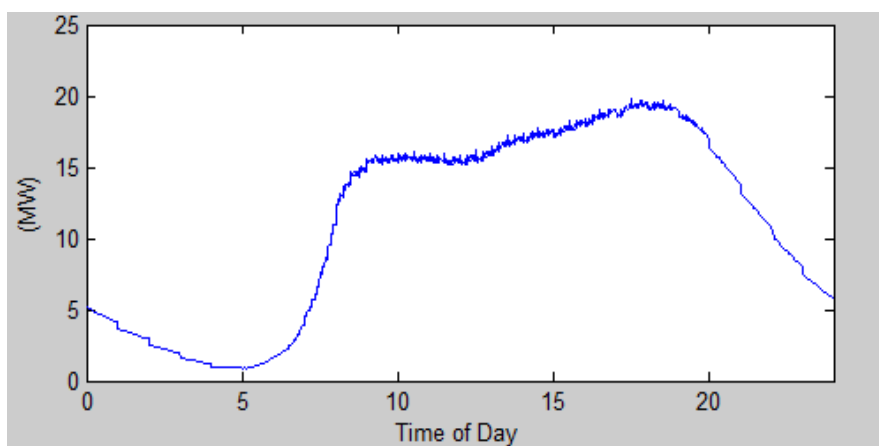


Figure 5.14. Load profile of PHEV-20; car type-3, year 2009.

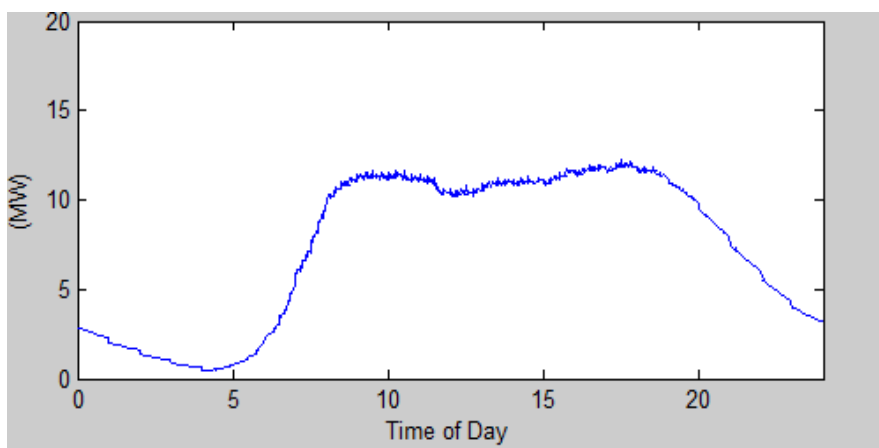


Figure 5.15. Load profile of PHEV-20; car type-4, year 2009.

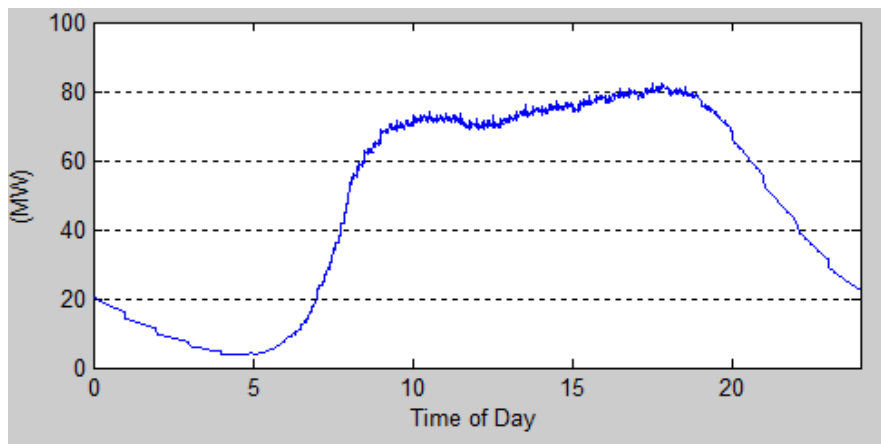


Figure 5.16. Load profile of PHEV-20; all car types, year 2009.

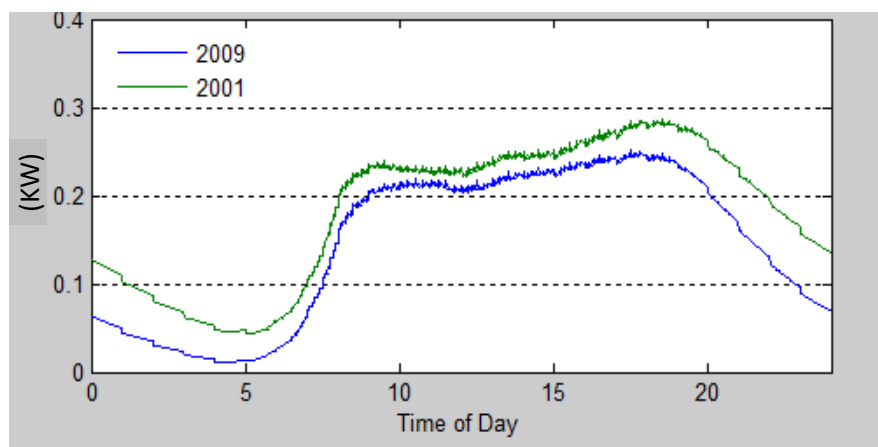


Figure 5.17. PHEV-20 load profile comparing; between years 2001 and 2009.

6. CONCLUSION

In this thesis, by using data of the national households travel survey (NHTS), the load profile of plug-in hybrid electric vehicle (PHEV) has been developed based on two different styles. To do so, arrival time and opportunity charging approaches, with the purpose of examining the effect of plug-in hybrid electric vehicles on the electricity demand profile have been employed.

It was found that opportunity method, in comparison with arrival time approach, suggests a more balance profile. By using opportunity method, the load profile covers almost all hours of day-time, which means drivers use more electric power, in comparison with arrival time mode. The peak power demand of the PHEV's load profile decreases slightly and apart from the evening rush over, another maximum appears in the morning.

Since the database includes most parts of the United States, it seems that the models can predict a clear picture of transportation electrification process and its effects on power production interaction stability and transmission line. Therefore, opportunity charging is suggested as a strong scenario for PHEV's load profile examination, and measuring vehicle-to-grid interaction.

SECTION

2. CONCLUSION

Opportunity charging and arrival time models have been developed for the load profile of plug-in hybrid electric vehicle (PHEV) analyses. This both models allow investigation of vehicle-to-grid interaction, which can present a clear picture of transportation electrification.

Comparing the results of two models shows that opportunity charging approach is able to offer a more efficient recharging process, resulting in less petroleum consumption, more opportunity of using renewable energy resources, and less negative impact on environment. Indeed, opportunity charging decrease the peak power on the grid in peak time, and as a result, better network stability and efficient way of using transmission line. The future work can continue by policy making, economic and environmental analysis of both models, including power grid production and grid stability viewpoints.

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VITA

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