Plug-in Hybrid Electric Vehicle in Smart Grid

Yin Yao

University of Denver

Follow this and additional works at: https://digitalcommons.du.edu/etd

Recommended Citation

https://digitalcommons.du.edu/etd/723

This Thesis is brought to you for free and open access by the Graduate Studies at Digital Commons @ DU. It has been accepted for inclusion in Electronic Theses and Dissertations by an authorized administrator of Digital Commons @ DU. For more information, please contact jennifer.cox@du.edu,dig-commons@du.edu.
PLUG-IN HYBRID ELECTRIC VEHICLES
IN SMART GRID

A Thesis
Presented to
The Faculty of Engineering and Computer Science
University of Denver

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by Yin Yao
November 2012
Advisor: David Wenzhong Gao
ABSTRACT

In this thesis, in order to investigate the impact of charging load from plug-in hybrid electric vehicles (PHEVs), a stochastic model is developed in Matlab. In this model, two main types of PHEVs are defined: public transportation vehicles and private vehicles. Different charging time schedule, charging speed and battery capacity are considered for each type of vehicles. The simulation results reveal that there will be two load peaks (at noon and in evening) when the penetration level of PHEVs increases continuously to 30% in 2030. Therefore, optimization tool is utilized to shift load peaks. This optimization process is based on real time pricing and wind power output data. With the help of smart grid, power allocated to each vehicle could be controlled. As a result, this optimization could fulfill the goal of shifting load peaks to valley areas where real time price is low or wind output is high.
Acknowledgment

Thanks to my thesis advisor, Dr. Wenzhong Gao. Without his advice and encouragement, this thesis project can not be accomplished.
Abbreviations

MPG “Mile per Gallon”
HEV “Hybrid Electric Vehicle”
PHEV “Plug-in Hybrid Electric Vehicle”
V2G “Vehicle to Grid”
SOC “State of Charge”
EDC “Electric Driving Capacity”
List of Figures

Figure 2.1.1 Three times of bus load simulation .............................................................. 11
Figure 2.1.2 Electric bus load curve in small scale.......................................................... 11
Figure 2.1.3 Load curve of public transportation vehicles in small scale....................... 16
Figure 2.2.1 Private vehicle load curve in small scale.................................................. 21
Figure 2.3.1 Separate PHEV load curve ....................................................................... 24
Figure 2.3.2 Subtotal PHEV load curve ....................................................................... 25
Figure 2.4.1 Flow chart of load curve prediction in large scale ...................................... 31
Figure 2.4.2 Load curve prediction in 2017 and 2020 ................................................. 32
Figure 2.4.3 Load curve prediction in 2020 and 2030 ................................................... 33

Figure 3.1.1 Reference regional price curve .................................................................. 35
Figure 3.1.2 Optimized bus load curve ........................................................................ 37
Figure 3.1.3 Optimized taxi load curve ......................................................................... 38
Figure 3.1.4 Optimized load curve for 3 types of vehicles ........................................... 39
Figure 3.1.5 Subtotal optimized load curve according to real-time pricing ................. 40
Figure 3.2.1 Wind power output curve on 1/1/2011 ..................................................... 42
Figure 3.2.2 Optimized load curve with both wind and reference regional price .......... 44
List of Tables

Table 2.1.1 BYD Electric bus parameters ................................................................. 7
Table 2.1.2 Time schedule for electric bus ............................................................... 8
Table 2.1.3 BYD e6 parameters ............................................................................ 13
Table 2.1.4 Time schedule for taxi ..................................................................... 14
Table 2.2.1 BYD S6DM Hybrid SUV parameters ................................................ 18
Table 2.2.2 Time schedule for private vehicle .................................................... 20
Table 2.4.1 Amount of PHEVs in 2017, 2020 and 2030 ...................................... 29
Chapter 1: Introduction

1.1 Background

After a new round of petroleum price increase, almost every aspect of our daily life is affected. For instance, the traveling cost of automobile and plane grows apparently. Consequently, cost of all kinds of merchandise increases. For every vehicle owner, more attention is paid to fuel efficiency to save cost on gasoline. As a result, the MPG (miles per gallon) value becomes an important criterion for customers who plan to purchase a new car. Commonly, for internal combustion engine vehicles, high MPG value usually means lower engine displacement, slow acceleration or compact size. To better utilize power from internal combustion engine, extra battery packs and electric motor are installed in hybrid electric vehicles (HEV). These battery packs’ capacity is much larger than that of current vehicle. They also get charged while internal combustion engine is working like normal vehicles. But, large capacity means it not only could power the air conditioner system, but also the electric motor for normal running. Less gasoline consumption also means less pollution to environment. This type of vehicles possesses two engines, combustion engine and electric motor. But all power comes from gasoline. This type of HEV is called conventional hybrid electric vehicle.
As to conventional hybrid electric vehicles, the most popular one should be Toyota Prius. Prius is the first type of hybrid vehicle that put into large-scale production in 1997. In 2001, Prius was sold to over 40 countries all over the world. Her largest market now is the United States. The success of Prius reveals a bright future for hybrid electric vehicles. Hybrid electric vehicles have two or even more energy sources. For Prius, they are combustion engine and electric motor. Other energy sources, such as hydrogen and fuel cell battery, are also options in future. Compared to hybrid electric vehicles, they are still in research stage. In recent years, engineers are trying to install more battery packs in hybrid electric vehicles and let these batteries be charged from the grid with the help of on/off board charger. This new type of hybrid electric vehicle is called Plug-in Hybrid Electric Vehicle (PHEV). In next two decades, it is hoped that automobiles will continuously become independent of petroleum, and PHEVs will replace conventional combustion engine vehicles gradually.

That oil resource is going to be exhausted is part of the reason. Besides, greenhouse gas output from combustion-engine vehicles is a serious threat to the environment, especially to the Atmosphere. Global warming is the most harmful phenomenon due to carbon gas output. Pure electric vehicle does not generate any carbon dioxide. They are friendlier to environment than conventional ones. If electricity is from renewable energy power plant, the output of carbon dioxide could be further decreased. There have been many studies about PHEVs’ impacts on current power grid. These can be classified as vehicle performance studies, supply adequacy, Vehicle to Grid (V2G)
studies and distribution system impact studies. This project is focused on large-scale PHEVs’ integration into power grid as charging loads and potential effects for the operation of the grid.

1.2 Methods and tools

Even if studies about PEV are popular, there are still two main drawbacks in PHEVs’ population: cost of large capacity battery and lack of charging station. Firstly, a large-capacity battery certainly means additional cost, weight and size. For instance, the cost of battery is about $1,700 per kWh [1]. Chevy Volt is a new type of PHEV which is available in market. An 8-kWh battery is installed on it. So, for Chevy Volt, only the battery cost is $13,600.

Recharging battery outside home is another problem. Public charging station and battery swap center are two options. But both of them are only in plan yet. Not available in most cities. So, current PHEV is designed to use gasoline when battery is exhausted for long distance driving. The electricity-only mileage for current PHEV is about 35 miles. And, a fully charge takes 10 hours at home [3]. If distance is more than 35 miles, current PHEV has to rely on gasoline like normal vehicles until they arrive at destination.
In conclusion, Current PHEVs are only suitable for short-distance commuting. Besides, their retail price is much higher than that of normal compact vehicles. So, the only way to analyze long-distance pure electric vehicles’ impact on the grid is simulation. Stochastic modeling method is introduced to simulate PHEVs’ load to the grid under different penetration levels. In stochastic approach, charging characteristics should be generated by probabilistic distribution of variables, such as State of Charge (SOC), vehicle arrival and departure time and battery full-charge time.

After the simulations in small scale, model is re-modified for large-scale simulation. Result from large-scale simulation shows that two load peaks would appear due to PHEVs’ charging and have a huge effect on the grid. So, the optimization process is necessary for the following three reasons.

1. Peak load shifting
2. Frequency and voltage stability
3. Utilization of renewable energy

After the optimization considering real-time pricing and wind power output data, charging schedules for both public and private vehicles is better organized. All of the calculations were run on Intel(R) Core(TM) i7-2760 QM CPU @ 2.40 GHz, 8.00 GB RAM, Microsoft 64 bit Windows 7 OS and Matlab 2008a.
Chapter 2: Stochastic Modeling for PHEVs

Charging patterns for PHEVs are affected by many factors, such as battery capacity, arrival, departure time and charging speed. So, it is better to define different charging patterns according to vehicle’s function. In this thesis, all PHEVs are categorized into two types: public transportation vehicles and private vehicles.

2.1 Public transportation vehicles charging pattern

Public transportation plays a more and more indispensible role in traffic system. Therefore, this portion of traffic system should not be omitted even public buses do not constitute significant share of all vehicles in many cities in the United States.

BYD electric bus is selected as the model because its electric driving capacity (EDC) is suitable for daily public bus operation. EDC is the miles that a PHEV could drive from battery electricity only, when its initial battery’s state of charge is 100 percent. EDC of BYD electric bus is 155 miles in urban condition. Average daily mileage for normal transportation bus is about 90 to 125 miles [2]. So, electric bus is capable for a whole day operation without needing to be charged based on the EDC. However, safety factor must be taken into consideration. Deeply discharging battery would also harm its
life. So, charging two times a day is essential. For school bus, daily mileage would be only one third of that of normal bus. Normal bus’s operation hour begins at around 5:30 am and ends at 10:00 pm [2]. In rush hours, almost twice buses should be added to fleet. Commuting hour is 6:30 to 9:00 and 16:30 to 7:00 [6]. In commuting hour, time interval between two bus trips is 5~7 minutes. In contrast, time interval increases to 10 to 15 minutes in normal operation hour.

The first charging period begins at about 10 am and ends at 4:30 pm between two commuting-hour periods. Since the charging time is quite limited. Three phase charger, C100D, is used for this charging period. The power for C110D is 100 kW. It takes three hours for the on-board batteries to be fully charged [3]. Another charging period begins at 11:00 pm and ends at 5:30 am. One hour is reserved for daily preparation and dispatch. There is enough charging time at night. Thus, in night, C60, 60kW three phase charger is used instead of C100D and the full-charge time is extended to 5 hours [3].
<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Length</th>
<th>39.37 ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Width</td>
<td>100.4 in</td>
</tr>
<tr>
<td></td>
<td>Height</td>
<td>126.0 in</td>
</tr>
<tr>
<td></td>
<td>Wheelbase</td>
<td>20.34 ft</td>
</tr>
<tr>
<td></td>
<td>Track (F/R)</td>
<td>82.5/72.4 in</td>
</tr>
<tr>
<td></td>
<td>Curb weight</td>
<td>30423.79 lb</td>
</tr>
<tr>
<td></td>
<td>GVWR</td>
<td>39683.21 lb</td>
</tr>
<tr>
<td></td>
<td>Seats</td>
<td>27+4 (foldable) +1 (driver)</td>
</tr>
<tr>
<td></td>
<td>Wheelchair position</td>
<td>2</td>
</tr>
<tr>
<td>Performance</td>
<td>Top speed</td>
<td>62.1 mph</td>
</tr>
<tr>
<td></td>
<td>Urban conditions</td>
<td>&gt;= 155 mi</td>
</tr>
<tr>
<td></td>
<td>Power consumption</td>
<td>120 kWh per 62 mi</td>
</tr>
<tr>
<td></td>
<td>Turning radius</td>
<td>&lt;40 ft</td>
</tr>
<tr>
<td></td>
<td>Min ground clearance</td>
<td>5.5 in</td>
</tr>
<tr>
<td></td>
<td>Approach/Departure angle</td>
<td>7 degrees/7 degrees</td>
</tr>
<tr>
<td>Chassis</td>
<td>Suspension</td>
<td>Front &amp; rear self-levering air suspension, ECAS system</td>
</tr>
<tr>
<td></td>
<td>Brakes</td>
<td>Front &amp; rear disc-braking. ABS+ASR</td>
</tr>
<tr>
<td></td>
<td>Steering</td>
<td>ZF8098 Electric hydraulic power steering gear</td>
</tr>
<tr>
<td></td>
<td>Tires</td>
<td>Michelin 275/70R22.5</td>
</tr>
<tr>
<td>Motor</td>
<td>Type</td>
<td>Permanent magnet synchronous motor</td>
</tr>
<tr>
<td></td>
<td>Max power</td>
<td>160 kW</td>
</tr>
<tr>
<td></td>
<td>Rated power</td>
<td>110 kW</td>
</tr>
<tr>
<td></td>
<td>Max torque</td>
<td>450Nm</td>
</tr>
<tr>
<td>Battery</td>
<td>Type</td>
<td>Fe battery</td>
</tr>
<tr>
<td></td>
<td>Capacity</td>
<td>600 Ah</td>
</tr>
<tr>
<td>Charging equipment</td>
<td>C100D</td>
<td>three phase 480 plus/minus 10% charge voltage, 100 kW</td>
</tr>
<tr>
<td></td>
<td>Charge time</td>
<td>3h</td>
</tr>
<tr>
<td></td>
<td>C60</td>
<td>three phase 208 plus/minus 10% charge voltage, 60 kW</td>
</tr>
<tr>
<td></td>
<td>Charge time</td>
<td>5h</td>
</tr>
<tr>
<td>Floor plan</td>
<td>Seats: 27 Seats + 4 Foldable + 1 Driver</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.1.1 BYD Electric bus parameters [3]
The starting state of charge (SOC) is assumed to follow a statistical normal distribution. SOC indicates the percentage of energy that remains in the battery. For example, Cap is the capacity for vehicle’s battery, the remaining energy in that battery is Cap*SOC. The battery capacity needed to be charged is Cap - Cap*SOC = Cap *(1-SOC).

For electric buses, when they come back to charging station, their SOC is generated according to equation (1). The expected average state of charge is set to 50% considering safety factor and life of battery. The standard deviation is set to 10%. Other parameters about time schedule for electric bus are summarized in Table 2.1.2.

\[
SOC^m_{\text{Bus}} = \text{random}(\text{norm}, \mu, \sigma) \\
\mu_{\text{Bus}} = 0.5 \\
\sigma_{\text{Bus}} = 0.1
\]

<table>
<thead>
<tr>
<th>Bus</th>
<th>Average daily mileage</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation time</td>
<td>5:30-6:00 to 22:00-23:00</td>
<td></td>
</tr>
<tr>
<td>Peak periods</td>
<td>6:30-9:00</td>
<td>Commuting hour</td>
</tr>
<tr>
<td></td>
<td>16:30-18:30</td>
<td></td>
</tr>
<tr>
<td>Interval</td>
<td>3-5 minutes</td>
<td>Commuting hour</td>
</tr>
<tr>
<td></td>
<td>7-8 minutes</td>
<td>Normal</td>
</tr>
<tr>
<td>Mileage capacity</td>
<td>155 miles</td>
<td></td>
</tr>
<tr>
<td>Charging times</td>
<td>2 times a day</td>
<td>Take safety factor into consideration</td>
</tr>
<tr>
<td>Charging periods</td>
<td>10:00-16:30</td>
<td>Day time</td>
</tr>
<tr>
<td></td>
<td>23:00-5:30</td>
<td>Night time</td>
</tr>
<tr>
<td>Starting SOC</td>
<td>Normal distribution N (0.5, 0.1)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.1.2 Time schedule for electric bus
The arrival and departure time are also assumed to follow normal distribution. And the standard deviation is set to 45 minutes considering different arrival and departure times for different bus lines. Note that in one day, there are 1440 minutes. \( AT_{am}^m \) means the arrival time in am for the \( m \)-th electric bus in array. \( AT_{am}^m \) follows normal distribution, with a mean value of 600, corresponding to the 600th minute in 1440 minutes within a day. In other words, the average arrival time is 10:00 am (600/60) after morning commuting hour. Standard deviation is assumed to be 45 minutes. \( DT_{am}^m \) is the departure time for \( m \)-th bus in am. \( AT_{pm}^m \) and \( DT_{pm}^m \) are arrival and departure time in pm.

\[
AT_{am}^m = \text{random('norm',} 600, 45) \tag{3}
\]

\[
DT_{am}^m = \text{random('norm',} 990, 45) \tag{4}
\]

\[
AT_{pm}^m = \text{random('norm',} 1380, 45) \tag{5}
\]

\[
DT_{pm}^m = \text{random('norm',} 1440 + 330, 45) \tag{6}
\]

In day time, \( m \)-th electric bus needs \( Tc_{am}^m \) minutes for its battery to be fully charged. In night time, \( Tc_{pm}^m \) minutes are needed. \( CS_{100kW} \) and \( CS_{60kW} \) are the charging speed for 100kW and 60 kW charger respectively. The unit for charging speed is percents per minute.

\[
Tc_{am}^m = (1 - SoC^m) / CS_{100kW} \tag{7}
\]

\[
Tc_{pm}^m = (1 - SoC^m) / CS_{60kW} \tag{8}
\]
The maximum charging time for \( m \)-th electric bus in day or night time is the time period between arrival and departure time. If \( m \)-th bus’s battery is fully charged before departure, the actual charging time is \( T_{c}^m \) (full-charge time for \( m \)-th bus’s battery). On the other hand, if the battery could not get fully charged before departure, the actual charging time would be \((DT^{m} - AT^{m})\) (time period between arrival and departure time). Therefore, the actual charging time for \( m \)-th electric bus is the minor value between full-charge time and maximum charging time.

\[
\text{Actual charging time} = \min[T_{c}^m, (DT^{m} - AT^{m})]
\]  

(9)

Other simulation requirements are

1. State of charge (SOC) \( \geq 0 \)

2. Departure time > Arrival time

All these parameters are input and simulation are run three times, From Fig 2.1.1. It can be easily figured out that the contours of load curves are similar. But, there are some slight differences between each time. The daytime peak lies at around 11:00 am. The nighttime one is at about 0:00 am. Daytime peak load is higher than night one by about 2400 kW.
Figure 2.1.1 Three times of bus load simulation

One sample from these three is selected as the result for electric bus charging load. The small-scale simulation size is 200 buses. From results in Figure 2.1.2, the day time peak is 14.3 MW at 10:49 am. Daytime peak is higher than night one by 2720 kW.

Figure 2.1.2 Electric bus load curve in small scale
Taxis are also a considerable part in urban transportation system, especially in highly-developed modern city, because parking is always a difficult problem in downtown area. Taxi become the first choice for many people if they not want to spend too much time in finding a parking lot or spend too much on parking fee.

Taxis’ daily mileage is about 217~310 miles [4]. Operation time for most of the taxis is 24 hours. But driver may change shifts. BYD e6 has been operated as taxi in Shenzhen, China, in small scale. So, it is chosen as the model of taxi. Its EDC is 186.4 miles [5]. Considering taxi’s long daily mileage, two times of charging in one day is necessary. Since the difference between commuting hour and normal hour is not quite obvious for taxi drivers, they may choose to charge battery when they have lunch break or they make shifts at mid night. As a result, the first charging period is from 11:30 am to 2:00 pm. Another charging period is from 2:00 am to 4:00 am at night time when they give taxi to another driver. Charger for both time periods must be fast three-phase charger. Parameters for taxi charging load simulation are listed in Table 2.1.4.
<table>
<thead>
<tr>
<th>Items</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dimensions &amp; Weight</strong></td>
<td><strong>Parameters</strong></td>
</tr>
<tr>
<td>L/W/H (Unload)</td>
<td>4560/1822/1630 (mm) 179.5/71.7/64.2 (in.)</td>
</tr>
<tr>
<td>F/R Overhan</td>
<td>920/810 (mm) 36.2/31.9 (in.)</td>
</tr>
<tr>
<td>Wheelbase</td>
<td>2830 (mm) 111.3 (in.)</td>
</tr>
<tr>
<td>Track (F/R)</td>
<td>1556/1558 (mm) 61.3/61.3 (in.)</td>
</tr>
<tr>
<td>Min ground clearance</td>
<td>1388 (mm) 5.4 (in.)</td>
</tr>
<tr>
<td>Min turning diameter</td>
<td>11 (m) 36.1 (ft)</td>
</tr>
<tr>
<td>Curb weight</td>
<td>23600 (kg) 5202.9 (lb)</td>
</tr>
<tr>
<td>Tire</td>
<td>225/65 R17</td>
</tr>
<tr>
<td><strong>Performance</strong></td>
<td><strong>Parameters</strong></td>
</tr>
<tr>
<td>Top speed</td>
<td>140 (km/h) 87.0 (mph)</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td><strong>Parameters</strong></td>
</tr>
<tr>
<td>Urban range</td>
<td>300 (km) 186.4 (mi)</td>
</tr>
<tr>
<td><strong>Motor</strong></td>
<td><strong>Parameters</strong></td>
</tr>
<tr>
<td>Max power</td>
<td>75 (kW) 100.6 (hp)</td>
</tr>
<tr>
<td>Max torque</td>
<td>450 (N<em>m) 332.1 (ft</em>lb)</td>
</tr>
<tr>
<td><strong>Suspension &amp; Steering</strong></td>
<td><strong>Parameters</strong></td>
</tr>
<tr>
<td>Front</td>
<td>Dual wishbone and independent suspension</td>
</tr>
<tr>
<td>Rear</td>
<td>Dual wishbone and independent suspension</td>
</tr>
<tr>
<td>Steering system</td>
<td>EHPS</td>
</tr>
<tr>
<td><strong>Recharge System</strong></td>
<td><strong>Parameters</strong></td>
</tr>
<tr>
<td>BYD C100D charger &amp; discharger</td>
<td>Power 100 (kW)</td>
</tr>
<tr>
<td>BYD C60 DC charger</td>
<td>Time 40 (min)</td>
</tr>
<tr>
<td>BYD C10 DC charger</td>
<td>Power 60 (kW)</td>
</tr>
<tr>
<td></td>
<td>Time 1.5 h</td>
</tr>
<tr>
<td>On-board charger</td>
<td>Power 10 (kW)</td>
</tr>
<tr>
<td></td>
<td>Time 6 h</td>
</tr>
<tr>
<td></td>
<td>Power 3.3 (kW)</td>
</tr>
<tr>
<td></td>
<td>Time 20 h</td>
</tr>
</tbody>
</table>

Table 2.1.3 BYD e6 parameters [5]
<table>
<thead>
<tr>
<th>Taxi</th>
<th>Average daily mileage</th>
<th>217-310 miles</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation time</td>
<td>24 hours</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak periods</td>
<td>6:30-9:00</td>
<td>Commuting hour</td>
<td></td>
</tr>
<tr>
<td></td>
<td>16:30-18:30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interval</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mileage capacity</td>
<td>186 miles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charging times</td>
<td>2 times a day</td>
<td>Take safety factor into consideration</td>
<td></td>
</tr>
<tr>
<td>Charging periods</td>
<td>11:30-14:00</td>
<td>Day time</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2:00-4:00</td>
<td>Night time</td>
<td></td>
</tr>
<tr>
<td>Starting SOC</td>
<td>Normal distribution N (0.3, 0.1)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 2.1.4 Time schedule for taxi**

Taking limited charging time and long daily mileage into consideration, the average starting SOC of taxi should be lower than that of bus and private vehicle. So, the average SOC is set to 30%.

\[
SOC_{Taxi}^{m} = \text{random('norm', } \mu, \sigma) \\
\mu_{Taxi} = 0.3 \\
\sigma_{Taxi} = 0.1
\] (10)
Arrival and departure time is defined similarly to electric bus case according to Tab 2.1.2

\[ AT_{am}^m = \text{random('norm', } 690, 30) \] 
\[ DT_{am}^m = \text{random('norm', } 840, 30) \] 
\[ AT_{pm}^m = \text{random('norm', } 120, 60) \] 
\[ DT_{pm}^m = \text{random('norm', } 240, 60) \]

\[ AT_{am}^m, DT_{am}^m, AT_{pm}^m \text{ and } DT_{pm}^m \] are all assumed to follow normal distribution. The time period between arrival and departure time is only about 2 hour. Consequently, Taxi drivers must use 100 kW three-phase charger in charging station. Taxi drivers have more room to choose their lunch time and shift time. So, standard deviation for AT and DT in daytime is larger than that of electric bus. The exact time that taxi drivers make shifts are mainly based on their preference. Thus, the standard deviation for AT and DT in night time is set to one hour.

\[ Tc_{am}^m = \frac{(1 - SoC_{am}^m)}{CS_{100kW}} \] 
\[ Tc_{pm}^m = \frac{(1 - SoC_{pm}^m)}{CS_{100kW}} \]

From Table 2.1.3, the full-charge time of BYD C100D charger is 40 minutes [5]. Therefore, the charging speed for BYD C100D charger is 2.5 percent per minute.
Compared to electric bus’s load curve, taxi load peaks are located at around 2:30 am and 11:00 am. The peak load is 19.4 MW. Taxi is the only type of vehicles with their batteries charged in a large scale at night. The subtotal loads of public transportation vehicles are illustrated in Fig 2.1.3. The subtotal load peak is 27.1 MW at 11:42 am.

Figure 2.1.3 Load curve of public transportation vehicles in small scale
2.2 Private vehicles charging pattern

Average daily mileage for private car is only about 42 miles a day [6] for commuting to and from work to school. The mileage is much fewer than that of bus and taxi. In this part, BYD e6 is still chosen as the model of main stream family sedan. Taking safety factor into consideration, owner of PHEV should charge battery once every two days at home or in workplace.

Private vehicle’s main function is commuting. So, charging periods starts when they arrive at working place or arrive home. The first charging period lies between 8:00 am and 5:00 pm. The second period begins at 7:00 pm and ends at next day 7:00 am. It can be easily figured out that there is comparatively abundant charging time for private car. Therefore, for both periods, slow charging mode is the first option. 100 kW fast charging mode is only for long distance travelling or emergency issues.

In United States, the ratio for sedan and SUV is about 6:4. Thus, SUV also accounts for a considerable share in private vehicles. BYD S6DM is selected as the model for SUV. In consideration of output power and EDC, S6DM is designed as a dual mode hybrid vehicle, not pure electric one. It also relies on gasoline to some extent. So, its charging loads would be much fewer than that of BYDe6 compact sedan. BYDe6 is pure electric vehicle. Detailed parameters for BYD S6DM are shown in Table 2.2.1.
<table>
<thead>
<tr>
<th>Items</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dimensions &amp; Weight</strong></td>
<td></td>
</tr>
<tr>
<td>L/W/H (Unload)</td>
<td>4810/1855/1725 (mm) 189.4/73.0/67.9 (in.)</td>
</tr>
<tr>
<td>Wheelbase</td>
<td>2715 (mm)</td>
</tr>
<tr>
<td>Fuel tank capacity</td>
<td>45 (L)</td>
</tr>
<tr>
<td>Tire</td>
<td>225/65 R17</td>
</tr>
<tr>
<td><strong>Performance</strong></td>
<td></td>
</tr>
<tr>
<td>Top speed</td>
<td>&gt;= 180 (km/h)</td>
</tr>
<tr>
<td>EV Range</td>
<td>&gt;= 60 (km)</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Motor</strong></td>
<td></td>
</tr>
<tr>
<td>Motor type</td>
<td>Permanent-magnet type synchronous motor</td>
</tr>
<tr>
<td>Max power</td>
<td>85 (kW)</td>
</tr>
<tr>
<td>Max torque</td>
<td>450 (N*m)</td>
</tr>
<tr>
<td><strong>Engine</strong></td>
<td></td>
</tr>
<tr>
<td>Engine model</td>
<td>BYD483QB</td>
</tr>
<tr>
<td>Displacement</td>
<td>1.998 (L)</td>
</tr>
<tr>
<td>Max power</td>
<td>103 (kW)</td>
</tr>
<tr>
<td>Max torque</td>
<td>186 (N*m)</td>
</tr>
<tr>
<td><strong>Suspension &amp; Steering</strong></td>
<td></td>
</tr>
<tr>
<td>Front</td>
<td>McPherson strut type</td>
</tr>
<tr>
<td>Rear</td>
<td>McPherson strut type</td>
</tr>
<tr>
<td>Steering system</td>
<td>EPS</td>
</tr>
<tr>
<td><strong>Recharge System</strong></td>
<td></td>
</tr>
<tr>
<td>Home charge</td>
<td>Power</td>
</tr>
<tr>
<td></td>
<td>2 (kW)</td>
</tr>
<tr>
<td></td>
<td>Time</td>
</tr>
<tr>
<td></td>
<td>8 h</td>
</tr>
</tbody>
</table>

Table 2.2.1 BYD S6DM Hybrid SUV parameters [7]

\(SOC_{p,v}^m\) is the starting SOC of \(m\)-th private vehicle. Mean value is 50% and standard deviation is 10%. Owners of PHEVs are suggested not to deeply discharge their batteries. Parameters about time schedule for private vehicles in daily commuting are summarized in Table 2.2.2. The modelling and simulation method is that same as that used in public transportation vehicle simulation. But parameters for charging schedule and battery charger need to be adjusted.
\[ SOC_{PV}^m = \text{random('norm', } \mu, \sigma) \]
\[ \mu_{PV} = 0.5 \quad (17) \]
\[ \sigma_{PV} = 0.1 \]

\[ AT_{am}^m = \text{random('norm', } 480, 45) \quad (18) \]
\[ DT_{am}^m = \text{random('norm', } 1020, 45) \quad (19) \]

\[ AT_{pm}^m = \text{random('norm', } 1140, 60) \quad (20) \]
\[ DT_{pm}^m = \text{random('norm', } 420, 60) \quad (21) \]

\textbf{Sedan}

\[ Tc_{am}^m = \frac{(1 - SoC_{am}^m)}{CS_{10kW}} \quad (22) \]
\[ Tc_{pm}^m = \frac{(1 - SoC_{pm}^m)}{CS_{10kW}} \quad (23) \]

\textbf{SUV}

\[ Tc_{am}^m = \frac{(1 - SoC_{am}^m)}{CS_{2kW}} \quad (24) \]
\[ Tc_{pm}^m = \frac{(1 - SoC_{pm}^m)}{CS_{2kW}} \quad (25) \]
<table>
<thead>
<tr>
<th>Private car</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average daily mileage</td>
<td>42 miles</td>
</tr>
<tr>
<td>Operation time</td>
<td>Commuting hour</td>
</tr>
<tr>
<td>Peak periods</td>
<td>6:30-9:00</td>
</tr>
<tr>
<td></td>
<td>16:30-18:30</td>
</tr>
<tr>
<td>Interval</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Mileage capacity</td>
<td>190 miles</td>
</tr>
<tr>
<td>Charging times</td>
<td>Once every two days</td>
</tr>
<tr>
<td></td>
<td>Take safety factor into consideration</td>
</tr>
<tr>
<td>Charging periods</td>
<td>8:00-17:00</td>
</tr>
<tr>
<td></td>
<td>19:00-7:00</td>
</tr>
<tr>
<td>Starting SOC</td>
<td>Normal distribution N (0.5, 0.1)</td>
</tr>
</tbody>
</table>

**Table 2.2.2 Time schedule for private vehicle**

Similar to the curves of bus and taxi, load peak still appears at noon. So, the highest peak at noon for subtotal PHEVs’ load could be expected. Due to long full-charge time, loads for private vehicle allocates more evenly.
Figure 2.2.1 Private vehicle load curve in small scale
In Figure 2.2.2, flow chart for small-scale PHEVs’ charging simulation is illustrated. First of all, the type $i$ of PHEV shall be decided, since parameter for each type is obviously different. There are four types of PHEVs that are included in this simulation: electric bus, electric taxi, private electric sedan and private electric SUV. Then, simulation starts from $m = 1$ vehicle in this type. The initial state of charge of the battery, arrival and departure time are generated following normal distribution that is designed for each of them. Obviously, the state of charge must be larger than zero. In addition, the departure time must later than the arrival time. After all parameters are generated, the actual charging time period is calculated under the criteria that stated above. Knowing the arrival, departure time and actual charging time, the charging period for $m = 1$ vehicle in type $i$ is obtained. Then simulation system move forward to $m + 1$ vehicle is till charging periods for all vehicles in type $i$ are generated. All charging periods for each vehicle in type $i$ are added together. Then, the amount of vehicles that are charging at each time point is acquired. Finally, the charging power of fast/home charger is multiplied with the summation of charging periods. The charging load pattern for type $i$ of PHEVs is obtained, then system move forward to next type of PHEVs.
Figure 2.2.2 Flow chart of charging load simulation in small scale
2.3 Small-scale charging pattern for all types of PHEVs

Charging load curves for all types of PHEVs are illustrated in Fig 2.3.1.

![PEV Load Curve](image)

**Figure 2.3.1 Separate PHEV load curve**

From Figure 2.3.1, loads of private vehicle take the largest part of all types of electric vehicles. Its load peak appears at 8:59 am and its value is about 25.7 MW. Load peaks for bus and taxi show up later at noon. Public bus’ charging peak is located at 10:49 am and its value is 14.3 MW. The latest load peak is taxis’. It appears at 11:50 am and its value is 19.4 MW. In night time, three load peaks for three types of vehicles arise separately. They are at 20:36 pm, 0:05 am and 2:20 am respectively.
Figure 2.3.2 Subtotal PHEV load curve

Loads for all types of PHEVs are summarized in Fig 2.3.2. In small-scale simulation, 200 buses, 500 taxis, 10,000 private sedans and 6000 private SUVs are included. Loads of private vehicles take the largest part of all types of electric vehicles. In subtotal, the load peak is at 11:35 a.m. The peak value is about 31.6 MW. Load grows continuously before the peak and drops suddenly after the peak. That means there is a lot of potential to shift the peak backwards to relieve the pressure to grid.

Since three loads peaks arise in the morning one by one, the total load is at high level from 8:30 am to 11:30 am. But, after the peak, load curve drops suddenly. Most vehicles have finished charging after noon. That means that there is a great potential to shift loads from morning to afternoon to relief the pressure to the grid. It should also be
mentioned that at commuting hour, loads in the grid is extremely low. Charging vehicles if they are not used at rush hour could be suggested.

2.4 Outlook of large-scale charging pattern for all types of PHEVs

To analyze the impact of large-scale PHEVs, firstly, the amount of each type of PEVs in next two decades should be predicted. As for private vehicles, the growth rate would be evenly distributed in next two decades. Although electric vehicles save a lot in gasoline consumption, owners of private vehicles might not change their car immediately due to high price of PHEV and worry about lack of charging station. So, this replacement of older internal combustion engine vehicles would be a continuous process. The annual growth rate for public bus and taxi is assumed to be 40% between 2017 and 2020 due to government subsidy. The average growth rate is reduced to 20% afterwards [6].

PHEV might have a bright future. But the beginning for PHEV seems not smooth. Referring to the latest forecast from Pike Research, a clean tech consulting organization, the United States will lag behind of President Obama’s goal of having one million plug-in electric vehicles on roads by 2015. Pike forecasts the number for cumulative sales of plug-in hybrid electric vehicles will be only 667,000 by 2015. But the good news is that the annual sales of PHEVs in 2016 will be 289,000, and will reach 303,000 by 2017. Referring to Pike’s forecast, the U.S. will reach one million by 2017 [9].
EV sales do not grow rapidly in the US. The most critical reason is that many electric vehicle launches are delayed. Referring to delayed introductions from Ford, Mitsubishi, Coda and Fisker, their new models of plug-in electric vehicles are all postponed to next year. As a result, there are only two models available in the market. They are Nissan Leaf and Chevy Volt. Other models, such as Fisker Karma and Ford Focus Electric may arrive, but the production would not be high. So, low sales of PHEV is mainly due to supply side not demand side.

On the other hand, the market may face a new turn in 2013. Many new manufacturers will join the electric vehicle market. For instance, Volkswagen, BMW and Hyundai will start selling plug-in electric vehicles. In addition, Toyota and Honda have potential to make impact on the market in future.

Even by 2017, Pike Research’s report “Electric Vehicle Market Forecasts” acclaimed that pure electric car represents mere 0.8% of the U.S. market, while plug-in hybrids will account for 1.2%.

Continued supply shortages and the high price of many models such as the $57,000-plus Tesla Model S are the two main reasons for low market share. However, we still have confidence in sales of plug-in hybrids. If PHEV is equipped with smaller batteries, that means lower cost. As mentioned before, Toyota would be that sleeping giant. Owners of the gas powered Prius is about one million. If the Prius Plug-in Hybrid
can meet the expectations from customers in quality and price aspects, owners may convert to Plug-in Hybrid in a large number.

It took ten years for sale of conventional hybrids to reach about 2% of auto sales. In contrast, plug-in hybrids would reach that market share in seven years. And the growth would be even faster in next ten years. Referring to the US Bureau of Transit Statistics for 2004, there are 243,023,485 registered passenger vehicles in the United States. About 136 million of them were normal 2-axle, 4-tire vehicles, such as sedan and compact car. They accounted for 56.13% share of total amount. 91 million (37.79%) were other 2-axle, 4-tire vehicles. For example, SUVs and buses are included in this type.

Not every registered vehicle is still on road. Many of them are just sitting idle or waiting for total loss. So, there are approximately 250 million vehicles on road in 2012. About 16 million brand new cars are sold annually. Considerable amount of old cars whose mileage is over 100,000 miles are also scraped annually, the number of all types of vehicles in 2017 would be about 320 million [6]. In contrast, only one million PHEVs will on the road. However, if the amount of PHEVs increases at this rate continuously, PHEVs will account for more and more share in the market. The detailed amount for each type of electric vehicle is listed in Table 2.4.1.
<table>
<thead>
<tr>
<th>Year</th>
<th>Public bus</th>
<th>Taxi</th>
<th>Sedan</th>
<th>SUV</th>
<th>Total amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>0.017</td>
<td>0.04</td>
<td>0.718</td>
<td>0.484</td>
<td>1.259</td>
</tr>
<tr>
<td>2020</td>
<td>0.047</td>
<td>0.11</td>
<td>1.97</td>
<td>1.328</td>
<td>3.455</td>
</tr>
<tr>
<td>2030</td>
<td>0.291</td>
<td>0.68</td>
<td>27.158</td>
<td>18.308</td>
<td>46.437</td>
</tr>
</tbody>
</table>

Table 2.4.1 Amount of PHEVs in 2017, 2020 and 2030

The annual growth rate for public bus and taxi is assumed to be 40% between 2017 and 2020. From 2020 to 2030, the average growth rate is reduced to 20%. With government’s subsidy, the replacement of conventional combustion engine vehicles with new generation plug-in electric vehicle would be smooth. However, when the generation change is over, growth rate should decrease evidently. In contrast, for private owners, they may set plug-in vehicles as their first choice for next car. But, they are not willing to buy them immediately considering PHEV’s high retail price. So, growth rate of private PHEVs is predicted to be more evenly distributed in next two decades.

In next twenty years, the total amount for PHEVs would increase rapidly. Therefore, the small-scale simulation method is no longer suitable. Matlab is not able to handle this large amount of calculation, since every parameter is generated in loop. Loop commands decrease the calculation efficiency significantly. As a result, Monte Carlo simulation method is introduced to save computation time. To further save computing time, time step is increased from 1 min to 10 min. After modification, the basic
simulation method does not change. The amount of each type of PHEVs predicted in Table 2.4.1 is input into the modified simulation model. Subtotal load curve for all PHEVs in 2017, 2020 and 2030 could be obtained. Results are illustrated in Fig 2.4.2 and 2.4.3.
Generate starting state of charge for all vehicles in type i

Generate arrival and departure time for all vehicles in type i

Compute the maximum charging time $y_{\text{max}} = DT - AT$

Compute the fully charged time $t_c = (1 - \text{SOC}) / \text{Charging speed}$

Starting from vehicle # $m = 1$

Actual charging time $c_t = \text{min} (y_{\text{max}}, t_c)$

Charging period $c_p(m, \text{AT: (AT+ct)}) = 1$

$m = \text{subtotal amount}$

Yes

Load = $P \times \text{sum}(c_p, 1)$
$P$ is the charging power

No

$m = m + 1$

% all characteristics that could be withdrawn from loop sentence are generated in advance.

% only one iteration statement is included. Conditional statement is also removed if possible

Figure 2.4.1 Flow chart of load curve prediction in large scale

31
Figure 2.4.2 Load curve prediction in 2017 and 2020

In 2017, the load peak at noon is expected to be 7.12 GW. This amount of loads from PHEVs’ charging will not have huge effect on the grid in 2017. However, this peak grows really fast. After 3 years, in 2020, it is already 19.49 GW. The load is almost tripled. Besides, two load peaks become more prominent, if owners are allowed to charge their vehicles freely with no guidance and regulation.
Figure 2.4.3 Load curve prediction in 2020 and 2030

After 10 years of development, PHEVs would take 30% share of all kinds of vehicles. That also means that its charging load would become a considerable part on the grid. Its peak at noon would be 263.56 GW. Compared to load curve in 2020, loads in the evening and morning after commuting hour increase evidently. That means loads from private vehicle become more and more important. In contrast, load peak in mid night become less significant.
Chapter 3: Peak Load Shifting Optimization

3.1 Load optimization according to real-time price

In simulation conducted in previous sections, owners of PHEVs start charging their vehicles when batteries are plugged into the grid. In [12], this charging scheme is called uncoordinated direct charging. There is great potential to re-coordinate the charging scheme, so as to relieve its impact on the grid. Firstly, the charging loads are concentrated at two time point, 8:30 am and 8:30 pm. Secondly, the available charging time for private vehicles is abundant. Those two factors would make optimization process effective and this process could be conducted according to real-time electricity price and wind power output curve.

The reasons why real-time pricing is selected as the criteria for optimization process are as follows: (1) Smart grid and smart meter make it possible that customers could know real time electricity price before they use electricity. Consequently, this will give them a strong incentive to charge their PEV when price is low and finally save money on daily commuting cost. As for taxis, they might get notice from operation centre to suggest them to charge battery when price is low. For instance, they might bring forward a lunch time break to charge battery at low price to save money. Since their daily
mileage is far more than that of private vehicle, the cumulative saving is considerable. (2) Time period of price peak commonly means there is a huge demand in this period. If charging in peak time period could be avoided wisely, the demand stress on the grid could be relieved.

![Reference Regional Price](image)

**Figure 3.1.1 Reference regional price curve**

A reference regional price curve in 7/8/2012 is shown in Fig 3.1.1 [13]. There are two obvious price peaks in the morning and evening. The morning peak is from 50 min to 65 min. The reference regional price is about $90 per MWh. The evening peak is quite short. It is from 107 min to 116 min. The peak value is about $95 per MWh. Based on this real-time pricing data, the objective function is constructed.
General objective function

\[
Cost = \sum_{m=1}^{m=N} \sum_{t=X_m}^{X_m+T_{cm}} P[t] \quad (26)
\]

\[
T_{cm} = \frac{(1 - SOC_m)}{CS_m}
\]

Constraints

\[
X_m \geq At_m
\]

\[
0.2 \leq SOC_m \leq 1
\]

$P[t]$ is the regional reference price curve. $X_m$ is the start charging time point for $m$-th vehicle. $T_{cm}$ is the full-charge time for $m$-th vehicle. It is decided by $SOC_m$, the state of charge for $m$-th vehicle. $CS_m$ is the charging speed for $m$-th vehicle. $N$ is the subtotal amount for vehicles of type i. In this optimization process, all PHEVs consist of 200 buses, 500 taxis, 1000 private sedans and 600 private SUVs. Its objective is to find minimum cost in the mean time vehicles also get charged as much as possible.

Optimized bus load curve is shown in Fig 3.1.2. Load peak at 11 am is clearly shifted rightwards. Recall the reference regional price curve, the peak period is from 9 am to 11 am. Load curve after optimization avoid peak period successfully. And, these loads are shifted to afternoon before departure. Similar optimization method could also be applied to taxi charging pattern and private vehicle charging pattern.
Figure 3.1.2 Optimized bus load curve
Similar to the results of electric bus, load of taxi also lies in the area where real-time price is low. That also reveals that there is great potential for charging loads from taxi, since charging schedule for taxis is more flexible than that of electric buses.
The overall load pattern for three types of vehicles after optimization according to real-time pricing is shown in Figure 3.1.5. Recall the results from small scale simulation, loads suddenly drops to zero after 11:30. However, in optimized load curve, loads are allocated more evenly, and loads decrease to zero until 3:00 pm. That means loads were shifted to afternoon successfully.
Figure 3.1.5 Subtotal optimized load curve according to real-time pricing
3.2 Load optimization according to wind power output curve

Besides real-time pricing, if wind output curve is also considered in objective function, excess wind power could be better utilized. The reasons why wind power should be coordinated with PHEV charging are as follows: (1) as is known to all that it is hard to control wind power output. Wind farm may suddenly generate many mega watts of power or drop to zero output in ten minutes. That is always a risk for voltage and frequency stability. Normally, if wind farm output increases abruptly, operation centre will have to decrease generation from other power plants to maintain the balance. Now, charging loads join the grid and when to charge these loads could be controlled since their charging time is pretty ample. These loads could be utilized to pick up this increase from wind farm without shutting down other power plant. (2) A lot of wind power in midnight is just wasted, and charging loads in midnight is able to utilize this excess power. (3) PHEV is friendly to environment. If electricity is also from clean energy, that means there is no carbon dioxide emission from energy source to every vehicle terminal.

Wind power output curve on 1/1/2011 is illustrated in Figure 3.2.1 [20]. The variability for wind power output is considerably large. The output is at high level from 0:00 to 15:00 and suddenly drops to zero. Nowadays, there are many methods to predict wind power output. If the predicted load curve could be utilized in optimization, which would surely help to better take advantage of wind power.
Figure 3.2.1 Wind power output curve on 1/1/2011

$W[t]$ is the wind power output curve. This output curve is from a 72 Mits Wind farm on 1/1/2011. $P[t]$ is the reference regional price curve. Since regional reference price curve and wind power output curve are not on the same scale, all of them should be normalized in order to assign similar importance to each one. $P1$ and $P2$ are two constants. $P1 + P2 = 1$. Operator may assign different values for $P1$ and $P2$ to lay more emphasis on real-time pricing or wind power output.
Main objective function

\[ J = P_1 \cdot \sum_{m=1}^{N_{\text{t}}} \sum_{t=X_m + Tc} p[t] + P_2 \cdot \sum_{m=1}^{N_{\text{t}}} \sum_{t=X_m} w[t] \]  

(27)

\[ Tc_m = \frac{(1 - SOC_m)}{CS_m} \]

Constraints

\[ X_m \geq At_m \]
\[ 0.2 \leq SOC_m \leq 1 \]

\[ p[t] = \frac{P[t] - \text{Min}\{P[t]\}}{\text{Max}\{P[t]\} - \text{Min}\{P[t]\}} \]

\[ w[t] = \frac{W[t] - \text{Min}\{W[t]\}}{\text{Max}\{W[t]\} - \text{Min}\{W[t]\}} \]

Considering wind power output curve, more vehicle charging loads were fulfilled when wind output is high. In Figure 3.2.1, the most productive area for wind power is from 60 min to 80 min. Compared to load curve without considering wind power in Fig 3.2.2, loads in this area increase to some extent clearly. In future work, besides wind power, solar power and other factor could also be taken into consideration. That would grant the operator more potential to optimize the charging pattern for PHEVs.
Figure 3.2.2 Optimized load curve with both wind and reference regional price
Chapter 4: Conclusion and Future Work

4.1 Conclusion

With the growth of penetration level of PHEVs, charging load of PHEVs would surely present a great burden on the grid. As a result, the impact of PHEVs’ penetration on grid operation should be estimated to prevent upcoming problems, such as transformer aging, insufficient capacity for charging infrastructure in community, voltage and frequency instability, etc. In distribution level, congestion problem may also appear due to this huge amount of loads in morning and night peak period.

To analyze PHEVs’ impact, stochastic modeling is introduced to simulate its impact on the grid. There are two types of PHEVs: public transportation vehicles and private vehicles. Different charging scheme and charging speed are applied to these two types of PHEVs for testing. The small-scale simulation result shows that load peaks at day and night time are quite prominent. Besides, the charging time is sufficient for private vehicles’ charging. These two factors indicate that there is enough potential and flexibility to better coordinate PHEVs’ charging in smart grid.
Firstly, optimization process is conducted considering reference regional price. This optimization helps owners of PHEVs save electricity bills. On the other hand, charging load peaks are also shifted to relieve loads demand pressure to the grid. The optimized result is promising. Charging load peaks in day and night time are shifted to time periods where real-time electricity price is comparatively low. Additionally, the charging completion rate is not affected, compared to direct uncoordinated method.

Secondly, wind power output curve is also taken into account in the optimization process for following reason: Charging loads are considered as demand side response. Dispatching charging loads with excess wind power output could help maintain system’s stability without affecting other power plants’ output.

4.2 Future Work

This thesis presents a stochastic modeling method to simulate PHEVs’ charging loads and two optimization processes to better coordinate their charging scheme. In future work, V2G study will be included. V2G means owners of PHEVs are allowed to sell energy to the grid. The incentive of V2G mainly depends on real-time pricing. In this thesis, one goal is to save money on charging PHEVs’ batteries considering real-time pricing. If V2G is also included, owner could even earn money from selling energy from vehicles in idle to the grid.
Solar power will also be considered in optimization process to build a hybrid solar–wind system. Considering PHEV’s battery as storage medium, the surplus solar energy at day time and excess wind energy at night time could be better utilized. Otherwise, some of power from wind or solar may have to be spilled because the grid cannot absorb the excess power. The purpose of replacing conventional combustion-engine vehicles with PHEVs is to get rid of dependence on petroleum and decrease carbon dioxide emission. If the electricity that is used to charge PHEVs’ batteries still comes from coal or gas power plants, the goal of sustainability is not achieved completely. Renewable energy will certainly play a larger role in future. If PHEVs’ battery charging on demand side could help the integration of renewable energy, that shall be a win-win situation. Owners of PHEVs could use abundant and cheap renewable energy for charging to save money on electricity bills.
Bibliography


[4] Columbia University’s school of international and public affairs and the earth institute, master of public administration program in environmental science and policy, workshop in applied earth system policy analysis, final workshop report.


[6] Research and Innovation Technology Administration Bureau of Transportation Statistics,


[20] NREL data.


[27] Christophe Guille, George Gross, “The Integration of PHEV Aggregations into a Power System with Wind Resources,” Bulk Power System Dynamics and Control (iREP) – VIII (iREP), 2010.


Appendices

Appendix A: Small-scale PHEVs’ charging load simulation

**Bus.m**

```matlab
function [BusLoad] = Bus()

cle

for m=1:1:200

    SOC(m)=random('norm',0.5,0.1);  %State of charge
    ATam(m)=random('norm',600,45);  %am arrival time
    DTam(m)=random('norm',990,45);  %am departure time
    ATpm(m)=random('norm',1380,45); %pm arrival time
    DTpm(m)=random('norm',330,45);  %pm departure time

    ymaxA(m)=DTam(m)-ATam(m);     %maxtime for charging am
    ymaxP(m)=(1440+DTpm(m))-ATpm(m); %maxtime for charging pm. DTpm should be added 1440, since departure time has passed 00:00.

    tcam(m)=(1-SOC(m))/0.00555;   %fully charged time am
    tcpm(m)=(1-SOC(m))/0.00333;   %fully charged time pm

for i=1:1:1440

    if ((i >= ATam(m)) && (i <= DTam(m)) && ((i - ATam(m)) <= tcam(m)))
```

53
Busam(m,i) = 1;
% be fully charged or maxtime am
else
    Busam(m,i)= 0;
end
if (i<=DTpm(m))&&(i+1440-ATpm(m)<=tcpm(m))
    Buspm(m,i)=1;
% be fully charged or maxtime pm
elseif i>=ATpm(m)
    Buspm(m,i)=1;
else
    Buspm(m,i)=0;
end
end
end
BusLoad=sum((Busam+Buspm),1);
for i=1:300
    BusLoad(i)=60*BusN(i);
end
for i=300:1000
    BusLoad(i)=100*BusN(i);
end

for i=1000:1440
    BusLoad(i)=60*BusN(i);
end

%subtotal of bus load

_____________________________________________________________

Taxi.m

function [TaxiLoad]=Taxi ()

for m=1:1:500
    SOCam(m)=random('norm',0.3,0.1); %State of charge
    SOCpm(m)=random('norm',0.3,0.1);
    ATam(m)=random('norm',690,30); %am arrival time
    DTam(m)=random('norm',840,30); %am departure time
    ATpm(m)=random('norm',120,30); %pm arrival time
    DTpm(m)=random('norm',240,30); %pm departure time
    ymaxA(m)=DTam(m)-ATam(m); %maxtime for charging am
    ymaxP(m)=DTpm(m)-ATpm(m); %maxtime for charging pm
    tcam(m)=(1-SOCam(m))/0.25;
    tcpm(m)=(1-SOCpm(m))/0.25;

    for i=1:1:1440
if ((i >= ATam(m)) && (i <= DTam(m)) && ((i - ATam(m)) <= tcam(m)))
    Taxiam(m,i) = 1; %fully charged or charge the battery for maxtime
else
    Taxiam(m,i)= 0;
end

if ((i >= ATpm(m)) && (i <= DTpm(m)) && ((i - ATpm(m)) <= tcam(m)))
    Taxipm(m,i)=1;
else
    Taxipm(m,i)=0;
end

e nd
end

e nd

TaxiN=sum((Taxiam+Taxipm),1);

for i=1:1440
    TaxiLoad(i)=100*TaxiN(i);
end  %subtotal of taxi load

function [PVSUVLoad] = PV()

cle
for m=1:1:1500
    SOCam(m)=random('norm',0.5,0.1);   %State of charge
    SOCpm(m)=random('norm',0.5,0.1);
    ATam(m)=random('norm',480,45);     %am arrival time
    DTam(m)=random('norm',1020,45);    %am departure time
    ATpm(m)=random('norm',1140,60);    %pm arrival time
    DTpm(m)=random('norm',420,60);    %pm departure time
    ymaxA(m)=DTam(m)-ATam(m);         %maxtime for charging am
    ymaxP(m)=1440-ATpm(m)+DTpm(m);    %maxtime for charging pm
    tcam(m)=(1-SOCam(m))/0.00208;
    tcpm(m)=(1-SOCpm(m))/0.00208;

for i=1:1:1440
    if ((i >= ATam(m)) && (i <= DTam(m)) && ((i - ATam(m)) <= tcam(m)))
        PVam(m,i) = 1; %fully charged or charge the battery for maxtime
    else
        PVam(m,i) = 0;
    end

if (i<=DTpm(m))&&((i+1440-ATpm(m))<=tcpm(m))
    PVpm(m,i) = 1;
elseif i>=ATpm(m)&& ((i-ATpm(m))<=tcpm(m))
    PVpm(m,i) = 1;
end
else
    PVpm(m,i)=0;
end
end
end
PVN=sum((PVam+PVpm),1);
for i=1:1440
    PVSUVLoad(i)=2*PVN(i);
end

_____________________________________________________________
PVe6.m

function [PVLoad] = PV()

clc

for m=1:1:2500
    SOCAm(m)=random('norm',0.5,0.1); %State of charge
    SOCPm(m)=random('norm',0.5,0.1);
    ATAm(m)=random('norm',480,45); %am arrival time
    DTAm(m)=random('norm',1020,45); %am departure time
    ATpm(m)=random('norm',1140,60); %pm arrival time
    DTpm(m)=random('norm',420,60); %pm departure time

y_{\text{max}A}(m) = DT_{\text{am}}(m) - AT_{\text{am}}(m); \text{ %maxtime for charging am}

y_{\text{max}P}(m) = 1440 - AT_{\text{pm}}(m) + DT_{\text{pm}}(m); \text{ %maxtime for charging pm}

t_{\text{cam}}(m) = (1 - SOC_{\text{am}}(m)) / 0.00278;

t_{\text{cpm}}(m) = (1 - SOC_{\text{pm}}(m)) / 0.00278;

for i=1:1:1440
    if ((i >= AT_{\text{am}}(m)) && (i <= DT_{\text{am}}(m)) && ((i - AT_{\text{am}}(m)) <= t_{\text{cam}}(m)))
        PV_{\text{am}}(m,i) = 1; \text{ %fully charged or charge the battery for maxtime}
    else
        PV_{\text{am}}(m,i) = 0;
    end
    if (i <= DT_{\text{pm}}(m)) && ((i+1440-AT_{\text{pm}}(m)) <= t_{\text{cpm}}(m))
        PV_{\text{pm}}(m,i) = 1;
    elseif i >= AT_{\text{pm}}(m) && ((i-AT_{\text{pm}}(m)) <= t_{\text{cpm}}(m))
        PV_{\text{pm}}(m,i) = 1;
    else
        PV_{\text{pm}}(m,i) = 0;
    end
end

PV_N = sum((PV_{\text{am}} + PV_{\text{pm}}), 1);

for i=1:1440
PVSLoad(i)=10*PVN(i);

end
Appendix B: Large-scale PHEVs’ charging load simulation

**Bus_LS.m**

function [BusLoad_LS]=Bus_LS()

clc

starttime=cputime;

N=17000;

SOCam=normrnd(0.5,0.1,N,1);

SOCpm=normrnd(0.5,0.1,N,1);

ATam=normrnd(60,4.5,N,1);

DTam=normrnd(99,4.5,N,1);

ATpm=normrnd(138,4.5,N,1);

DTpm=normrnd(33,4.5,N,1);

ymaxA=DTam-ATam;

ymaxP=DTpm-ATpm+144.*ones(N,1);

tcam=(ones(N,1)-SOCam)./0.0555;

tcpm=(ones(N,1)-SOCpm)./0.0333;

Bus0=zeros(N,144);

for m=1:1:N

tam(m)=min(ymaxA(m),tcam(m));

tpm(m)=min(ymaxP(m),tcpm(m));
Bus0(m,round(ATam(m)):.round((ATam(m)+tam(m))))=1;

Bus0(m,round(ATpm(m))):144)=1;

Bus0(m,1:round((ATpm(m)+tpm(m)-144)))=1;

end;

BusN=sum(Bus0,1);

for i=1:30
    BusLoad_LS(i)=60*BusN(i);
end

for i=30:100
    BusLoad_LS(i)=100*BusN(i);
end

for i=100:144
    BusLoad_LS(i)=60*BusN(i);
end

Time=cputime-starttime

_____________________________________________________________

Taxi_LS.m

function [TaxiLoad_LS]=Taxi_LS()

clc

starttime=cputime;
N=40000;
SOCam=normrnd(0.3,0.1,N,1);
SOCpm=normrnd(0.3,0.1,N,1);
ATam=normrnd(69,3,N,1);
DTam=normrnd(84,3,N,1);
ATpm=normrnd(12,3,N,1);
DTpm=normrnd(24,3,N,1);
ymaxA=DTam-ATam;
ymaxP=DTpm-ATpm;
tcam=(ones(N,1)-SOCam)/0.25;
tcpm=(ones(N,1)-SOCpm)/0.25;
Taxi0=zeros(N,144);

for m=1:1:N
    tam(m)=min(ymaxA(m),tcam(m));
    tpm(m)=min(ymaxP(m),tcpm(m));
    Taxi0(m,round(ATam(m)):round((ATam(m)+tam(m))))=1;
    if round(ATpm(m))>=1
        Taxi0(m,round(ATpm(m)):round((ATpm(m)+tpm(m))))=1;
    else
        Taxi0(m,round((144+ATpm(m))):144)=1;
        Taxi0(m,1:round(ATpm+tpm(m)))=1;
    end
end
end
end;
TaxiN=sum(Taxi0,1);
TaxiLoad_LS=100.*TaxiN;
Time=cputime-starttime

PVe6_LS.m
function [PVLoad_LS]=PVe6_LS()
clc
starttime=cputime;
N=71800;
SOCam=normrnd(0.5,0.1,N,1);
SOCpm=normrnd(0.5,0.1,N,1);
ATam=normrnd(48,4.5,N,1);
DTam=normrnd(102,4.5,N,1);
ATpm=normrnd(114,6,N,1);
DTpm=normrnd(42,6,N,1);
ymaxA=DTam-ATam;
ymaxP=DTpm-ATpm+144.*ones(N,1);
tcam=(ones(N,1)-SOCam)./0.0278;
tcpm=(ones(N,1)-SOCpm)./0.0278;
PV0=zeros(N,144);

for m=1:1:N
    tam(m)=min(ymaxA(m),tcam(m));
    tpm(m)=min(ymaxP(m),tcpm(m));
    PV0(m,round(ATam(m)):round((ATam(m)+tam(m))))=1;
    if round(ATpm(m)+tpm(m))<=144
        PV0(m,round(ATpm(m)):round((ATpm(m)+tpm(m))))=1;
    else
        PV0(m,round(ATpm(m)):144)=1;
        PV0(m,1:round((ATpm(m)+tpm(m)-144)))=1;
    end;
end;

PVN=sum(PV0,1);
PVL1d_LS=10.*PVN;

Time=cputime-starttime

__________________________________________________________

PVSUV_LS.m

function [PVSUVLoad_LS]=PVSUV_LS()

clc

starttime=cputime;
N=48400;
SOCam=normrnd(0.5,0.1,N,1);
SOCpm=normrnd(0.5,0.1,N,1);
ATam=normrnd(48,4.5,N,1);
DTam=normrnd(102,4.5,N,1);
ATpm=normrnd(114,6,N,1);
DTpm=normrnd(42,6,N,1);
ymaxA=DTam-ATam;
ymaxP=DTpm-ATpm+144.*ones(N,1);
tcam=(ones(N,1)-SOCam)./0.0208;
tcpm=(ones(N,1)-SOCpm)./0.0208;
PV0=zeros(N,144);

for m=1:1:N
    tam(m)=min(ymaxA(m),tcam(m));
    tpm(m)=min(ymaxP(m),tcpm(m));
    PV0(m,round(ATam(m)):round((ATam(m)+tam(m))))=1;
    if round(ATpm(m)+tpm(m))<=144
        PV0(m,round(ATpm(m)):round((ATpm(m)+tpm(m))))=1;
    else
        PV0(m,round(ATpm(m)):144)=1;
    end
    PV0(m,1:round((ATpm(m)+tpm(m)-144)))=1;
end
end;

end;

PVN=sum(PV0,1);

PVSUVLoad_LS=2.*PVN;

Time=cputime-starttime
Appendix C: Optimization considering real-time pricing

BusObj.m

function retval=BusObj (x)

PFbus=[55 55 54 55 55 55 55 55 55 55 55 55 55 55 54 55 54 50....
          51 52 50 50 50 50 50 56 55 55 56 56 56 56 56 56 56 56 56 66 66 66....
          70 67 75 77 65 75 76 76 90 90 90 90 90 89 88 90 90 89 89 87....
          87 85 78 75 75 80 79 75 75 77 76 75 77 75 76 76 76 73 76....
          75 72 75 75 66 66 67 66 66 56 56 56 56 56 56 56 56 56 58 58 59....
          66 73 72 75 87 96 96 96 96 95 92 87 85 84 75 84 75 82....
          85 75 72 72 62 64 72 67 71 69 62 59 59 57 58 59 55 56 62 56....
          58 59 55 55 53....
          55 55 54 55 55 55 55 56 55 55 55 55 55 55 55 55 55 54 55 54 50....
          51 52 50 50 50 50 50 56 55 55 56 56 56 56 56 56 56 56 56 66 66 66....
          70 67 75 77 65 75 76 76 90 90 90 90 90 89 88 90 90 89 89 87....
          87 85 78 75 75 80 79 75 75 77 76 75 77 75 76 76 76 73 76....
          75 72 75 75 66 66 67 66 66 56 56 56 56 56 56 56 56 56 56 58 58 59....
          66 73 72 75 87 96 96 96 96 95 92 87 85 84 75 84 75 82....
          85 75 72 72 62 64 72 67 71 69 62 59 59 57 58 59 55 56 62 56....
          58 59 55 55 53];

for m=1:1:10
SOC(m)=random('norm',0.5,0.1); %State of charge

tc(m)=(1-SOC(m))/0.0555;

A(m)=round(x(m));

B(m)=round(x(m)+tc(m));

BusC(m)=trapz(A(m):1:B(m),PFbus(A(m):1:B(m)));  
end

for m=11:1:20  
SOC(m)=random('norm',0.5,0.1); %State of charge

tc(m)=(1-SOC(m))/0.0333;

A(m)=round(x(m));

B(m)=round(x(m)+tc(m));

BusC(m)=trapz(A(m):1:B(m),PFbus(A(m):1:B(m)));  
end

retval=sum(BusC); %subtotal of bus loadsum

**BusOpt.m**

clc

A=-1*eye(20);

for m=1:10

    c(m)=random('norm',60,4.5);

end
for m=11:20
    c(m)=random('norm',138,4.5);
end
b=-1*c;

%x=fmincon(@myfun,x0,A,b,Aeq,beq,lb,ub,@mycon)
x0=[63 63 63 65 63 65 63 65 63 63....
   140 145 140 145 140 150 140 150 145 140];
BusObj(x0);
lb=[55 55 55 55 55 55 55 55 55 55....
   133 133 133 133 133 133 133 133 133];
   288 288 288 288 288 288 288 288 288];

options = optimset('Algorithm','interior-point');
[X,FVAL,EXITFLAG,OUTPUT]=fmincon(@BusObj,x0,A,b,[],[],lb,ub,[],options)
global tc
bus0=zeros(20,144);

for m=1:20
    Y(m)=round(X(m)+tc(m));
    X(m)=round(X(m));
    if Y(m)<=100
bus0(m,X(m):Y(m))=100;
else
bus0(m,X(m):Y(m))=60;
end
end
BusLoad=sum(bus0,1)

---

**TaxiObj.m**

function retval=TaxiObj(x)

global tcTaxi

Price=[55 55 54 55 55 56 55 55 55 55 55 55 55 55 55 54 55 54 50....
51 52 50 50 50 50 50 56 55 55 56 56 56 56 56 56 56 56 56 59 66 66 66....
70 67 75 77 65 75 76 76 90 90 90 90 89 88 90 90 89 89 87....
87 85 78 75 75 80 79 75 75 77 76 75 77 75 75 76 76 73 76 76....
75 72 75 75 66 66 67 66 66 56 56 56 56 56 56 56 56 58 58 59....
66 73 72 75 87 96 96 96 96 95 92 87 87 85 84 75 84 75 82....
85 75 72 72 62 64 72 67 71 69 62 59 59 57 58 59 55 56 62 56....
58 59 55 55 53....
55 55 54 55 55 55 56 55 55 55 55 55 55 55 55 54 55 54 50....
51 52 50 50 50 50 50 56 55 55 56 56 56 56 56 56 56 59 66 66 66....
70 67 75 77 65 75 76 76 90 90 90 90 89 88 90 90 89 89 87....

71
for m=1:1:25
    SOC(m)=random('norm',0.3,0.1); %State of charge
    tcTaxi(m)=(1-SOC(m))/0.25;
    A(m)=round(x(m));
    B(m)=round(x(m)+tcTaxi(m));
    TaxiC(m)=trapz(A(m):1:B(m),Price(A(m):1:B(m)));
end

for m=26:1:50
    SOC(m)=random('norm',0.3,0.1); %State of charge
    tcTaxi(m)=(1-SOC(m))/0.25;
    A(m)=round(x(m));
    B(m)=round(x(m)+tcTaxi(m));
    TaxiC(m)=trapz(A(m):1:B(m),Price(A(m):1:B(m)));
end
retval = sum(TaxiC);  % subtotal of bus load

**TaxiOpt.m**

cle

A = -1*eye(50);

for m = 1:25
    c(m) = random('norm', 69, 3);
end

for m = 26:50
    c(m) = random('norm', 12, 3);
end

b = -1*c;

%x = fmincon(@myfun, x0, A, b, Aeq, beq, lb, ub, @mycon)

x0 = [70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 ... 
12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12];

TaxiObj(x0);

lb = [64 64 64 64 64 64 64 64 64 64 64 64 64 64 64 64 64 64 64 64 64 64 64 64 64 ... 
7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7];

ub = [77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 ... 
17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17];

options = optimset('Algorithm', 'interior-point');
[X,FVAL,EXITFLAG,OUTPUT]=fmincon(@TaxiObj,x0,A,b,[],[],lb,ub,[],options)

global tcTaxi

Taxi0=zeros(50,144);

for m=1:50
    Y(m)=round(X(m)+tcTaxi(m));
    X(m)=round(X(m));
    Taxi0(m,X(m):Y(m))=100;
end

TaxiLoad=sum(Taxi0,1)

------------------------------------------------

PVe6Obj.m

function retval=PVe6Obj(x)

global tcPV

Price=[55 55 54 55 55 55 56 55 55 55 55 55 54 55 54 50....
      51 52 50 50 50 50 50 56 55 55 56 56 56 56 56 59 66 66 66....
      70 67 75 77 65 75 76 76 90 90 90 90 90 89 89 89 80 88 89 89 89 87....
      87 85 78 75 75 80 79 75 75 77 76 76 76 76 76 76 76 73 76....
      75 72 75 75 75 66 66 67 66 66 56 56 56 56 56 56 56 58 58 59....
      66 73 72 75 87 96 96 96 96 96 96 96 95 92 87 85 84 75 84 75 82....
      85 75 72 72 62 64 72 67 71 69 62 59 59 57 58 59 55 56 62 56 56....

74
%x=[63 62 64 65 61 139 141 140 139 140];

for m=1:1:25
  SOC(m)=random('norm',0.5,0.1); %State of charge
  tcPV(m)=(1-SOC(m))/0.0278;
  A(m)=round(x(m));
  B(m)=round(x(m)+tcPV(m));
  PVC(m)=trapz(A(m):1:B(m),Price(A(m):1:B(m)));
end

for m=26:1:50
  SOC(m)=random('norm',0.5,0.1); %State of charge
  tcPV(m)=(1-SOC(m))/0.0278;
end
A(m)=round(x(m));
B(m)=round(x(m)+tcPV(m));
PVC(m)=trapz(A(m):1:B(m),Price(A(m):1:B(m)));  
end

retval=sum(PVC); %subtotal of bus loadsum

PVe6Opt.m

clec
A=-1*eye(50);
for m=1:25
    c(m)=random('norm',48,4.5);
end
for m=26:50
    c(m)=random('norm',114,6);
end
b=-1*c;
%x=fmincon(@myfun,x0,A,b,Aeq,beq,lb,ub,@mycon)
x0=[40 7 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 ....
    12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 ];
PVe6Obj(x0);
lb=[40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 ....
    76
options = optimset('Algorithm','interior-point');

[X,FVAL,EXITFLAG,OUTPUT]=fmincon(@PVe6Obj,x0,A,b,[],[],lb,ub,[],options)

global tcPV

PV0=zeros(50,144);

for m=1:50
    Y(m)=round(X(m)+tcPV(m));
    X(m)=round(X(m));
    PV0(m,X(m):Y(m))=10;
end

PVLoad=sum(PV0,1)

PVSUVOBJ.m

function retval=PVSUVOBJ(x)
global tcPVSUV

Price=[55 55 54 55 55 55 55 55 55 55 55 55 54 55 54 50....
51 52 50 50 50 50 56 55 55 56 56 56 56 59 66 66 66....
70 67 75 77 65 75 76 76 90 90 90 90 89 88 90 90 89 89 7....
87 85 78 75 75 80 79 75 75 77 76 75 77 75 76 76 73 76....
75 72 75 75 66 66 67 66 66 56 56 56 56 56 58 58 59....
66 73 72 75 87 96 96 96 96 96 95 92 87 85 84 75 84 75 82....
85 75 72 72 62 64 72 67 71 69 62 59 59 57 58 59 55 56 62 56....
58 59 55 55 53....
55 55 54 55 55 55 55 55 55 55 55 55 55 54 55 54 50....
51 52 50 50 50 50 50 56 55 55 56 56 56 56 59 66 66 66....
70 67 75 77 65 75 76 76 90 90 90 90 89 88 90 90 89 89 7....
87 85 78 75 75 80 79 75 75 77 76 75 77 75 76 76 73 76....
75 72 75 75 66 66 67 66 66 56 56 56 56 56 56 58 58 59....
66 73 72 75 87 96 96 96 96 96 95 92 87 85 84 75 84 75 82....
85 75 72 72 62 64 72 67 71 69 62 59 59 57 58 59 55 56 62 56....
58 59 55 55 53];
%x=[63 62 64 65 61 139 141 140 139 140];

for m=1:1:15
SOC(m)=rand('norm',0.5,0.1); %State of charge
tcPVSUV(m)=(1-SOC(m))/0.0208;

78
A(m) = round(x(m));

B(m) = round(x(m) + tcPVSUV(m));

PVSUVC(m) = trapz(A(m):1:B(m), Price(A(m):1:B(m))); 
end

for m = 16:1:30
SOC(m) = random('norm', 0.5, 0.1); % State of charge 

tcPVSUV(m) = (1 - SOC(m)) / 0.0208;

A(m) = round(x(m));

B(m) = round(x(m) + tcPVSUV(m));

PVSUVC(m) = trapz(A(m):1:B(m), Price(A(m):1:B(m))); 
end

retval = sum(PVSUVC); % Subtotal of bus load

PVSUVOpt.m

cle

A = -1*eye(30);

for m = 1:15

c(m) = random('norm', 48, 4.5);

end
for m=16:30
    c(m)=random('norm',114,6);
end

b=-1*c;

%x=fmincon(@myfun,x0,A,b,Aeq,beq,lb,ub,@mycon)
x0=[45 45 45 45 45 45 45 45 45 45 45 45 45 45 110 110 110 110 110 110 110 110 120 120 120 120 120 120 120];
PVSUVObj(x0);

lb=[40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 108 108 108 108 108 108 108 108 108 108 108 108 108];

options = optimset('Algorithm','interior-point');

[X,FVAL,EXITFLAG,OUTPUT]=fmincon(@PVSUVObj,x0,A,b,[],[],lb,ub,[],options)
global tcPVSUV
PVSUV0=zeros(30,144);

for m=1:30
    Y(m)=round(X(m)+tcPVSUV(m));
    X(m)=round(X(m));
PVSUV0(m, X(m): Y(m))=2;
end

PVSUVLoad=sum(PVSUV0, 1)
Appendix D: Optimization considering both real-time pricing and wind power output data

**BusObj_W.m**

function retval=BusObj_W(x)

global tcBus

Wind=[0.95 0.94 0.93 0.91 0.89 0.88 0.87 0.87 0.86 0.84 0.81 0.81 0.78 0.77....
    0.76 0.75 0.78 0.81 0.82 0.81 0.82 0.78 0.73 0.70 0.74 0.79 0.83 0.84....
    0.85 0.85 0.82 0.78 0.82 0.89 0.92 0.93 0.92 0.85 0.72 0.64 0.65 0.66....
    0.70 0.69 0.64 0.63 0.61 0.63 0.72 0.73 0.75 0.78 0.82 0.84 0.81 0.78....
    0.78 0.81 0.86 0.87 0.88 0.95 0.96 0.98 0.96 0.97 0.98 0.99 0.99 0.99....
    0.99 0.99 1.00 0.99 0.99 0.99 0.99 0.99 0.98 0.98 0.98 0.97 0.99 0.99....
    0.99 0.99 1.00 1.00 0.99 0.97 0.92 0.78 0.60 0.52 0.41 0.24 0.14 0.08....
    0.03 0.01 0.01 0.03 0.04 0.04 0.03 0.02 0.03 0.05 0.08 0.10 0.11 0.11....
    0.10 0.11 0.12 0.11 0.10 0.09 0.07 0.08 0.06 0.04 0.03 0.02 0.01 0.01....
    0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.01 0.04 0.07 0.09 0.12....
    0.14 0.15 0.17 0.18....
    0.95 0.94 0.93 0.91 0.89 0.88 0.87 0.87 0.86 0.84 0.81 0.81 0.78 0.77....
    0.76 0.75 0.78 0.81 0.82 0.81 0.82 0.78 0.73 0.70 0.74 0.79 0.83 0.84....
    0.85 0.85 0.82 0.78 0.82 0.89 0.92 0.93 0.92 0.85 0.72 0.64 0.65 0.66....
    0.70 0.69 0.64 0.63 0.61 0.63 0.72 0.73 0.75 0.78 0.82 0.84 0.81 0.78....
    0.78 0.81 0.86 0.87 0.88 0.95 0.96 0.98 0.96 0.97 0.98 0.99 0.99 0.99....
    0.99 0.99 1.00 0.99 0.99 0.99 0.99 0.99 0.98 0.98 0.98 0.97 0.99 0.99....

82
0.99 0.99 1.00 1.00 0.99 0.97 0.92 0.78 0.60 0.52 0.41 0.24 0.14 0.08....
0.03 0.01 0.01 0.03 0.04 0.04 0.03 0.02 0.03 0.05 0.08 0.10 0.11 0.11....
0.10 0.11 0.12 0.11 0.10 0.09 0.07 0.08 0.06 0.04 0.03 0.02 0.01 0.01....
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.01 0.04 0.07 0.09 0.12....
0.14 0.15 0.17 0.18];

Price=[0.11 0.11 0.09 0.11 0.11 0.11 0.11 0.13 0.11 0.11 0.11 0.11 0.11....
0.11 0.09 0.11 0.09 0.00 0.02 0.04 0.00 0.00 0.00 0.00 0.00 0.13....
0.11 0.11 0.13 0.13 0.13 0.13 0.13 0.20 0.35 0.35 0.35 0.43 0.37 0.54....
0.59 0.33 0.54 0.57 0.57 0.87 0.87 0.87 0.87 0.87 0.87 0.87 0.87 0.87....
0.85 0.85 0.80 0.80 0.76 0.61 0.54 0.54 0.65 0.63 0.54 0.54 0.59 0.57....
0.54 0.59 0.61 0.59 0.54 0.54 0.57 0.57 0.50 0.57 0.54 0.48 0.54 0.54....
0.54 0.35 0.35 0.37 0.35 0.35 0.13 0.13 0.13 0.13 0.13 0.13 0.13 0.17....
0.17 0.20 0.35 0.50 0.48 0.54 0.80 1.00 1.00 1.00 1.00 1.00 1.00 0.98....
0.91 0.80 0.76 0.74 0.54 0.74 0.54 0.70 0.76 0.54 0.48 0.48 0.26 0.30....
0.48 0.37 0.46 0.41 0.26 0.20 0.20 0.15 0.17 0.20 0.11 0.13 0.26 0.13....
0.17 0.20 0.11....
0.11 0.11 0.09 0.11 0.11 0.11 0.11 0.13 0.11 0.11 0.11 0.11 0.11 0.11....
0.11 0.09 0.11 0.09 0.00 0.02 0.04 0.00 0.00 0.00 0.00 0.00 0.13....
0.11 0.11 0.13 0.13 0.13 0.13 0.13 0.20 0.35 0.35 0.35 0.43 0.37 0.54....
0.59 0.33 0.54 0.57 0.57 0.87 0.87 0.87 0.87 0.87 0.87 0.87 0.87 0.87....
0.85 0.85 0.80 0.80 0.76 0.61 0.54 0.54 0.65 0.63 0.54 0.54 0.59 0.57....
for m=1:1:10
    SOC(m)=random('norm',0.5,0.1); %State of charge
    tcBus(m)=(1-SOC(m))/0.0555;
    A(m)=round(x(m));
    B(m)=round(x(m)+tcBus(m));
    BusC(m)=trapz(A(m):1:B(m),Price(A(m):1:B(m)));
    BusCW(m)=trapz(A(m):1:B(m),Wind(A(m):1:B(m)));
end

for m=11:1:20
    SOC(m)=random('norm',0.5,0.1); %State of charge
    tcBus(m)=(1-SOC(m))/0.0333;
    A(m)=round(x(m));
    B(m)=round(x(m)+tcBus(m));
    BusC(m)=trapz(A(m):1:B(m),Price(A(m):1:B(m)));
end
BusCW(m)=trapz(A(m):1:B(m),Wind(A(m):1:B(m)));  
end

P1=2;
P2=1;

retval=P1*sum(BusC)-P2*sum(BusCW); %subtotal of bus loadsum

**BusOpt_W.m**

clc
A=-1*eye(20);
for m=1:10
    c(m)=random('norm',60,4.5);
end
for m=11:20
    c(m)=random('norm',138,4.5);
end
b=-1*c;
%x=fmincon(@myfun,x0,A,b,Aeq,beq,lb,ub,@mycon)
x0=[63 63 63 65 63 65 63 65 63 63 140 145 140 145 140 140 150 140 150 145 140];
BusObj_W(x0);

lb=[55 55 55 55 55 55 55 55 55 55.
    133 133 133 133 133 133 133 133 133];

    288 288 288 288 288 288 288 288 288 288];

options = optimset('Algorithm','interior-point');

[X,FVAL,EXITFLAG,OUTPUT]=fmincon(@BusObj_W,x0,A,b,[],[],lb,ub,[],options)

global tcBus

bus0=zeros(20,144);

for m=1:20
    Y(m)=round(X(m)+tcBus(m));
    X(m)=round(X(m));
    if Y(m)<=100
        bus0(m,X(m):Y(m))=100;
    else
        bus0(m,X(m):Y(m))=60;
    end
end

BusLoad=sum(bus0,1)
function retval=TaxiObj_W(x)

global tcTaxi

Price=[0.11 0.11 0.09 0.11 0.11 0.11 0.11 0.13 0.11 0.11 0.11 0.11 0.11...
      0.11 0.09 0.11 0.09 0.00 0.02 0.04 0.00 0.00 0.00 0.00 0.00 0.13....
      0.11 0.11 0.13 0.13 0.13 0.13 0.13 0.20 0.35 0.35 0.35 0.43 0.37 0.54....
      0.59 0.33 0.54 0.57 0.57 0.87 0.87 0.87 0.87 0.87 0.85 0.83 0.87 0.87....
      0.85 0.85 0.80 0.80 0.76 0.61 0.54 0.54 0.65 0.63 0.54 0.54 0.59 0.57....
      0.54 0.59 0.61 0.59 0.54 0.54 0.57 0.57 0.50 0.57 0.54 0.48 0.54 0.54....
      0.54 0.35 0.35 0.37 0.35 0.35 0.13 0.13 0.13 0.13 0.13 0.13 0.13 0.17....
      0.17 0.20 0.35 0.50 0.48 0.54 0.80 1.00 1.00 1.00 1.00 1.00 1.00 0.98....
      0.91 0.80 0.76 0.74 0.54 0.74 0.54 0.70 0.76 0.54 0.48 0.48 0.26 0.30....
      0.48 0.37 0.46 0.41 0.26 0.20 0.20 0.15 0.17 0.20 0.11 0.13 0.26 0.13....
      0.17 0.20 0.11....
      0.11 0.11 0.09 0.11 0.11 0.11 0.11 0.13 0.11 0.11 0.11 0.11 0.11....
      0.11 0.09 0.11 0.09 0.00 0.02 0.04 0.00 0.00 0.00 0.00 0.00 0.13....
      0.11 0.11 0.13 0.13 0.13 0.13 0.13 0.20 0.35 0.35 0.35 0.43 0.37 0.54....
      0.59 0.33 0.54 0.57 0.57 0.87 0.87 0.87 0.87 0.87 0.85 0.83 0.87 0.87....
      0.85 0.85 0.80 0.80 0.76 0.61 0.54 0.54 0.65 0.63 0.54 0.54 0.59 0.57....
      0.54 0.59 0.61 0.59 0.54 0.54 0.57 0.57 0.50 0.57 0.54 0.48 0.54 0.54....
      0.54 0.35 0.35 0.37 0.35 0.35 0.13 0.13 0.13 0.13 0.13 0.13 0.13 0.17....
      0.17 0.20 0.35 0.50 0.48 0.54 0.80 1.00 1.00 1.00 1.00 1.00 1.00 0.98....

87
\begin{verbatim}
0.91 0.80 0.76 0.74 0.54 0.74 0.70 0.76 0.54 0.48 0.48 0.26 0.30....
0.48 0.37 0.46 0.41 0.26 0.20 0.20 0.15 0.17 0.20 0.11 0.13 0.26 0.13....
0.17 0.20 0.11];

Wind=[0.95 0.94 0.93 0.91 0.89 0.88 0.87 0.87 0.86 0.84 0.81 0.81 0.78 0.77....
0.76 0.75 0.78 0.81 0.82 0.81 0.82 0.78 0.73 0.70 0.74 0.79 0.83 0.84....
0.85 0.85 0.82 0.78 0.82 0.89 0.92 0.93 0.92 0.85 0.72 0.64 0.65 0.66....
0.70 0.69 0.64 0.63 0.61 0.63 0.72 0.73 0.75 0.78 0.82 0.84 0.81 0.78....
0.78 0.81 0.86 0.87 0.88 0.95 0.96 0.98 0.96 0.97 0.98 0.99 0.99 0.99....
0.99 0.99 1.00 0.99 0.99 0.99 0.99 0.99 0.98 0.98 0.97 0.97 0.97 0.99....
0.99 0.99 1.00 1.00 0.99 0.97 0.92 0.78 0.60 0.52 0.41 0.24 0.14 0.08....
0.03 0.01 0.01 0.03 0.04 0.04 0.03 0.02 0.03 0.05 0.08 0.10 0.11 0.11....
0.10 0.11 0.12 0.11 0.10 0.09 0.07 0.08 0.06 0.04 0.03 0.02 0.01 0.01....
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.01 0.04 0.07 0.09 0.12....
0.14 0.15 0.17 0.18....
0.95 0.94 0.93 0.91 0.89 0.88 0.87 0.87 0.86 0.84 0.81 0.81 0.78 0.77....
0.76 0.75 0.78 0.81 0.82 0.81 0.82 0.78 0.73 0.70 0.74 0.79 0.83 0.84....
0.85 0.85 0.82 0.78 0.82 0.89 0.92 0.93 0.92 0.85 0.72 0.64 0.65 0.66....
0.70 0.69 0.64 0.63 0.61 0.63 0.72 0.73 0.75 0.78 0.82 0.84 0.81 0.78....
0.78 0.81 0.86 0.87 0.88 0.95 0.96 0.98 0.96 0.97 0.98 0.99 0.99 0.99....
0.99 0.99 1.00 0.99 0.99 0.99 0.99 0.99 0.98 0.98 0.98 0.97 0.97 0.99....
0.99 0.99 1.00 1.00 0.99 0.97 0.92 0.78 0.60 0.52 0.41 0.24 0.14 0.08....
\end{verbatim}
for m=1:1:25
    SOC(m)=random('norm',0.3,0.1);  %State of charge
    tcTaxi(m)=(1-SOC(m))/0.25;
    A(m)=round(x(m));
    B(m)=round(x(m)+tcTaxi(m));
    TaxiC(m)=trapz(A(m):1:B(m),Price(A(m):1:B(m)));
    TaxiCW(m)=trapz(A(m):1:B(m),Wind(A(m):1:B(m)));
end

for m=26:1:50
    SOC(m)=random('norm',0.3,0.1);  %State of charge
    tcTaxi(m)=(1-SOC(m))/0.25;
    A(m)=round(x(m));
    B(m)=round(x(m)+tcTaxi(m));
    TaxiC(m)=trapz(A(m):1:B(m),Price(A(m):1:B(m)));
    TaxiCW(m)=trapz(A(m):1:B(m),Wind(A(m):1:B(m)));
end
P1=2;
P2=1;

retval=P1*sum(TaxiC)-P2*sum(TaxiCW); %subtotal of bus loadsum

**TaxiOpt_W.m**

clc
A=-1*eye(50);
for m=1:25
    c(m)=random('norm',69,3);
end
for m=26:50
    c(m)=random('norm',12,3);
end

b=-1*c;
%x=fmincon(@myfun,x0,A,b,Aeq,beq,lb,ub,@mycon)
x0=[70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70 70....
    12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12];
TaxiObj_W(x0);

lb=[64 64 64 64 64 64 64 64 64 64 64 64 64 64 64 64 64 64 64 64....
    7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7];
ub=[77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 77 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17];

options = optimset('Algorithm','interior-point');

[X,FVAL,EXITFLAG,OUTPUT]=fmincon(@TaxiObj_W,x0,A,b,[],[],lb,ub,[],options)

global tcTaxi

Taxi0=zeros(50,144);

for m=1:50

Y(m)=round(X(m)+tcTaxi(m));

X(m)=round(X(m));

Taxi0(m,X(m):Y(m))=100;

end

TaxiLoad=sum(Taxi0,1)

___________________________________________

PVe6Obj_W.m

function retval=PVe6Obj_W(x)

global tcPV

Price=[0.11 0.11 0.09 0.11 0.11 0.11 0.13 0.11 0.11 0.11 0.11 0.11 0.11 0.11 0.11 0.11 0.11 0.11 0.11 0.11 0.11 0.11 0.11 0.11 0.09 0.11 0.09 0.00 0.02 0.04 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.13 0.11 0.11 0.13 0.13 0.13 0.20 0.35 0.35 0.35 0.35 0.35 0.43 0.37 0.54....

91
Wind=[0.95 0.94 0.93 0.91 0.89 0.88 0.87 0.87 0.86 0.84 0.81 0.81 0.78 0.77....
0.76 0.75 0.78 0.81 0.82 0.81 0.82 0.78 0.73 0.70 0.74 0.79 0.83 0.84....}
for m=1:1:25
SOC(m)=random('norm',0.5,0.1); %State of charge

tcPV(m)=(1-SOC(m))/0.0278;

A(m)=round(x(m));

B(m)=round(x(m)+tcPV(m));

PVC(m)=trapz(A(m):1:B(m),Price(A(m):1:B(m)));

PVCW(m)=trapz(A(m):1:B(m),Wind(A(m):1:B(m)));

end

for m=26:1:50

SOC(m)=random('norm',0.5,0.1); %State of charge

tcPV(m)=(1-SOC(m))/0.0278;

A(m)=round(x(m));

B(m)=round(x(m)+tcPV(m));

PVC(m)=trapz(A(m):1:B(m),Price(A(m):1:B(m)));

PVCW(m)=trapz(A(m):1:B(m),Wind(A(m):1:B(m)));

end

P1=2;
P2=1;

retval=P1*sum(PVC)-P2*sum(PVCW); %subtotal of bus loadsum
PVe6Opt_W.m
clc
A=-1*eye(50);
for m=1:25
    c(m)=randn('norm',48,4.5);
end
for m=26:50
    c(m)=randn('norm',114,6);
end
b=-1*c;
%x=fmincon(@myfun,x0,A,b,Aeq,beq,lb,ub,@mycon)
x0=[45 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45 45.
    110 110 110 110 110 110 110 110 110 110 120 120 120 120 120 120 120 120
    120 120 120 120 120];
PVe6Obj_W(x0);
lb=[40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40 40.
    108 108 108 108];
    106 106 106 106 106 106 106....]
options = optimset('Algorithm','interior-point');

[X,FVAL,EXITFLAG,OUTPUT]=fmincon(@PVe6Obj_W,x0,A,b,[],[],lb,ub,[],options)

global tcPV
PV0=zeros(50,144);

for m=1:50
    Y(m)=round(X(m)+tcPV(m));
    X(m)=round(X(m));
    PV0(m,X(m):Y(m))=10;
end

PVLoad=sum(PV0,1)

PVSUVOBJ_W.m

function retval=PVSUVOBJ_W(x)

global tcPVSUV

Price=[0.11 0.11 0.09 0.11 0.11 0.11 0.13 0.11 0.11 0.11 0.11 0.11 0.11 0.11 0.11 0.11 ........
       0.11 0.09 0.11 0.09 0.00 0.02 0.04 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.13 ......
       0.11 0.11 0.13 0.13 0.13 0.13 0.20 0.35 0.35 0.35 0.35 0.43 0.37 0.54 .......
Wind=[0.95 0.94 0.93 0.91 0.89 0.88 0.87 0.87 0.86 0.84 0.81 0.81 0.78 0.77....
0.76 0.75 0.78 0.81 0.82 0.81 0.82 0.78 0.73 0.70 0.74 0.79 0.83 0.84....
97
0.85 0.85 0.82 0.78 0.82 0.89 0.92 0.93 0.92 0.85 0.72 0.64 0.65 0.66....
0.70 0.69 0.64 0.63 0.61 0.63 0.72 0.73 0.75 0.78 0.82 0.84 0.81 0.78....
0.78 0.81 0.86 0.87 0.88 0.95 0.96 0.98 0.96 0.97 0.98 0.99 0.99 0.99....
0.99 0.99 1.00 0.99 0.99 0.99 0.99 0.99 0.98 0.98 0.98 0.97 0.99 0.99....
0.99 0.99 1.00 1.00 0.99 0.97 0.92 0.78 0.60 0.52 0.41 0.24 0.14 0.08....
0.03 0.01 0.01 0.03 0.04 0.04 0.03 0.02 0.03 0.05 0.08 0.10 0.11 0.11....
0.10 0.11 0.12 0.11 0.10 0.09 0.07 0.08 0.06 0.04 0.03 0.02 0.01 0.01....
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.01 0.04 0.07 0.09 0.12....
0.14 0.15 0.17 0.18....
0.95 0.94 0.93 0.91 0.89 0.88 0.87 0.87 0.86 0.84 0.81 0.81 0.78 0.77....
0.76 0.75 0.78 0.81 0.82 0.81 0.82 0.78 0.73 0.70 0.74 0.79 0.83 0.84....
0.85 0.85 0.82 0.78 0.82 0.89 0.92 0.93 0.92 0.85 0.72 0.64 0.65 0.66....
0.70 0.69 0.64 0.63 0.61 0.63 0.72 0.73 0.75 0.78 0.82 0.84 0.81 0.78....
0.78 0.81 0.86 0.87 0.88 0.95 0.96 0.98 0.96 0.97 0.98 0.99 0.99 0.99....
0.99 0.99 1.00 0.99 0.99 0.99 0.99 0.99 0.98 0.98 0.98 0.97 0.99 0.99....
0.99 0.99 1.00 1.00 0.99 0.97 0.92 0.78 0.60 0.52 0.41 0.24 0.14 0.08....
0.03 0.01 0.01 0.03 0.04 0.04 0.03 0.02 0.03 0.05 0.08 0.10 0.11 0.11....
0.10 0.11 0.12 0.11 0.10 0.09 0.07 0.08 0.06 0.04 0.03 0.02 0.01 0.01....
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.01 0.04 0.07 0.09 0.12....
0.14 0.15 0.17 0.18];

for m=1:1:15
SOC(m)=random('norm',0.5,0.1); %State of charge

tcPVSUV(m)=(1-SOC(m))/0.0208;

A(m)=round(x(m));

B(m)=round(x(m)+tcPVSUV(m));

PVSUVC(m)=trapz(A(m):1:B(m),Price(A(m):1:B(m)));

PVSUVCW(m)=trapz(A(m):1:B(m),Wind(A(m):1:B(m)));

end

for m=16:1:30

SOC(m)=random('norm',0.5,0.1); %State of charge

tcPVSUV(m)=(1-SOC(m))/0.0208;

A(m)=round(x(m));

B(m)=round(x(m)+tcPVSUV(m));

PVSUVC(m)=trapz(A(m):1:B(m),Price(A(m):1:B(m)));

PVSUVCW(m)=trapz(A(m):1:B(m),Wind(A(m):1:B(m)));

end

P1=2;

P2=1;

retval=P1*sum(PVSUVC)-P2*sum(PVSUVCW); %subtotal of bus loadsum
PVSUVOpt_W.m

cle

A=-1*eye(30);

for m=1:15
    c(m)=random('norm',48,4.5);
end

for m=16:30
    c(m)=random('norm',114,6);
end

b=-1*c;

%x=fmincon(@myfun,x0,A,b,Aeq,beq,lb,ub,@mycon)
x0=[45 45 45 45 45 45 45 45 45 45 45 45 45 45 ....
    110 110 110 110 110 110 120 120 120 120 120 120 120 120];

PVSUVObj_W(x0);

lb=[40 40 40 40 40 40 40 40 40 40 40 40 40 40 ....

    288 288 288 288 288 288 288 288 288 288 288 288 288 288];

options = optimset('Algorithm','interior-point');
[X,FVAL,EXITFLAG,OUTPUT]=fmincon(@PVSUVObj_W,x0,A,b,[],[],lb,ub,[],options)

global tcPVSUV

PVSUV0=zeros(30,144);

for m=1:30
    Y(m)=round(X(m)+tcPVSUV(m));
    X(m)=round(X(m));
    PVSUV0(m,X(m):Y(m))=2;
end

PVSUVLoad=sum(PVSUV0,1)