The Impact of PHEV On Energy Demand Pattern In Distribution Network

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ABSTRACT
Plug-in hybrid electric vehicles or commonly called PHEV is known to be an advance generation of hybrid electric vehicle or HEV. PHEV has larger battery capacity compared to HEV which can be charged by plugging into standard electrical outlet a few hours each day. The charging activity of PHEVs by consumers will certainly introduce new load to the power grid. Mainly in distribution network, penetration of PHEVs may introduce potential challenges to electric utility. Battery capacity determine how long is needed to be fully charged. The larger the battery capacity, the longer the charging activity and the longer it will affect the hourly demand curve. This paper studies the energy demand pattern and the effect on distribution network due to the introduction of PHEV in electrical system. The simulation results show that, charging activity introduce new peak load to the demand curve. Compare to slow charging option, fast charging option introduced highest peak load and uncontrolled charging activity during peak hour using fast charging option could risk distribution network into danger. It’s advisable to all users to charge their PHEV during off-peak period to lower the impact to the connected distribution network.

Keywords: Plug-in hybrid electric vehicle (PHEV), energy demand pattern, distribution network

1. Introduction

Demand of hybrid electric vehicles (HEV) is rising in time globally as awareness towards clean, green and healthy world environment is increasing in society. Hybrid electric vehicles (HEV) have attracted public attention due to claims as the best method to improve vehicle gasoline usage, by using combination of gasoline engine and battery to supply vehicle power thus reducing the vehicle combusting that contribute to air pollution (Dickerman and Harrison, 2010). Plug-in hybrid vehicle (PHEV) is an advancement version of HEV which battery can be charged by standard electrical power outlet. Compare to a normal HEV, PHEV
can be driven further in all electric-mode without consuming gasoline due to its larger battery capacity (Dickerman and Harrison, 2010). According to Curtin, Shrago and Mikkelsen, (2009), plug-in hybrids electric vehicle depend on the electric supply from the grid for charging activity in order to offer them with functionality. The charging activity of PHEVs by consumers will introduced new load to the power system network. Mainly, a distribution network will face changes in their usage pattern due to the addition PHEV during charging period (Hadley, 2006).

To evaluate the adaptability of a distribution network to support PHEVs charging activity, thorough studies has to be done to avoid any unwanted problems which can be introduced during PHEVs charging activity. Uncontrolled PHEVs charging activity can cause overloading of a transformer which is the most fatal problem in a distribution network (Farmer, Hines, Dowds and Blumsack, 2010).

The main objective of this paper is to model energy demand pattern in distribution network taking into account PHEV and to see in what way PHEV will affect the hourly demand pattern. Beside the main objective, this project will also study a brief description of PHEV charging characteristics on the distribution network. The demand pattern of distribution network will be viewed in graphical form where several scenarios of charging period is examined to get better look on the impact to grid load curve due to the PHEV charging activity. Two basic question of how will PHEVs effect the hourly demand (load) curve and when is the best time to charge PHEV will be answered at the end of the paper. This paper will review all current studies on the impacts of PHEVs on the power system network mainly on distribution network, compare and contrast to those same past studies, and propose any possible upcoming work.

2.0 LITERATURE REVIEW

Nowadays PHEV have become a common topic for research and development. With concerns in societies worldwide about global warming and rising petroleum fuel price has forced major car manufactures with the introduction of plug-in hybrid electric vehicles. The major benefits of the PHEVs include the reduction of fossil fuels consumption, the productions of greenhouse gases, and the operation cost (spending less through buying electricity rather than gasoline to drive the same distance) (Dickerman and Harrison, 2010). Plug-in hybrid electric vehicles commonly called PHEV is a vehicle which can be plugged and charged using standard electrical power outlet and proven to be less dependent on petroleum fuel (Curtin, Shrago and Mikkelsen, 2009).

PHEVs are being developed globally to enhance the engine and battery operations for more efficient operations of both during battery discharging process and when electricity from grid is used to recharge the battery power. The charging process of PHEV will somehow affect the behaviour of grid system technically. However, common expectation that the grid will not be majorly affected by the charging process due to recharging process will only occur during off-peak hours. But this expectation could be wrong as end users have the power to control the recharging period, to be said that the users will surely recharge their PHEVs when
convenient to them, rather than when utilities would favour (Putrus, Suwanapingkarl, Johnston, Bentley and Narayana, 2009).

2.1 Battery capacity versus charging time

The main component of any PHEV is the battery. Battery holds a major and crucial role in PHEV technology of storing energy from electric grid and transfer the energy to the motor. Battery energy storage capacity (kWh) is very crucial factor since it will directly define the distance the vehicle can drive in all electric mode, as well as the size of the battery pack (Duvall, 2005). To recharge the used PHEV battery, it requires an electric supply from normal electrical power system network. Nemry, Leduc and Munoz, (2009) suggest that there are three type of charging process to recharge PHEVs. The three types of charging method are level 1, level 2 and level 3 method. Level 1 method uses standard 120V, 15A branch circuit which can be found in the residential and commercial buildings. Level 2 method is based on 240V, single phase, branch circuit with up to 40A and requires a dedicated circuit. This method could also be implemented in the residential and commercial buildings. The last, method 3 provide fast charging through public facilities based on 480V, three-phase circuit and enabling 60 to 150 kWh charging power. This option needs specific safety precautions. In a research on Scenario-Based Analysis on the impacts of plug-in hybrid electric vehicles’ (PHEV) penetration into the transportation sector, Li, (2007) found that charging strategy significantly affects the electricity consumptions. In another research on PHEV batteries, Yilmaz and Krein, (2013) have studied the current status and implementation of battery chargers, charging power levels and infrastructure for plug-in electric vehicles and hybrids to find the impact of PHEV charging activity.

Generally, different energy capacity of a battery require different period of time to recharge. Larger battery capacity needs more time to recharge compared to lesser battery capacity, but using charger with larger voltage and amperage could reduce the time while in the same time consume more power from the grid. Furthermore, electronic devices present in a PHEV’s charger induced power quality problem to an electrical network. Small power quality problems in a network could lead to a bigger problem to an electrical network if no mitigation is done. Any disruption in electrical network will affect the energy demand pattern in a network.

2.2 Peak power demand

The basic effects that PHEVs will have upon the grid based upon their characteristics are covered by Hadley, (2006). The impacts of PHEVs are determined through regional grid analysis based upon the number of vehicles, vehicle demand profile, and the effect that demand has on supply and demand. According to Shafiee, Fotuhi-Firuzabad and Rastegar, (2013) the voltage deviation is not a major issue in the distribution systems, while peak load and loss increment are both the big concern to the widespread use of PHEVs in distribution systems due to coincidence of daily peak load and charging time of PHEVs. A comprehensive model is needed to study the PHEV impacts on distribution system load demand. By modelling utility distribution circuit, Taylor, Maitra, Alexander, Brooks and Duvall, (2009) found that distribution network problems tend to increase linearly as the
penetration of PHEVs increases. A time coordinated optimal flow model for integrating PHEVs, vehicle-to-grid (V2G), and PHEV storage units in order to minimize power loss is suggested in Acha, Green and Shah, (2010). They found that, vehicle-to-grid (V2G) will have major effects on distribution as it helps decrease energy losses in areas that are further away from the slack bus.

Denholm and Short W. (2006) evaluated the utility system impacts and benefits of optimally dispatched plug-in hybrid electric vehicles. They studied the effects of optimal PHEV charging, under the assumption that utilities will indirectly or directly control when charging takes place, providing consumers with the absolute lowest cost of driving energy. They also considered the ability of PHEVs to discharge into the grid to replace conventional capacity that provides peaking and peak reserve capacity. Based on results from the PHEV-load tool, they concluded that large-scale deployment of PHEVs will have limited, if any, negative impacts on the electric power system in terms of additional generation requirements. Dyke, Schofield, and Barnes, (2010) studied the impact of transport electrification on electrical networks. A series of well-defined electric vehicle loads that are subsequently used to analyse their electrical energy usage and storage in the context of more electrified road transportation are established. These requirements are then applied to a European Union residential load profile to evaluate the impact of increasing electrification of private road vehicles on local loads and the potential for vehicle and residential load integration in the U.K. Utilization and effect of plug-in hybrid electric vehicles in the United States power is studied in Jenkins, Rossmaier and Ferdowsi, (2008). The viability of the PHEV as a mobile energy storage unit connected to the power grid is examined from a power system perspective, involving an examination of practicality, reliability, short- and long-term economics, and alternative energy storage units. Bevis, Hacker, Edrington, and Azongha, (2009) have done a review of PHEV grid impacts in the United States of America. Although the current electrical grid system has the potential to charge a significant amount of PHEV vehicles, it has become very evident that the current grid technology is not sufficient for the U.S. to maximize the possibilities of the plug-in hybrid electric vehicles. Also, the grid is not currently very receptive to rapid small scale renewable energy growth such as the use of V2G.

In a research article by Hadley and Tsvetkova, (2009), Major questions are addressed for guiding the study. Would the increase in PHEVs in market impact electricity demand, generation structure, and emissions levels in the near future? To forecast the effects of PHEVs’ market penetration on electricity demand, supply, price, and emissions, they used the ORCED model developed at Oak Ridge National Laboratory to examine numerous aspects of a restructured electricity market. The result of their research is that, the power demand, generation, electricity prices, and emissions from the utilities created by the introduction of PHEVs are expected to go up and will lead to negative consequences if nothing is changed.

In a study of the impact of plug-in hybrid electric vehicles on California’s electricity grid, Wynne, (2009) summarised that, although PHEVs may have a significant impact on the electric grid in large numbers, these impacts will be gradual as plug-ins begin to capture the market allowing time for utilities to adequately adapt to the additional demand. In the short term, most demand from PHEVs will be met by existing natural gas units in California. In
research study of the impact of plug-in electric light vehicles on the electrical system for the University of Bath, Pu, Parry, Redfern, and Dunn, (2011) found that allowing vehicles to fast recharge without a DMS power control system could cause catastrophic consequences for the University of Bath network with a high penetration of EVs parking on campus. Even recharging at the trickle rate brings the total campus demand very close to breaching network limits.

Shao, Pipattanasomporn and Rahman, (2009) found the impacts of charging PHEVs on a residential distribution network with different charging strategies. Using MATLAB Simulink to simulate real world cases, they found that all different charging strategies will create new load peaks seen by a distribution transformer the load must be control through advanced and smart techniques such as the advanced metering infrastructure (AMI). The impact on the Belgium distribution grid through the analysis of current Belgium traffic and driving patterns is discussed in Clement, Haesen, and Driesen, (2008). The important section of this paper examines the load flow analysis when PHEVs are added into the distribution network. Three different cases of uncontrolled charging are examined. The study of the impact of charging plug-in hybrid electric vehicles on a residential distribution grid is conducted by Nyns, Haesen and Driesen, (2010). The research emphasized the improvements in power quality that are possible by using coordinated charging or smart metering and also highlighted that uncoordinated charging of PHEVs decreases the efficiency of the distribution grid.

In another research, Clement, Haesen, and Driesen, (2009) studied the coordinated charging of multiple plug-in hybrid electric vehicles in residential distribution grids. In the paper, the analysis is elaborated to stochastic data. These stochastic aspects reflect an error in the forecasting of the daily load profiles. The impact of PHEVs on the distribution grid of multiple cities in Stockholm is studied in Karnama, (2009). The cars are demonstrated as a regular load. The penetration of the PHEVs is varied based upon the population and commercial density of each area and multiple types of both regulated and unregulated charging are modelled. The author found that the residential areas will be problematic with regards to the integration of PHEVs as the concentration of people (and thus PHEVs) is higher in these areas. It is also concluded that regulated charging will allow greater amounts of PHEVs to be integrated with the distribution grid.

A research on coordinated charging of plug-in hybrid electric vehicles to minimize distribution system losses is done by Sortomme, Hindi, MacPherson, and Venkata, (2011). In the work, the relationship between feeder losses, load factor, and load variance is explored in the context of coordinated PHEV charging. From these relationships, three optimal charging algorithms are developed which minimize the impacts of PHEV charging on the connected distribution system. For the conclusion, if the distribution system is a single feeder from the substation with all loads connected at the end, then minimizing losses maximizes the load factor and minimizing load variance minimizes losses exactly. For practical systems, minimizing load variance will minimize losses approximately. In research article by Pieltain, Gomez, Cossent, Domingo, and Frías, (2011) assessment of the impact of plug-in electric vehicles on distribution networks is carried. The article proposed a comprehensive approach for evaluating the impact of different levels of PEV penetration on distribution network.
investment and incremental energy losses. The proposed approach is based on the use of a large-scale distribution planning model which is used to analyse two real distribution areas. Two large-scale distribution areas with several voltage levels have been deeply analysed. The obtained results show that, with the estimated levels of driving and charging patterns in peak hours, the required network reinforcements can reach values up to 19% of total actual network costs in a situation without PEVs. The required investment is higher in the urban area with high load density. If PEV smart charging strategies are implemented, hence decreasing charging simultaneity factors, up to 60%–70% of the required incremental investment can be avoided.

The researches do not come to a specific conclusions about optimal charging patterns or energy demand pattern of distribution network integrated with PHEVs, but it does suggest that work must be done to further investigate how PHEVs will impact the grid. For effective economic dispatch and to avoid large installations of fast-response generation, electrical networks incorporating electric vehicles must form an interdependent relationship. This allows present residential peaks and fast acting loads to be met by PHEVs charging activity. It is still difficult to determine whether or not PHEVs and vehicle to grid technology will become profitable and reasonable in the future. PHEV technology such as battery capacity and drive train design is constantly undergoing research and testing, and new results and models are produced that affect the dynamic and direction of the industry. Though more tests are being performed in order to determine the future of the industry, there is still much that must be examined and analysed.

In general, the integration of PHEVs deeply affects the power losses and voltage deviations in the distribution grid and that these changes are far too essential to ignore. The impacts of PHEVs on the distribution network must be measured and quantified in order to maintain the reliability of the electrical system network. Coordinated charging of plug-in hybrid electric vehicles can lower power losses and voltage deviations by flattening out peak power. However, when the choice of charging periods is rather arbitrary, the impact of the PHEV penetration level is large. The research conclude that, in general, the coordinated charging of PHEVs can improve power losses and voltage deviations by flattening out peak power, although in some cases grid enhancement will be necessary.

2.2 Transformer

Adding PHEVs to a distribution network will not just introduce new peak load to a transformer. As the number of PHEVs increase in a system, the temperature of a transformer and cables in the system will also increase (Farmer, Hines, Dowds and Blumsack, 2010). Rising temperature of a transformer and cables will result in energy and power losses in the system. Any power loss in electrical system will reduce the efficiency of a network. The impact of charging PHEVs on a typical distribution feeder in Blacksburg, VA is examined by Shao, Pipattanasomporn, and Rahman, (2009). The network consists of five homes and two PHEVs, each of which is a Chevy Volt. Two charging strategies are considered: All PHEVs charging at 6 p.m. and all PHEVs charging at off-peak hours. The first case represents the worst case and results in a transformer load increase to 68/52% in winter/summer. The latter case results in a transformer load increase to 58/52% in winter/summer.
Roe, Meisel, Meliopoulos, Evangelos, and Overbye, (2009) evaluated power system level impacts of PHEVs. They investigate various aspects of how plug-in hybrid electric vehicles (PHEVs) could impact the electric power system. The investigation is focused on impacts on the power system infrastructure and impacts on the primary fuel utilizations due to PHEV charging. In conclusion, when PHEVs were included in the simulation, a 93% reduction of the expected life of the distribution transformer was calculated for a specific scenario. The impact on the infrastructure can be substantial and methodologies must be developed to solve these issues. Gong, Midlam-Mohler, Marano, and Rizzoni, (2011) experimentally study the impact of PEVs on the power grid focusing on residential transformer life estimation. Using real world data mass simulation of virtual PHEVs fleet study has been conducted. At the end of their study the results showed that large penetration of PHEVs can have great impact on the power grid particularly in the case with poor coordination of charging times. Equally, low penetration of PEVs is not harmful to the transformer life, especially if charging is coordinated to some degree. Green, Wang and Alam, (2011) studied the impact of plug-in hybrid electric vehicles on distribution networks. They survey all current studies on the effects of PHEVs on the grid, compare and contrast those same studies. They presented an overview of the state of the art in measuring and modelling the impact that PHEVs will have on the distribution grid. These impacts are built through a combination of driving patterns, charging characteristics, charge timing, and vehicle penetration.

2.3 Power quality

Dharmakeerthi, mithulananthan and saha, (2011) review the impacts of plug-in electric vehicles on the power grid. Key topics discussed in the paper are characteristics of PHEV, PHEV impacts on grid stability, the effect on supply demand balance, power quality issues like voltage regulation, phase balance and harmonics, as a result of PEV getting charged from the grid and the grid power losses associated with PEV integration. Depending on the PEV concentration at a certain location at a given time, its level of charging, SOC of battery and the charger characteristics, there could be a wide variety of impacts to the grid. A survey by Liu, Dow, and Liu, (2010) of PEV Impacts on Electric Utilities provides a narrative literature survey of the development and impact of PHEVs. Subjects covered are PHEV, industry trends, charge and discharge scenarios, and impacts on distribution systems. Hadley, (2006) studied the impact of plug-in hybrid vehicles on the electric. He identifies some of the complexities in analysing the integrated system of PHEVs and the grid. Depending on the power level, timing, and duration of the PHEV connection to the grid, there could be a wide variety of impacts on grid constraints, capacity needs, fuel types used, and emissions generated.

Voltage imbalances, voltage deviations, lines and equipment overloading, increased grid power losses, supply demand imbalances, instability problems are some of the serious impacts introduced by PHEV. Some impacts like harmonic impacts and voltage imbalances will be eased with added diversity with increased PHEV penetration. But this may not be the case during early stage of PHEV development. The other impacts like grid losses, voltage regulation, and thermal limit violations will increases with increasing penetration. Depending
on the charging technologies and possible penetrations, impacts on power distribution system may include power quality, voltage variation and shorten transformer life.

2.4 Environment

It is known by fact that vehicles are one of the main consumer of petroleum and contributors of hazardous gas emission to the environment. The main purpose of using PHEVs is to reduce the dependency of petroleum and to minimise the emission of hazardous gas to the environment. Meyer, Schneider and R. Pratt, (2007) technically analysed the emission level and petroleum usage as the number of PHEVs in a market increase. They have summarised that the petroleum dependency will drop and the emission of hazardous gas will decrease gradually as the number of PHEVs rise in a market. Roe, Meliopoulos, Meisel, and Overbye, (2008) did a research power system level impacts of plug-in hybrid electric vehicles using simulation data. The investigation is focused on the impact of the additional electrical load PHEV charging will have on primary energy source utilization and subsequent environmental air pollution (EAP) as emissions are transferred from vehicle tailpipes to power plants. Examples of energy source utilization impacts are presented for various levels of PHEV penetration on a specific power system. In general, PHEVs cause a shift of fuel utilization from gasoline. It was found that replacing a portion of the vehicles in the power system area with PHEVs would increase total NOx production and decrease total CO2 production. Although the finding of these researches is not related to the project, environmental issues plays by PHEV cannot be neglected.

2.5 Smart grid

In a research by Galus and Andersson, (2008) on demand management of grid connected plug-in hybrid electric vehicles (PHEV), they have proposed a modelling approach for PHEVs, an integration scheme into future power systems modelled by energy hubs and a demand management approach. Three different types of agents, the energy hub, the PHEV manager and the PHEV agent have been introduced and modelled, separately. The PHEV agents were modelled to increase their value of energy autonomously over time as they try to attain a certain goal. Real-time model of a fleet of plug-in vehicles performing vehicle-to-grid (V2G) power transactions is presented in research paper by Venayagamoorthy, Mitra, Corzine, and Huston, (2009). Two sets of four vehicles are connected to both the grid and to each other through a short transmission line. The real-time modeling is carried out on a Real-Time Digital Simulator (RTDS). An evaluation of PHEV contributions to power system disturbances and economics in discussed in Judd and Overbye, (2008). The paper focused on the support PHEVs can provide to grid security and possible economic benefits for grid operation. Plug-in hybrids also have a large potential to save money for those that own one. An analysis of the economic benefit to individual owners are also described. A research on PEV charging profile prediction and analysis based on vehicle usage data is carried by Ashtari, Bibeau, Shahidinejad, and Molinski, (2012). The study addresses gaps in the literature: predicting PEV charging behavior based on vehicle usage habits using a relatively large database of driver behaviour.
In general they observed that grid faults can be detrimental to the vehicles during V2G transactions. Advanced control and protection is needed to avoid any adverse effects caused from the large bidirectional power surges to the batteries and the inverters of individual plug-in vehicles. Smart charging method can be implemented to optimize the chargeable power in each period while meeting the charging requirements, and achieve smoother load profile, less power loss and better voltage quality (Li, Bai and Tan, 2012). Smart charging method is proposed to reduce the great pressure caused by random charging in high PHEV penetration and achieve win-win benefits of the grid operators and PHEV owners. Plug-in hybrids have been shown to be a promising advancement toward meeting our future personal transportation needs. PHEV reduces dependence on foreign oil imports, and reduce overall pollution.

Integrating PHEVs into building energy management has the potential of improving the energy and comfort management in a building environment. Wang, (2012) found that an intelligent PHEV control system is able to wisely manage the charging/discharging patterns for each PHEV for enhancing the overall comfort level of the smart building while minimizing the overall cost of gasoline. Smart buildings and plug-in hybrid vehicles PHEVs are two emerging novel technologies because of their potential economic and environmental benefits.

3.0 METHODOLOGY

Regarding the literature review, hypothesis have been developed as following:

- **H1**: There is an increase in power demand during PHEV charging activity.
- **H2**: It is advisable to charge PHEV during off-peak hour.

In order to prove the hypotheses and to fully understand the PHEV charging behaviour and effect to the grid, electrical distribution network has to be designed. The distribution network is designed based on real distribution network technical data and simulated using software called PSCAD.

3.1 Network Modelling

A typical distribution network is used in the analysis. The distribution network model consists of supply coming from 11kV, substation containing transformer stepping down voltage from 11kV to 0.415kV and distributed to 100 load or houses with 15kW consumption. Meters are placed at the transformer end, node end and at the load end where current and voltage are measured in each case. In this model, 11kV voltage source is modelled as three phase voltage source with 50hz frequency to represent the switching station. For this model, 3 phase 2 windings transformer is selected and the primary winding with a voltage of 11kV coming from the 3 phase voltage source and secondary winding of 0.415kV supplying to the load. The rated burden of the transformer is set to bet at 1MVA operating in 50Hz frequency. The primary winding is delta type winding and the secondary winding is star type winding which is typical winding type used in real distribution network transformer in a substation. Double storey bungalow type of house is to be used in the model.
with maximum demand of 15kW. The Complete detail distribution networks with 100 houses is shown in figure 1.

![Diagram of distribution networks](image)

**Figure 1: Complete detail distribution networks with 100 houses**

### 3.2 Charging Scenarios

5 scenarios were studied with variation of charging styles together with different number of PHEV penetration in an area while charging. The first scenario is a normal state of load when no PHEV is connected at the load side. In second scenario is when 50% total load (50 houses) is connected with PHEV using slow charging option. The third scenario is with slow charging option 100% of PHEV penetration in the network. The next 2 scenarios is by using fast charging option where 50% and 100% PHEV penetration in the selected network.

### 4.0 SIMULATION RESULT

#### 4.1 Distribution Network

Network shown in figure below is used in the simulation. Total numbers of 100 houses are connected in the network as loads as shown in figure 2.

![Diagram of distribution network](image)

**Figure 2: Distribution network**

#### 4.1.1 Scenario 1: Network With No Penetration Of PHEV

This simulation result act as a reference for other scenario result for comparison purposes. Below are the results when simulation is done.
4.1.2 Scenario 2: Network With 50% Of PHEV Penetration Using Slow Charging Option

Figures 3-5. The simulated output current at transformer end is $3.6kA$ while the output current at the node meter is measured to be $361A$ and current at the load is measured to be $36A$.
Figure 7: Transformer current with 50% PHEV penetration (slow charging)

Figure 8: Node current with 50% PHEV penetration (slow charging)

Figure 9: Load current with 50% PHEV penetration (slow charging)

From figures 7-9, the simulated output current at transformer end with 50% of PHEV penetration in the network is 3.78kA while the output current at the node meter is measured to be 378A and current at the load is measured to be 38A.

4.1.3 Scenario 3: Network With 100% Of PHEV Penetration Using Slow Charging Option

Figure 10: Distribution networks with 100% PHEV penetration (slow charging)
The simulation results show that the current at the transformer side is measured at 3.95kA while meter at node side give a reading of current of 390A. Current at load is measured to be at 39A.

4.1.4 Scenario 4: Network With 50% Of PHEV Penetration Using Fast Charging Option
The simulation results show that the current at the transformer side is measured at 4.34kA while meter at node side give a reading of current of 430A. Current at load is measured to be at 43A.

4.1.5 Scenario 5: Network With 100% Of PHEV Penetration Using Fast Charging Option
Figures above show simulation result using fast charging option with 100% PHEV penetration in the network. It can be seen from the result, the measured transformer current is 5.06kA and meter at node side gave a reading of 510A. The current at load end is measured at 51A.
4.1.5 Summarised Result

Table 1: summarised all result of all simulation scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Transformer current (kA)</th>
<th>Node current (A)</th>
<th>Load current (A)</th>
<th>Network power demand (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.6</td>
<td>361</td>
<td>36</td>
<td>1.49</td>
</tr>
<tr>
<td>2</td>
<td>3.78</td>
<td>378</td>
<td>38</td>
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<td>3</td>
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<td>1.63</td>
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<td>4</td>
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<td>434</td>
<td>43</td>
<td>1.80</td>
</tr>
<tr>
<td>5</td>
<td>5.06</td>
<td>510</td>
<td>51</td>
<td>2.10</td>
</tr>
</tbody>
</table>

4.2 Load Curve

Generally, different energy capacity of a battery require different period of time to recharge. Larger battery capacity needs more time to recharge compared with lesser battery capacity but using charger with larger voltage and amperage could reduce the time while in the same time consume more power from the grid. Dr. Mark S. Duvall at the DOE Plug-in Hybrid Electric Vehicles Workshop provided several characteristics for evaluating PHEV impacts on the grid (Duvall 2006). Table 2 shows a comparison of time required for recharging. This table shows the time taken for 20-mile battery range (PHEV 20) to recharge from 20% state of charge to fully charge, 100%.

Table 2: PHEV battery charging time

<table>
<thead>
<tr>
<th>PHEV 20 vehicle</th>
<th>Pack size</th>
<th>Charger circuit</th>
<th>Charging time 20% SOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compact Sedan</td>
<td>5.1kWh</td>
<td>120VAC/15A</td>
<td>3.9 - 5.4 hrs</td>
</tr>
<tr>
<td>Mid-size Sedan</td>
<td>5.9kWh</td>
<td>120VAC/15A</td>
<td>4.4 - 5.9 hrs</td>
</tr>
<tr>
<td>Mid-size SUV</td>
<td>7.7kWh</td>
<td>120VAC/15A</td>
<td>5.4 - 7.1 hrs</td>
</tr>
<tr>
<td>Full-size SUV</td>
<td>9.3kWh</td>
<td>120VAC/15A</td>
<td>6.3 - 8.2 hrs</td>
</tr>
</tbody>
</table>

Dr. Mark S. Duvall also provided another table table 3 showing the approximate amount of energy required and schedule for recharging PHEV. Note that this charging schedule will be different between different cars and battery used in the car.

Table 3: Distributed charging time

<table>
<thead>
<tr>
<th>Hour</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<td></td>
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<td></td>
<td></td>
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<td></td>
<td>Compact Sedan</td>
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<td>1.4</td>
<td>1.4</td>
<td>0.91</td>
<td>0</td>
<td>0</td>
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Assuming a constant energy needed for fully charging the battery, higher voltages or current would reduce the time required to fully charge. The real demand curves would differ more as the battery approached full charge and be dependent on other factors. Any battery charging
will vary the amperage as the battery approaches full state of charge, such that the power needs will oscillate and tail off towards the end of the charging time. The approximated power demand of PHEV 20 is shown in the below graph comparing between different level of charging (voltages and currents).

The power demand in the network calculated and can be viewed in graphical form. Adding the power demand data to the hourly load curve can demonstrate clearly the effect of PHEV charging to the grid system. The load curve also can give other important parameters which is crucial for further analysis of the network. Looking at the load curve information such as temperature of the system can be deduced.

4.2.1 Reference Load Curve

Figure below shows the reference curve which is the typical load curve when no PHEV is connected to the house or at load side. This curve is important to compare and to look at the effect of PHEV charging. The curve below represents the load curve for a house.

4.2.2 Evening charging (peak period)

Figure below shows the power demand when PHEV is charging using both slow charging and fast charging option during evening time. It is assumed that PHEV is charged as soon as the user arrives at home from work.


4.2.3 Off-Peak Charging

Figure below shows the effect when PHEV is charged during off-peak time when load demand at its lowest.

5.0 CONCLUSION

Hybrid vehicles have proven to be the best method to improve gasoline mileage, by using technology combining both engine combustion and battery to provide power to move the vehicle. Latest trends in the automotive technologies have led to rising in demand to use electrical system. At the same time, growth of PHEV introduces some challenges for the existing distribution network. In this project some issues concerning about the impact of PHEV were provided and case study scenarios were built for investigation of load profile with changes in PHEV penetration and charging option. The simulation result shows that the level of current in the network depends on levels of PHEV penetration and charging option. As the levels of PHEV penetration increases, the total current flow in the network will also increase. Using fast charging requires less time to fully charge the battery but in the same time introduce high peak power demand while using normal charging option takes longer time with lower peak demand. Small penetration of PHEV in the distribution network does not affect the network significantly. For a network which is not at the peak demand capacity will not be affected significantly to the uncontrolled charging of PHEV activity. However, for network that is near their peak demand will have an adverse impact due to uncontrolled PHEV charging activity. Transformer will likely to overload if uncontrolled charging activity takes place in the network with near peak demand capacity.
It can be concluded that PHEV penetration to distribution network create substantial changes on the network. Charging activity of PHEV introduced new peak load to hourly load curve and it is highly recommended to charge PHEVs during off-peaks period to avoid any introduction of problems to the connected distribution network.

References


REFERENCES


