

Review Article

Impact of Plug-in Hybrid Electric Vehicle on Power Distribution System Considering Vehicle to Grid Technology: A Review

A. Aljanad and Azah Mohamed

Department of Electrical, Electronic and Systems Engineering, Universiti Kebangsaan, Malaysia

Abstract: This study presents a comprehensive review of the potential technical impacts of plug-in hybrid electric vehicles on power distribution and transmission systems. This review also presents various power quality impacts on the power system in several aspects. This review conveys a detailed analysis of electric vehicle charging strategies on electrical distribution networks. The two charging aspects (coordinated/uncoordinated) and intelligent scheduling of charging are discussed in terms of their impacts on power systems. Vehicle to grid technology are investigated, elaborated and evaluated based on technical, suitability and configuration aspects.

Keywords: Charging coordination, Distribution Networks (DN), electrical power system, PHEV, Vehicle to Grid (V2G)

INTRODUCTION

Most countries worldwide have exerted much effort to develop their economic and environmental statuses, particularly independence from oil consumption. Plug-in Hybrid Electric Vehicles (PHEV) are promising technology that will alleviate dependency and excessive use of oil. PHEVs have been distributed worldwide, because of their contribution to society in terms of decreasing CO₂ intensity and mitigating gasoline consumption. PHEVs provide substantial support to economic and environmental issues. Large-scale production of PHEVs in most countries with automotive market widely influences the electricity grid in different aspects, such as power generation, peak and base load demand. Under uncontrolled PHEV charging, the harmful impacts are obtained during peak load. However, the use of Vehicle to Grid (V2G) technology in conjunction with PHEVs could supply temporary power to the grid, ensuring that the demand does not exceed the generating capacity. The immense benefits of PHEVs will lead to a sharp production increase in the future, resulting in massive effects to the grid without emphasizing the possible impacts. The emergence of PHEVs is expected to reach 100,000 by 2020 as reported by the Malaysia Federal State. With large-scale production of Electric Vehicles (EVs) in the future, the capacity they provide raises many questions with regard to how far these vehicles could utilize its built-in storage system and how this system could be used as an energy source to the power grid.

These questions should be resolved to provide solutions for unexpected peak loads. A new and evolving V2G technology has been introduced in the

power system to provide power to the grid for PHEVs. Previous studies revealed that EVs were parked almost 95% of the time. Thus, much work has been conducted to study the use of existing idle energy storage system from EVs to provide feedback power to the grid under the concept of V2G. Other ancillary services, such as peak power shaving, spinning reserve and voltage and frequency regulations, are delivered to the grid through V2G (Ehsani *et al.*, 2012). Ongoing research focuses on evaluating this novel technology.

An increased rate of PHEVs significantly affects the current electricity sector of any country; this finding implies that a fast response to increasing amounts of suddenly exposed loads caused by a massive need to acquire hybrid EVs must be established, considering their significant contribution. Most recent studies analyze the factors caused by the extra load of EVs on the grid during recharging time; these factors include charging behavior, optimization of energy cost, driving patterns and battery life (Azadfar *et al.*, 2015).

This review illustrates the potential impacts of PHEV distribution in the market. The present study reviews the most common technical challenges of PHEVs by providing a survey of all current studies on the effects of PHEVs on the distribution grid, compare and contrast those same studies. Results may confer assistance in long-term planning process and provide future insights in to the possibility of merging PHEVs in the national power grid.

MATERIALS AND METHODS

PHEV charging strategies: Charging profiles is a major factor that affects distribution networks prior to

Corresponding Author: A. Aljanad, Department of Electrical, Electronic and Systems Engineering, Universiti Kebangsaan, Malaysia

This work is licensed under a Creative Commons Attribution 4.0 International License (URL: <http://creativecommons.org/licenses/by/4.0/>).

vehicle charging. Charging EVs by using the supply grid significantly affects the levels of voltage. Thus, approach and control methods of charging EVs must be studied. Different charging strategies could be considered to manage the time and frequency of EV charging:

- Controlled/coordinated charging
- Not-Controlled/un-coordinated
- Charging delayed charging
- Off-peak charging

In studying PHEV charging, no single impact study can represent or be applicable to any utility grid or

country because of unpredictable PHEV charging patterns and diversity of PHEV circuit characteristics from one circuit to another. Moreover, lack of indispensable data, such as charging patterns and penetration levels, may increase the uncertainty. Table 1 shows the different penetration levels of uncoordinated charging indifferent countries. Two main perspectives can represent the initiation and worsening of impacts on the distribution grid.

From the consumer perspective, vehicle batteries should be charged to allow driver to use the vehicle with a full battery. PHEV batteries could be recharged at home, public car park, or work place. Regardless of the optimal recharging location, the main issue is the

Table 1: Penetration levels of uncoordinated charging in different countries

Countries	EV level of penetration (%)	Peak load increment (%)	Reference
USA (Los Angeles)	5-20	3.03-12.47	Markel <i>et al.</i> (2009)
USA (California)	10-20	17-43	Shiau <i>et al.</i> (2009)
USA (New York)	50	10	Lopes Peas <i>et al.</i> (2009)
Portugal	11	14	Peças Lopes <i>et al.</i> (2009)
Western Australia	17-31	37-74	Galus <i>et al.</i> (2010)
Belgium	30	56	Clement-nyns <i>et al.</i> (2010)
United Kingdom	10-20	17.9-35.8	Qian <i>et al.</i> (2011)
Netherlands	30	54	Weiller (2011)

Problem Size

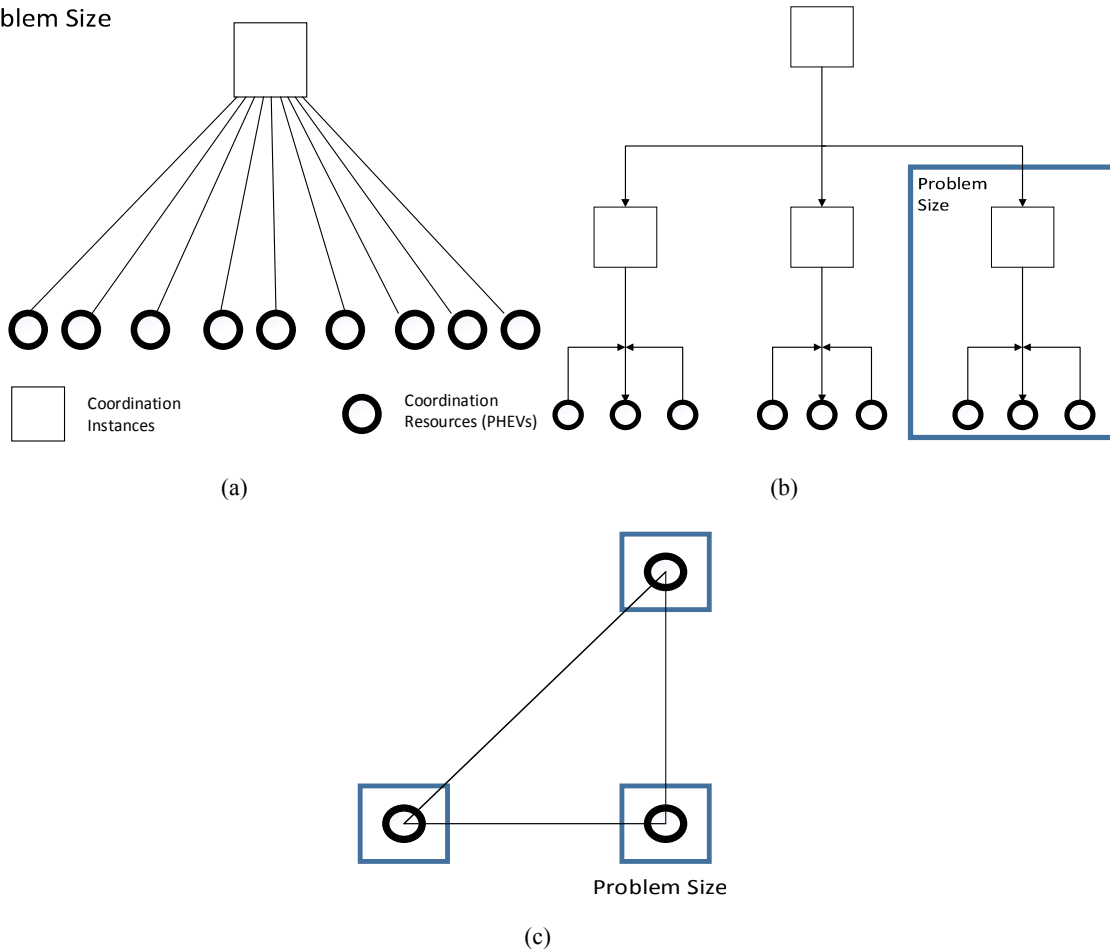


Fig. 1: PHEV charging coordination, Malone (1987); (a): Centralized; (b): Hierarchical; (c): Decentralized

uncoordinated power consumption, which may exist as a consequence of uncertain charging behavior and may result in grid deficiency. The impacts of these vehicles to the distribution grid could be mainly attributed to the large-scale consumption of electrical energy and this demand could possibly result in extra-large and undesirable peaks in energy consumption. The main impact of these extra single-phase electrical loads can be analyzed in terms of power losses and voltage unbalances. From the point of view of the distribution system operator, power losses during charging is an economic concern and transformer and feeder overloads are reliability and safety concerns (Farmer *et al.*, 2010). Power quality (e.g., voltage profile, unbalance and harmonics) is essential to the distribution grid operator and grid customers. Voltage deviations are regarded as a definite power quality concern (Geth *et al.*, 2012). In this regard, measuring these voltage imbalances over a distribution grid caused by wide electricity consumption for charging PEVs is the central procedure

in developing solutions, such as “smart” or “coordinated charging”.

PHEV charging coordination: The coordination of the charging process of PHEVs is highly recommended and must be implemented based on the given objective. The coordination of charging of PHEVs could be performed via different control architectures:

- Centralized
- Hierarchical
- Decentralized

Figure 1 provides a basic classification of the two charging coordination architectures under inclusion of the mixed hierarchical architecture. Following the predominant centralized control paradigms of the traditional power system, Table 2 provides an overview of the main research objective, coordination approach and scope covered by the model.

Table 2: Characteristics of the related literature with technical focus

Authors	Main objectives	Coordination approach	Model scope				Findings
			Grid constraints	Ancillary services	Renewable modeling	Trip modeling	
Shao <i>et al.</i> (2009)	Studied the possible impact of charging PHEVs on a typical distribution feeder in Blacksburg, VA. Two PHEVs (Chevrolet) and five homes were studied and the two strategies were considered for charging PHEVs at 6 p.m. and charging PHEVs at off-peak hours.	Central	Yes	Yes	Yes	Yes	The first scenario was the worst, the test concluded in raising the transformer load to 68/52%. The second scenario resulted in raising the transformer load to a slightly lesser percentage than the first case with 58/52%.
Shahnia <i>et al.</i> (2011)	Mainly studied and analyzed the voltage imbalance sensitivity and stochastic evaluation to acquire the location and determine the PEVs charging/discharging levels at low voltage distribution systems.	Central	Yes	No	Yes	No	The highest effected voltage imbalance levels are at the distribution feeder end.
Zhang <i>et al.</i> (2012)	Focused to show the impacts of V2G on the distribution grid modeling and power system stability that includes the steady state analysis.	Central	Yes	No	Yes	Yes	Intelligent charging and discharging methods are supposedly to be exposed to mitigate the power loss that caused by the adoption of large scale PHEVs to the power grid.
Shafiee <i>et al.</i> (2013)	Evaluated the PHEVs impacts on the residential distribution network from different time horizons by using the IEEE 34-node test feeder	Central	Yes	No	Yes	No	Peak load and loss increment are both of big concerns to the widespread use of PHEVs in distribution systems because of the coincidence of daily peak load and charging time of PHEVs.
Khamphanchai <i>et al.</i> (2014)	Proposed a decentralized voltage control algorithm to identify the possible EV penetration impact on load and voltage profiles at a distribution transformer. The study aimed to stabilize the nodal voltage at a distribution transformer within the acceptable limit to prevent the load profile and the transformer overload.	De-central	Yes	No	No	Yes	Electric vehicles penetration can result in driving the transformer load as well as voltage sags out of the acceptable limit.
Shaaban and El-Saadany (2014)	Proposed a multi-objective planning algorithm that confer capability of adapting scenarios of high penetration of EVs, along with the injection of renewable distributed generation.	Central	Yes	Yes	Yes	Yes	The main contributions of the study were basically, developing a probabilistic annual model of energy consumption for a fleet of EVs based on the Monte Carlo simulation, the second main contribution as the investigation of renewable distributed interaction units along with the requirements of EVs load.

Table 2: Continue

Technical focus	Authors	Main objectives	Coordination approach	Model scope			Findings	
				Grid constraints	Ancillary services	Renewable modeling		Trip modeling
	Bashash and Fathy (2014)	Provided further elaboration of the PHEV's possible constraints such as existing idle battery capacity, energy price and remaining charging time. In addition, the proposed framework was implemented to show the impacts of bidirectional V2G power flow as well as the updated hourly prices due to the PHEV battery's resistance during optimal charging.	Central	Yes	Yes	No	Yes	The demonstrated framework has the potential to adopt large-scale V2G optimization and control studies.
	Fazelpour <i>et al.</i> (2014)	Proposed optimization to assess integrating PHEVs with renewable energy resource (RES). He performed that by using the genetic algorithms (Gas).	De-central	Yes	No	Yes	Yes	There is a noticeable alleviation in real power losses and improvement of voltage profile in the distribution lines.
	Azadfar <i>et al.</i> (2015)	Has concerns on the possible technical impacts on PHEV recharging behaviors and charging patterns. At the same giving an overview of the most key factor that plays a prominent role in.	Central	Yes	No	No	Yes	The several key factors that most able to inflict damage to the electricity grid were elaborated. These two factors are: the PHEVs charging infrastructure and the battery performance. The study is also useful for planning future transport systems and for the utility sector.

Centralized charging control architectures: These architectures were built based on scheduling procedures, which also consider the requirements of individual charging jobs. These paradigms often rely on planned schedules, which are communicated through a central scheduling instance or assume a Direct Load Control (DLC) scheme to organize the overall charging process, thereby obtaining particular technical constraints (Gonzalez Vaya and Andersson, 2012).

A centralized approach presents advantages with regard to the reliability of charging control and easy integration into existing power system control paradigms. However, the centralized control architectures require a high degree of knowledge to facilitate accurate planning with the central instance (Li and Shahidepour, 2015).

Hierarchical charging control architectures: Hierarchical coordination procedures can be a hybrid form that incorporates aspects of centralized and decentralized control paradigms. These procedures incorporate the centralized control and scheduling mechanisms, but only address solutions for defined areas or parts of the overall system.

Decentralized charging control architectures: Decentralized charging coordination was built based on price-based mechanisms. Decentralized charging decisions enable vehicle owners or users to decide when and according to which objective to organize the charging process. The coordination mechanism must therefore incorporate the decisions of individual PEV owners to allow an effective and reliable operation of the system while guaranteeing supply for the vehicles.

RESULTS AND DISCUSSION

Impact of PHEV on Electrical Power System (EPS):

An electric grid consists of generation, transmission and distribution systems. The generation system is composed of power plants that generate electricity from a variety of sources, such as coal, gas, solar and wind. The impact of PEV charging on the electric grid as a whole is mainly influenced by two aspects:

- Level of PEV penetration
- Point in time and duration of PEV charging

Many studies have been performed to analyze the potential impact of large-scale integration of EVs into the existing power system. Study on integration of EVs into the grid was first started in the 1980s. In Heydt (1983) found that the charging demand of EVs coincides with the overall peak load. This study mainly focused on estimating the possible impacts on loads in different regions when the penetration growth rate of EVs changes. Results showed that uncoordinated charging scenarios of EVs occur along with the peak load on the grid, thereby affecting the performance of the grid.

Several papers reported the potential impacts of PHEVs without coordination on the charging behavior. A prominent and detailed study was conducted in Portugal; according to Camus *et al.* (2009), the power capacity of the Portuguese EPS may be inadequate if uncontrolled charging were conducted even at low penetration levels.

The peak power increased by about 30% for a penetration level of 17%, but the energy consumption

only increased by about 3.2% for the same penetration level. Andersson *et al.* (2010) also investigated the impact of PEV charging on the Sweden EPS under different scenarios. The most severe scenario presented that 80% of all vehicles in Sweden would be PEVs by 2030, resulting in increased electricity consumption of about 6% or approximately 9.5 TW h/year. The total power used for charging is dependent on the individual charge power and distribution of the charging time. With one phase of 230 V/10 per charging, the accumulative total power would reach a maximum of 3000 MW, which is about 10% of the installed capacity in Sweden. Hence, the capacity must be increased on a national level or coordinate the charging to take place during off-peak hours. According to Kintner-Meyer (2012), above 70% of American vehicles may be converted to PEVs without exceeding the existing generation capacity if the charging would be conducted during off-peak hours. However, the maximum possible PEV share varied from 18 to 127% in different states.

The distribution system mainly consists of substations and transformers to decrease electricity to a level used by end-user customers, particularly residential customers consuming 120/240 V and commercial and industrial customers consuming larger voltage levels. PEVs are more likely to affect the distribution system than the generation and transmission systems. A distribution system can be affected by PEV charging by:

- The level of PEV penetration
- The point in time and the duration of PEV charging

The relationship between the penetration level of PEVs and the components of the distribution system, such as feeders, substations and transformers; at high penetration levels of PEVs, the components may become overloaded. Overloading the transformer does not immediately result in device failure, but reduces its lifespan (Farmer *et al.*, 2010). A low-voltage grid cannot handle situations where everyone is simultaneously charging. Local demand profiles may significantly change because of simultaneous or uncoordinated charging. Several PEV owners simultaneously charging their vehicles in a district will cause a major impact on local infrastructure and local peak demand. Several studies have concluded that PEVs influence the distribution grid at a certain level. The extent of the impact depends on the penetration level of PEVs and their charging behavior Taylor *et al.* (2009a). Azadfar *et al.* (2015) assessed the possible technical impact on PHEV recharging behavior and charging patterns. This study emphasized the two main keys that could affect or shape PHEV charging patterns

and driving behavior. These two factors are charging infrastructure and battery performance.

Power loss: The Portuguese DS analyzed by Lopes *et al.* (2011) would experience problems with voltage drops and power loss at penetration levels below 10% if no controls were applied. Simulations were conducted in PSS/E by considering the average drive distance; the charge time would be calculated according to the electricity consumed/day instead of according to the size of the battery, which is also important to obtain reliable results. Instead of charging daily, charging was performed when the battery was assumed empty. Impact assessment of EVs was extensively presented by Torquato *et al.* (2014) by using two operation methods. Voltage drop, increase losses and cable overload were the main core impacts of PHEV connection on the distribution network. A privileged and prominent study of PHEV impacts on power quality in electrical distribution system was conducted by Gray and Morsi (2015). Saberbari *et al.* (2014) also evaluated PHEV impacts on the distribution grid in Iran with regard to power loss and voltage drop. Results emphasized the importance of having a coordinated plan for PHEVs, particularly during peak time; otherwise, PHEVs would disrupt grid strategies, decrease voltage and increase power losses. Another study conducted by Baharin and Abdullah (2013) revealed the potential impact of large-scale adoption of PHEV in Malaysia residential area. Geographic information system simulation software was used to identify and investigate the impact of different penetration levels of PHEVs on selected residential network. Cable size upgrading would significantly improve power losses.

Harmonics impacts: The unexpected number of PEV charging during peak demand hours may affect the overall residential load curve, increase system losses, overload lines and increase harmonics introduction into the system. According to Deilami *et al.* (2012) two PEV charging regime was used to analyze detrimental effects. The maximum bus-voltage deviation was observed in the uncoordinated random charging scenario. However, total power losses and THD for voltage was lower in the case of scheduled coordinated charging. Moreover, THD distortion was insignificant and can be ignored when PEV penetration was approximately 20%. Moses *et al.* (2011) demonstrated that the current harmonics are produced because of the nonlinear behavior of PEV loads, resulting in increased losses and temperature, reduced efficiency, premature insulation and winding failure. After 1 year, a pioneer work related to the impact of EVs to the power system was conducted by Emanuel (1984). The expected harmonics current, active power, reactive power and power factor were classified in five different types of EV battery chargers. The possible effects of the random

location of each type of charger and the typical distribution network were evaluated. A statistical method was proposed by Staats *et al.* (1998) to reveal the effect of electric vehicle battery charging on the harmonic voltage levels. The method resulted in appearance of the total harmonic distortion in voltage in the system nodes.

The basic effects of injecting PHEVs on the grid based on their characteristics were investigated by Hadley and Tsvetkova (2009). Analyzing the economic aspects of merging PHEVs to the US electric grid was demonstrated by Scott *et al.* (2007); the general economic proposition showed that that off-peak power revenues from PHEV owners are attractive and beneficial for electricity service provider and rate payers. Jenkins *et al.* (2008) demonstrated the importance of investigating the dynamic effects of PHEV on the US grid; nevertheless, the feasibility of integrating V2G technology is still early to be judged. Clement *et al.* (2009) and Sortomme *et al.* (2011) proposed strategies, such as coordinating charging to mitigate the imminent overload on the distribution transformers and cables, when charging many EVs at the same time. Taylor *et al.* (2009b) emphasized the issue of generation capacity. Many studies also presented a clear picture about the ability of existing infrastructure to adopt the resulting increase in the load. Shafiee *et al.* (2013) evaluated PHEV impacts on the residential distribution network from different time horizons by using the IEEE 34-node test feeder. Peak load and loss increment also contributed to the widespread use of PHEVs in distribution systems, as evidenced by the coexisting daily peak load and charging time of PHEVs.

Voltage imbalance: The imbalance effects were classified in three phase systems when voltages, magnitude and phase vary (Committee *et al.*, 2009). With the expected increase in quantities of EVs, the main connection points and the penetration level remain undetermined; this aspect would result in voltage imbalance in the three phase systems with the current availability of single-phase EV chargers in residential networks. Many prominent studies were conducted on the impact of voltage imbalance. Shahnian *et al.* (2011) mainly studied and analyzed the voltage imbalance sensitivity and stochastic evaluation to acquire the location and determine PEV charging/discharging levels at low voltage distribution systems. The highest affected voltage imbalance levels are located at the distribution feeder end. Meyer *et al.* (2011) presented the actual measurements of voltage imbalance in a distribution network by using five different chargers. A statistical analysis of the impact of voltage imbalance impact was conducted. In contrast, a case study with IEEE13-Node system was performed by Jiménez and Garcia (2012) to prove his proposed algorithm for

power-flow calculation with the integrated EVs in a distribution network.

Transformer overloading: The possible impact of charging PHEVs on a typical distribution feeder in Blacksburg, VA was studied by Shao *et al.* (2009); two PHEVs (Chevrolet) and five homes were examined using two strategies: charging PHEVs at 6 p.m. and charging PHEVs at off-peak hours. The first scenario was the worst and the test concluded that the transformer load increased to 68%/52%. The second one resulted in increasing the transformer load to a slightly lesser percentage than the first case with 58%/52%. Farmer *et al.* (2010) discussed PHEV effects on transformer; three different scenarios could possibly occur upon adoption of PHEV on a power grid. Introduction of power electronics increased the harmonics because the load increased, followed by an increase in the transformer temperature. This phenomenon will lead to wear and tear on the transformer bushings because of the flattened load efforts. Other researchers, such as Khamphanchai *et al.* (2014), proposed a decentralized voltage control algorithm to identify the possible EV penetration impact on load and voltage profiles in a distribution transformer. In this study, the nodal voltage was stabilized in a distribution transformer within the acceptable limit to prevent load profile and transformer overload. The results illustrated that EV penetration enhanced transformer load and decreased voltage beyond the acceptable limit.

Challenges of PHEV battery charger topologies: As operation of EV battery charger is dependent on electronic components and control strategy, it must be emphasized. Over the last years, many studies proposed a variety of circuit topologies and control strategies associated with their designs. The two types of EV charging are:

- Unidirectional charging
- Bi-directional charging

The first topology is considered the conventional type, with a diode rectifier as its first stage. In this topology, the local reactive power can reduce the complexity of managing and controlling heavy loads. A bidirectional charger can also operate in two different modes: G2V referred to as charging mode and Vehicle to Grid (V2G) referred to as discharging mode. Many researchers extensively studied the possible charging impact on the distribution network. Niaazari *et al.* (2014) improved the power factor and voltage profile during PHEV charging and proposed a probabilistic model, including specific parameters, such as daily travelled distance and battery size or capacity. Frequency deviation during PHEV charging and

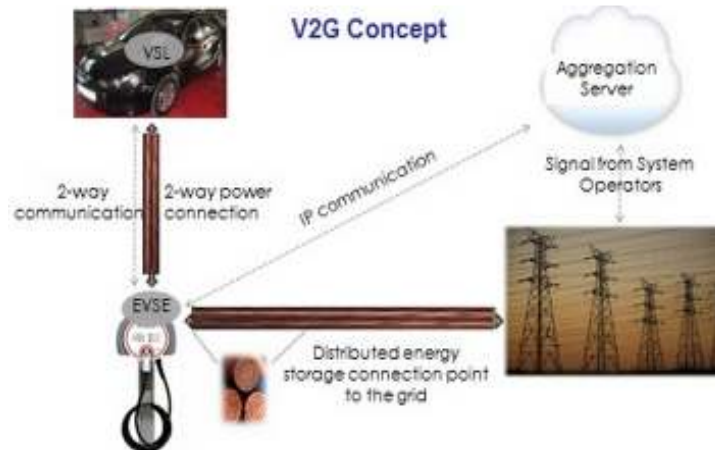


Fig. 2: Vehicle to grid concept

discharging on the grid system was extensively elaborated by Pahasa and Ngamroo (2015); they presented the model predictive control to effectively stabilize the frequency on grid system and produce the desired value of the state of charge.

Integration of V2G technology: The unique aspect of power flow in V2G vehicles is bi-directionality, indicating that vehicles can provide power to the grid during discharging time or absorb power from the grid during charging time as shown in Fig. 2. V2G could play an important role in boosting up the amount of distributed generation during peak hours. Basically, V2G is crucial to address the requirements needed for integrating both PHEVs and V2G with the current introduction of PHEVs into the transportation sector. More than half of the available literature addresses business models that allow slow charging of PHEVs, fast charging of EVs and set up battery swapping facilities for EVs. A bidirectional distribution system management role is attributed to PHEVs as storage devices to work in V2G mode when possible. Davis (2010) demonstrated aggregator as an entity in the center of the suggested business model, thereby using EV power when required and providing battery replacement and free charging or at reduced prices. Han *et al.* (2010) presented ideas on the types of services that aggregators could offer, depending on the types of available vehicles. Moreover, the authors addressed the vital volume of V2G to integrate large-scale intermittent renewable energy resources and quantitatively concluded that a fairly low penetration of PHEVs was necessary to maintain a 20% firm capacity of wind power. Much research work illustrated the most appropriate ancillary service provided by PHEVs (Sortomme and El-Sharkawi, 2012; Tomić and Kempton, 2007). Complete theoretical frameworks for integration of PHEVs as active elements in the electricity grids were demonstrated by several authors to address diverse issues, such as market

integration, communication architecture, management infrastructure, aggregator responsibilities and geographic dispersion (Al-Awami and Sortomme, 2012). Nevertheless, not all aspects were covered as most researchers tend to focus on other issues.

Various studies also exposed the technical issues of V2G impacts on the system stability. Pillai and Bak-jensen (2011) used an aggregated EV with a battery storage to represent the V2G system. Fernández *et al.* (2011) studied and analyzed three different charging scenarios with 35, 51 and 62%, respectively of PEV penetration for each area, which demonstrated the adaptation of the V2G strategy. The results revealed that if strategies are defined where PEVs are charged at off-peak hours, it would reduce up to 5 to 35% of the required investment. This system also enhanced operation by flattening the demand curve and reducing operational reserve requirements, causing a sharp decrease in the total and average system operation costs. Other researchers provided further elaboration of the PHEV possible constraints, such as existing idle battery capacity, energy price and remaining charging time (Bashash and Fathy, 2014).

V2G modeling: Other researches mainly focused on the impact of V2G on the distribution grid (Wu *et al.*, 2011; Zhang *et al.*, 2012). The effects emphasized modeling and power system stability, including steady-state analysis. Zhang *et al.* (2012) concluded that intelligent charging and discharging methods are exposed to mitigate the power loss caused by adoption of large-scale PHEVs to the power grid. However, implementing the market signal was strongly recommended by Boulanger *et al.* (2011) to support off-peak charging and achieve the valley filling and peak shaving.

Renewable Energy Source (RES): Several studies mainly focused on the integration of RES and how far it could provide power and energy balancing and

flattening the daily load profile. Rotering and Ilic (2011) and Ma *et al.* (2012) used intelligent charging and discharging methods to emphasize previously discussed issues. Other researchers, such as Khodayar *et al.* (2012), integrated EVs and wind energy in a power system by using a specific model called Stochastic SCUC. Nevertheless, challenges and hindrance exist when integrating V2G concept by determining benefits and other issues, such as profits. All of these aspects were revealed and elaborated by Mullan *et al.* (2012) and Yilmaz and Krein (2013). Some studies mainly focused on exposing the most optimal techniques for allocating power to each of PHEV that go to the charging station (Rahman *et al.*, 2014). Shaaban and El-Saadany (2014) proposed a multi-objective planning algorithm that confers the capability of adapting scenarios of high penetration of EVs, along with the injection of renewable distributed generation. The main contributions of the study were developing a probabilistic annual model of energy consumption for a fleet of EVs based on the Monte Carlo simulation and investigation of renewable distributed interaction units along with the requirements of EV load. Another research study presented the expected impact of EVs by considering probability of occurrence (Elnozahy *et al.*, 2014). Fazelpour *et al.* (2014) also proposed an optimization method to assess integrating PHEV RES by using genetic algorithms. The result indicated a noticeable alleviation in real power losses and improvement of voltage profile in the distribution lines.

CONCLUSION

Development of alternative sources of clean energy becomes a priority while reducing the use of fossil fuels. The huge consumption of gasoline has become a major issue and has been in the governments' top priority agenda and policies because of its importance in boosting up and improving economic and environmental features. The number of PHEVs rapidly increases in the market and expected to penetrate up to 35% by 2020, as reported by Nemry and Brons (2010). Thus, adopting large-scale PHEVs on the power grid could cause constraints and may overwhelm the electrical network depending on time and place when they are added. Therefore, the possible major technical issues affected by PHEVs include generation adequacy, load diagram modifications and electricity grid robustness; these issues should be deliberately and considerably studied and analyzed in accordance to the existing power grid without implementing a new infrastructure.

A couple of statements may be found in most studies: first, the increased energy demand is not a major problem because the energy needed is minor compared with the total energy consumption in most countries. Second, the generation and transmission capacities are the limiting factors in the massive

introduction of PEVs. This limitation could be solved by controlling the time of charging, either by legislation or by giving customers incentives to optimally adjust the timing of charging. Thus, the impact on the EPS would likely be more severe for countries with low electricity consumption per capita than for countries with higher consumption. For countries with low electricity consumption, the EPS and generation capacity are designed for lower consumption and the added load from charging PEVs would be a larger share of the total load compared with countries with high consumption.

REFERENCES

- Al-Awami, A.T. and E. Sortomme, 2012. Coordinating vehicle-to-grid services with energy trading. *IEEE T. Smart Grid*, 3(1): 453-462.
- Andersson, S.L., A.K. Elofsson, M.D. Galus, L. Göransson, S. Karlsson, F. Johnsson and G. Andersson, 2010. Plug-in hybrid electric vehicles as regulating power providers: Case studies of Sweden and Germany. *Energ. Policy*, 38(6): 2751-2762.
- Azadfar, E., V. Sreeram and D. Harries, 2015. The investigation of the major factors influencing plug-in electric vehicle driving patterns and charging behaviour. *Renew. Sust. Energ. Rev.*, 42: 1065-1076.
- Baharin, N. and T.A.R.T. Abdullah, 2013. Challenges of PHEV penetration to the residential network in Malaysia. *Proc. Technol.*, 11: 359-365.
- Bashash, S. and H.K. Fathy, 2014. Cost-optimal charging of plug-in hybrid electric vehicles under time-varying electricity price signals. *IEEE T. Intell. Transp.*, 15(5): 1958-1968.
- Boulanger, A.G., A.C. Chu, S. Maxx and D.L. Waltz, 2011. Vehicle electrification: Status and issues. *P. IEEE*, 99(6): 1116-1138.
- Camus, C., C.M. Silva, T.L. Farias and J. Esteves, 2009. Impact of plug-in hybrid electric vehicles in the portuguese electric utility system. *Proceeding of the International Conference on Power Engineering, Energy and Electrical Drives (POWERENG'09)*, pp: 285-290.
- Clement, K., E. Haesen and J. Driesen, 2009. Coordinated charging of multiple plug-in hybrid electric vehicles in residential distribution grids. *Proceeding of IEEE/PES Power Systems Conference and Exposition (PSCE '09)*, pp: 1-7.
- Clement-Nyngs, K., E. Haesen and J. Driesen, 2010. The impact of charging plug-in hybrid electric vehicles on a residential distribution grid. *IEEE T. Power Syst.*, 25(1): 371-380.
- Committee, D., I. Power and E. Society, 2009. IEEE recommended practice for monitoring electric power quality. *IEEE Std 1159™-2009*.
- Davis, U.C., 2010. Vehicle-to-Grid Power: Battery, Hybrid and Fuel Cell Vehicles as Resources for Distributed Electric Power in California.

- Deilami, S., A.S. Masoum, P.S. Moses and M.A.S. Masoum, 2012. Voltage profile and THD distortion of residential network with high penetration of plug-in electrical vehicles. *Proceeding of IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT Europe)*, 4: 1-6
- Ehsani, M., M. Falahi and S. Lotfifard, 2012. Vehicle to grid services: Potential and applications. *Energies*, 5(12): 4076-4090.
- Elnozahy, M.S., S. Member and M.M.A. Salama, 2014. A comprehensive study of the impacts of PHEVs on residential distribution networks. *IEEE T. Sustain. Energ.*, 5(1): 332-342.
- Emanuel, A.E., 1984. Alt (TC is., 1(4): 727-734.
- Farmer, C., P. Hines, J. Dowds and S. Blumsack, 2010. Modeling the impact of increasing PHEV loads on the distribution infrastructure. *Proceeding of 43th Hawaii International Conference on System Sciences*, pp: 1-10.
- Fazelpour, F., M. Vafaiepourb, O. Rahbarib and M.A. Rosen, 2014. Intelligent optimization to integrate a plug-in hybrid electric vehicle smart parking lot with renewable energy resources and enhance grid characteristics. *Energ. Convers. Manage.*, 77: 250-261.
- Fernández, L.P., T.G.S. Román, R. Cossent and C.M. Domingo, 2011. Assessment of the impact of plug-in electric vehicles on distribution networks. *IEEE T. Power Syst.*, 26(1): 206-213.
- Galus, M.D., M. Zima and G. Andersson, 2010. On integration of plug-in hybrid electric vehicles into existing power system structures. *Energ. Policy*, 38(11): 6736-6745.
- Geth, F., N. Leemput, J. Van Roy and J. Buscher, 2012. Voltage droop charging of electric vehicles in a residential distribution feeder. *Proceeding of 3rd IEEE PES International Conference and Exhibition on Innovative Smart Grid Technologies (ISGT Europe)*, pp: 1-8.
- Gonzalez Vaya, M. and G. Andersson, 2012. Centralized and decentralized approaches to smart charging of plug-in vehicles. *Proceeding of IEEE Power and Energy Society General Meeting*, pp: 1-8.
- Gray, M.K. and W.G. Morsi, 2015. Power quality assessment in distribution systems embedded with plug-in hybrid and battery electric vehicles. *IEEE T. Power Syst.*, 30(2): 663-671.
- Hadley, S.W. and A.A. Tsvetkova, 2009. A potential impacts of plug-in hybrid electric vehicles on regional power generation. *Electr. J.*, 22(10): 56-68.
- Han, S., S. Han and K. Sezaki, 2010. Development of an optimal vehicle-to-grid aggregator for frequency regulation. *IEEE T. Smart Grid*, 1(1): 65-72.
- Heydt, G.T., 1983. The impact of electric vehicle deployment on load management strategies. *IEEE T. Power Ap. Syst.*, 5: 1253-1259.
- Jenkins, S.D., J.R. Rossmair and M. Ferdowsi, 2008. Utilization and effect of plug-in hybrid electric vehicles in the United States power grid. *Proceeding of IEEE Vehicle Power and Propulsion Conference*, pp: 1-5.
- Jiménez, A. and N. Garcia, 2012. Unbalanced three-phase power flow studies of distribution systems with plug-in electric vehicles. *Proceeding of North American Power Symposium (NAPS, 2012)*, pp: 1-6.
- Khamphanchai, W., M. Pipattanasomporn, S. Rahman and A.T. Al-Awami, 2014. Impact of electric vehicles on household voltage profiles and possible mitigation approach. *Proceeding of IEEE PES Innovative Smart Grid Technologies, Europe*, pp: 1-6.
- Khodayar, M.E., L. Wu and M. Shahidepour, 2012. Hourly coordination of electric vehicle operation and volatile wind power generation in SCUC. *IEEE T. Smart Grid*, 3(3): 1271-1279.
- Kintner-Meyer, M., 2012. Impacts assessment of plug-in hybrid vehicles on electric utilities and regional. *Technical Assesment*, pp: 1-20.
- Li, T. and M. Shahidepour, 2015. Price-based unit commitment: A case of lagrangian constants. 20(4): 2015-2025.
- Lopes, J.A.P., F.J. Soares and P.M.R. Almeida, 2011. Integration of electric vehicles in the electric power system. *P. IEEE*, 99(1): 168-183.
- Lopes Peas, J.A., F.J. Soares and P.M.R. Almeida, 2009. Identifying management procedures to deal with connection of electric vehicles in the grid. *Proceeding of IEEE Bucharest PowerTech*, pp: 1-8.
- Ma, Y., T. Houghton, A. Cruden and D. Infield, 2012. Modeling the benefits of vehicle-to-grid technology to a power system. *IEEE T. Power Syst.*, 27(2): 1012-1020.
- Malone, T.W., 1987. Modeling coordination in organizations and markets. *Manage. Sci.*, 33(10): 1317-1332.
- Markel, T., M. Kuss and P. Denholm, 2009. Communication and control of electric drive vehicles supporting renewables. *Proceeding of IEEE Vehicle Power and Propulsion Conference*, pp: 27-34.
- Meyer, J., S. Hahle, P. Schegner and C. Wald, 2011. Impact of electrical car charging on unbalance in public low voltage grids. *Proceeding of 11th International Conference on Electrical Power Quality and Utilisation (EPQU)*, pp: 1-6.
- Moses, P.S., M.A.S. Masoum and K.M. Smedley, 2011. Harmonic losses and stresses of nonlinear three-phase distribution transformers serving plug-in electric vehicle charging stations. *Proceeding of IEEE PES Innovative Smart Grid Technologies (ISGT)*, pp: 1-6.
- Mullan, J., D. Harries, T. Bräunl and S. Whitely, 2012. The technical, economic and commercial viability of the vehicle-to-grid concept. *Energ. Policy*, 48: 394-406.

- Nemry, F. and M. Brons, 2010. Plug-in hybrid and battery electric vehicles market penetration scenarios of electric drive vehicles. JRC 58748 Technical Note.
- Niazazari, I., H.A. Abyaneh, M.J. Farah and F. Safaei, 2014. Voltage profile and power factor improvement in PHEV charging station using a probabilistic model and flywheel. Proceeding of 19th Conference on Electrical Power Distribution Networks (EPDC), pp: 6-7.
- Pahasa, J. and I. Ngamroo, 2015. PHEVs bidirectional charging/discharging and SoC control for microgrid frequency stabilization using multiple MPC. IEEE T. Smart Grid, 6(2): 526-533.
- Peças Lopes, J.A., F.J. Soares, P.M. Almeida and M. Moreira da Silva, 2009. Smart charging strategies for electric vehicles: Enhancing grid performance and maximizing the use of variable renewable energy resources. Proceeding of the EVS24 International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium, pp: 1-11.
- Pillai, J.R. and B. Bak-jensen, 2011. Integration of vehicle-to-grid in the western danish power system. IEEE T. Sustain. Energ., 2(1): 12-19.
- Qian, K., C. Zhou, M. Allan and Y. Yuan, 2011. Modeling of load demand due to EV battery charging in distribution systems. IEEE T. Power Syst., 26(2): 802-810.
- Rahman, I., P.M. Vasant, B.S.M. Singh and M. Abdullah-Al-Wadud, 2014. Intelligent energy allocation strategy for PHEV charging station using gravitational search algorithm. AIP Conf. Proc., 1621: 52-59.
- Roter, N. and M. Ilic, 2011. Optimal charge control of plug-in hybrid electric vehicles in deregulated electricity markets. IEEE T. Power Syst., 26(3): 1021-1029.
- Saberbari, E., S. Member and H. Saboori, 2014. Evaluating PHEV impacts on domestic distribution grid in terms of power losses and voltage drop. Proceeding of 19th Conference on Electrical Power Distribution Networks (EPDC, 2014), pp: 6-7.
- Scott, M.J., M. Kintner-Meyer, D.B. Elliott and W.M. Warwick, 2007. Impacts assessment of plug-in hybrid vehicles on electric utilities and regional U.S. Power Grids Part 1: Economic Assessment. Pacific Northwest National Laboratory.
- Shaaban, M.F. and E.F. El-Saadany, 2014. Accommodating high penetrations of PEVs and renewable DG considering uncertainties in distribution systems. IEEE T. Power Syst., 29(1): 259-270.
- Shafiee, S., M. Fotuhi-Firuzabad and S. Member, 2013. Investigating the impacts of plug-in hybrid electric vehicles on power distribution systems. IEEE T. Smart Grid, 4(3): 1351-1360.
- Shahnia, F., A. Ghosh, G. Ledwich and F. Zare, 2011. Voltage unbalance sensitivity analysis of plug-in electric vehicles in distribution networks. Proceeding of 21st Australasian Universities Power Engineering Conference (AUPEC), pp: 1-6.
- Shao, S., M. Pipattanasomporn and S. Rahman, 2009. Challenges of PHEV penetration to the residential distribution network. Proceeding of IEEE Power and Energy Society General Meeting, pp: 1-8.
- Shiau, C.S.N., C. Samaras, R. Hauffe and J.J. Michalek, 2009. Impact of battery weight and charging patterns on the economic and environmental benefits of plug-in hybrid vehicles. Energ. Policy, 37(7): 2653-2663.
- Sortomme, E. and M.A. El-Sharkawi, 2012. Optimal scheduling of vehicle-to-grid energy and ancillary services. IEEE T. Smart Grid, 3(1): 351-359.
- Sortomme, E., M.M. Hindi, S.D.J. MacPherson and S.S. Venkata, 2011. Coordinated charging of plug-in hybrid electric vehicles to minimize distribution system losses. IEEE T. Smart Grid, 2(1): 198-205.
- Staats, P.T., W.M. Grady, A. Arapostathis and R.S. Thallam, 1998. A statistical analysis of the effect of electric vehicle battery charging on distribution system harmonic voltages. IEEE T. Power Deliver., 13(2): 640-646.
- Taylor, J., A. Maitra, M. Alexander and D. Brooks, 2009a. Evaluation of the impact of plug-in electric vehicle loading on distribution system operations. Proceeding of IEEE Power and Energy Society General Meeting (PES'09), pp: 1-6.
- Taylor, J., D. Brooks, M. Alexander and M. Duvall, 2009b. Integrating plug-in- electric vehicles with the distribution system arindam. Proceeding of 20th International Conference and Exhibition Electricity Distribution-Part 1, pp: 1-5.
- Tomić, J. and W. Kempton, 2007. Using fleets of electric-drive vehicles for grid support. J. Power Sources, 168(2): 459-468.
- Torquato, R., L.C.P. da Silva, W. Freitas and B. Kurth, 2014. Impact assessment of the two-way operation of plugin electric vehicles on distribution networks. Proceeding of IEEE PES General Meeting | Conference and Exposition, pp: 1-5.
- Weiller, C., 2011. Plug-in hybrid electric vehicle impacts on hourly electricity demand in the United States. Energ. Policy, 39(6): 3766-3778.
- Wu, D., D.C. Aliprantis and K. Gkritza, 2011. Electric energy and power consumption by light-duty plug-in electric vehicles. IEEE T. Power Syst., 26(2): 738-746.
- Yilmaz, M. and P.T. Krein, 2013. Review of the impact of vehicle-to-grid technologies on distribution systems and utility interfaces. IEEE T. Power Electr., 28(12): 5673-5689.
- Zhang, P., K. Qian, C. Zhou and B.G. Stewart, 2012. A methodology for optimization of power systems demand due to electric vehicle charging load. IEEE T. Power Syst., 27(3): 1628-1636.