Review Article

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

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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 CO$_2$ 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...
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>
<thead>
<tr>
<th>Countries</th>
<th>EV level of penetration (%)</th>
<th>Peak load increment (%)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA (Los Angeles)</td>
<td>5-20</td>
<td>3.03-12.47</td>
<td>Markel et al. (2009)</td>
</tr>
<tr>
<td>USA (California)</td>
<td>10-20</td>
<td>17-43</td>
<td>Shiau et al. (2009)</td>
</tr>
<tr>
<td>USA (New York)</td>
<td>50</td>
<td>10</td>
<td>Lopes Peas et al. (2009)</td>
</tr>
<tr>
<td>Portugal</td>
<td>11</td>
<td>14</td>
<td>Peças Lopes et al. (2009)</td>
</tr>
<tr>
<td>Western Australia</td>
<td>17-31</td>
<td>37-74</td>
<td>Galus et al. (2010)</td>
</tr>
<tr>
<td>Belgium</td>
<td>30</td>
<td>56</td>
<td>Clement-ynys et al. (2010)</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>10-20</td>
<td>17.9-35.8</td>
<td>Qian et al. (2011)</td>
</tr>
<tr>
<td>Netherlands</td>
<td>30</td>
<td>54</td>
<td>Weiller (2011)</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Technical focus</th>
<th>Authors</th>
<th>Main objectives</th>
<th>Coordination approach</th>
<th>Model scope</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shao et al. (2009)</td>
<td>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.</td>
<td>Central</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Shahnia et al. (2011)</td>
<td>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.</td>
<td>Central</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Zhang et al. (2012)</td>
<td>Focused to show the impacts of V2G on the distribution grid modeling and power system stability that includes the steady state analysis.</td>
<td>Central</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Shafee et al. (2013)</td>
<td>Evaluated the PHEVs impacts on the residential distribution network from different time horizons by using the IEEE 34-node test feeder</td>
<td>Central</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Khamphanhais et al. (2014)</td>
<td>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. 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.</td>
<td>De-central</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Shaaban and El-Sebady (2014)</td>
<td>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.</td>
<td>Central</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
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 Shahidehpour, 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% indifferent 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. Shafee 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. Shahnia 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. Niazazari 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
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; Tomic 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 Ilić (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 Yılmaz 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 confirms 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 Nenry 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**


