Impact Assessment of PEV Charging Demand on Smart Grid

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With an increasing high demand for plug-in electrical vehicles (PEVs), their potential impacts on the power system need to be investigated, in order to develop a cost-effective PEV charging infrastructure and to ensure stability and efficiency of the smart grid. This article discusses system models for estimating the aggregate PEV charging demand over a geographical area and key system state characteristics that affect the spatial–temporal PEV charging demand distribution.

Due to its environmental and economic benefits, plug-in electrical vehicles (PEVs) have become one of the main applications of the smart grid. However, the future deployment of PEVs will lead to an increase in electricity demand, and large-scale penetration of PEVs is expected to significantly influence peak demand, feeder loss, and voltage fluctuations in the electrical power distribution systems. To assess the impacts on the smart grid, an estimation of PEV charging demand is required, which will help utilities to mitigate the PEV impacts and to ensure a reliable and safe operation of power systems.

The estimation of system-wide PEV charging demand in a given area is a complex task, because the demand is a stochastic process, depending on various factors such as the driving behavior, remaining battery state of charge (SOC), charging location and charging time, which varies from one customer to another. The estimation is required to evaluate the impact of PEV integration on power systems and to develop a plan for necessary upgrade of the current distribution system (e.g., transformers, cables, and protection devices). Moreover, the estimation will help utilities in establishing new charging infrastructure and new generation sources, dispatching existing generation sources, and implementing demand side management (DSM) programs.

In order to estimate the system-wide PEV charging demand, three subsystem models are used in tandem, where each model utilizes the outcomes of the previous model(s). These models are: travel pattern; energy consumption; and power consumption.

The travel pattern model estimates the daily travel distance of PEVs, together with where and when PEVs will be charged. The information can be represented by a time varying distribution of the number of simultaneously charging PEVs at each distribution node. Usually, national travel surveys or database obtained by GPS recording devices installed in PEVs are used to obtain the information. The data can be analyzed directly by deterministic methods; however, stochastic simulation methods are preferred in order to account for the uncertainty of PEV dynamics.

The energy consumption model characterizes the SOC of PEV batteries at the starting time of the charging process. This model captures the PEV battery discharging characteristics. The SOC of a PEV battery is a random variable that depends on various system variables. One is the energy consumed by PEV per unit travel distance, which is a function of vehicle characteristic parameters (such as vehicle weight and aerodynamics drug coefficient), driving habits, geographical location, road condition, and so on. Another variable is the PEV daily travel distance in all electric range (AER), which can be extracted from the travel pattern model. Other variables include the energy required to maintain the cabin temperature comfortable for the vehicle driver and passengers.

The power consumption model estimates the charging power of the aggregated PEV load profiles in the charging locations. This model requires various system state information including:

- Number of simultaneously charging PEVs in the system – The statistics of this variable can be extracted from the travel pattern model which provides the spatial and temporal distribution of the number of PEVs in charging state;
- Charging scenarios – It can include both controlled and uncontrolled charging. In uncontrolled charging, a PEV starts charging immediately after plugged into the power grid, and the charging rate is fixed. Controlled charging, on the other hand, can be price based control or direct control (smart charging), with some coordination over charging process of PEVs;
- Charging level – The standard charging levels for PEVs include AC level 1, AC level 2, and DC fast charging. AC level 1 charger is for use at home, which requires a small power (1.4-1.9 kW) over a long charging time (17-7h). On the other hand, AC level 2 and DC fast charger require a huge amount of power (19.2-40kW) to charge over a short period (3h-20min). They are suitable for charging in public and commercial areas;
- Charging duration – There are different types of PEV batteries, and each battery type has its unique characteristics. Charging duration depends on charging level, charging rate, PEV battery capacity, and the available SOC at the beginning of the charging process, whose statistics can be estimated from the energy consumption model.

Based on the spatial–temporal PEV charging demand distribution, utilities can estimate the total system loads, including the conventional load demand profile and the PEVs charging profile. Impact analysis of PEV charging load on the distribution system can then be carried out. There are three major time-varying impact indicators: the first is line congestion, which indicates the shortage in transmission line capacity to meet the waiting load; the second index is nodal voltage deviation, which determines the voltage drop in system nodes; and the third index is system energy loss rate, which represents the daily percentage energy loss in the total energy consumption.

In facing all technical challenges in the integration of PEVs into the smart grid, optimal planning of charging infrastructure can mitigate negative impacts of PEVs on the power system. Further research is necessary to accurately model various uncertain characteristics of PEVs and driving patterns for optimal planning of PEV charging infrastructure. Such planning should account for various system aspects, including PEV characteristics, PEV owner driving behaviors, the transportation and distribution network constraints, economic and security issues in the power system.

Author Biographies

Ahmed Abdalrahman Ahmed received the BSc. degree (First Class Hons.) from Thebes Higher Institute of Engineering, Egypt, in 2008; and the MSc. degree from Ain Shams University, Egypt, in 2013, all in Electrical Engineering. He is a research assistant and currently working towards his Ph.D. degree at the Department of Electrical and Computer Engineering, University of Waterloo, Canada. His research interests include smart grids, and PEV charging infrastructure planning.

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