Signal Processing Techniques for EV Charging

UMA MAHESH REDDY IPPALA
Final year student
Department of Electronics & Communication,
R.V.College of Engineering,
Bangalore-560059.

GAGAN N
Final year student
Department of Electronics & Communication,
R.V.College of Engineering,
Bangalore-560059.

AMRUTHESHA S
Final year student
Department of Electronics & Communication,
R.V.College of Engineering,
Bangalore-560059.

ADARSH J K
Final year student
Department of Electronics & Communication,
R.V.College of Engineering,
Bangalore-560059.

Abstract—**With the conventional energy resources diminishing at a rapid rate, it has become extremely important that alternate sources of energy be found to drive vehicles. Electricity is one such option. But it has been observed that by making use of electricity a slight change in the vehicular hardware is required. As a result the plug-in hybrid electric vehicles (PHEV) and the plug-in electric vehicles (PEV) have been developed. These vehicles have to be charged for their usage. It is observed that the electric power distribution grid is not currently prepared to effectively accommodate the increase in load caused by charging of the Electric Vehicle (EVs) batteries. Solving this issue involves infrastructure development such as establishment of smart grids and also application of a number of signal processing techniques. This paper introduces the main issues related with the operation of EVs in a smart grid infrastructure and the different signal processing techniques can be applied in this context.**

Index Terms—**Coordinated charging, distribution grid, smart grid, plug-in hybrid electric vehicles,plug-in electric vehicles, dynamic programming, quadratic programming.**

I. INTRODUCTION

IT would not be very long before the available energy sources to drive vehicles, namely, the fossil fuels, completely vanish. As a result there would be no fuel to power transportation vehicles. Therefore, it is the need of the hour to find out the forms of the energy that can be used to power vehicles. Of late it has been observed that with minor modifications done to vehicular hardware, electricity can be used as the energy source to drive cars and other vehicles.

While the release of new models for plug-inhybrid electric vehicles (PHEVs) andplug-in electric vehicles (PEVs) bringattention on theprogress towards reducing carbon emissionsand other greenhouse gases, the work in this areainvolves not only the vehicles themselves but, importantly, alsothe electric power grid infrastructurethat will support them. Forecasting results are emphasizing theobservation that the electric power distribution grid is not currentlyprepared to accommodate the predicted increase in load caused by chargingof the EVs batteries. Solving this issue requires infrastructure developmentsuch as the use of smart grid technology and a number ofsignal processing techniques. In this sense, EVs prove to be a challengeforresearch that interweaves signal processing with numerous othertechniques aimed at integrating and managing in a unified system a regional electric grid with distributed local powergeneration, storage, and intelligent loads. Furthermore, the integration of EVs intothe smart grid is significant since the involved signal processing techniques will lead to and be a prime application forthe development of a unified smart infrastructure.

The growing deployment of EVs is still a recent area of research. As such, the focus of ongoing research is the work that studies the effect of the extra loading from EVs on the electric grid. The role of signal processing in this research is both in the forecasting methods to predict the impact on the grid and with techniques to address the observed issues.

II. EVS AND SMART GRID

PHEVs and PEVs are vehicles powered by electricity which is stored in onboard energy storage devices—in most cases batteries—that are charged by plugging them into the electric grid. These vehicles may or may not have additionally an internal combustion engine for cruising or for powering the car after the batteries are discharged. The vehicles that are exclusively powered by onboard batteries are called PEVs and those with an additional internal combustion engine are called PHEVs. Naturally, PEVs are equipped with a larger battery capacity than PHEVs.

The EV batteries need to be periodically charged even though PEVs and PHEVs feature technologies to maximize the energy stored in the batteries, such as using some of the car’s kinetic energy to charge back the batteries when the vehicle brakes are applied (a technique called regenerative braking), and in the case of PHEVs, batteries are supported by a gasoline engine. Autonomy exclusively from electricity is limited by the batteries large size and weight.

It is expected that EVs are to be charged in between every day to three days. To charge the batteries, EVs are connected to the electric grid, which provides different connection options called "charging levels."The most widely accepted charging profile characterization produced by the Society of Automotive Engineers, SAE J1772 [1], involves three charging levels. Level I is the slowest of charging levels, taking a PHEV between seven to ten hours to be fully charged and a PEV between 17 to 22 hoursto be charged, assuming that the EVs are completely discharged. The next, faster charging level is Level II. Level II charging requires a 240 V outlet. Its maximum power rating is 20 kW.At this power level, completely discharged PEVs and PHEVs can be fully charged in a little over an hour and in a little less than half an hour, respectively.Level III is the fastest charging approach for EVs. Its power rating is over 20 kW, with the most commonly found rating of 50 kW.

With the introduction of EVs, electrification helps to address the issues in the vehicular transportation industry arising from the use of internal combustion engines (such as the un-sustainability of oil resources and environmental concerns from the increase in greenhouse gasses emissions), but it may also create issues to electric grids.One important issue is that even at the slowest charging regime, PHEVs and PEVs double the load of a typical home. This issue is particularly true where power distribution transformers typically serve three to five homes, so any significant load increaseas represented by PHEVs and PEVs will translate into a significant relative load increase for transformers that are not designed to accommodate.

However, since a home's load is not constant, the proposed solution to this problem is to charge EVs at night, when the home load is at its minimum. Still, to control when to charge an electric car, there mustexist a communication and information exchange between the grid and the EV charging hardware. However, in conventional power grids, there are no communication and control mechanisms embedded at such level of the distribution grid. To address these and other issues, conventional power grids have recently started to be transformed to add technologies that, importantly, include distributed communications and control systems. These systems are key enabling technologies, added to conventional grids because they provide the possibility of having the bidirectional flow of information and control actions in power grids. These enhanced power grids, with added technologies that enable an integrated bidirectional flow of power, information, and control actions, have come to be known as smart grid.

Currently, many smart grids initiatives feature basic levels of technology development, in which the key fundamental addition to conventional grids are smart meters at the consumers' homes and businesses. The smart meters transmit energy consumption information at a grid connection point, back to the utility so as to implement some basic control actions, such as demand response programs. The basic principle behind demand response programs is to control demand levels based on various mechanisms, such as through differentiated pricing that motivate users to charge their EVs at night. In extreme cases, the control signal may directly disconnect the EV charging circuit until load levels are reduced. Hence, demand response programs act as a virtual energy storage mechanism that shift load during the day based on information and control action exchanges. A number of techniques that may be seen within the demand response category will be discussed in the "Signal Processing Techniques for PHEVs/PEVs Charging Management" section. Nevertheless, operations of this basic smart grid still relies on a relatively unreliable and inflexible centralized architecture in which demand increases need to be match instantaneously with an additional generation output in large power plants. The responsibility for controlling generation output typically relies in a centralized dispatch center that evaluates voltage and frequency deviations and considers economic aspects and lines loading to decide the optimal way of serving the load.

A more complex smart grid further expands the portfolio of technologies added to conventional grids by including advanced autonomous distributed controls, home energy management systems, distributed generation, e.g., PV modules, fuel cells, and micro turbines, and actual local energy storage. The addition of these technologies provides significant added operational flexibility that allows addressing the integration of a disruptive technology, such as EVs, and use of renewable energy sources (which introduce the challenge of exhibiting avariable output power profile), in a more comprehensive way. For example, local energy storage can be combined with local PV generation to be able to store the excess power generated by the PV modules during the day so as to rapidly charge an EV at night. With this approach, the extra power consumption of the car is not being presented to the grid. These are resources that would not typically fall within the control domain of the dispatch center found in conventional power grids and basic smart grids. Implicit within this solution is the need for anticipating demand adequately, so energy can be managed effectively and impact on the grid of EV charging is reduced or eliminated. This demand forecasting function can be implemented through embedded algorithms both on the utility side system controllers and in the customer side home energy management systems.

III. EFFECT OF EVs ON THE GRID

The growing deployment of EVs is still a recent area of research. As such, the focus of ongoing research is works that study the effect of the extra loading from EVs on the electric grid. The role of signal processing in this research is both in the forecasting methods to predict the impact on the grid and with techniques to address the observed issues. One of the first studies in the recent epoch of smart grid development is [2]. Here, it is acknowledged the complexity in studying the effects of EVs on the smart grid because the results depend on many variables (power level, timing, duration of the EV connection to the grid) and the effects could be on several factors (capacity needs, emissions generated).From the perspective of envisioning demand forecasting mechanisms, the grid load results in [2] appear as signals with clear periodic components. While the introductions of EVs affects the loads, specially increasing the peak demand, these periodic components still remain, this is a useful observation in the development of forecasting algorithms.

A charging EV may present a load to the electric grid of the same order of magnitude as a typical home. The connection of loads of this magnitude may create power quality problems, such as momentary voltage drops. With today’s grid, these drops can be exemplified by, and related to, what is commonly observed at homes when the lights dim as the air conditioner or the dishwasher is turned on. The impact of charging EVs is studied from the perspective of this type of effect on the quality of the electric power distribution to homes. Specifically, the quality is evaluated by estimating the deviations in the supplied voltage, i.e., voltage drops, from a nominal target value.

One other important perspective when studying the effect of EVs on the electric grid is its stability. Indeed, since most of the involved components, e.g., the distribution grid or the batteries’ equivalent models, are in effect resistive, inductive, capacitive (RLC) circuits, the whole grid-EV system can be thought of as a filter, where the signal is the voltage or current delivering power to the loads. Albeit being based on a simplified grid model, the work presents a study of the effects of EVs on the stability of the grid. The results, derived from solving linear circuit equations to calculate the grid-EV Eigenvalues and transfer function, show that while the system without EVs is reasonably damped, the introduction of charging EVs notably increases the amplitude and duration in the angle and voltage oscillations, both signs of increased grid instability.

The design of future EV charging management algorithms will need to consider this effect so as to stabilize the grid, by introducing damping components when controlling the charging of the EV.

EVs will also have an impact on the operation of the grid, not as a load but as a source for local electrical power by dis-charging their batteries into the grid, in V2G applications. In these applications, signal processing algorithms may be used to control both real and reactive power injected back into the grid. For example, signal processing techniques may be used to control the delivery of energy from EVs to maintain grid stability (by measuring frequency deviations) while considering the batteries state of charge estimate and the near future EVs charge scheduling need for transportation use. The work is an example of this class of algorithms, where a simple charging-discharging control is implemented by estimating batteries state of charge and considering the maximum and minimum values for it. Power flow is set based on the supply-demand imbalance of the power system estimated from the frequency deviation at the plug-in terminal.

IV. SIGNAL PROCESSING TECHNIQUES FOR CHARGE MANAGEMENT OF EVs

Un-coordinated charging of EVs may result in degradation of electric energy distribution quality. Thus, it will be necessary to build into the smart grid technologies to manage the charging of PHEVs and PEVs. A number of these techniques rely on data and controls provided by the smart grid. Voltage drops can be possibly thought as an “error signal,” few techniques are presented to manage EV charging.

A. Techniques Based on Error Signal

These techniques aim to solve the same problem: finding the EVs charger power, subject to limitations on the maximum charging power, which minimize the voltage drop such that the EV batteries are fully charged.

Voltage drop due to PEV charging is considered as “error signal” [3]and two techniques are presented to manage EV charging. Both of the techniques aim to find the optimal EVs charger power, which minimizes the voltage drop and charges EVs batteries fully.While one technique solves the problem through quadratic programming, the other uses dynamic programming.

In [4] and [5], the total load at a time t is separated into a part from EVs, $L^{ev}(t)$, and a remainder part from other appliances. The load from EVs is assumed to be proportional to the number of charging EVs, N(t), by a factor -g: $L^{ev}(t) = -g\ N(t)$. The problem of predicting the load becomes that of predicting N(t) through estimation of the parameters of a queuing system that models arrivals of charging vehicles and their charging. Two scenarios were considered: uncontrolled vehicles charging and controlled vehicles charging. N(t) is modeled as Poisson random variable with a mean

$$m(t) = E[N(t)] = E\left[\int_{t-c}^{t} \lambda(\mathrm{u})\mathrm{d}(\mathrm{u})\right]$$
$$= E[\lambda(\mathrm{t} - \mathrm{Ce})]E(T\ c)$$

Where λ (t) the arrival rate at time t, Tc isis the vehicles charging time, and *Ce*is a random variable. The arrival rate of charging vehicles, λ (t) is not directly observable, and so it is estimated from counting the number of arriving vehicles over a period of time T, C (t).

In the second scenario in [5] the EVs are entered into a queue to wait for authorization to charge. The state of this queue evolution is modeled as

$$S_t = S_{t-1} - \alpha_{t-1} + D_t$$

Where D_t is the number of vehicles arriving during the time interval *t* into the system to be charged and$\alpha_t$is a matrix of Poisson random variables that specify the number of vehicles that can be charged.Using this model, the control center can estimate the statistics of $S_t$and decide on the next action.

B. Decentralized Charging Algorithm

In [6], a decentralized charging algorithm is proposed where EVs can plug in at different times, with different battery charge, and have different maximum charging speed and deadlines. This algorithm is designed with the goal of minimizing the aggregated demand from EVs during the charging period.

The proposed algorithm is divided into two parts that are executed iteratively. In the first part, each EV calculates a charging profile so as to minimize the objective function.

In the second part of the algorithm, the utility sets the price profile using a relation directly related with the aggregate demand. Higher the demand, higher the price charged by the utility in the next iteration.

C. Local and Global Strategies

Local and Global strategies are proposed in [7], the difference being that in the local strategy, charging involves a single vehicle and other loads include a single house, where as for global strategy multiple EVs and the whole residential area is considered.

Charging management algorithms for the local and global strategies share the same goal in determining the charging loads for the EVs so that the difference between the actual load and an optimal load is minimized.

The optimal load is calculated as the sum of the average of the original base load profile over a time interval[t1,t2] and a constant averaged charging load.

D. Charge Scheduler

Another technique that manages charging of EV includes implementation of a charge scheduler [8]. Charge scheduler is implemented using a multi agent system. Two agents are defined: a "PHEV agent," which is the software controlling the charging of one PHEV and a "transformer agent," which is the software that controls the power delivered through a transformer so that the load profile is flattened.

In this technique, first a PHEV sends a request for maximum charging power. A transformer agent receives this request and calculates the peak. This calculated peak load is smoothed through low-pass filtering and the resulting smoothed power profile "signal" is delivered by a high-voltage transformer as long as it does not exceed a maximum limit.

E. Grid Frequency Algorithm

From a signal processing perspective, another signal that can be used in EV management algorithms is the grid frequency. This is because changes in this variable indicate imbalance between the power being introduced to the grid and the power required by the load. In [9], a control loop is designed based on this phenomenon for a smart EV grid interface.Depending on the frequency variation, the interface allows for EV charging or even to inject power to the grid.

V. CONCLUSION

Currently, power distribution utilities plan their grid locally within the area of the distribution utility, and no information about loads of neighbouring electric power distribution utilities is considered.However, due to the mobile nature of EVs a given utility will need to know not only how the load behaves locally, but also to anticipate charging behaviour of EVs in other zones outside the utility area.Therefore, extending signal processing analysis to electric power distribution planning processes and tools will be a certain future challenge.

Also EVs appear as a prime application for the development of a unified smart infrastructure seamlessly integrating energy generation and distribution, intelligent transportation systems, and ubiquitous communications and data networking. The future challenge will then be to develop signal processing technology that will be able to collect information from the different types of sources in a unified smart infrastructure and make effective use of them through joint processing.

VI. ACKNOWLEDGEMENT

The authors would like to thank our guide, Prof. N. Ramavenkateswaran, Asst.Professor, Prof.Uttarakumari, Head of the Electronics and Communication Department, for her encouragement and also thank Prof. B.S. Satyanarayana Principal, RV College of Engineering, Bangalore, for his support and motivation to carry out this project. The authors thank Dr.S.Sridhar, Professor and Dean, Cognitive & Central Computing Facility of R. V. College of Engineering, Bangalore, India for having

communicated this work in the form of paper to this journal.

REFERENCES

[1] SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler, Standard J1772, Jan. 15, 2010.

[2] S. W. Hadley. (2006, Oct.).Impact of plug-in hybrid vehicles on the electric grid, ORNL Report [Online].Available:http://apps.ornl.gov/~pts/prod/pubs/ldoc3198_plug_in_paper_final.pdf

[3] K. Clement-Nyns, E. Haesen, and J. Driesen, "The impact of charging plug-in hybrid electric vehicles on a residential distribution grid," IEEE Trans. Power Syst., vol. 25, no. 1, pp. 371–380, Feb. 2010.

[4] M. Alizadeh, A. Scaglione, and R. J. Thomas, "Direct load managementof electric vehicles," in Proc. IEEE Int. Conf. Audio, Speech and Signal Processing(ICASSP), 2011, pp. 5964–5967.

[5] M. Alizadeh, A. Scaglione, and Z. Wang, "On the impact of Smart Grid metering infrastructure on load forecasting," in Proc. Allerton Conf. Communication, Control, and Computing, 2010, pp. 1628–1636.

[6] L. Gan, U. Topcu, and S. Low, "Optimal decentralized protocols for electric vehicle charging," in Proc. Conf. Decision and Control, 12–15 Dec. 2011, pp. 5798–5804.

[7] K. Mets, T. Verschueren, W. Haerick, C. Develder, and F. De Turck, "Optimizing smart energy control strategies for plug-in hybrid electric vehicle charging," in Proc. 2010 IEEE/IFIP Network Operations and Management Symp. Workshops (NOMS), Apr. 19–23, 2010, pp. 293–299.

[8] S. Vandael, N. Boucke, T. Holvoet, and G. Deconinck, "Decentralized demand side management of plug-in hybrid vehicles in a smart grid," in Proc. 1st Int. Workshop Agent Technologies for Energy Systems, 2010, pp. 67–74.

[9] J. A. P. Lopes, F. J. Soares, and P. M. R. Almeida, "Integration of electric vehicles in the electric power system," Proc. IEEE, vol. 99, no. 1, pp. 168–183, Jan. 2011.