Signal Processing in the Electrification of Vehicular Transportation

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INTRODUCTION

Electric vehicles bring more and more attention to general public due to their environmentally friendly advantage and lower price. To make this come to real life, the electric power generation and distribution grid infrastructure need to be improved a lot to support the significant extra load provided by these kinds of new vehicles. Through observing the consumption of the grid each day, there always exists certain regular patterns. By using the signal processing techniques, forecasting results can be obtained to accommodate the predicted increase in load caused by charging EVs. Furthermore, this technique will maintain the whole grid even users charging the EV's batteries in a few minutes.

CHARACTERISTICS

The two models of electric vehicles:

- Plug-in hybrid electric vehicles (PHEVs)
- Plug-in electric vehicles (PEVs)

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. The vehicles that are exclusively powered by onboard batteries are called PEVs and those with an additional internal combustion engine are called PHEVs. To charge the batteries, EVs are connected to the electric grid, which provides different connection options called "charging levels."

Charging Level	Charging Time	Power Rating	Charging Voltage
Level I	PHEVs: 7-10 hours PEVs: 17-22 hours	2kW	120V
Level II	PHEVs: 7 hours PEVs: 3-4 hours	3.5kW	240V
Level III	PHEVs: less than 30 mins PEVs: about 1 hour	Over 20kW, Commonly about 50kW	Very Provided for Homes

Table 1. The Charging Level of EVs

IMPACT OF EVs ON THE GRID

The growing deployment of EVs is still a recent area of research. It is acknowledged the complexity in studying the effects of EVs on the smart grid because the results depend on many variables variables and the effects could be on several factors.

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.
Signal processing perspective simulation results:

Without EV Charging Case	Voltage increases smoothly from a 4.3% to a 1.7% drop
With EV Charging Case	Much more random behavior with average voltage drops around 5%-10.3%

Table 2. How the voltage supplied to a house change with and without EV charging

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 discharging their batteries into the grid, in vehicles-to-gird (V2G) applications. In these applications, signal processing algorithms may be used to control both real and reactive power injected back into the grid.

METHODOLOGY

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.

The EV charging load prediction:

The total load at a time t is separated into a part from EVs, $L^{EV}(t) = -g\,N(t)$. $N(t)$ is the number of charging EVs and is modeled as a Poisson random variable with a mean $E[N(t)]$ if there are no cars waiting to be charged.

$$m(t) = E[N(t)] = E\left[\int_{t-C}^{t} \lambda(u)du\right] = E[\lambda(t - C_e)]E[T_c]$$

$$F_{C_e}(t) = \frac{1}{E[T_c]}\int_0^t (1 - F_C(v))dv,\ \ t \le 0$$

$F_C(u)$ is the average of charging times, $\lambda(t)$ is the arrival rate of charging vehicles. However, $\lambda(t)$ is not directly observable and changing over time, autoregressive integrated moving average (ARIMA) process is introduced. Here is the model:

$$(1 - \sum_{i=1}^{p-d} a_i' D^i)(1 - D)^d C(t) = (1 + \sum_{i=1}^{q} b_i D^i)\varepsilon(t)$$

D is unit time delay operator, $\varepsilon(t)$ is the error term. Therefore, the task of estimating $\lambda(t)$ becomes that of estimating the parameters p, q, d, a_i' and b_i.

What if the cars waiting to be charged is not zero? $S_t = S_{t-1} - \alpha_{t-1} + D_t$ is used. D_t is the number of vehicles arriving during the time interval t and α_{t-1} is a matrix of poisson random variables. We can derive S_t from previously realized D_{t-1} with knowing the allowed charging action a_{t-2} and decide on the next action.

Rapid charging system:

In some situation, the user will start a trip without having enough charge

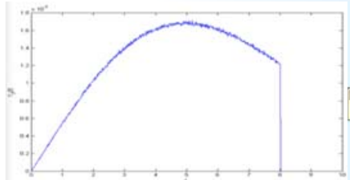

Fig. 1. Distribution of EV charge times

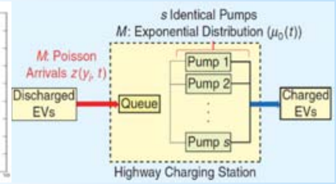

Fig. 2. Rapid charging station system

to reach their destination. For those case, it will necessary to develop an infrastructure of rapid charging stations that will allow users to charge the EVs' batteries in a few minutes.

An EV could be recharged in under four minutes but consuming more than 30 times the electrical power. A rapid charging station to draw peak powers of this magnitude would result in important power quality problems, the rapid charging stations should be designed with energy storage systems from which to draw the charging energy without loading the grid.

For here, we design a stochastic fluid dynamic model to find the expected charging demand for a charging station at the exit of a highway the expected number of busy rapid charging stations. For this model required the information and characterize of the vehicles into, out of and inside sections of a highway with rapid charging stations at the exits.

$$\frac{d < r(x,t) >}{dt} + \left[\frac{\partial v(x,t)}{\partial x} + < \gamma(x,t) >\right] < r(x,t) > = < b_d^+(x,t) > - < b_d^-(x,t) >$$

The mean arrival rate of discharged EVs at the ith exit charging station :

$$< z(y_i,t) > = < h_d(y_i,t) > - < \beta_i(t) >$$

The expected charging demand of the ith exit charging station :

$$E[P_d(y_i,t)] = p_{av} < z(y_i,t) > / \mu_0(x)$$
$$\mu_0(x) = k_{mh} p_{av} / soc_{av}$$

To estimate the expected charging demand, this technique only requires as input traffic information.

FUTURE CHALLENGES

- Will lead the huge change in both electric utilities and automotive industries
- Multiple signal processing research
- Signal processing analysis

REFERENCES

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