Comprehensive Management Strategy for Plug-in Hybrid Electric Vehicles using National Smart Metering Program in Iran (Called FAHAM)

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Keywords: Billing Solutions, Charging Management, Plug-in Hybrid Electric Vehicles, Smart Metering.

Abstract: Plug-in hybrid electric vehicles charging management as well as billing solutions may be the most important challenges in the coming years. In this paper, a comprehensive management strategy (CMS) for plug-in hybrid electric vehicles (PHEV) using national smart metering program in Iran (called FAHAM) is proposed. The proposed strategy considers PHEVs charging management and billing solutions as well. An optimization method is applied in order to shift PHEVs' charging load and maximize load factor.

1 INTRODUCTION

Although the widespread implementation of plug-in hybrid electric vehicles (PHEV) may introduce a solution to the world fossil fuel shortage as well as the air pollution crisis, the anticipation of connection of PHEVs into the power network may bring up many technical drawbacks that need to be addressed properly. In the near future, a huge number of PHEVs will add a large-scale energy demand to power systems. An emerging issue is that a large number of EVs simultaneously will be connected to the grid that may put at risk the overall power system quality and stability (Sortomme & El-Sharkawi, 2012; Sousa et al., 2012; Pillai & Bak-Jensen, 2011).

The intelligent scheduling and control of PHEVs as loads or power sources have great potential for evolving a sustainable integrated electricity and transportation infrastructure (Honarmand et al., 2014; Honarmand et al., 2014; Honarmand et al., 2015; Brahman et al., 2015). Large numbers of EVs have the potential to put at risk the stability of the power network. The charging demand of PHEVs needs to be managed very carefully in order to avoid interruption when several thousand of them are introduced into the system over a short period of time.

In this paper, a comprehensive management strategy (CMS) for PHEVs using national smart metering program in Iran (called FAHAM) is proposed in order to consider PHEVs charging management and billing solutions as well. The proposed strategy is capable of controlling charging procedure of PHEVs.

The rest of this paper is organized as follows: National smart metering project in Iran is presented in Section II. The comprehensive management strategy for PHEVs is stated in Section III. The problem formulation for maximizing the load factor is presented in Section IV. Simulation data and results are presented and discussed in Section V. Finally, the conclusion is given in Section VI.

2 NATIONAL SMART METERING PROGRAM IN IRAN (CALLED FAHAM)

Deploying an Advanced Metering Infrastructure (AMI) is an essential early step to grid modernization. AMI is not a single technology but it is an integration of many technologies such as smart meter, communication network and management system that provides an intelligent connection between consumers and system operators (Jadid et al., 2013; Modaghegh & Zakariazadeh, 2013). AMI gives system operator and consumers information they need to make smart decisions, and also the ability to execute those decisions that they do not currently able to do.

Honarmand, M., Gilani, N. and Modaghegh, H.
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In *Proceedings of the 5th International Conference on Smart Cities and Green ICT Systems (SMARTGREENS 2016)*, pages 252-256
ISBN: 978-989-758-184-7

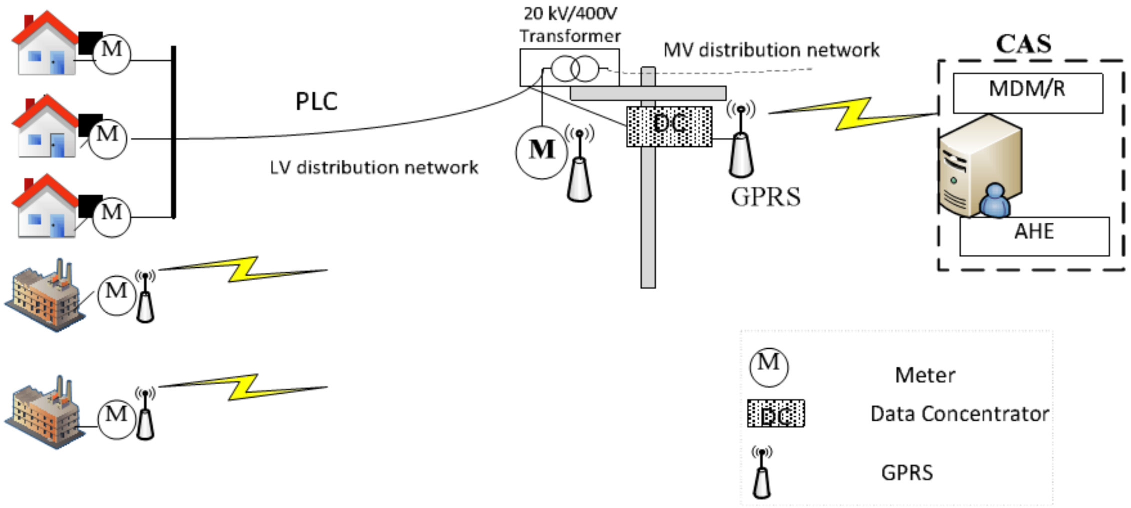

Figure 1: The communication architecture of FAHAM project (Jadid et al., 2013).

In Iran, like many other developed countries, Smart Grid implementation is regarded as a unique way for encountering many serious environmental and economic challenges. FAHAM is the National Smart Metering Program in Iran. The functional, technical, security, economic, and general requirements of this project is published as a document after a long-time workgroup of various stakeholders including representative of grid operators, meter manufactures, communication providers, business layer software providers, domestic and international consultants. Iran Energy Efficiency Organization (IEEO) is responsible for implementation and deployment of FAHAM. The IEEO follows promoting energy efficiency and load management, improve system reliability, and reduce operational costs by implementing national smart metering project.

The simple structure of communication system in FAHAM project is shown in Fig. 1 which consists of:

- Smart meters: These may be single phase or three phase smart meters. Electricity meter provides the various information for customers such as amount of consumption (kWh, KVarh), consumption parameters (voltage and current), equipment status and last information of water and gas meters.
- Communication interface: Power Line communication (PLC) and General packet radio service (GPRS) are two communication interface that connect two different part of FAHAM subsystem together. Data concentrators installed in 20kV/400V transformer to manage all smart meters "measured data" from such installations. Data concentrators integrate PLC communications that exchange information with smart meters to communicate with central meter data management systems.
- Central Access Systems (CAS): CAS is responsible for the management of all information and data related to smart metering, as well as the configuration, control and operation of all system components. The CAS in order to manage the FAHAM network shall have 2 following parts: a) AMI Head End (AHE) that has the responsibility to manage the configuration, WAN and LAN network management system, managing the network equipment, Registration of equipment and Operation & Maintenance of filed equipment in the network. b) MDM/R that manages and archives the acquired data from the AHE.
- Legacy Systems: These are the existing commercial or technical systems that manage the business processes of the utility.

3 COMPREHENSIVE MANAGEMENT STRATEGY FOR PHEVS

As the number of PHEVs increases, charging points in both parking structures and private garages will become more prevalent. These charging points will be responsible for meeting the requirements of the distribution grid and PHEV owners. These charging points should perform many functions such as supporting the RFID cards, metering and communication.

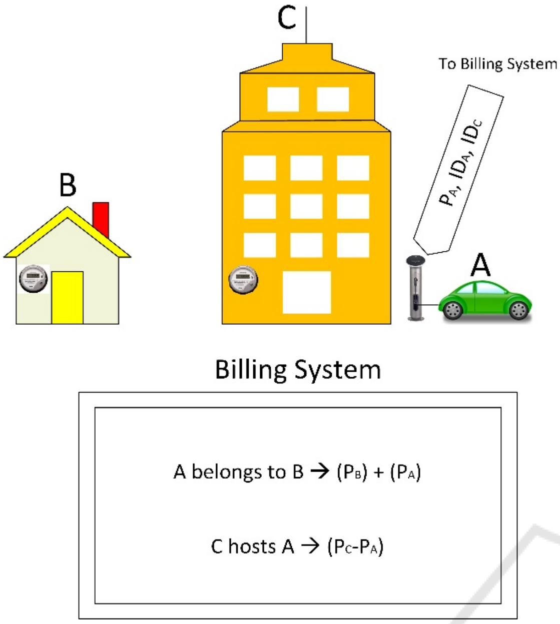

Figure 2: Separate billing using CMS.

The proposed CMS supports all possible charging forms such as charging in homes, offices, commercial buildings, charging stations, etc. To achieve this goal, using RFID chargers has been taken into account. In this strategy, each PHEV takes smart energy RFID card. These cards cover both aspects of energy sources which are used by PHEVs, gasoline and electricity.

RFID tags inside the smart energy cards and chargers equipped with RFID readers together with middleware and a charging controller to authorize, assign, and enable charging is required.

In order to simplify the charging authorization process and make it more convenient for users, an authentication system based on an RFID is proposed. The layered architecture for managing a variety of automatic identification hardware, communicates directly with a network coordinator and charging control server.

The other important capability of the CMS is to separate charging bill and the general bill. In this strategy, the PHEV owner can charge his/her PHEV by plugging it into every possible charging facility provided in the electrical grid and still has a separated bill. As an example assume that PHEV "A" which belongs to home "B", is charging in official building "C". The RFID charger located at "C" reads the PHEV's ID number and sends it along with the consumed energy and the charger's ID number to the data management center at the end of the charging procedure. By subtracting the consumed energy from the meter reading of the main meter located in "C" and adding it to the charging bill of "A", the separated bills will be obtained, and at the specified periods of time two separated bills will be sent for "B".

4 PROBLEM FORMULATION

An optimization is applied in order to shift PHEVs' charging load for achieving the following objective function which is maximizing load factor.

$$OBJ = \left[\left(\frac{\sum_{t=1}^{24} \left(P_L^t + \sum_{i=1}^{N} P_{Ch,PHEV}^{i,t} \right)}{24} \right) / \, MD \right] \qquad (1)$$

where P_L^t is the basic load of the feeder, $P_{Ch,PHEV}^{i,t}$ is the charging load of the i th charger, and MD is the maximum demand of the feeder.

The maximization of the objective function is subjected to the following constraints:

- PHEV's charger constraint:

$$P_{Ch,PHEV}^{i,t} \le P_{Ch,max}^{i} \quad ; \quad \forall t \qquad (2)$$

where $P_{Ch,max}^{i}$ is the maximum charging power of the i th charger. This constraint determines the maximum charging rate that the charger can provide.

- SOC limits:

$$SOC_{min}^{i} \le SOC^{i,t} \le SOC_{max}^{i} \quad ; \quad \forall t \qquad (3)$$

where SOC_{max}^{i} and SOC_{min}^{i} are the maximum and minimum SOC of the i th PHEV, respectively. This constraint allows the SOC to vary between predefined minimum and maximum SOC.

- Charging rate limits:

$$\Delta SOC^{i,t} \le \Delta SOC_{max}^{i} \quad ; \quad \forall t \qquad (4)$$

where ΔSOC_{max}^{i} is the maximum allowable rate for charging of the i th PHEV. The charging rate of battery are limited by this constraint.

- Battery charging constraint:

$$P_{Ch,PHEV}^{i,t} \times \eta_{G2V} \times \Delta t \le RBC^{i,t-1} \times Cap^{i,t} \quad ; \quad \forall t \qquad (5)$$

where η_{G2V} is the PHEV's battery charging efficiency, $RBC^{i,t-1}$ is the remaining battery capacity, and $Cap^{i,t}$ is the battery capacity. This constraint limits the charging power of each PHEV based on the remaining battery capacity in each period of time.

The proposed model is solved using mixed integer linear programming (MILP) solver CPLEX under GAMS on a Pentium IV, 2.6 GHz processor with 4 GB of RAM.

5 SIMULATION AND RESULTS

The Arrival and departure times of PHEVs are assumed as random variables. A commercial feeder is considered for this study and the PHEVs' penetration is considered 30 percent. In this paper, the distribution system operator manages the charging procedure of each PHEV considering its arrival time, approximate duration of presence in the parking lot, and open market pricing signal. After that the main controller uses the processed data to optimally schedule the charging procedure of PHEVs.

There are several types of electric vehicles in the market with various battery capacities from 8 kWh to 48 kWh (Pieltain Fernandez et al., 2011). In this paper, all electric vehicles supposed to be Chevy Volt which it is an average electric vehicle with 16.5 kWh battery capacity.

The initial SOC of each EV is considered as a continuous uniform random number between 0.1 and 0.7. Table 1 provides the hourly electricity price of the open market. Fig. 3 depicts the basic load of a typical commercial feeder.

In order to analyze the robustness of the CMS, the problem is addressed in two scenarios:

- Scenario 1: There is no control on the charging procedure of the PHEVs.
- Scenario 2: The distribution system operator manages the charging procedure of PHEVs in order to maximize the load factor and flatten the load profile of the feeder.

Fig. 4 shows the basic load profile of a typical commercial feeder together with PHEVs charging demand in scenario 1. It is obvious that the uncontrolled charging demand of PHEVs can cause difficult situations for distribution feeders by overloading the feeders.

Fig. 5 shows the basic load profile of a typical commercial feeder together with PHEVs charging demand in scenario 2. As illustrated, by applying

Table 1: The hourly electricity price in the open market.

Hour	Price	Hour	Price
1	0.033	**13**	0.215
2	0.027	**14**	0.572
3	0.020	**15**	0.286
4	0.017	**16**	0.279
5	0.017	**17**	0.086
6	0.029	**18**	0.059
7	0.033	**19**	0.050
8	0.054	**20**	0.061
9	0.215	**21**	0.181
10	0.572	**22**	0.077
11	0.572	**23**	0.043
12	0.572	**24**	0.037

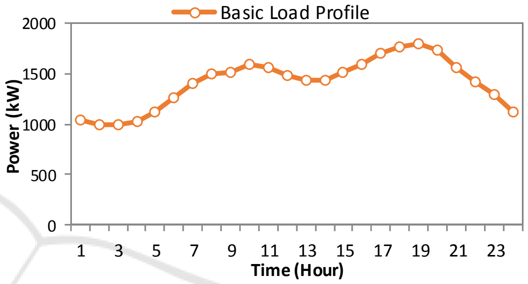

Figure 3: The basic load profile of a typical commercial feeder.

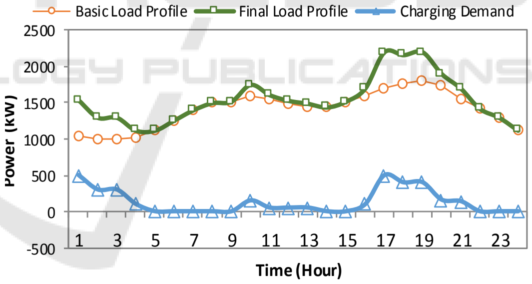

Figure 4: The basic load profile of a typical commercial feeder together with the PHEVs charging demand in scenario 1.

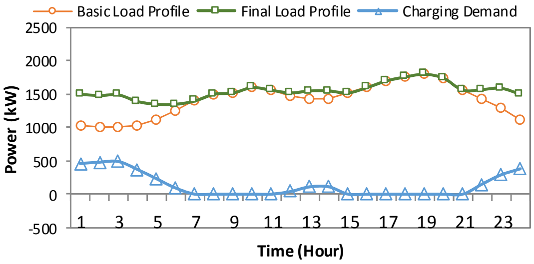

Figure 5: The basic load profile of a typical commercial feeder together with the PHEVs charging demand in scenario 2.

controlled charging through FAHAM infrastructure and CMS strategy, the load profile of the feeder is flattened.

The Table 2 shows the load factor of the feeder in basic load, scenario 1, and scenario 2.

Using controlled charging leads to higher load factor, and this can be considered as a big opportunity of FAHAM infrastructure for the system operator to achieve a system with much more efficiency.

Table 2: Load Factor.

	Basic Load	**Scenario 1**	**Scenario 2**
Load Factor	0.785	0.703	0.859

6 CONCLUSIONS

The integration of PHEVs in the power networks makes new challenges; accordingly, there is a growing necessity to address the implications of this technology on the power network. In this paper, a comprehensive management strategy based on national smart metering program in Iran is proposed. The proposed strategy helps the system operator to enhance the overall system efficiency. The results showed that the charging was carried out in the hours with lower loading, while in the hours with higher loading, the charging demand was curtailed. Simulation results evidenced that the use of FAHAM infrastructure for managing of the charging of PHEVs has eliminated the risk of an electricity demand growth during the peak load of the network.

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