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Intelligent battery energy management and control for vehicle-to-grid via cloud computing network

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HIGHLIGHTS

- The intelligent battery energy management substantially reduces the interactions of PEV with parking lots.
- The intelligent battery energy management improves the energy efficiency.
- The intelligent battery energy management predicts the road load demand for vehicles.

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ABSTRACT

Plug-in Electric Vehicles (PEVs) provide new opportunities to reduce fuel consumption and exhaust emission. PEVs need to draw and store energy from an electrical grid to supply propulsive energy for the vehicle. As a result, it is important to know when PEVs batteries are available for charging and discharging. Furthermore, battery energy management and control is imperative for PEVs as the vehicle operation and even the safety of passengers depend on the battery system. Thus, scheduling the grid power electricity with parking lots would be needed for efficient charging and discharging of PEV batteries. This paper aims to propose a new intelligent battery energy management and control scheduling service charging that utilize Cloud computing networks. The proposed intelligent vehicle-to-grid scheduling service offers the computational scalability required to make decisions necessary to allow PEVs battery energy management systems to operate efficiently when the number of PEVs and charging devices are large. Experimental analyses of the proposed scheduling service as compared to a traditional scheduling service are conducted through simulations. The results show that the proposed intelligent battery energy management scheduling service substantially reduces the required number of interactions of PEV with parking lots and grid as well as predicting the load demand calculated in advance with regards to their limitations. Also it shows that the intelligent scheduling service charging using Cloud computing network is more efficient than the traditional scheduling service network for battery energy management and control.

1. Introduction

Plug-in Electric Vehicles (PEVs), which include all Electric Vehicles (EVs) and Plug-in Hybrid Electric Vehicles (PHEVs), need to draw and store energy from an electrical grid to supply propulsive energy for the vehicle. Recently a study by Khayyam et al. [1] showed that PEVs significantly increase the load on the grid and vehicle electrification can play a major role in stabilization of voltage and load of an electric network. Their analysis also showed that scheduling the grid power electricity of parking lots is necessary for smooth operation of PEVs. Other studies including [2–4] also showed that the storage devices such as PEV batteries constitute usable tools for electricity usage optimization. It is also shown that the consideration of the PEV battery energy management and control, significantly affects the efficiency of the distribution network [5]. The basic task of a PEV battery energy management and control is to optimize the use of the energy inside the battery powering the

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portable product and to reduce the risk of damage inflicted upon the battery. This is achieved by monitoring and controlling the battery's charging and discharging process with proper scheduling of vehicle-to grid (V2G) parking lots. The main task of the above system are as follows [6]:

- Control charging of the battery and reducing the chance of overcharging to enhance the life of the battery.
- Monitor the discharge of the battery to ensure that the battery is not loaded when the battery is near empty.
- Keep track of the battery's SOC, control charging and discharging of the battery and communicate the value of the battery SOC to the user.

The scheduling of V2G and parking lots are very important [7,8] and their issues will continue to arise as a result of the increase in the numbers of vehicles, PEV dynamic positions, number of parking lot availability during any time, parking lot where the best price is offered, and optimal time to charge and discharge [9]. In addition, the PEV driver's limitations must be determined. These factors make the scheduling process very complex and uncertain requiring intelligent optimization of PEVs electrification infrastructure [5,10]. Based on the scheduling of V2G and PEVs infrastructure, a number of researches have explored different strategies. Existing solutions [11–15] focus on complex optimization techniques that arise from well-defined mathematical problems. Del Valle et al. [13] has used the Particle Swarm Optimization (PSO) method that is an iterative stochastic optimization algorithm. PSO optimize the number of gridable vehicles of V2G in the constrained parking lots. Clement-Nyns et al. [14] indicated the significance of coordinating the charging and discharging activities by using an objective function of the optimization problem for minimization of the cost function. Guille and Gross [15] proposed a framework that recognized the central role of the aggregator in V2G and can appropriately accommodate its critical role in collecting the battery vehicles to form aggregations and dealing with Energy Service Providers (ESPs) and the ISO/RTO for the purchase/provision of energy and capacity services.

A real-time model of a fleet of plug-in vehicles performing V2G power transactions just for two sets of four vehicles and two parking lots was presented in [16]. Output power levels and charge/discharge times were scheduled in order to maximize profits from grid transactions based on one-day ahead electricity pricing. Research study [12,17] showed that the communication network between the PEVs and parking lots via aggregative by grid system operator are more manageable than communication network required under the direct, deterministic architecture.

Despite the ongoing investigation of the scheduling of V2G for PEVs, there is still a gap. Most of the existing scheduling services do not take into account the real-time impact of issues such as availability of parking lots, time limitations and price of parking lots, dynamic PEV position, dynamic PEV battery SOC and the associated impacts on the operational of PEVs. The innovative aspect of the proposed approach is that it leverages the power of Cloud-based technology [18] to allow drivers to connect their vehicles to information services and efficiently manage the batteries in their electric vehicles. This approach would eliminate the need of instantly elaborate hardware and software in the vehicle. Cloud computing can utilize greater computing power while saving on the following cost, space, power consumption and facility [19]. Cloud computing will also provide effective communication network between utilities and vehicles such that fast, efficient charging is provided to optimize a plug-in hybrid's powertrain efficiency. This paper presents an intelligent vehicle-to-grid scheduling service charging for battery energy management and control that improves its efficiency by using Cloud computing network with specified parking lot for any PEVs in real-time. The features of the proposed model include:

- Find the least expensive parking lot regarding PEV battery SOC and road load demand.
- Intelligently determine and predict of PEV battery SOC and road load demand at any time.
- Fast response communication with high utilization to find parking lot availability for multiple requests.
- Low cost communication with matching power price for PEV.
- The least number of PEVs which fail the charging process.
- Improve battery energy management and efficiency by control charging, monitor the discharge and keep track of the battery's SOC.

The rest of the paper is organized as follows. Section 2 describes the PEV and problem overview. Sections 3 demonstrate the Cloud-based PEV system model. Section 4 presents the intelligent scheduling service architecture. The experimental results and associated discussions are presented in Section 5. Finally, the concluding remarks are given in Section 6.

2. Plug-in Electric Vehicles and problem overview

Using rechargeable batteries in Plug-in Electric Vehicles (PEVs) provide a new opportunity to deliver fuel consumption and exhaust emission reduction by drawing power from the electric grid. PEVs utilize one or more electric motors and battery for propulsion whereas PHEV unites have both an internal combustion engine and batteries for propulsion. Smooth operation of these vehicles requires the knowledge that when PEV batteries are available for charging and discharging. Therefore, the Energy Storage System (ESS) of PEVs has to monitor the battery State-of-Charge (SOC) quite frequently. PEVs can be fully charged before driving which means ESS begins at its maximum battery SOC waiting to charge depletion. Their performances can be affected by factors such as road conditions, environmental conditions and driver behaviour. Hence, advanced control systems and strategies are often employed to manage the operation of the internal components. In PHEVs, engines can run continuously in their preferred operating range, whereas the drive-trains are driven by electric machine. The overview of the optimization problem in PHEV is shown on Fig. 1. Whenever a PEV battery requires to be plugged-in at a charging parking lot, data regarding the battery parameters like initial SOC, battery capacity, road load demand, PEV position and other user specific details have to be acquired.

2.1. Battery energy management and control

In the PEV, the nonlinear nature of the electrochemical processes in its batteries is magnified due to dramatic current flowing in and out of one batteries and the larger range of the temperature variation. A simple battery model uses constant discharging and recharging efficiencies neglecting the fact that the power losses are related to the battery current. A slightly more elaborate battery model [20] which considers the open circuit voltage U_o and the internal resistance R_i, shown in Fig. 2a, used in this study. Battery manufacturers produce the battery capacity Amp-hours with the hours multiplied by the maximum constant current and in our model the battery can supply for 20 h at 20 °C, down to a predetermined terminal voltage per cell. The PEV battery can draw up to 50 kW h from the grid power, depending on charge infrastructure. The important parameter of a battery is the State-of-Charge (SOC). SOC is defined as the ratio of the remaining capacity to