An Ideal Charging and Discharging Scheme for Electric Vehicles Using Smart Electrical Car Parks

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Abstract- **In this paper we represent a smart car parking system for the power flows between the electrical vehicle and also so from the grid. We propose optimal charging and discharging methodology. In this strategy we can make more efficient and less expenditure in hourly electric price. Also here we can also and buy power in the form of active or reactive power, i.e. kWh and/or kVARh, from or to the main grid to improve the power quality according to the capacity of the battery of electrical vehicle, customers and the grid demands, a control center makes the decisions and sends the instructions of specific charging/discharging mode to each charging station. The performance of the proposed charging/discharging algorithm is simulated in Matlab. A comparison with and without the use of proposed algorithm in the car parks is introduced. The results demonstrate that the proposed scheme can achieve better economic profits for EV customers and increase the commercial benefits for the car park owner.**

I. INTRODUCTION

Since petroleum fuel vehicles are widely used nowadays fast depletion of fossil fuels and the increase in pollution is a promise so there for this electrical vehicle has a scope for future and will be widely used in the future Furthermore, the battery banks of EVs consume huge amounts of electricity from the power grid. New vehicle-to-grid(V2G) and vehicle-to-vehicle (V2V) technologies are being developed to store the energy in these rechargeable batteries. This helps balancing of the power grid between the demand and supply, and delivering the energy among EVs.

Compare with electrical vehicles used for public transportation private electrical vehicles are more in number also considering its usage for 96% of the time it’s been parked and 4% percentage of time in day it’s been used for transportation, this brings the idea of a smart car park for Electrical vehicles. it would be a good idea to develop their energy storage capability to provide secondary service in the electricity market. A smart electrical car park, with a large number of parked EVs, can be regarded as a large capacity energy storage unit. Taking advantage of the new V2G technology and appropriate economic strategy, this car park is able to yield profits by providing effective services to the EV customers and the electricity supplier. Inspired by this issue, we propose an approach of a smart electrical car park to enable the personal EVs to participate in the energy market.

In recent electric vehicles literature, considering the EV batteries as controllable parts in the power system, numerous papers pay attention to optimizing EVs charging and discharging modes to participate in ancillary services in the smart grid. Some works have been studied to minimize the expense for EVs’ owner or reduce the total cost of the aggregator separately. The work of and indicate that the proposed charging strategies using the real realistic analysis of EVs driving profiles can cut down the charging cost for EV owners. A smart charging and discharging method for multiple plug-in hybrid electric vehicles(PHEVs) in a building car park to optimize the energy consumption for this building. An energy cost-sharing model and a distributed algorithm were presented to minimize the peak load and the total energy cost at the same time.

With bidirectional chargers, the EV batteries can exchange the active power with the utility grid in G2V and V2G operations. The EV batteries can also meet the reactive power command from the grid, which is known as vehicle-for-grid (V4G). In this operation mode, EV batteries function as static var compensators, capacitor banks, etc. In this paper, the proposed car park system also benefits from supplying the reactive power to the grid with the agreed annual rate.

In general, novelties of this paper can be summarized as follows:

(1) Taking the real hourly electricity rate and EVs batteries constraints into consideration, the proposed smart car park system can minimize the expenditure for EV owners and reduce the cost for the car park operators at the same time.

(2) The proposed control method enables the EVs to be plugged in the grid during the off-peak hours. Meanwhile, the EVs discharge the power to the grid during the peak hours to balance the loads. The model with the optimal charging scheme is simulated in Matlab with an optimization problem solver named Cplex.

(3) Apart from G2V and V2G operations, the new V4G operation achieves the bidirectional reactive power flow between the grid and the smart car park system. An extra economic benefit can be obtained for the system operator.

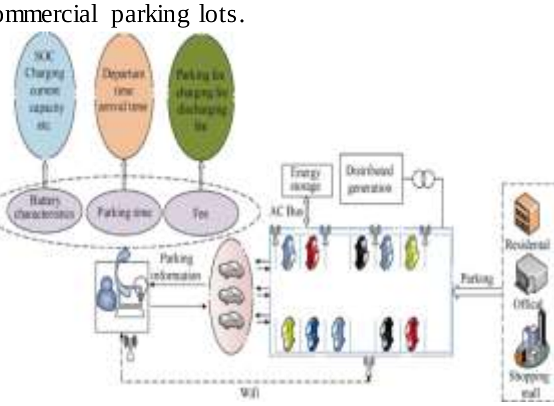
The rest of this paper is organized as follows. Section 2 sketches the smart electrical car park model. An optimal charging strategy is proposed, which calculates the charging rates of EVs during one-time slot economically and reasonably. Section 4 investigates the possible parking hours and charging demands of EVs. Section 5 presents and discusses the simulation results pertaining to the costs of EVs customers and the benefits of car park owners with the proposed optimal charging/discharging method.

II.SYSTEM MODEL

In this section, a smart electrical car park model is introduced. As shown in Fig.1, this smart electrical car park system is made up of a number of smart charging stations, it is mainly composed of a center controller and energy storage devices. The smart charging stations have touch screen panels to interact with the customers, which enables the customers to type their demands and typical needs. These touch panels are connected with a control center through either cable or Wi-Fi. The central controller collects all the basic information from the main grid and EVs. The EVs' information includes battery capacity characteristics (i.e., rated capacity, available capacity, voltages, expected charging and discharging currents), the initial state of charge(SOC), the final SOC, the parking time(arrival and departing time), etc. The charging rates of EVs obtained from the charging scheme are sent to the chargers by the controller every time slot. With the G2V and V2G technologies, EV batteries can exchange the active power with the main grid. However, the active power commands from the EV batteries and the utility grid might be different sometimes. Therefore, energy storage devices, such as super-capacitor banks, are used to compensate the power difference between the grid and the EV batteries within its capacity. It is of great assistance to keep the balance of the active power for the grid.

Apart from delivering the active power, this car park can supply the reactive power to support the grid in the V4G operation. During this operation, EV batteries function as static var compensators. It is important to note that the EV batteries lifetime cannot be reduced during the reactive power operation. Other components, such as the dc-link capacitors might be affected due to the increasing charging-discharging cycles.

This kind of smart electrical car parks can be located in office, shopping mall, and residential community in the future. According to the charging time in the report, 30 minutes is the minimum charging period for EVs parking in office, home, public or commercial parking lots.



III.RANGE OF CHARGING AND DISCHARGING POWERS

In order to avoid overcharging or over-discharging of EV batteries, the charging power constraint for each EV should be considered before participating in the G2V and V2G process. Since the charging rate varies depending on the types and conditions of EV batteries, EVs are divided into several categories according to the initial SOC, the final SOC, the charging type and the parking time. The information can be set by the customers through the touchscreen panels.

A parameter L is introduced to represent the charging type, defined as

$$L=\begin{cases} 1, & \text{this EV can only be charged} \\ 0, & \text{this EV can be charged and discharged} \\ -1, & \text{this EV can only be discharged} \end{cases}$$

Some of EVs only park for a short time, thus, the priority objective is to meet the demand of customers rather than to charge more economically. In order to solve this problem, the maximum idle parking time for mth EV $t_{m,p,\max}$ is employed, which is calculated as

$$t_{m,\mathrm{p},\max} = t_{m,\mathrm{p}} - \frac{E_{m,\mathrm{need}}}{p_{m,\max}} \quad (1)$$

where $t_{m,p}$ is the parking time, $E_{m,\mathrm{need}}$ the needed charging/discharging energy, and $p_{m,\max}$ the maximum charging/discharging power, for mth EV. If the maximum idle parking time $t_{m,p,\max}$ is less than one-time slot Δt, the charging or discharging rate is set to the maximum value.

IV. ELECTRICITY PRICE

The hourly electricity price is a function of the time, which can be denoted as f(t). Average hourly electricity prices over a month, used for simulation during the car park opening hours from 7 A.M. to 10 P.M., are presented in Fig.2. It is used to calculate the electricity fee for the EVs drivers and the car park owner.

The car park owner purchases the electricity from the grid at a wholesale rate, as well as selling it to the grid[5]. Meanwhile, the EV customers buy or sell it at a general price as individuals. Therefore, four price- coefficients (δ1, δ2, δ3 and δ4), are introduced to describe the prices for EV customers and car park owners buying and selling electricity, respectively.

The prices of EV customers and car park owners charging and discharging electricity can be formulated as price

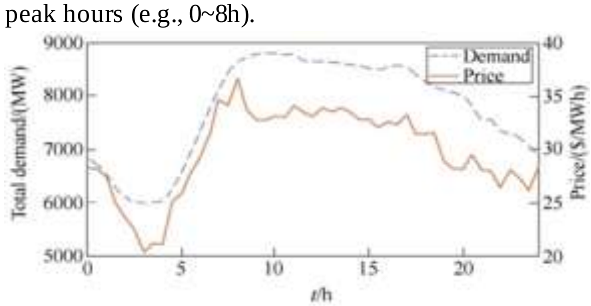
$$\mathrm{price}_k(t) = \{\delta_k \times f(t), k=1,2,3,4\}$$

where k=1 means EV customers charge the electricity from the grid, then δ1 is equal to 1, as the EVs act as individual customers; K = 2 means EV customers discharge the electricity to the grid; K = 3 or 4 means the car park charges electricity or discharges energy, respectively. Normally, δ3is less than or equal to δ1 since the car park buys electricity at a wholesale price. δ2 is less than or equal to δ4 because the car park has the ability to sell a large amount of electricity to the grid according to its demands, while an EV customer just sells quite little electricity to the car park as an individual at random periods of time.

V.GRID DEMAND

Another benefit for this smart electrical car park is that it provides the stored energy to the grid during peak hours and behaves as a load during off-peak hours.

It can be observed that the electricity price is high when the demand is increasing, and vice versa. Therefore, it can be assumed that the electricity demand of the main grid is proportional to the electricity price generally. This means that if EVs discharge the energy to the main grid during periods of high loading (e.g., 8~24h), it can relieve the pressure on the grid. On the other hand, more EVs can be connected to the grid to be charged during off-peak hours (e.g., 0~8h).



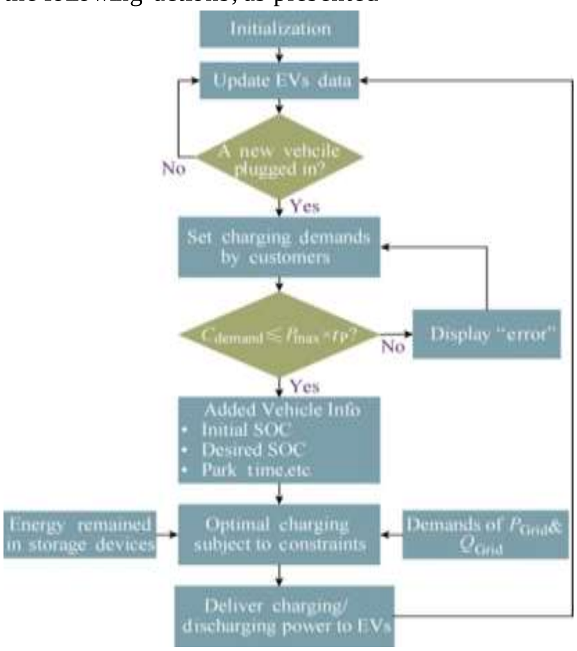
VI. SYSTEM CONSTRAINT

Nth EV
Total number of EVs
Nth period
Total periods
Total parking duration of mth EV
Energy of mth EV in nth period
Current stored energy in EV
Charging energy of EV
Discharging Energy of EV
Battery capacity of EV
Final State of charging of EV
Initial State of charging of EV
Charging and discharging power of EV in nth period
Maximum charging power of EV

Maximum discharging power of EV
All this constraints and physical variables are considered and has specific formulas to make up corresponding Principle algorithm.

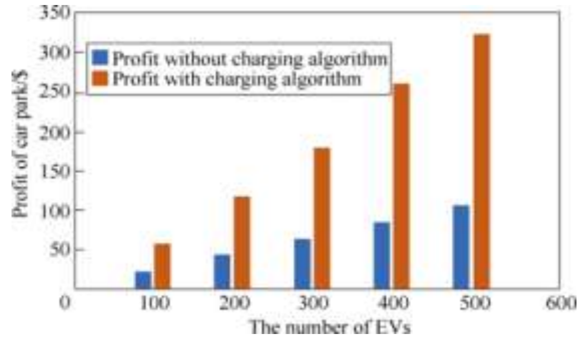
VII.ALGORITHM

The mathematics model is set up in Matlab by using Yalmip Wiki and the optimization problem is solved by the solver-IBM ILOG Cplex Optimizer 12.6.1.
At the beginning of one day, the central controller updates the system information, such as the amount of the energy stored in energy devices. Then, at the beginning of a time, the central controller performs the following actions, as presented



VIII.PROFIT MADE BY ELECTRIC CAR PARK

The profit of a smart electrical car park is composed of two parts, as depicted in figure. One is the electricity price gap by exchanging the active power between the EVs and the grid. Another is the income by working as a static var compensator to provide the reactive power. The profit of exchanging the active power can be divided into two subparts: the charging profit and the discharging profit.
Fig the profits for the car park using the proposed charging method are around 3 times of that obtained by unregulated charging with different car park sizes M.



IX.PROFIT MADE BY EV CUSTOMERS

The costs for EVs customers and the car park owner with the charging scheme are much lower than the ones with the traditional scheme, respectively. Specifically, the costs for customers can be reduced by 47% on average, compared with the unregulated charging method.
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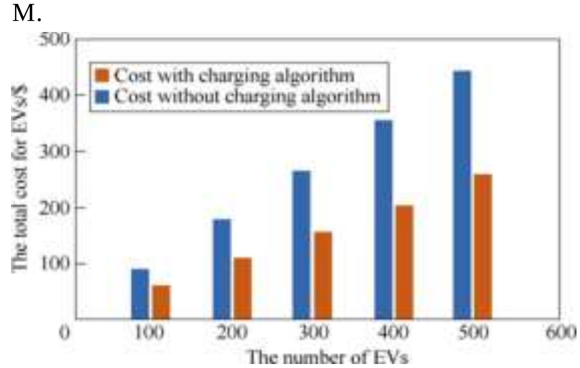
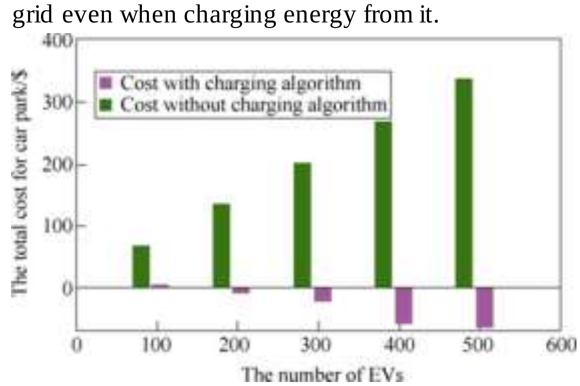


Fig shows that the cost of the car park with the optimal scheme are negative, which means that the car park does not have to pay money to the power grid even when charging energy from it.



X.CONCLUSION

An unregulated charging/discharging scheme is used to compare with the proposed method. With this method, EVs will be charged/discharged with an average power rate during the parking hours. The power rate is calculated by using the expected charging/discharging energy divided by the parking time. It can be seen from figures that the costs for EVs customers and the car park owner with the charging scheme are much lower than the ones with the traditional scheme, respectively. Specifically, the costs for customers can be reduced by 47% on average, compared with the unregulated charging method.

This paper presents a smart electrical car park model involving the V2G and G2V technology, which enables the bidirectional power flow. In order to calculate the optimal charging powers, the real hourly electricity price is collected and analysed. An optimal charging scheme has been proposed. It aims at making profits for the car park owner and minimizing the cost for EV customers. The simulation is performed in Matlab with the real-world parking information collected from an underground car park at UTS. Compared with the results of the conventional charging algorithm, the simulation results show that the benefit of the car park owner can be increased by approximately 300%. Also, the related costs for EV customers is reduced by 47% on average. At the same time, the SOCs of EVs at their departure times can reach the expected values set by customers. Furthermore, this system provides the solution that is very close to optimal, which can be of great benefits to customers, car park owners and the main grid simultaneously.

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