

Improving Scheduling Performance of EV Charging using Binary Programming

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ABSTRACT

Due to the global warming problem and the increment of the fossil fuel price, the Electric Vehicles (EVs) have been developed and implemented on the cutting edge of power distribution system. The EVs can be performed a different role of either generation or load consumption. However, if the charging management of EVs system is not effective, it may lead to an unreliable grid system, which is one of the major concerns in EVs applicability. The objective of this research is to propose an effective scheduling method for charging EVs. Our approach presents a new objective function that includes a waiting time to charge, earliest deadline, and time to fully charge into consideration that is able to efficiently allocate the limited energy and also improve the Peak-to-Average Ratio (PAR) by using binary integer programming as an optimization method. The database used in this study is based on National Household Travel Survey organization (NHTS 2009), which is widely used in implementation of EVs scheduling. In addition, IEEE 69 bus is also applied as a grid system in our experiments. The simulation results show that the proposed scheduling method is not only able to reduce the peak demand of the system but to help improving the PAR as well. The main advantage of the proposed method can improve the overall performance of the EVs charging system without necessarily reconfiguring the distribution system to support the emerging of the EVs. Hence, the proposed method can be applied to manage EVs scheduling with different power system configuration.

Keywords: *Electric Vehicles, Charging Scheduling, Peak-to-Average Ratio, Binary Programming*

1. INTRODUCTION

Electric Vehicles (EVs) are one of the intelligent electrical devices which are expected to be connected to power system in the future. In terms of energy efficiency of the EVs, it is better up to 3 times than conventional engine cars. Although, using EVs also helps to reduce air pollution in transportation sector, EVs can make the power system unreliable [1]. Without proper charging management, these EVs can deteriorate the quality, efficiency, and stability of the distribution system such as network losses, voltage unbalance, under-frequency and harmonics distortion [2]. In practice, smart meter can be used to control the charging system of the EVs so that the EVs need not to be charged immediately [3] comparing to regular loads. The EVs charging scheduling have been proposed by many research groups. Soares *et al.*, [4] proposed a method to schedule the EVs charging based on optimal cost using linear programming in which the EVs can be charged arbitrarily. Another approach [6] is to maximize the number of EVs' charging with the criteria of power capability and voltage level in consideration. However, both proposed methods do not concern time to charge during the peak hours. Monica *et al.*, [7] proposed a method of EVs charging schedule to smooth the load profile by applying Genetic Algorithm (GA) but this method does not take into account the travel behavior i.e., %SOC (state of charge), arrival time, and departure time of consumption pattern on weekdays and weekends. The concept of charging schemes can be divided into two categories: centralized optimization and decentralized methods. In centralized schemes, the EVs charging are fully controlled by central authority via communication system. The other scheme is to control the charging behavior by pricing mechanism [8]. This research focuses on centralized optimization by proposing a method to improve Peak-to-Average Ratio (PAR) of the distribution system with limited energy based on shifting time to charge from peak hours to non-peak hours.

The rest of the paper is organized as follows. In section 2, an introduction of EVs charging system is present. The framework of our proposed method is detailed in section 3. Experimental procedure and results are illustrated in section 4. Finally, we draw a conclusion in section 5.

2. BACKGROUND

2.1 Standard Charging Power Level and Battery Size

In IEC 61851-1[10], EVs charging is categorized into 4 modes. Mode 1 corresponds to slow charging, mode 2 is quick charging, mode 3 is fast charging, and mode 4 is ultra-fast charging. This study assumes all EVs are charged in mode 1, the most preferred charging infrastructure in residence. The charging level results from EVs measurement reports of Provincial Electricity Authority of Thailand (PEA), which used constant charging rate at 3.4 kilowatts [11]. Two sizes of battery used in this research are 16 kWh which corresponds to the Mitsubishi iMiEV and the Chevy Volt and 24 kWh of the Nissan LEAF.

2.2 Traveling Behavior

In this study, we employ the data from the organization National Household Travel Survey (NHTS), the Ministry of Transport, USA to model the charging behaviour and parameters of EVs such as arrival time, departure time, and %SOC. The types of

vehicles consist of passenger cars, vans, and SUV used in urban areas [9]. In fact, travelling behaviours are different between the workday and the weekend. Figure 1 illustrates an example of arrival time of the workday and weekend. It is obvious that the peak hour of the workday is between 5 - 7 p.m. corresponding to the time to get back home after work. In contrast, the peak hours on the weekend is not explicitly defined because the activities of the weekend are uncertain and quite various for each family. Based on NHTS data, an average time of EVs plugging-in is about 14 hours with a standard deviation of 4 hours [2]. So, the departure time can be computed from the arrival time from the NHTS with the addition of the period of plug-in hours as describe above.

The remaining power of EVs is displayed in terms of %SOC, which is calculated from the daily miles driven and total range per charge and is represented by (1).

$$\%SOC = \frac{D_{\max} - D_{\text{drive}}}{D_{\max}} \times 100\% \quad (1)$$

where %SOC is the percentage of remaining battery capacity.

D_{\max} is the maximum driving range of a vehicle using only power from its battery pack (Total range per charge).

D_{drive} is the daily driving range of a vehicle.

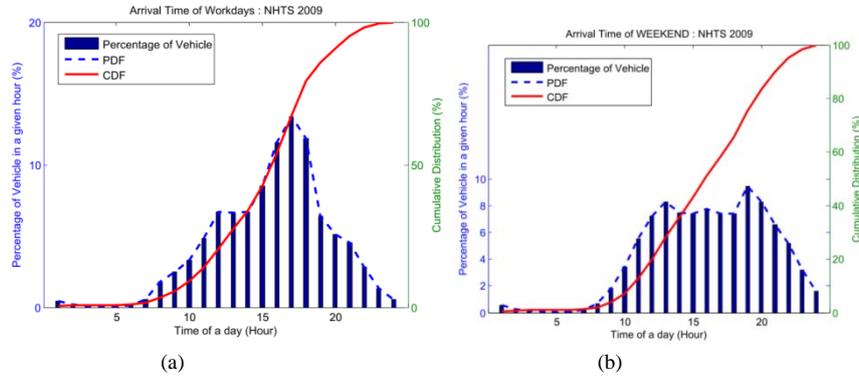


Fig. 1 (a) The arrival time of workday, (b) The arrival time of weekend.

2.3 The Compared Charging Scheduling

This paper proposed the objective function based on a scheduling of central processing unit (CPU). The performance evaluation of the proposed method consisting of the peak demand, PAR, load factor, and

the average plug-out SOC is compared with the FCFS, [4] shown in (2), and [5] expressed in (3). The goal of method in [4] is to minimize the power consumption by EVs represented by (2).

$$\min\left(\sum_{i=1}^n P_i x_i\right) \quad (2)$$

where n is the number of EVs in the standby mode.

P_i is the EV_i 's power consumption in an hour (including system loss due to charging EV_i).

The other method proposed in [5] aims to maximize the number of charging EVs and is formulated by (3).

$$\max\left(\sum_{i=1}^n EV_i x_i\right)$$

where EV_i is the i^{th} EV that already connected to the system (in standby mode).

3. The Proposed Charging Scheduling Algorithm

The aims of the proposed method are to schedule the number of EVs charging as much as possible without problems to distribution system and also improve the PAR. The PAR, an indicator of the level of reserved margin, is the value derived from the ratio between the maximum power and the average power in a day. The proposed method is able to maintain the peak demand not greater than the level without EVs connecting to the system, and improve the average power of the system by shifting the EVs charging to the lower power demand period.

3.1 Proposed Objective Function

The concept of our method tries to maximize the number of EVs connection in any time in which the chosen EVs don't affect to the charging of other EVs. The novel objective function is expressed by (4).

$$\max \sum_{i=1}^n (W_i x_i + D_i x_i + T_i x_i) \quad (4)$$

where n is the number of EVs in the standby mode.

W_i is the time that EV_i is waiting to be charged.

D_i is the deadline that EV_i will leave by the next day.

T_i is the duration time that EV_i will be fully charged.

x_i is a binary indicator to represent whether EV_i is chosen to charge or not.

The first term, $W_i x_i$, refers to the PEVs with the longest plug-in time is more likely to be selected. The

second term, $T_i x_i$, refers to select the PEVs with minimal remaining SOC (required more time to charge) to be selected. The last term, $D_i x_i$, refers to select the PEVs with the closest time of leaving home to be charge. As a result of the process, which PEV is selected to charge at the determine time, the x result will be 1 and if there is not be selected to be charge, the x result will be 0.

At any time, total power in the system including base load (without EVs) and EVs load must not exceed the maximum power. So, we add the constraints to the previous objective function as shown in (5) and (6).

$$P_{Quota}^{(k)} = \gamma \cdot (P_{max} - P_{baseload}^{(k)}) \quad (5)$$

where $P_{Quota}^{(k)}$ is the energy that the system can accommodate to EVs charging at time k .

γ is the factor to limit a maximum power.

P_{max} is the peak load demand of the system from historical events or specified by the

utility.

$P_{baseload}^{(k)}$ is the base load at time k .

$$\sum_{i=1}^n P_i^{(k)} x_i \leq P_{Quota}^{(k)} \quad (6)$$

where $P_i^{(k)}$ is the EV_i 's power requirement at time k . Note that this power includes the

charging energy and the system loss due to charging EV_i .

3.2 System Specification and Daily Load Profiles

In our experiment, we assume that the probability of connecting EVs to each bus is uniform. The system configuration for testing the proposed method is based on IEEE 69 bus which is a radial system with 12.66 kV normal voltage. The daily load profile data of workday and weekend is acquired from Southern California Edison [13].

3.3 Procedure of the Proposed Algorithm

The illustration of the proposed procedure is shown in Fig. 2 The input requirements of the proposed method comprise system configuration, daily load profile and the EVs characteristics. We assumed that the initial hour starts at 1.00 a.m. The first step is to compute available power to charge new EVs by using (2) and (3). If the

available power is less than zero (no more energy to charge), the proposed algorithm will consider to rearrange of the existing EV charging by removing the current maximum %SOC to reserved queue so that the new EVs can be plugged into the system. On the other hand, if the distribution system has adequate power to support other EVs, the algorithm will choose the EVs

for that timeslot by optimizing the objection function in (4) based on binary integer programming. The chosen EVs will be charged until an SOC is 100%, or it reaches the departure time. Then, load flow analysis is used to compute total power including loss in the system. These steps will be repeated as describe above until completing 24 hours.

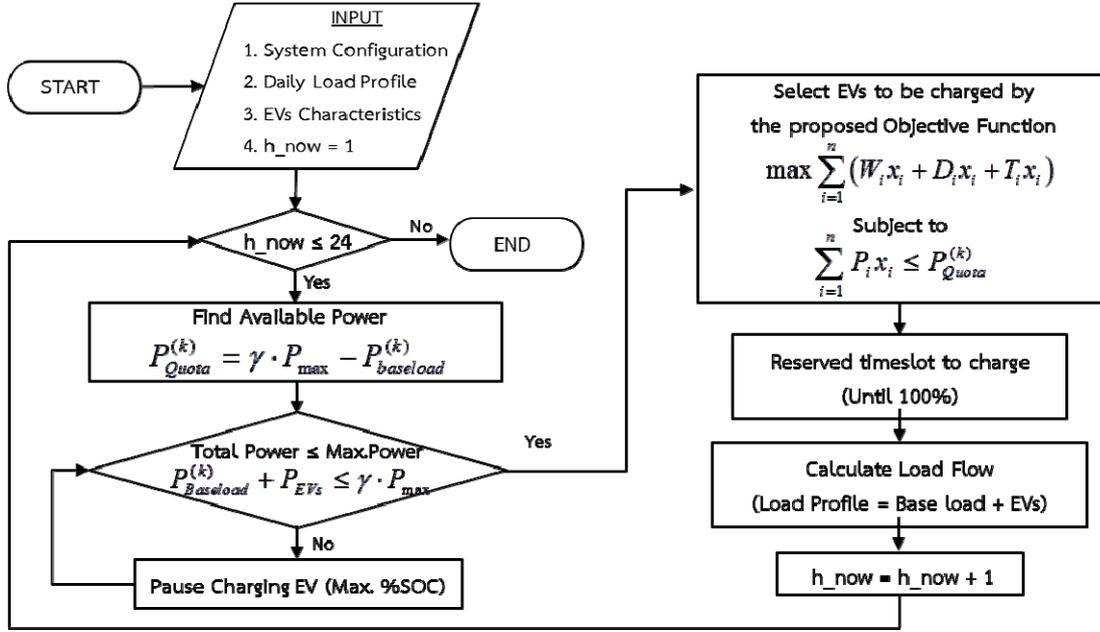


Fig. 2 The Proposed EVs charging scheduling process.

4. Experimental Procedure and Results

In our experiment, we choose different number of EVs penetration level by 100, 300 and 500. Each EV will be assigned randomly to IEEE 69 bus system. The performance evaluation of our proposed method will be compared with other methods in terms of the following formulations.

1. Peak Demand, the highest demand point in a day.

$$P_{Peak} = \max_{i=1:24} (P_i) \quad (7)$$

where P_i is the requirement power of the system in the i^{th} hour

2. Peak-to-average Ratio (PAR), indicates how extreme the peaks are in daily load profile. The high PAR indicates that the load profile have higher peaks or decreased efficiency of power consumption.

$$PAR = \frac{Power_{peak}}{Power_{mean}} \quad (8)$$

3. Load Factor (LF), the ratio of average load divided by peak load in a specified time. This value is always less than one. A high LF means power usage is relatively constant; Low LF shows that occasionally a high demand is set.

$$LF = \frac{Power_{mean}}{Power_{peak}} \quad (9)$$

4. Average Plug-out SOC, the average final SOC before the driver using in the next day. This value is show the satisfaction of customers by using the scheduling EVs charging method.

$$SOC_{avg} = \frac{1}{N} \sum_{i=1}^N SOC_i \quad (10)$$

where N is total number of EV penetration in one day and SOC_i is the SOC of the i^{th} EV.

The experimental results for different charging scheduling methods are summarized in Table 1 and 2, respectively. Table 1 and Table 2 show the results acquired by 100, 300 and 500 EVs penetration connected to IEEE 69 bus on workday and weekend. In this study, the peak demand of base load (no EVs) is 3.97 MW on workday and 1.90 MW on weekend. When the EVs are connected to the system without charging scheduling, the proportion of peak demand steadily increases depending on the number of EVs penetration

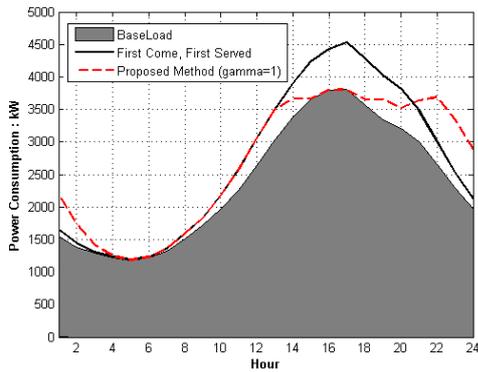
level. That means PAR and LF would be degraded. Similarly, objective function (2) [4] and (3) [5] provide equivalent results to the FCFS method because both functions allow to add EVs charging as long as it does not exceed the capacity or cause instability to the system. Thus, the average plug-out SOC of both methods are 100% but the PAR grows up and LF is lower. Note that the higher PAR value, the lower system efficiency. Comparing with our proposed methods on workday and weekend, it is obvious that while EVs penetration levels are increased, both PAR and LF are improved since the constraint of the P_{quota} in (5) is able to limit the maximum power demand. As a result, the EVs charging during the peak demand is shifted to other time slots leading to slightly decrease the average plug-out SOC. In our method, we can adjust the parameter $\gamma \leq 1$ which is useful to system stability in case of emergency. For example, if γ is chosen equal to 0.9, this means 90% of power capacity is provided to accommodate the EVs charging and the remaining 10% can be used as a backup or safety margin.

Table 1 The results of various EVs penetration levels connected to IEEE 69-bus system in workday.

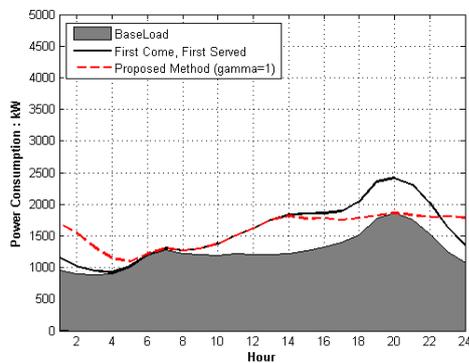
Objective Function	EVs Penetration	Peak Demand (kW)	PAR	Load Factor	Average Plug out SOC
Base load	-	3,972.98	1.623	0.616	-
1 (FCFS)	100	4,140.29	1.669	0.599	100
	300	4,454.02	1.750	0.572	100
	500	4,531.32	1.770	0.565	100
2 [4]	100	4,140.29	1.669	0.599	100
	300	4,454.02	1.750	0.572	100
	500	4,531.32	1.770	0.565	100
3 [5]	100	4,140.29	1.669	0.599	100
	300	4,454.02	1.750	0.572	100
	500	4,531.32	1.770	0.565	100
4 ($\gamma = 1$)	100	3,972.98	1.601	0.693	99.970
	300	3,972.98	1.561	0.641	99.835
	500	3,972.98	1.523	0.707	99.487

Table 2 The results of various EVs penetration levels connected to IEEE 69-bus system in weekend.

Objective Function	EVs Penetration	Peak Demand (kW)	PAR	Load Factor	Average Plug out SOC
Base load	-	1,900.531	1.484	0.674	-
1 (FCFS)	100	2,032.176	1.548	0.646	100
	300	2,269.420	1.647	0.607	100
	500	2,515.070	1.747	0.572	100
2 [4]	100	2,032.176	1.548	0.646	100
	300	2,269.420	1.647	0.607	100
	500	2,515.070	1.747	0.572	100
3 [5]	100	2,032.176	1.548	0.646	100
	300	2,269.420	1.647	0.607	100
	500	2,515.070	1.747	0.572	100
4 ($\gamma = 1$)	100	1,900.531	1.448	0.691	99.95
	300	1,900.531	1.381	0.724	99.95
	500	1,900.531	1.319	0.758	99.94



(a)



(b)

Fig. 5 (a) Daily Load Profile in Workday (b) Daily Load Profile in Weekend of with/without charging scheduling.

The illustrations of the load profiles obtained from different methods are compared in Fig. 5. From this plots, it is found that the proposed method can maintain the peak demand on both workday and weekend while the number of EVs penetration is increased.

5. Conclusion

This paper proposes an algorithm of EVs charging scheduling in which a new objective function is able to efficiently allocate the limited energy and also improve the Peak-to-Average Ratio (PAR), load factor (LF), and average plug-out SOC of the system grid without causing any problems. In addition to consideration of a remaining SOC, an arrival time, and a departure time derived from National Household Travel Survey (NHTS) organization, the key ingredient of our approach also includes a waiting time to charge, earliest deadline, and time to fully charge in the objective function. Moreover, additional constraint is to maintain a peak demand whether there are EVs plug-in to the

system. The experimental results based on IEEE 69 bus demonstrate that our method can enhance the PAR and LF on the workday and the weekend without unnecessary reconfiguring or improving the existing distribution system to support the increasing of EVs. By the ability to maintain maximum power, this method can extend the lifetime of the equipments in the distribution system, such as power lines or transformers as well.

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