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BASIC POWER ALLOCATION STRATEGIES FOR PLUG-IN HYBRID ELECTRIC VEHICLE CHARGING STATION

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Abstract

The high penetration of electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) can cause serious impact to the entire grid: from power plants to local distribution systems. In particular, the demand charging of EVs may vary over stochastic with time. Uncoordinated EVs charging may increase the load with all the time, which increases the peaks, even can possible produce super-high peak. Therefore, a comprehensive study on the impact of EVs to existing grid needs to be conducted to make the appropriate charging strategies with the future EVs demand. In this paper, the basic power allocation strategies for EVs as first come first serve strategy (FCFS), lowest state of charge (SoC) first strategy (LSF), equally allocation method (EAM) and shortest charging time first strategy (STF) are proposed. The simulation is completed using MATLAB. The result of the methods is analyzed, evaluated, and compared together.

Keywords: *Plug-in Hybrid Electric Vehicles (PHEVs), Electric Vehicles (EVs), State of Charge (SoC) and Power allocation.*

1. Introduction

The excessive emissions of greenhouse gases, Lead to global climate warming trend intensified [1,2]. Electric vehicles as a new generation of transport, which in energy conservation, reduce human's dependence on traditional fossil energy aspect, compared to conventional cars have unparalleled advantages. Currently the countries all over the world have taken the appropriate policies to promote the development and application of electric vehicles. Can be estimated, with the future popularity of electric vehicles, large-scale electric vehicle charging will be connected to the grid planning and operation of power generation system cannot be ignored. Specifically, the penetration with a large-scale electric vehicles into the grid bring a great impact to the grid as load growth, the distribution grid is overloaded, voltage drop [3, 4], the distribution grid losses increase [5, 6], the distribution transformer overload [7, 8] and other issues. Especially at the peak time, the EVs charging loads will further exacerbate the difference between the power peaks and valleys.

On the other hand, the electric vehicle as a new type of moving load, the charging behavior has strong uncertainty of time and space. A large amount of electric car widely access will increase the difficulty in operation control of the power grid.

Thus, to the maximization of customer satisfaction and minimization of burdens on the grid, a complicated control mechanism will need to be addressed in order to govern multiple battery loads from a numbers of electric vehicles appropriately [9]. The total demand pattern will also have an important impact on the electricity industry due to differences in the needs of the PHEVs parked in the deck at certain time [10]. Only efficient management can ensure strain minimization of the grid and enhance the transmission and generation of electric power supply.

In the paper, the basic power allocation strategies for EV included the first come first serve strategy (FCFS), lowest SoC strategy (LSF), equally allocation method (EAM) and shortest charging time first strategy (STF) are used to solve the problems are presented above.

The rest of this paper is organized as follows. Section two isproblem formulation which provides the detail of the basic power allocation strategiesfor EVs. In section three, we provide the simulation results and analysis. Finally, the conclusion and future work is given in section four.

2. Problem formulation

2.1. A Battery of the electric vehicle charging process

The SoC is an important parameter of battery. It measures the percentage of battery energy power that has been used and indicates how far a vehicle can drive on it. The SoC is defined as the remaining capacity of a batter in ref. [11].

$$\text{SoC=Remaining Capacity/Rated Capacity} \tag{1}$$

If the Ah capacity is used, the change of SoC can be expressed as:

$$\Delta SoC = SoC_{i,t+1} - SoC_{i,t} = \frac{1}{C_i}\int_t^{t+1} \mathrm{i}_{i,t}dt \tag{2}$$

Where, C_i is the rated capacity of the battery.

The charging current is assumed to be constant over charging time interval Δt.

$$\left[SoC_{i,t\text{-}1} - SoC_{i,t}\right]C_i = I_{i,t}\Delta t \tag{3}$$

$$SoC_{i,t+1} = SoC_{i,t} + \frac{I_{i,t}\Delta t}{C_i} \tag{4}$$

Where, $I_{i,t}$ is the charging current over Δt. We assume that the battery charging is modeled as a capacitor circuit and followed capacitor equation. C_b is capacitance in Farads (the Farad being the capacitance unit of measure).

$$C_{\mathrm{b}}\frac{dU_i}{dt} = I_{i,t} \tag{5}$$

Take integration for both sides of above equation, we have:

$$\int_t^{t+1} C_{\mathrm{b}}\frac{dU_i}{dt}dt = \int_t^{t+1} I_{i,t}dt \tag{6}$$

Because C_b, $I_{i,t}$ are constant, so:

$$C_b\left(U_{i,t+1} - U_{i,t}\right) = I_{i,t}\Delta t \tag{7}$$

$$U_{i,t+1} = \frac{I_{i,t}\Delta t}{C_{\mathrm{b}}} + U_{i,t} \tag{8}$$

Since the variable is the power allocated $P_{i,t}$ to EVs, the relation between charging current $I_{i,t}$ and power $P_{i,t}$ can be expressed as follow.

$$I_{i,t} = \frac{P_{i,t}}{\bar{U}_{i,t}} = \frac{P_{i,t}}{0.5\left[U_{i,t+1} + U_{i,t}\right]} \tag{9}$$

Substituting (9) into (8), we obtain:

$$U_{i,t+1}^2 = U_{i,t}^2 + \frac{2P_{i,t}\Delta t}{C_b} \tag{10}$$

$$U_{i,t+1} = \sqrt{\frac{2P_{i,t}\Delta t}{C_b} + U_{i,t}^2} \tag{11}$$

Substituting (9) into (4), we obtain

$$SoC_{i,t+1} = SoC_{i,t} + \frac{2P_{i,t}\Delta t}{C_i\left[U_{i,t+1} + U_{i,t}\right]} \tag{12}$$

Substituting (11) into (12), finally we obtain:

$$SoC_{i,t+1} = SoC_{i,t} + \frac{2P_{i,t}\Delta t}{C_i\left[\sqrt{\frac{2P_{i,t}\Delta t}{C_b} + U_{i,t}^2} + U_{i,t}\right]} \tag{13}$$

2.2. Basic power allocation strategies

2.2.1. First come first serve (FCFS)

In the first come first serve strategy (FCFS), the total vehicles charged in each time step includes the vehicles left from the previous time steps and just arriving. The vehicle comes first will be served first and will only leave when it is fully charged or the customer requiring time is out (remaining charging time equal zero). The number of total vehicles charged in each time step is counted by the division of total power of station and the maximum power (Pi,tmax) that can be absorbed by a specific vehicle plus the binary variable n0 (n0 is 1 as the remainder of the division is nonzero and n_0 equal 0 as the as the remainder of the division is zero). The FCFS strategy is demonstrated in the following formula (14):

$$\mathrm{N}_{\mathrm{ch,t}} = \frac{P_{S\_\max}}{P_{\mathrm{i,t}}^{\max}} + \mathrm{n}_0 \tag{14}$$

Where;

$$\mathrm{n}_0 = \begin{cases} 0 & \sum_{1}^{N_{ch,t}} \mathrm{P}_{\mathrm{i,t}}^{\max} = P_{S-\max} \\ 1 & \sum_{1}^{N_{ch,t}} \mathrm{P}_{\mathrm{i,t}}^{\max} \neq P_{S-\max} \end{cases} \tag{15}$$

Where, $N_{ch,t}$ is the total number of vehicles to be charged at time step t, n_0 is a binary variable. How we applied FCFS to the power allocation to electric vehicle problem is shown in figure 1.

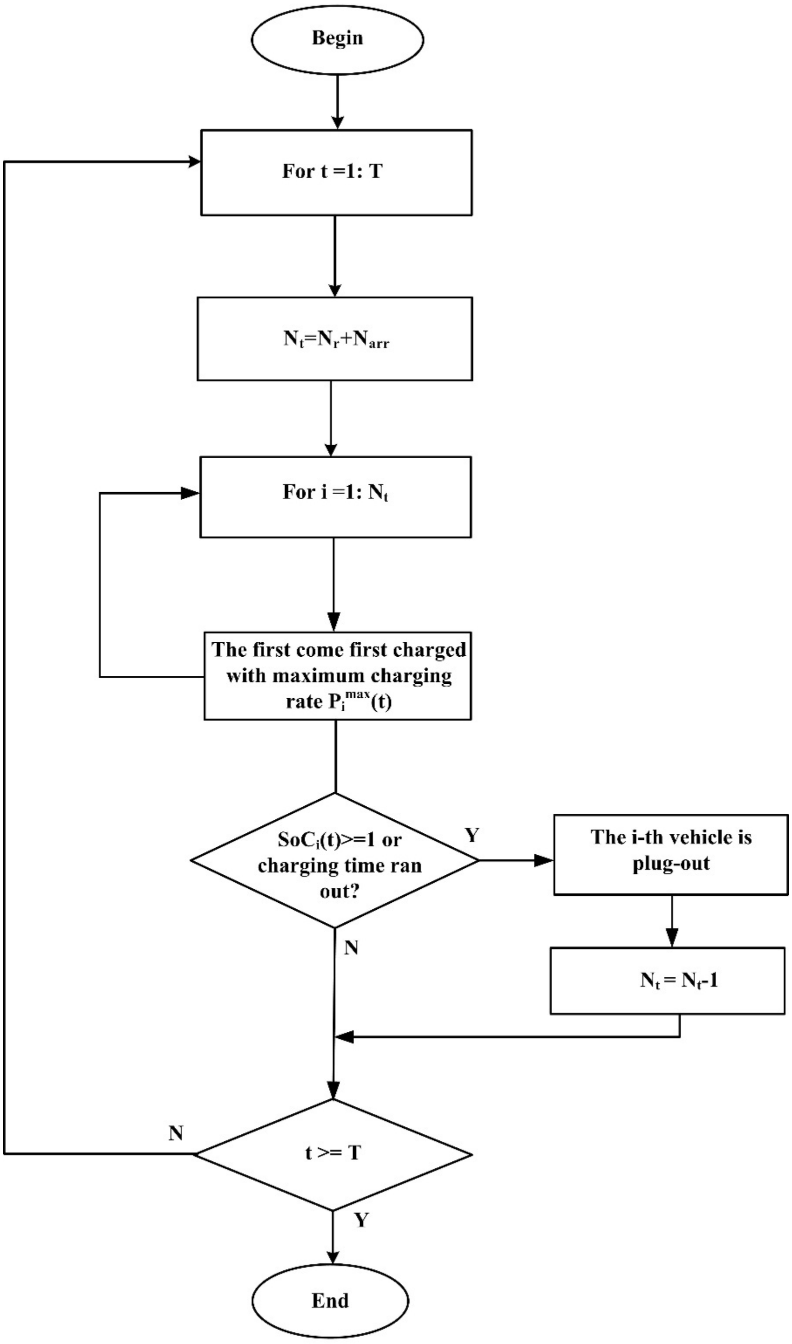

Figure 1. *Flowchart of Implementation*

2.2.2. Lowest SoC first (LSF)

In the lowest state of charge first strategy (LSF), the total number of vehicles in the station at each time step includes the remaining vehicles from the previous time step and the new arrival vehicles to the station. The SoC value of these EVs will be compared to each other; the vehicle with lowest SoC value will be prioritized charging first with the maximum charging rate (Pi,tmax). The remaining vehicles will be charged sequentially from the vehicles with lower SoC value to the vehicles with higher SoC value. The process only stops until the capacity of station is equal 0 or all the vehicles have been charging. The number of total vehicles are charged at each time step is counted by the division of the capacity of station and the maximum charging rate (Pi,tmax) plus the binary variable n0 (n0 equal 1 as the remainder of the division is nonzero and n_0 equal 0 as the as the remainder of the division is zero). The FCFS strategy is demonstrated in the following formula**:**

$$\mathrm{N}_{\mathrm{ch,t}} = \frac{P_{S\_\max}}{P_{\mathrm{i,t}}^{\max}} + \mathrm{n}_0 \tag{16}$$

Where;

$$\mathrm{n}_0 = \begin{cases} 0 & \sum_{1}^{N_{ch,t}} \mathrm{P}_{\mathrm{i,t}}^{\max} = P_{S-\max} \\ 1 & \sum_{1}^{N_{ch,t}} \mathrm{P}_{\mathrm{i,t}}^{\max} \neq P_{S-\max} \end{cases} \tag{17}$$

Where, $N_{ch,t}$ is the total number of vehicles to be charged at time step t, n_0 is a binary variable.

Applying the Lowest state of charge first strategy (LSF) to the power allocation to EVs problem is presented in Figure 2.

2.2.3. Equally allocation method (EAM)

Equally allocation method (EAM), the total capacity of the charging station at each time step will be equally allocated among the vehicles waiting at the station, with the constraint $P_{i,t} \leq P_{i,t}^{max}$. The equal allocation method can be expressed as follow:

$$P_{i,t} = \frac{P_{\text{S-max}}}{N_t} \tag{18}$$

S.t

$$P_{i,t} \leq P_{i,t}^{\max} \tag{19}$$

Where $P_{i,t}$ is power allocated to i-th vehicle at the time step t, N_t is the number of the vehicles at the time step t, $P_{i,t}^{max}$ is the maximum power that vehicles can get at each time step and $P_{S_max}$is the maximum power of charging station.

Applying the equally capacity allocation method (EAM) to the power allocation to EVs problem is presented in Figure 3.

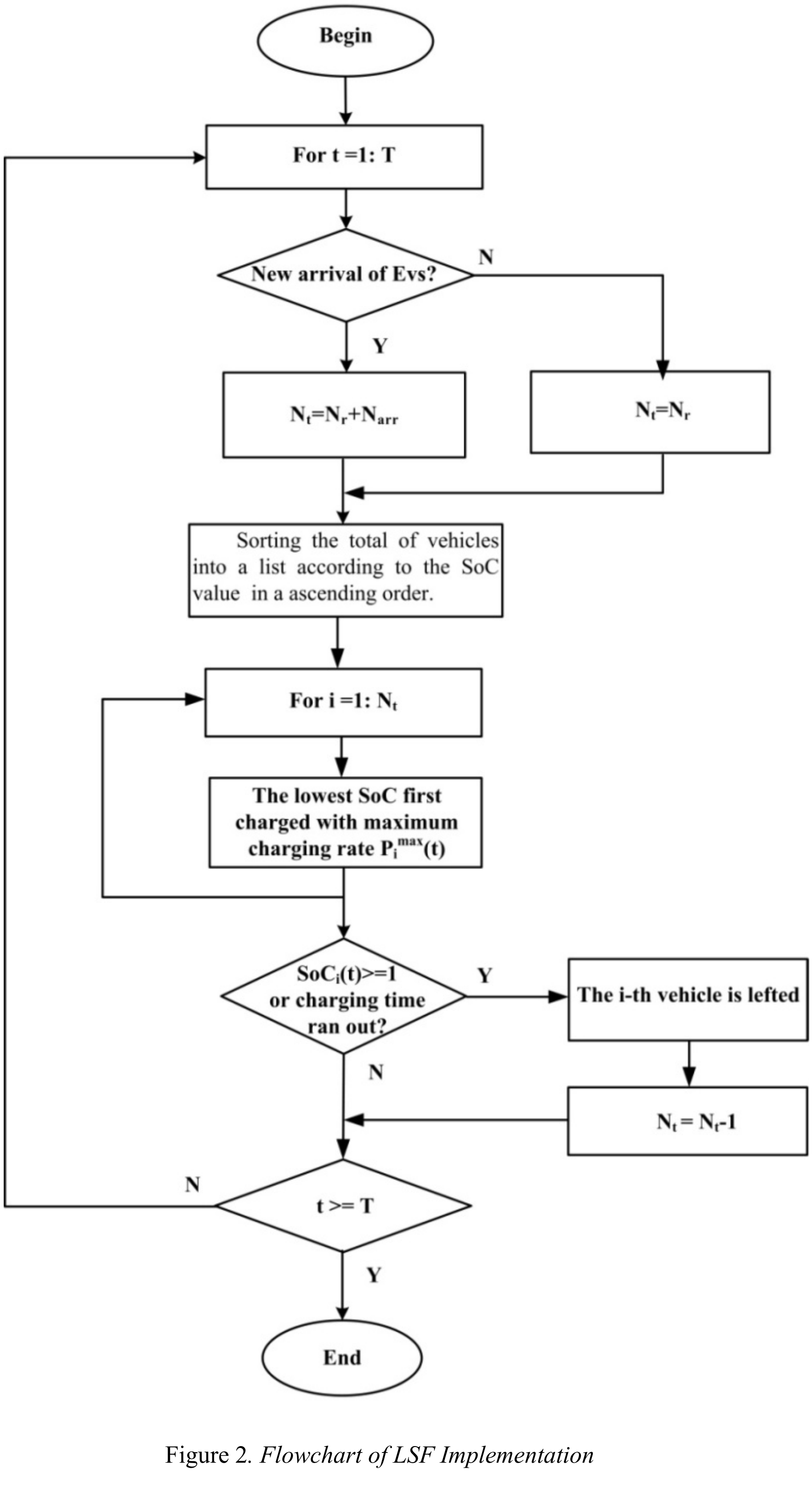

Figure 2. *Flowchart of LSF Implementation*

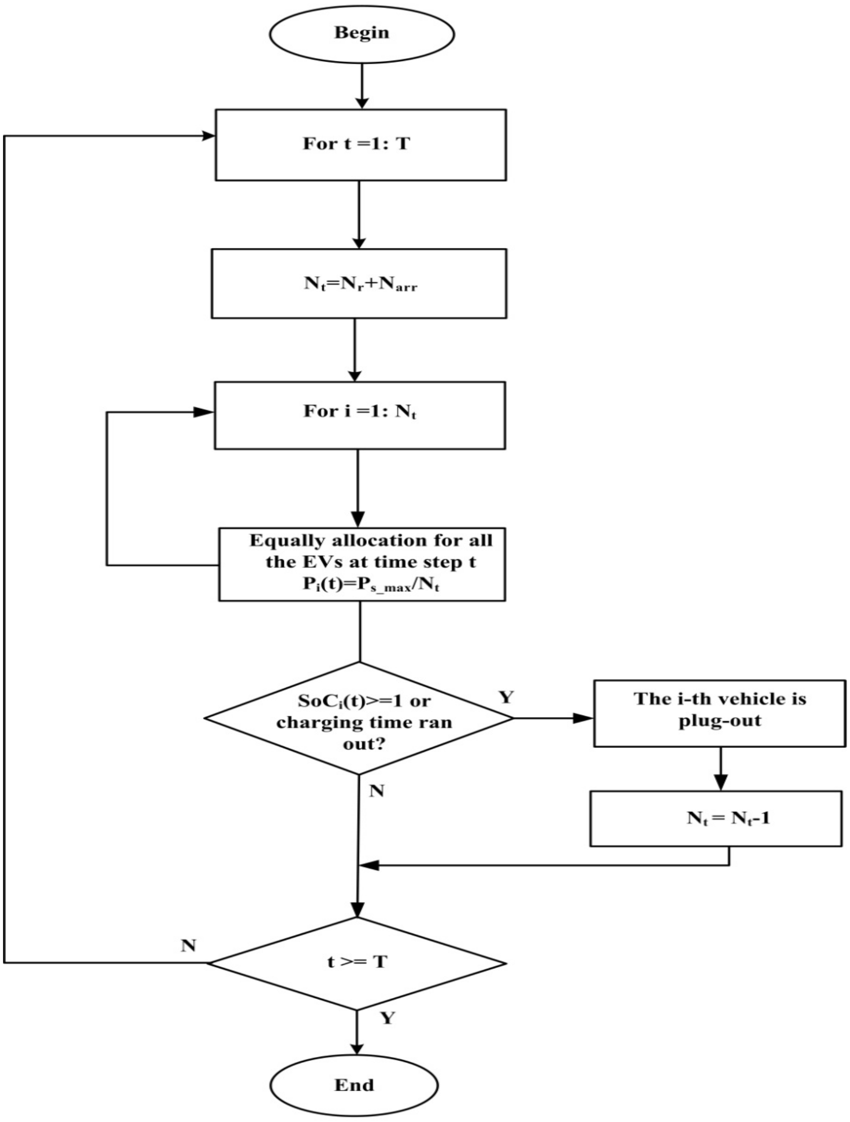

Figure 3. *Flowchart of EAM Implementation*

2.2.4. Shortest charging time first (STF)

In the lowest state of charge first strategy (STF), the total number of vehicles in the station at each time step includes the remaining vehicles from the previous time step and the new arrival vehicles to the station, the remaining charging time of these EVs will be compared to each other; the vehicle with shortest SoC value will be prioritized charging first with the maximum charging rate (Pi,tmax). The remaining vehicles will be charged sequentially from the vehicles with shorter remaining charging time to the vehicles with larger remaining charging time, the process only stop if the capacity of station equal 0 or the vehicles have been charging. The number of total vehicles charged at each time step is counted by the division of the capacity of station and the maximum charging rate (Pi,tmax) plus the binary variable n0 (n0 equal 1 as the remainder of the division is nonzero and n0 equal 0 as the as the remainder of the division is zero). The FCFS strategy is demonstrated in the following formula:

$$\mathrm{N_{ch,t}} = \frac{P_{S\_\max}}{P_{\mathrm{i,t}}^{\max}} + \mathrm{n_0} \tag{20}$$

Where;

$$\mathrm{n_0} = \begin{cases} 0 & \sum_{1}^{N_{ch,t}} \mathrm{P_{i,t}^{max}} = P_{S-\max} \\ 1 & \sum_{1}^{N_{ch,t}} \mathrm{P_{i,t}^{max}} \neq P_{S-\max} \end{cases} \tag{21}$$

Where, $N_{ch,t}$is the total number of vehicles to be charged at time step t, n_0 is a binary variable.

Applying the shortest charging time first strategy (STF) to the power allocation to EV problem is presented in Figure 4.

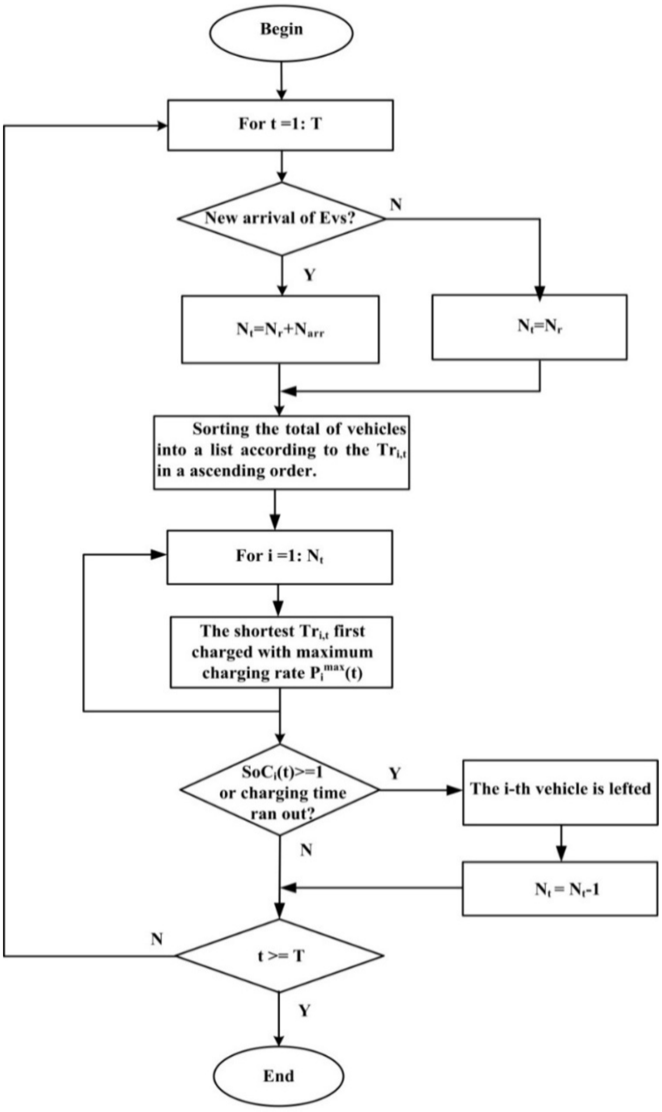

Figure 4. *Flowchart of STF Implementation*

3. SIMULATION RESULTS AND ANALYSIS

In this test, we considered 106 vehicles out of the total 183 vehicles ran out of time in the charging station for 32 time steps corresponding to 8 hours, the sample time was set for each time step is 15 minutes.

Due to lack of real market data, some of parameters are estimated or simulated according to published work and public data [9,10,12]. Battery chargers fall into three categories by voltage and power level. Level 2 is typically described as the primary or standard method for both private and public charging, and specifies a single-phase branch circuit with typical voltage 240 VAC. In this paper, all the battery chargers are assumed to be Level 2 and maximum PHEV charger limit $P_{i,t}^{max}$ is 6.7kW. The station capacity (PS-max) in the test P_{S_max}= 152kW.

For this test, the number of vehicles *n(t)* arriving to station at each time step to request charging service is stochastic. In such a case, arrival times are assumed to follow Poisson distribution with mean parameter lambda λ, the probability mass function of *n(t)* is given by:

$$f = (n(t)\,|\,\lambda) = \frac{\lambda^{\mathrm{m}(t)} e^{-\lambda}}{\mathrm{m}(t)!} \tag{22}$$

Where, n(t) is the number of arrived PHEVs to the charging station each time step; e is Euler's number (e = 2.71828...).

The initial SoC of the arrived vehicles are assumed to follow log-normal distribution with mean μ and standard deviation σ. Therefore, the probability that initial SoC can be computed as:

$$f\left(SoC_i|\mu,\ \ \sigma\right) = \frac{1}{SoC_i\sqrt{2\pi\sigma^2}} e^{-\frac{\left(\ln SoC_i-\mu\right)^2}{2\sigma^2}} \tag{23}$$

Figure 5 and figure 6 demonstrate the initial SoC and the departure SoC, while, the initial SoC is generated randomly and follows log-normal distribution. Figure 6 (a), (b), (c) and (d) illustrate the departure SoC when the LSF, FCFS, STF and EAM method are applied. Figure 6 shows that the number of vehicles SoC equal 1 (the EVs is fully charged) at the STF method is the greatest, while the all of vehicles with SoC greater than 0.7 when leaving the charging station. Meanwhile, the all vehicles at the LSF method with SoC smaller than 1 and greater than 0.5 when leaving station, it shows that this method are suitable for the customers with low SoC and short charging time. Because the capacity of the station is limited, while at every time step the new vehicle with low SoC may arrive the charging station to require charging, the customers with relatively high initial SoC, possibly during time in the charging station are only allocated a small amount capacity, even not allocated capacity. Figure 6 (b), (d) show that in the FCFS and EAM method, the number of vehicles with SoC equal to 1 is relatively large; but there is also a relatively large number of the vehicles with SoC smaller than 0.4. Especially, in the FCFS method, there are some vehicles with SoC equal 0.2, which means that these vehicles are not charged or only charged a small amounts capacity.

Above analysis shows that each power allocation method for electric vehicles has its advantages suitable for charging station in the particular case. However, in order satisfy the charging demand of the customers, the STF method can guarantee that all customers always receive an appropriate energy level when leaving the charging station. However in fact, there are many customers for a mandatory reason to leave the charging station earlier than expected. When leaving the station, the customer wanted to receive a reasonable level of energy. As can be seen from figure 6, in the methods LSF, EAM and FCFS, each customer leaving station receive a certain power level, especially at the FCFS method. Whereas in method STF the customers leave the charging station earlier than expected are unallocated.

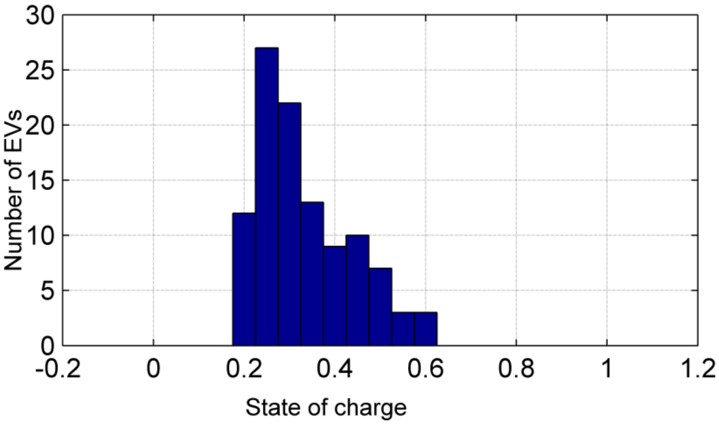

Figure 5. *Initial SoC of 106 EVs ran out of time in the station for 183 EVs case*

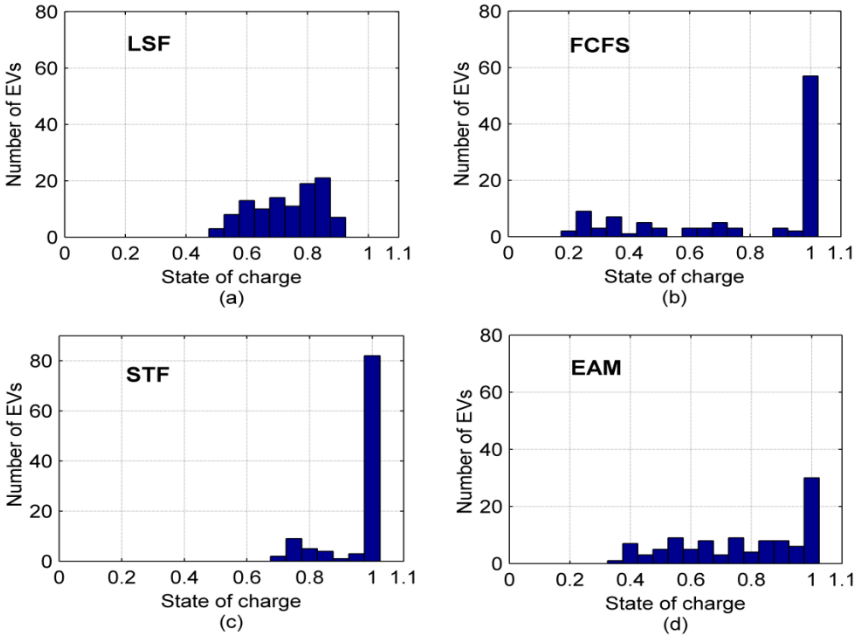

Figure 6. *Departure SoC of 106 EVs ran out of time in the station for 183 EVs case*

In order proceed with building the electric vehicle charging stations and investment, the number of chargers are considered in many different aspects, in which the application effective the power allocation methods also contribute an important part. Note that the number of vehicles at each time step in the each method is different. The more the number of the vehicles in the station, the larger space and the more the number of chargers are required.

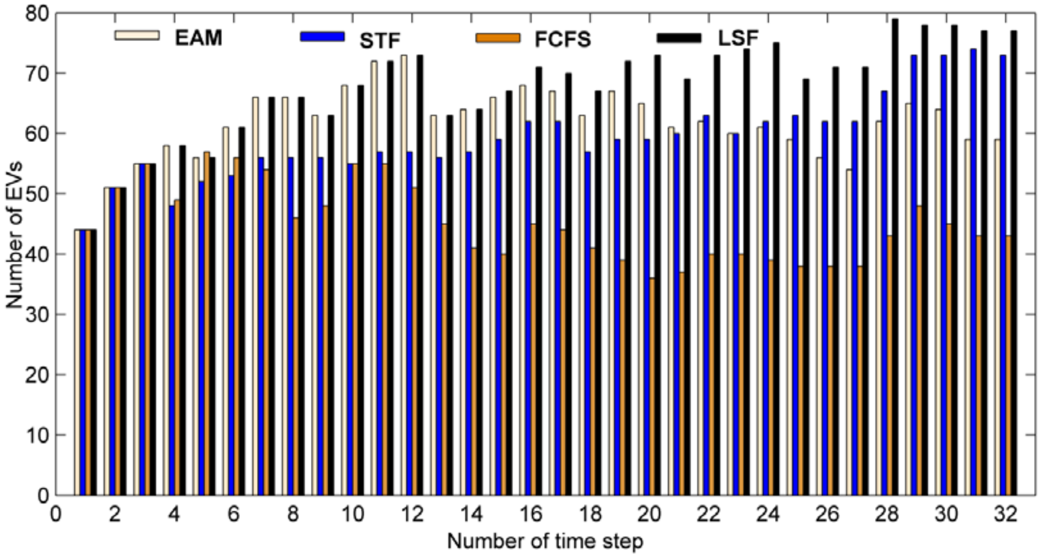

Figure 7. *The number of EVs at each time step*

Figure 7 represents the number of vehicles in the charging station at each time step when the basic power allocation methods for electric vehicles charging station is applied. It is obvious that the number of vehicles in the charging station at each time step corresponding to each allocation methods differ quite large. Specifically, the number of vehicles in the charging station at the LSF method is the largest, followed by the STF method, the EAM method and the FCFS method. Thus, it can be seen that applying LSF based method requires construction of charging stations with the largest scale as compared with other methods.

4. Conclusions

This paper provides an overview of some of the basically power allocation method for the electric vehicle charging stations, specifically as lowest state of charge first (LSF), first come first serve (FCFS), equally allocation method (EAM) and shortest charging time first (STF). We used MATLAB to simulate the allocation methods. The simulation results show that each method has its own advantage and disadvantage. Specifically, the FCFS method can ensure fairness in the allocation of capacity for electric vehicles, construction costs and smaller number of chargers that need investment. However, if there are large numbers of electric vehicles in the station, this method is not suitable for the customers with short charging time. Meanwhile, the LSF and EAM methods ensure that all customers leaving the stations are allocated a amount capacity. However, to apply the LSF method requires the large-scale charging stations. While the EAM method requires the large number of chargers, because all vehicles are charged at each time step.

Simulation results show that, the STF method satisfies the demand of the customers the best. In this method, all customers leaves the station with SoC greater than 0.7, while many customers are fully charged. However, this method is not suitable for the customers who leave the station abruptly, and requires a relatively large charging stations space.

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CÁC CHÍNH SÁCH PHÂN BỔ CÔNG SUẤT CƠ BẢN CHO TRẠM SẠC XE ĐIỆN

Tóm tắt

Sự thâm nhập của xe điện (electric vehicles) và xe điện lai (plug –in hybrid electric vehicles) có thể gây ảnh hưởng nghiêm trọng đến toàn bộ lưới điện, từ nhà máy điện đến các trạm phân phối địa phương, đặc biệt nhu cầu sạc của xe điện là ngẫu nhiên. Nếu thiếu sự phối hợp sạc cho xe điện có thể gây mất cân bằng lưới điện ở nhiều thời điểm khác nhau, làm tăng các tải đỉnh nhọn thậm chí còn có thể xuất hiện các siêu tải đỉnh nhọn. Do đó một nghiên cứu toàn diện về tác động của xe điện và xe điện lai lên lưới điện hiện có, cần được thực hiện bằng các chính sách sạc hợp lý cho nhu cầu sạc của xe điện trong tương lai. Trong bài báo này các chính sách phân bổ công suất cho xe điện như: Chính sách đến trước phục vụ trước; chính sách ưu tiên sạc trước cho trạng thái sạc pin thấp nhất; chính sách phân bổ đều và chính sách ưu tiên sạc trước thời gian sạc ngắn nhất đã được đề xuất. Sử dụng Matlab tính toán mô phỏng cho các chính sách phân bổ công suất, kết quả mô phỏng các chính sách phân bổ được phân tích, đánh giá và so sánh với nhau

Từ khóa: *Xe điện lai, Xe điện, Trạng thái nạp của Pin và Phân bổ công suất.*