Smart Plug-in Electric Vehicle Charging to Reduce Electric Load Variation at a Parking Place

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***Abstract*—Electricity demand having less variation at different times in a day avoids any detrimental effect on power electronic equipments, reduces electricity cost, and simplifies the electric energy demand prediction from the smart grid. This paper delineates an intelligent aggregator architecture to automate Plug-in Electric Vehicle (PEV) charging in large parking places to reduce dynamic load variation. We present a set of novel rectangle placement based algorithms to schedule the PEV charging based on their arrival, departure time at parking place and their charging requirement. The proposed algorithms also determine the voltage level at which PEVs should be charged to improve demand side electric load profile. The presented algorithms meet the charging requirement of every PEV, reduce load variation, and increase load factor at the parking place. Simulation results interpret that the proposed method provides significant improvement regarding load variation and load factor. Notably, the methodology performs better than the traditional First come, First serve (FCFS) based PEV charging at a parking lot.**

I. Introduction

The emission of greenhouse gases and rising petroleum prices have led to the adoption of renewable sources of energy. The introduction of Plug-in Electric Vehicle (PEV) which use electricity as the source of energy has the potential to electrify transport sector thus alleviating the dependency on fossil fuels. Beside environmental concerns, the energy required for PEV charging is cheaper as compared to gasoline-based fuel refilling. PEVs also have better performance with smooth acceleration and make less noise [1].

Although PEVs have several benefits, their wide-scale adoption is challenging since an extensive charging infrastructure need to be developed for their realization. With the anticipated growth of PEVs as a popular transportation choice, their confluence with smart grid and Electric Vehicle Supply Equipment (EVSE) is of utmost importance [2]. The large-scale penetration of PEVs will add up the electricity demand putting pressure on the power grid. Additionally, the extensive energy required for PEV charging, unpredictable nature of PEV load, and their disparate charging requirement reshape the electricity demand curve of the consumer. Therefore, PEV charging need to be synergized such that it does not affect the electricity demand profile severely.

An uncoordinated PEV charging may cause sudden load change since many PEVs may be plugged in for charging within a small time interval. A sudden load change leads to voltage fluctuation which may affect the performance of appliances tied to the same transmission system [3]. An abrupt load variation also results in the early aging of power electronic instruments like transformers. Furthermore, it induces power loss and harmonic distortions [4], [5]. Beside unexpected load change, an uncoordinated PEV charging spurs electric load variation at the different time in a day, thus resulting in peak electricity demand differ to a considerable extent than the average electricity demand. The load variation decreases the value of the load factor, which is the ratio of average power demand to peak power demand. Contrarily, consumers with less difference between peak demand and average demand, one with high load factor, are charged less as compared to the consumers with low load factor [6]. Additionally, the electricity generation and management depend upon short-term or day ahead energy demand [7], [8]. An electric load profile with less variations eases the problem of the load forecasting such that the load prediction is better thus assisting in better supply side management.

Since reducing load variation is a key aspect for coordinate PEV charging, we investigate feasibility and mechanism of a centralized aggregator to schedule PEVs for charging. The proposed aggregator model makes charging decision on behalf of PEVs to reduce power variation and improve load factor. The main contributions of this work are as follows:

- We portray a novel aggregator architecture for PEV charging at a parking place. The proposed model automates the PEV charging process to meet every PEV's charging requirement, reduces electric load variation at different times of the day, and improves the value of the load factor.
- We propose an iterative process which combines a voltage level selection algorithm and shift rectangle algorithm. The proposed algorithms are executed iteratively after an initial rectangle placement algorithm to schedule PEV charging and select their charging level.
- Our initial rectangle placement algorithm assigns the possible time and charging level to PEVs giving priority to their arrival time at the parking place.
- We describe a voltage level selection algorithm that decides the charging rate at which different PEVs should be charged.
- We propose a shift rectangle algorithm that shifts the position of rectangles to smoothen the electricity demand

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curve. Voltage level selection algorithm and shift rectangle algorithm are repeated a number of times to make load profile better after initial rectangle placement.

The rest of this paper is organized as follow. Section II briefly describes the literature survey. In section III, we present the proposed system model. Section IV provides a description of the problem statement and proposed algorithms. In section V, simulation experiments and results are presented and section VI concludes this paper.

II. Literature Survey

There has been work done in the literature on coordinated PEV charging. In [9], Deilami et al. has presented a load management scheme to reduce power loss and improve voltage profile. The proposed method schedule PEVs in real time to improve voltage profile and reduces cost. The scheme reduces grid loss and cost of generating electricity by adopting real-time load management. Nafi et al. has proposed a Software-defined Network (SDN) based load management scheme in [10] that maximizes the number of PEVs being charged when net power demand is low. In this description, Nafi et al. has proposed a linear prediction algorithm to predict load demand. The expected load demand is used to allocate power in different regions. The load forecast is used to schedule PEVs for maximizing the number of PEVs being charged when the predicted electricity load is less. The model was designed to utilize generated power from the grid efficiently. Shaaban et al. has described a coordinated PEV scheduling process to improve power system resources efficiently in [11]. The presented architecture reduces system operating cost and also meet power system constraints. The given work has proposed a prediction scheme to determine load due to PEV charging in advance. The PEVs in the model are considered to have the same driving range and power limit. Sharma et al. has explained a smart charging schedule for unbalanced residential distribution systems in [12]. This work has considered various parameters like energy drawn, cost of energy from local distribution company, and total cost of PEV charging to describe a smart electricity distribution system architecture. The paper has examined the impact of uncontrolled charging on peak demand, voltage, and current values and proposed a framework which does not violate grid constraints.

The works mentioned above have primarily focused on mitigating the effects of the peak electric load demand. Henceforth, aforementioned works have attempted to schedule PEVs such that very few number of PEVs are plugged in for charging when the electric load is high such that electric load is within grid constraint. Variation in electric load and load factor which are essential aspects both for the utilities and consumers have not been explored in works as mentioned earlier. This paper proposes a hybrid method where PEV scheduling is coupled with charging voltage level selection to improve load profile by reducing load fluctuation. The proposed method is desirable to the demand side as well as supply side. The consumers are favored regarding cost and voltage fluctuation. Utilities are benefitted because a constant load demand does not hurt power electronic instruments and the energy forecast is made easier.

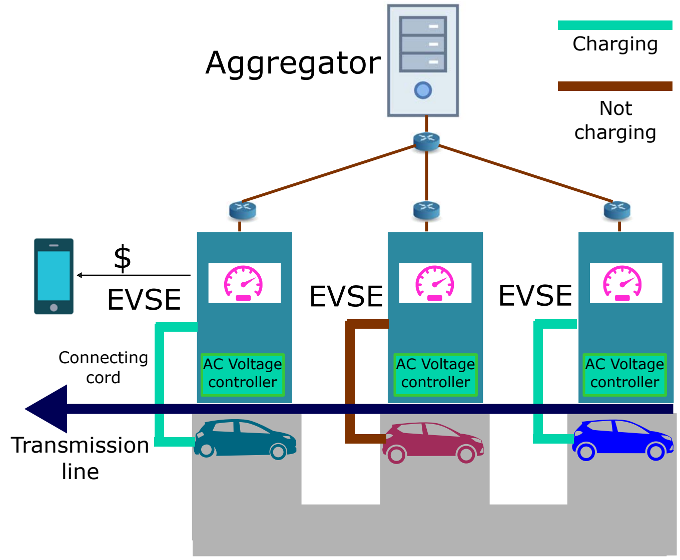

Fig. 1. System model

III. System model

Figure 1 presents the proposed system model. The model consist of Plug-in Electric Vehicles (PEVs), Electric Vehicle Supply Equipments (EVSEs), and an aggregator. EVSE is used for providing electricity for PEV charging. The aggregator is a centralized controller which collects data from PEVs and EVSEs and schedule PEVs for charging based on their arrival time, departure time, and charging requirements. We consider the scheduling problem for large parking places where electric load due to PEV charging is large. For example, in a university campus or office building number of vehicles are of the order of 100 during working hours. Such large number of vehicles make sizable electic load. We examine the PEV scheduling problem for the scenario where arrival and departure time of PEVs at the parking place is known in advance. For example, in offices arrival or departure time of vehicles mainly depends upon working hours. Similarly, in the university campus, the arrival and departure depends upon class schedule.

We consider the futuristic scenario where every parking slot in the parking place has an EVSE for PEV charging. EVSE consists a connector which can be plugged into the PEV inlet for charging. The EVSE for the proposed model is considered to supply 120-volt Alternating current (AC) level 1, 220-volt AC level 2, and less known 220-volt AC level 3 voltage for charging. The different voltage level charge PEV with different rate [13]. A higher voltage level charge PEV in less time drawing more power from EVSE. The availability of variable voltage level charging is leveraged to flatten load profile by charging at the higher level when fewer vehicles are present and charging at the lower level when many PEVs need to be charged. The investigation of Combined Charging Systems (CCS) has enabled the same connector to be used for AC level 1 or level 2 charging [14], [15]. This eases the charging process when different level of charging is supplied by the same EVSE as connector need not be replaced based on the voltage supplied by EVSE. The user only has to plug in CCS connector to the PEV inlet, and the process of charging level selection can be automated. To monitor the charging status of the vehicle, EVSE establishes a communication link with PEV. The dedicated wire in CCS connector is used for sharing information between PEV and EVSE [14]. AC voltage controller installed in EVSEs convert 120 (or 220) volt supply to 220 (or 120) volt supply. This enable EVSEs to provide different voltage for charging without having separate dedicated lines for 120 and 220 voltage.

The PEVs are installed with a Radio Frequency Identification (RFID) device for their unique identification and authorization. After the PEV is parked in a parking slot, RFID device is automatically scanned by sensors for its identification and authentication. The information about the parking slot within the parking place where a PEV is parked is sent to the aggregator. The user plugs in the charging connector to the PEV and leaves, but the charging process may not be immediately started. The charging decision is made by the aggregator. The PEV charging automatically begins at the time scheduled by the aggregator and connectors stops supplying electricity once PEV gets charged. The smart meter in EVSE tracks the amount of power consumed by the PEV. After charging process, the electricity price and the charging information is automatically sent to the user mobile phone.

IV. Methodology

A. Problem Statement

We consider a total number of N PEVs where each PEV is represented by a variable i such that $i \in \{1, 2, ...N\}$. We discretize time in slots each of length τ. A particular time slot is represented by a variable j such that $j \in \{1, 2, 3, ...M\}$ and M is the total number of slots required for charging all PEVs.

We represent V_l as the charging voltage supplied by EVSE at level l. The amount of current used by PEV depends upon voltage level V_l supplied by the EVSE for PEV charging and the PEV battery circuit that is specific to a PEV. We represent I_l^i as the current supplied by EVSE when PEV i is charged at voltage V_l. The required energy to charge PEV i called as a Status of Charge SOC_r^i. The arrival time and departure time of PEV i at the parking place is given by t_a^i and t_d^i. The number of slots required to charge PEV i at charging level l, represented as n_l^i, is given by equation 1. In equation 1, product $V_l^i \times I_l^i$ is the power (energy per unit time) supplied by the EVSE.

If a PEV i arrives at time t_a^i and departs at time t_d^i then its arrival slot τ_a^i and departure slot τ_d^i are given by equations 2 and 3. The t_{in} is considered as the starting reference time. For example, if time slot length is 5 minutes and starting reference time is 7:00 AM then 7:00 AM-7:05 AM is zeroth slot, 7:05 AM-7:10 AM is first slot, 7:10 AM-7:7:15 is second slot and so on. If a PEV arrives at 7:03 AM then its arrival slot is considered as 7:05 AM-7:10 AM which is slot number 1. If it departs at 4:02 PM then its departure slot is 107 (3:55 PM-4:00 PM). If the PEV requires 30 slots to charge with some voltage level then these slots should be allocated between slot number 1 and 107 for its charging.

$$n_l^i = \lceil \frac{SOC_r^i}{V_l \times I_l^i \times |\tau|} \rceil \tag{1}$$

$$\tau_a^i = \lceil \frac{t_a^i - t_{in}}{|\tau|} \rceil \tag{2}$$

$$\tau_d^i = \lfloor \frac{t_d^i - t_{in}}{|\tau|} \rfloor \tag{3}$$

The net electricity load at the parking place in slot j is given by equation 4 subject to the constraints 5 and 6. The variable x_l is a binary variable which represents whether EVSE is charging at level l voltage. The inner summation in equation 4 adds over all charging levels. Equation 5 and 6 guarantees that only single charging level is used for charging a PEV. The outer summation adds the power requirement for every vehicle in parking lot in slot j. Variable y_i^j is a binary variable to determine if a PEV i is being charged in slot j. If the value of y_i^j is 1 then the PEV is being charged in slot j. Otherwise, the PEV is connected to EVSE but does not draw current.

$$P_j = \sum_{i=1}^{N} (\sum_{l=1}^{L} V_l I_l^i x_l) y_i^j \tag{4}$$

$$\sum_{l=1}^{L} x_l = 1 \tag{5}$$

$$x_m \times x_n = 0 \ \forall \ m \neq n, \ m, n \in 1...L \tag{6}$$

The change in PEV load between two consecutive time slots is given by equation 7.

$$\delta P_j = P_j - P_{j-1} \tag{7}$$

The optimization objective given by equations 8 and 9. Equation 8 minimizes average power deviation over various time slots and equation 9 maximizes load factor (ratio of average power to peak power). P_{avg} is the average of the power assigned at various time slots.

$$min\{\frac{\sum_{j=1}^{M} \delta P_j}{M}\} \tag{8}$$

and

$$max\{\frac{P_{avg}}{max\{P_1, P_2 ... P_M\}}\} \tag{9}$$

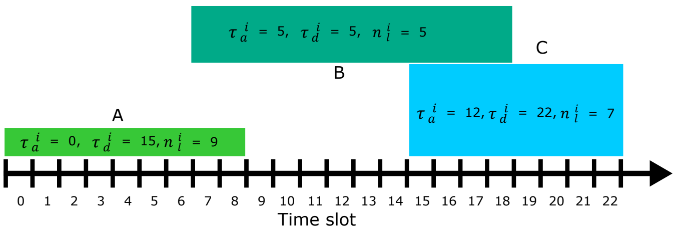

Fig. 2. Rectangle placement

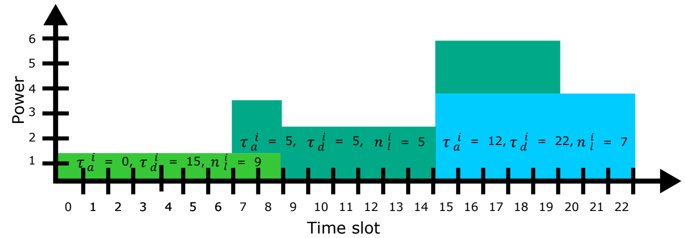

Fig. 3. Total power

B. *PEV schedule using rectangle placement*

We solve the problem of reducing electric load variation by scheduling PEVs such that they are charged according to the time decided by the proposed algorithms. For every PEV, we consider a rectangle whose length is the time PEV need for charging and height is the power required for its charging. For example, if a PEV i requires n_l^i slots to charge with the voltage level V_l and current I_l^i then for PEV i we consider a rectangle of length $n_l^i \times |\tau|$ and height $V_l \times I_l^i$. The area of the rectangle which is the product of length (time) and height (power) represents required energy SOC_r^i for PEV charging. Since height of one rectangle is the power needed to charge one PEV, the net height of the rectangles, at a particular time slot, after they are placed horizontally to the time scale is the power required for charging all PEVs scheduled for charging at that time slot. Figure 2 illustrate the rectangle placing scenario for 3 PEVs. Rectangle A in figure requires 9 slots to charge. Its arrival and departure slots are 0 and 15 respectively. Thus, the PEV corresponding to the rectangle A need to be scheduled for charging between time slot 0 and 15 such that the rectangle A is to be placed between slots 0 and 15 occupying 9 slots. Similarly, rectangle B requires 12 time slots for charging and need to be placed between its arrival slot (5) and departure slot (20) and rectangle C is to be placed between slots 15 and 22 occupying 7 slots . If rectangles are placed as in Figure 2, the electric load at various time slots can be represented like in Figure 3. The graph in Figure 3 presents net required electric power at various time slots is called as *load profile*. For the given schedule, between time slots 0-6 only A is being charged, between slots 7-8 A and B are being charged, in interval 9-14 B is charged, in slots 15-19 both B and C are being charged, and between slots 20-22 C is charged.

The proposed algorithms assign slots for placing rectangles such that the deviation in height of the load profile is minimum. For instance, in Figure 3 the height (required power) is low between slots 0 and 6 and high between slots 15 and 19 resulting in deviation in height (required power) of the load profile. The presented algorithms place rectangles to minimize deviation in height at various time slots.

1) Main algorithm: To solve the problem of reducing electric load variation between various time slots algorithm 1 is used. Algorithm 1 places the rectangles corresponding to every PEV to minimize deviation in height of the load profile. Algorithm 1 use algorithms 2-4 for optimal rectangle placement. Algorithm 1 takes list of vehicle charging request V as an input and provides charging schedule for every PEV in list. In step 1, algorithm 1 runs algorithm 2. Algorithm 2 does the initial rectangle placement corresponding to every PEV request. Initial rectangle placement algorithm gives priority to the arrival time of the PEV and use level 2 charging. Step 2 saves the assignment in a temporary variable $tmpaSlotP$. Based on the initial rectangle placement, step 3 determines the load factor LF_{curr} and step 4 sets the variable maximum load factor LF_{max} to the current load factor LF_{curr}. Step 5 finds the minimum height P_{ref} of the load profile. P_{ref} is also called as the reference height of the load profile. Step 4 determines the maximum height P_{max} of the load profile. Steps 8-15 are repeated in a loop. In step 8 algorithm 3 and in step 9 algorithm 4 are executed. The vehicle charging request list V and the value of P_{ref} are passed as parameters to both the algorithms. Algorithm 3 changes the charging level of some vehicles from level 2 to level 1 or level 3 to reduce variation in height of the load profile. Algorithm 4 shifts the position of rectangles to further flatten height of the load profile. Step 10 determines the load factor LF_{curr} after voltage level switching and rectangle shifting. If the new load factor LF_{curr} is greater than the previous maximum load

Algorithm 1 Main algorithm

Input: V - Vehicle charging request list
Output: $aSlotP$ - Assigned power at all slot
1: $InitialRectanglePlacement(V)$
2: $tmpaSlotP = aSlotP$
3: $LF_{curr} = \dfrac{avg(aSlotP)}{max(aSlotP)}$
4: $LF_{max} = LF_{curr}$
5: $P_{ref} = min(aSlotP)$
6: $P_{max} = max(aSlotP)$
7: **while** $P_{ref} < P_{max}$ **do**
8: $\quad VolageLevelSelection(V,\ P_{ref})$
9: $\quad ShiftRectangle(V,\ P_{ref})$
10: $\quad LF_{curr} = \dfrac{avg(aSlotP)}{max(aSlotP)}$
11: $\quad$ **if** $LF_{curr} > LF_{max}$ **then**
12: $\quad\quad LF_{max} = LF_{curr}$
13: $\quad\quad aSlotP = tmpaSlotP$
14: $\quad$ **end if**
15: $\quad P_{ref} = P_{ref} + h$
16: **end while**

Algorithm 2 Initial rectangle placement

Input: V- Vehicle charging request list
  P_r - Reference power
Output: $aSlotP$ - Assigned slots
  LF - Load factor
1: $V.sort(arrivalTime)$
2: $aSlotP.all() = 0$
3: **for** $i \leftarrow 1$ **to** $|V|$ **do**
4:   $w = 0$
5:   $a = False$
6:   **while** $a \,! = True$ **do**
7:     **for** $j \leftarrow V(i).\tau_a^i$ **to** $V(i).\tau_d^i - n_l^i$ **do**
8:       **if** $all(aSlotP(j : j + n_l^i) < w$ **then**
9:         $all(aSlotP(j : j + n_l^i)) += V_l \times I_l^i$
10:         $a = True$
11:       **else**
12:         $w = w + wI$
13:       **end if**
14:     **end for**
15:   **end while**
16: **end for**

factor then the values of maximum load factor LF_{max} and assigned slots for PEVs are updated (steps 11-14). In step 15, the variable reference height P_{ref} is incremented by a small value h. Since reference height P_{ref} is the minimum height of the load profile, the loop terminates when reference height is increased to such extent that it becomes greater than the maximum height P_{max} (obtained after the initial rectangle placement).

2) Initial rectangle placement: Algorithm 2 does the initial rectangle placement giving priority to the arrival time of PEVs. In step 1, the list of PEV charging requests V is sorted in increasing order of arrival time. The required power at every time slot is initially set to 0 in step 2 ($aSlotP$ is the list that represents information about electric load at various time slots). Steps 4-15 are repeated for every PEV request in sorted list V. $|V|$ denotes the number of elements in the set V. The algorithm uses a window w, the initial size of which is set to 0 in step 4. The variable a keeps the track of whether the rectangle is placed in load profile is initially set to $False$ (step 5). For every PEV i, step 7 checks for the consecutive n_l^i slots between arrival time τ_a^i and departure time τ_d^i where the height of the load profile is between 0 and w (values 0 and w are included). If such consecutive slots exist then the rectangle is placed on those slots, the net power in those slots is increased, and variable a is set to $True$ (steps 8-10). If they do not exist then the window size is increased in step 12. Consecutive slots where rectangle can be placed are then searched for larger value of w. The process ensures that the rectangle is initially placed between arrival and departure slot of PEV over load profile where height is minimum.

3) Voltage level selection: After initial rectangle placement, algorithm 3 switches the charging level of some PEVs from level 2 to level 1 or level 3 based on the height of the load

Algorithm 3 Voltage level selection

Input: V- Vehicle charging request list
  P_{ref} - Reference power
Output: $aSlotP$ - Assigned slots
  LF - Load factor
1: **for** $i \leftarrow 1$ **to** $|V|$ **do**
2:   **if** $all(aSlotP.(i)) < P_{ref}$ **then**
3:     **if** $all(aSlotP.(i)([sSlot_i : n_l^i]) - V_l \times I_l^i + V_{l-1} \times I_{l-1}^i < P_{ref}$ **then**
4:       $all(aSlotP.(i)(sLot : n_l^i)) -= V_l \times I_l^i$
5:       $nSlot = \lceil SOC_r^i/(V_{l+1} \times I_{l+1}^i \times \tau) \rceil$
6:       $aSlotP.(i)[sSlot_i : nSlot] += V_{l+1} \times I_{l+1}^i$
7:     **end if**
8:   **end if**
9:   **if** $all(aSlotP.(i)) > P_{ref}$ **then**
10:     **if** $all(aSlotP.(i)[sSlot_i : n_l^i])) - V_l \times I_l^i + V_{l-1} \times I_{l-1}^i > P_{ref}$ **then**
11:       $all(aSlotP.(i)[sLot : n_l^i]) - V_l \times I_l^i$
12:       $nSlot = \lceil SOC_r^i/(V_{l-1} \times I_{l-1}^i \times \tau) \rceil$
13:       $aSlotP.(i)[sSlot_i : nSlot] += V_{l-1} \times I_{l-1}^i$
14:     **end if**
15:   **end if**
16: **end for**

profile at various slots. It modifies the load profile obtained from initial assignment by switching charging level voltage. Algorithm tries to bring the height of the load profile near the P_{ref} for every time slot. Steps 2-15 are repeated for every PEV to determine if its charging level can be switched to obtain better load profile. Variable $aSlot$ contains the information about every PEV's charging schedule. $sSlot_i$ is the starting slot number in which PEV i is scheduled for charging. Step 2 finds if all the slots assigned for a particular PEV has net height less than the P_{ref}. If this is the case then step 3 determines whether increasing voltage to level 3 still keeps the height of the load profile in those slots less than but closer to P_{ref}. If the condition is true then the voltage level for that PEV is switched to level 3 (steps 4-6). Steps 9-14 are similar to steps 2-8 except the portion in the load profile where height is greater than P_{ref} are being checked (steps 9 and 10). If the condition is satisfied then the charging level voltage for the PEV is switched to level 1 (steps 11-13).

Algorithm 4 Shift rectangle

Input: V- Vehicle charging request list
  P_{ref} - Reference power
Output: $aSlotP$ - Assigned slots
  LF - Load factor
1: **for** $i \leftarrow 1$ **to** $|V|$ **do**
2:   **if** $all(aSlotP[sSlot_i : n_l^i]) > P_{ref}$ **then**
3:     $all(aSlotP[sSlot_i : n_l^i] -= V_l \times I_l^i$
4:     $all(aSlotP[\tau_d^i - n_l^i : \tau_d^i] += V_l \times I_l^i$
5:   **end if**
6: **end for**

TABLE I
SIMULATION PARAMETERS

Parameter	Value
Arrival time	7 AM - 5 PM
Departure time	8 AM - 2 AM
SOC_r^i	15 kWh - 49 kWh
AC level 1	120 V, 16.6mA/33.3mA
AC level 2	220 V, 72.72mA/90.9mA/109mA
AC level 3	220 V, 218.18mA/245.45mA/272.72mA

4) Rectangle shift: Algorithm 4 shifts the rectangles from region where height of the load profile is greater than the P_{ref} to the region where height is less than P_{ref}. Steps 2-5 are repeated for every PEV. Step 2 determines if height of the load profile at assigned slots for a PEV is greater than P_{ref}. If the height is greater than P_{ref} then the rectangle is shifted towards the right, such that PEV charging ends at its departure slot. We shift some rectangles to the right because in step 1 the priority was given to the arrival time (arrival time is in left). To balance that effect, this step shifts some rectangles to right to make height constant.

The algorithm 3 and 4 run for different values of P_{ref} obtained from algorithm 1 for optimum rectangle placement. After these algorithms are run for all possible values of P_{ref}, the final position of rectangles is used to schedule PEV charging.

V. RESULTS

We conducted an extensive set of experiments in python based framework to determine the deviation in power at various time slots. The proposed algorithms are compared with the First come, First serve (FCFS) based PEV charging. Simulation results are compared for different metrics to determine the extent to which PEV load varies in different time slots. To determine steepness in power curve, we introduce the metric *slope-variation*. Slope-variation is defined as the ratio of cumulative power variations in different time slots and the number of times the load profile changes. For example, in Figure 4 the height of the load profile changes to 2 units at the start of slot 4 and 1 unit in slot 10. The slope-variation for the mentioned example is average of cumulative height change at these two points $((2+1)/2)$.

A. Simulation parameters

Table I presents the simulation parameters for the experiments. Parameters were selected randomly between chosen range. Table also gives the voltage and current values for different levels of PEV charging. For example, AC level 1 charging use 120 V. Some PEVs for AC level 1 charging require 16.6 mA of current and some other need 33.3 mA. The length of time slot is chosen as 5 minutes.

B. Analysis of power variation

Figure 5 depicts the average power change over all time slots. As shown in the figure, the average power change is lower using proposed algorithms as compared to FCFS based PEV charging. For less number of PEVs, the gap between presented and FCFS algorithm is small. However, as number of PEVs increase the proposed methods shows better performance.

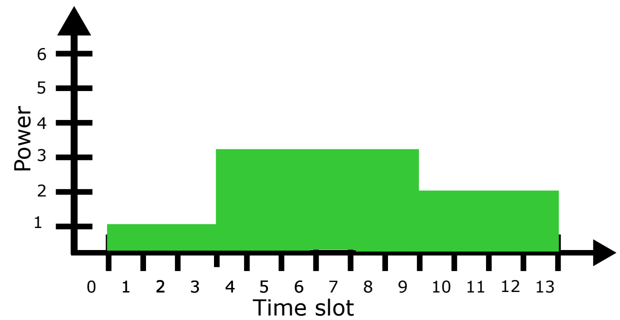

Fig. 4. Load profile

Figure 6 compares the slope-variation obtained from the proposed approach and the FCFS algorithm. The figure illustrate that for the proposed approach, the slope varies gradually when compared with FCFS. Here also, the gap between proposed and traditional method increases with the number of PEVs. Therefore, the importance of our approach lies in the large scale PEV charging at parking place.

Figure 7 compares the load factor between the proposed and FCFS method. The proposed algorithms show a performance gain in terms of load factor. Henceforth, the given method is also economically beneficial due to high value of the load factor.

C. Timing analysis

Figure 8 depicts the cumulative execution time of the presented algorithms as the number of PEVs are varied. We run our algorithms in two different CPU configurations (8 cores, 3.6 GHz and 4 cores, 2.4 GHz) in ubuntu operating system. Figure interprets that the run time of the algorithm is less than 6 seconds for both configurations. The lower execution time makes them feasible to implement in the aggregator.

VI. CONCLUSIONS

This paper highlighted the importance of reducing load variation due to PEV charging at a parking lot. We presented the smart aggregator architecture that automates PEV charging process. Our proposed rectangle placement based algorithms assign the time at which PEVs should be charged. We also presented charging voltage level selection to find the voltage at which a PEV should be charged. Rectangle placement combined with charging level selection makes load profile smooth as compared to traditional FCFS based charging. The simulation results characterize that our method reduces power deviation and load factor. Furthermore, our proposed architecture is feasible to implement in aggregator due to its lower execution time.

ACKNOWLEDGEMENT

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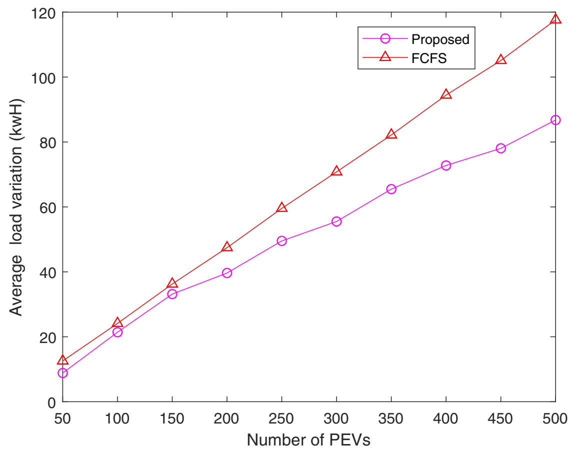

Fig. 5. Average power variation per time slot as number of PEVs are varied

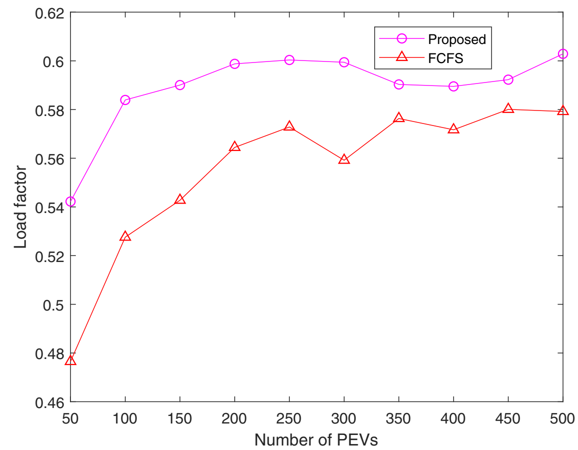

Fig. 7. Load factor as number of PEVs are varied

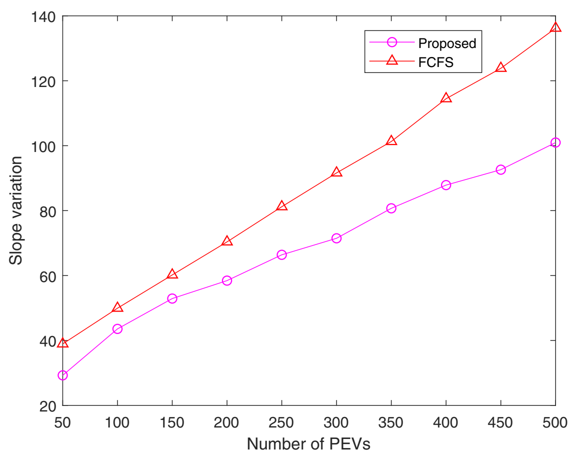

Fig. 6. Average slope variation as number of PEVs are varied

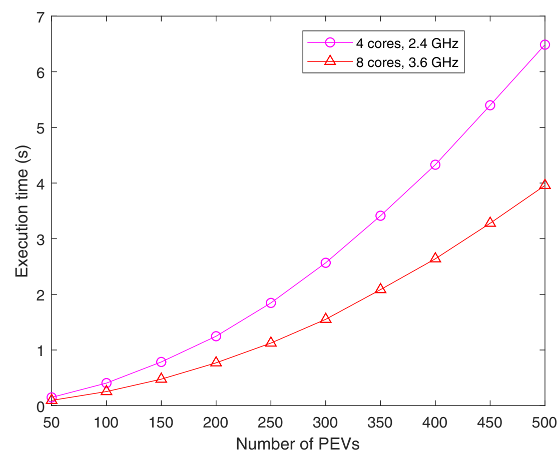

Fig. 8. Execution time

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