Guidance Model for EV Charging Service

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Abstract—**High Electric Vehicle (EV) penetration increases smart grid solicitation especially with various EV charging demands at peak load times. The EV charging process at public supply station (EVPSS) has to be managed in the way to promote the EV satisfaction levels while preserving smart grid stability. The waiting time for the EV charging service is an important factor in assessing the effectiveness of any interaction system between EVs and smart grid. In this paper, we present a system-guidance model to minimize the waiting time for an EV to be plugged-in for the charging service at public supply stations. We propose an algorithm for directing vehicles to charging stations in a way to minimize their searching time to join a supply station. The simulations conducted to evaluate its performance while satisfying the defined constraints proved the effectiveness of the proposed approach.**

Keywords -EV, waiting time, smart grid, V2G

I. Introduction

The smart grid is expected to enable the penetration of intermittent generation sources, enable adaptive electricity pricing [1,2,3], be self-healing, and optimize assets [4,5]. In addition to counting and pricing in smart grid, the real-time control over smart grid infrastructure and energy usage promises one of the largest potentials in load management and energy saving [6,7,8]. However, by 2015, the number of Electric Vehicles (EVs) on the road will increase rapidly, and will bring about many changes on the electricity distribution systems due the newly deployed infrastructure for EV charging/discharging. In fact, the load introduced by EVs charging operations will be one of the most important challenging issues for demand response systems in the smart grid.

The high market penetration of EVs translates into a high number of EVs needing a charging service at any time. On the one hand, massive EVs penetration can disrupt grid stability both by potential overloads on regional transformers and by causing excessive power demands on the electric distribution especially in peak time. Indeed, this impact can be intense in areas such as in a city especially when EVs start the charging or discharging process at the same time. On the other hand, if the number EVPSSs planned and deployed does not meet the demand, consumer satisfaction will be negatively impacted.

Finding a vacant Electric Vehicle Plug in Supply station (EVPSS) to plug-in, especially in peak hours, can be time consuming and frustrating to the drivers. Therefore, not only the smart grid needs to satisfy EVs demands, it also needs to meet EV users' expectations in terms of availability of nearby plug-in sockets, of fast time to-plugin, and of fast charging, all while preserving grid stability.

In this work, we consider the problem of the EV charge scheduling where EVs are able to communicate wirelessly with the smart grid, prior to plugin, in order to know, at a given time, the best available EVPSS in terms of waiting time before the plug-in phase (i.e., while the EV is on road side). The EV and the smart will exchange information such as EV and EVPSS status. As a result, the EV can be informed of the nearest available EVPSS so as to minimize its waiting time prior to charging, and therefore its total time to complete the charging process. The grid will make this decision based on the current status of EVPSSs, and the number of vehicles waiting to be served, while preserving grid stability.

We present a guidance system for EV, which can be seen as an intelligent planning service of EVs charging at EVPSSs before the plug-in phase, where the intelligent planning service is seen by the smart grid as a tread-off between consumer satisfaction in terms of waiting time, and grid stability.

Our contributions are: 1) To the best of our knowledge, we are the first to consider the EV guidance model for the EV charging service; 2) we present a system-guidance model to study the waiting time for an EV to be plugged-in for charging service, 3) we propose an algorithm called SMART-EV-Guidance for directing vehicles to charging stations in a way to minimize their searching time to join a supply station, 4) we demonstrate that this algorithm can effectively satisfy EVs charging demand within the defined constraints. The numerical results obtained verify that our scheme minimizes the time for vehicles EV to complete the charging under the defined constraints while considering realistic EV charging characteristics.

The remainder of the paper is organized as follows. Section 2 we present some related works. Section 3 presents our EV-guidance model to manage the EV charge scheduling process in an efficient way by minimizing the waiting time to be served at an EVPSS. The simulation results are presented in Section 4, and the conclusions are drawn in Section 5.

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II. RELATED WORKS

A Stochastic modeling for EV charging processes has been described in [9]. Their model provides a characterization of grid operation conditions, voltage profiles, branch loading, grid peak power and energy losses. In the work in [10] the system load due to EVs was represented with a Monte Carlo model representing real vehicle commuting patterns. In [11], authors derived the parameters needed for scheduling EVs charging without taking into account factors such as as EVs priority or maximum charging time for each individual EVs. However, in all these works, the problem of directing EVs to charging stations in order to minimize their charging times was not addressed.

Works [12] and [15] made a summary of current architectures and protocol standards for EV and grid interaction. In [13], the principles of standard Vehicle-to Grid (V2G) communication interfaces for control communication which are under specification in the ISO/IEC are presented. In [14] a generic V2G information model is presented which allows negotiating scheduling between EVs and grid operators. The work discusses a system model with theoretical concerns without treating a specific charging mode (slow, rapid or fast) as in realistic situations and does not consider the case where EVs need to communicate with the grid to know the most suitable EVPSS in terms of waiting time.

III. SYSTEM EV- GUIDANCE MODEL

We consider a system such as illustrated in Fig. 1, where N EVs and m EVPSSs are sharing a road infrastructure area. Furthermore, we suppose that EVs can communicate wirelessly with the smart grid prior to plugin, and that the smart grid and all EVPSSs are linked by some communication technologies. We study the influence of the cumulative state of charge (SoC) (see Fig.2) needed by a set of EVs which are in the charging process or are already waiting for service, on the waiting time for the next EV which needs the charging service. By the end of this section, we present our SMART-EV-Guidance algorithm.

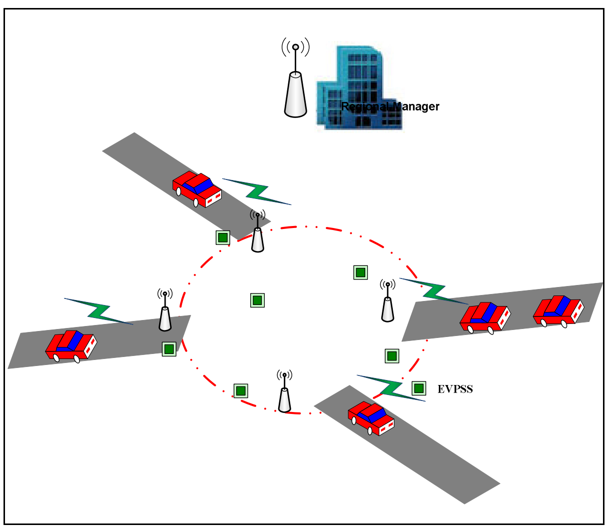

FIG.1: SYSTEM OVERVIEW

The proposed model assumes that an EV which needs to charge its battery can communicates its position and priority level and its current state of charge (SoC) to the smart grid via a Road Side Unit (RSU) to know the nearest available EVPSS. We suppose a simple case of a set of EVs which ARE assigned to the same EVPSS, and we estimate the waiting time for the last ranked EV to be plugged-in. Table.1 presents the notations used hereafter.

TAB. 1: NOTATION FOR OUR MODEL

Notation	Description
λ	EV Arrival intensity
D_{ch}	Charging rate
N_{EV}	Number of EV
N_{EVPSS}	Number of EVPSS
$N_{sockets}$	Number of plug-in sockets in a single EVPSS
SoC (i)	State of Charge of vehicle i
P_r	The probability to have (r) EVs assigned to the same EVPSS

We suppose that EVs arrival follows a Poisson process. The probability to have (*r*) EVs assigned to the same EVPSS is given by:

$$P_r = \frac{1}{N_{EVPSS}}\left[\sum_{k=1}^{r}\frac{\lambda^k}{k!}e^{-\lambda}\right] \quad (1)$$

The last EV which is ranked *r* will wait all the cumulative time needed by the other (r-1) EVs to be fully charged. The waiting time needed by the EV ranked *r* is given by:

$$W_{EV_r} = \sum_{i=1}^{r-1}[1 - SoC(i)]\frac{1}{D_{ch} * N_{socket}} = \frac{1}{D_{ch} * N_{socket}}\left[(r-1) - \sum_{i=1}^{r-1}[SoC(i)]\right] \quad (2)$$

The maximum waiting time for the EV numbered (*r*) is given by:

$$\underset{SoC(i)}{Max}\left(W_{EV_r}\right) = \underset{SoC(i)}{Max}\left(\frac{1}{D_{ch} * N_{socket}}\left[(r-1) - \sum_{i=1}^{r-1}[SoC(i)]\right]\right) \quad (3)$$

Given that the parameters D_{ch} and N_{socket} are considered constant, equation (3) can be rewritten as:

$$\underset{SoC(i)}{Max}\left(W_{EV_r}\right) = \left\{\frac{1}{D_{ch} * N_{socket}}\quad(r-1)\right\} \quad (4)$$

And the minimum of the waiting time is given by

$$\underset{SoC(i)}{Min}\left(W_{EV_r}\right) = 0 \quad (5)$$

In order to satisfy EVs as charging service users, it is clear that the waiting time needed by an EV to be plugged-in at an EVPSS needs to be reduced in the EV charge scheduling service.

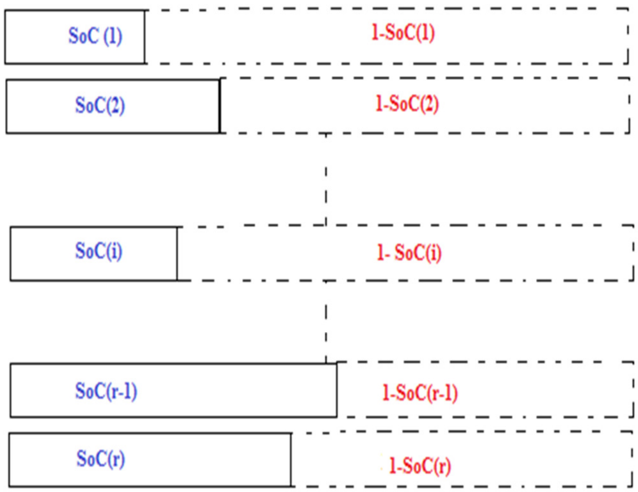

FIG .2: RANDOM EV SOCS

To this end, we present our SMART-EV-Guidance algorithm where the smart grid can find out the available EVPSS in terms of the smallest searching time. This algorithm takes into account the initial EV SoC, the EV priority level, the initial EV position and updates EVPSS state after each EV satisfaction. We assume that any initial EV SoC is enough to join the farest EVPSS.

Algorithm . *SMART-EV-Guidance*

Input: initial EV_Vector status (EV_SoC, position, priority)
EVPSS_Vector status (distance, occupancy),
EV_Number.
Output: @ EVPSS_Vector /* selected station vector */

1. RSU broadcast the EV charging service
2. Each EV sends to the RSU its profile (priority, position and SoC) /* EV_Vector profile */
3. New_EV_Vector = EV_Vector according to MAX(priority) /*Put EV in order of decreasing priority*/
4. **For** i=1:EV_Number
5. **Select** EVPSSs_grpe [i] according to EV_SoC is enough to join it
6. **Select from** EVPSSs_grpe [i] according to

   {*MIN(occupancy)* and *MIN(distance)*}

   /*Put EVPSS in order of in increasing distance and occupancy level */
7. **Assign** EV[i] **to** Selected_EVPSS
8. **End for**
9. RSU sends a vector of suitable EVPSS @ to EVs
10. Update EVPSS_Vector

    /*smart grid send to RSU the new EVPSS status*/

IV. SIMULATIONS RESULTS

In this section, we present the simulation results and discussions about the performance of our SMART-EV-Guidance. We consider a scenario where 1000 EVs and 20 EVPSSs are sharing a 8Km by 8Km road infrastructure area. We suppose that the EVPSSs positions distribution is random. All vehicles are travelling at a maximum speed of 50 Km/h.

We used MATLAB to perform the simulations. The EVs arrival flow variation is modeled by Poisson distribution in all our study. We assume that all EVPSSs are equipped with a level 3 plug-in which is the most rapid kind of EV charger. This kind of charger is the one expected to be available in most EVPSSs. The parameters for our EV charging process study as presented in Table 2.

TAB.2: SIMULATION PARAMETERS

Notation	Value
λ	1/3, ½, ¾ [1/min]
D_{ch}	20 kW/h
Charging time Max	20 min
N_{EV}	1000 EV
N_{EVPSS}	10,15,20
SoC	Uniform distribution between 1% and 90%
N_{socket}	A random value between 1 and 10
Maximum EV SoC	7kW

We suppose the scenarios where an EV has to be assigned to an EVPSS with 5 plug-in sockets. This EV arrives after a set of EVs which are assigned to the same EVPSS

Given the EVs arrival flow variation (λ) which is modeled by Poisson distribution and according to Eq. (1), the probabilities of a set of EVs assigned to the same EVPSS versus λ variation and EVPSS number are shown respectively in Fig.3 and Fig.4. We observe that this probability follows directly the λ variations and it follows inversely the EVPSS number.

We present in Fig.5 to Fig.7 the average waiting time for an EV to be plugged-in. We observe that this average waiting time which id highlighted by the blue curve is sensitive to the number of EVs assigned before to the same EVPSS.

We show in Fig.8 the average waiting time for an EV to be plugged-in considering a set of EVs assigned before to the same EVPSS, versus plug-in sockets number. This waiting time also follows inversely the plug-in socket number. Indeed, when the plug-in socket number increases, the waiting time decreases and remains taking minimum values (green curve). The red curve highlights the maximum waiting time for the EV to be plugged-in which is given by Eq. (4).

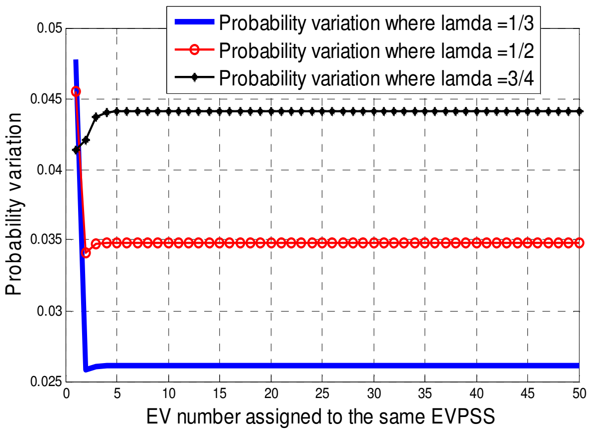

FIG .3: PROBABILITY VARIATION VERSUS λ

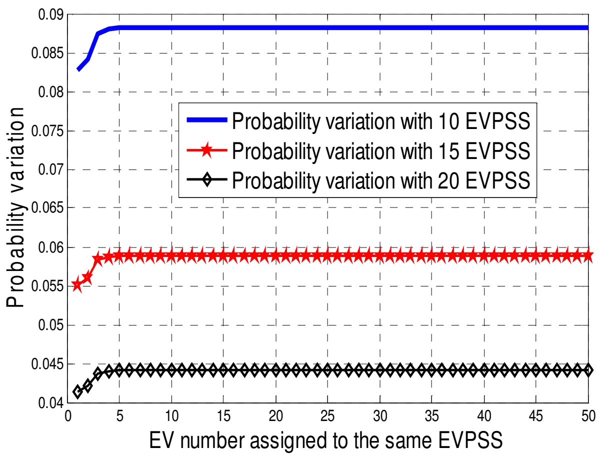

FIG .4: PROBABILITY VARIATION VERSUS EVPSS NUMBER

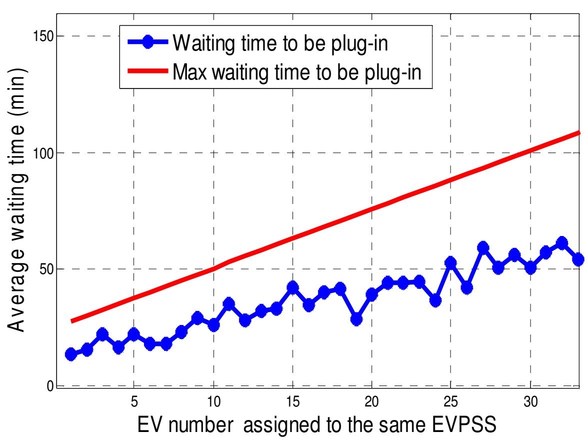

FIG .5: AVERAGE WAITING TIME FOR AN EV ARRIVED AFTER A SET OF EVS (EV NUMBER IS FROM 1 TO 35)

Now, we study the efficiency of our SMART-EV-Guidance algorithm compared with the ORDINARY-EV-Guidance algorithm in terms of searching time for each EV to join an EVPSS. We investigate the impact of the occupancy status of EVPSS on the average EV searching time.

These two algorithms will be running in the RSU which can communicate with EVs and with the smart grid. The searching time is defined as the time interval between the instant when an EV receives the EVPSS address from the RSU and the instant when it arrives at one of the EVPSSs plug-in sockets. Also, we define the occupancy status of each EVPSS as the percentage (%) of its occupied plug-in sockets: occupancy=0 represents unoccupied and 1 represents occupied.

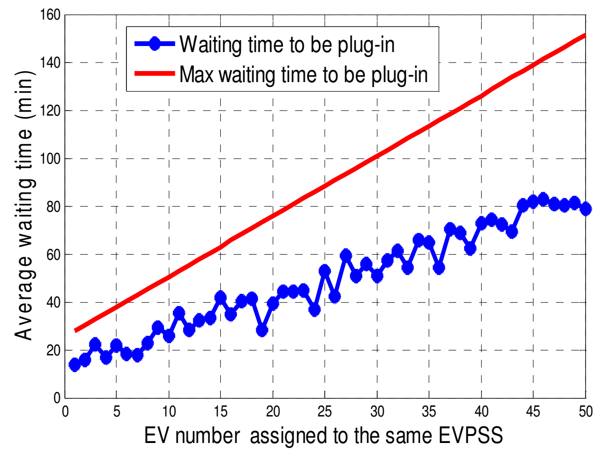

FIG .6: AVERAGE WAITING TIME FOR AN EV ARRIVED AFTER A SET A EVS (EV NUMBER IS FROM 1 TO 50)

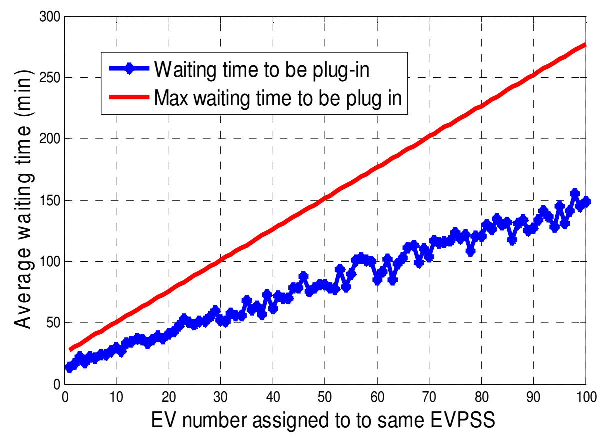

FIG .7: AVERAGE WAITING TIME FOR AN EV ARRIVED AFTER A SET A EVS (EV NUMBER IS FROM 1 TO 100)

In the ORDINARY-EV-Guidance algorithm, an EVPSS is selected by the RSU for an EV according to its distance. In fact, the arriving EV is directed to the nearest EPVSS without taking into account EPVSSs availability such as the number of plug-in sockets unoccupied. For each case, we run simulations 100 times, and the average searching time is considered. As shown in Fig.9, when EVPSS occupancy is less than a certain threshold (46%), it is easy for an EV to join a nearby EVPSS, and therefore there no big difference between SMART and ORDINARY cases. However, for the ORDINARY-EV-Guidance algorithm, with the increase of the occupancy ratio, especially after the occupancy ratio reaches 46% the searching time for an EVPSS plug-in sockets increases significantly. When the occupancy is higher than a certain threshold (46%), the advantage of the SMART-EV-Guidance algorithm over the ORDINARY-EV-Guidance algorithm is evident.

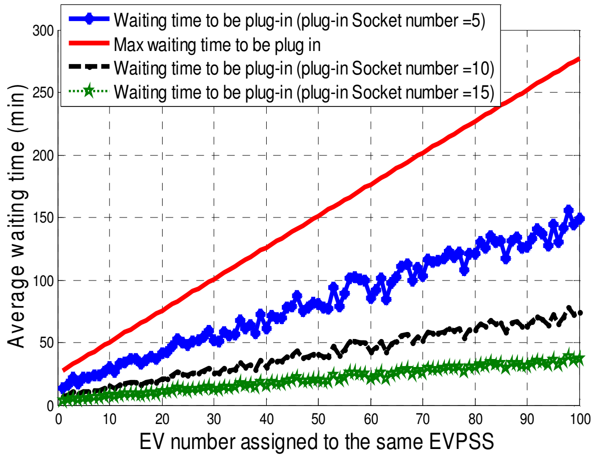

FIG .8: AVERAGE WAITING TIME VERSUS PLUG-IN SOCKETS NUMBER

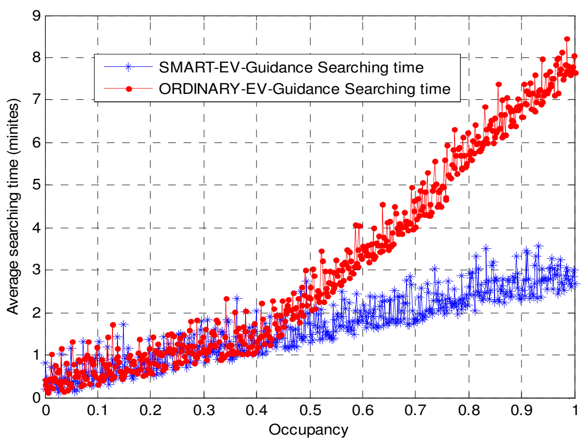

FIG.9: AVERAGE SEARCHING TIME COMPARISON UNDER DIFFERENT EVPSS OCCUPANCY

TAB.3: AVERAGE SEARCHING TIME COMPARISON BETWEEN ORDINARY AND SMART CASES

	ORDINARY case	SMART case	Saving rates (%)
Occupancy in [0 0.46]	2.7	2.4	11.1
Occupancy in [0.47 1]	8.6	3.7	56.9

Table 3 presents the observation results obtained from Fig.9, which illustrate the performance comparison between the SMART case where we use our SMART-EV-Guidance algorithm to manage the charging process and the ORDINARY one, in terms of time to plug-in variation. As shown in Table 3, it is clear that our SMART-EV-Guidance algorithm reduces the searching time with a saving rate of more than 11.1 %, and 56.9%, respectively, for the two ranges of occupancy levels [0 0.46] and [0.47 1]. This result proves the effectiveness of the SMART-EV-Guidance algorithm in reducing the waiting time for EVs.

V. CONCLUSION

In this paper, we propose the SMART-EV-Guidance algorithm which is used to manage EVs charging process planning at EVPSSs by minimizing EVs waiting time before plugin while preserving grid stability. We studied the influence of the cumulative state of charge (SoC) needed by a set of EVs which are in the charging process or are already waiting for service, on the waiting time for the next EV which needs the charging service. We provided a guidance model which was tested through simulations considering realistic EVs and EVPSS constraints. Simulations show that the SMART-EV-Guidance algorithm manages the EV charge scheduling process in an efficient way. In the future, we plan to use the SMART-EV-Guidance algorithm with additional constraints. For example, the constraints could include possible incentives for EV users to allow discharging their EVs at peak time periods, when the price and demand are both high, to promote grid stability.

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