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Impact of demand response management on chargeability of electric vehicles

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ABSTRACT

Large-scale penetration of electric vehicles (EVs) would significantly increase the load requirements of buildings in highly urbanized cities. EVs exhibit higher degree of charging flexibility when compared to other interruptible loads in buildings. Hence, EVs can be assigned lower priority and interrupted before interrupting any other loads. Any temporary interruption will have minimum impact on EV owner's satisfaction/comfort. However, it should be ensured that the EVs could be charged to the owner's required state of charge (SOC) by the time of departure. The scheduling algorithms that are used to manage the EV charging process ensure that the charging requirements are fulfilled even when there are temporary interruptions. The capability of the scheduling algorithms to manage mismatches decreases with the decrease in time available for charging. In this paper, the impact of demand response management (DRM) on the chargeability of the EVs while using different priority criteria is examined. Subsequently, the proportion of interruption for each EV with different priority criteria and the need for determining the chargeability of EVs before shedding them are studied. A scheduling driven algorithm is proposed which can be used for determining the chargeability of EVs and can be used in combination with DRM.

1. Introduction

Deployment of Electric Vehicles (EVs) is considered as one of the solutions for achieving cleaner and greener mobility in highly urbanized cities around the world. In the case of highly urbanized cities, EVs are generally parked in multi-storey car parks and is inevitable in commercial and office buildings. Hence, EV deployment will eventually increase the load demand of buildings from which EVs are electrically charged. The detrimental impact of EV penetration and uncoordinated charging on residential grid is clearly highlighted in Ref. [1]. The analysis presented in Ref. [2] gives an overview on the impact of EV penetration on investment as well as increment in energy losses. Furthermore, there is high risk that the total demand of building exceeding the limit imposed by utilities if the EV load demand added is not managed adequately [3,4]. However, if it can be ensured that the EVs can be charged to the desired SOC at the time of departure, lower priority could be assigned to EV load demand. This is owing to the fact that any temporary interruption in EV charging will have insignificant effect on satisfaction/comfort of the EV owner. Various dynamic charging algorithms such as [5] are available for managing the EV charging in parking lots. The capability of the dynamic charging algorithms decreases correspondingly with the decrease in time available for charging. Hence, ability of the dynamic charging algorithms to manage the mismatches in final desired SOCs is restricted in many cases. In Ref. [6], the authors have classified the customers and demand response (DR) programs into various categories namely large/small commercial and industrial, and residential. It is obvious that the EV owners prefer to charge their EVs using overnight off-peak power at cheaper prices. However, if EVs are used for auxiliary storage functions, discharging and charging of EVs can happen at commercial/office buildings as well [7,8]. Since there is a higher probability of the total load demand exceeding demand limits imposed by utility in commercial/office buildings, DRM functionality is much higher in such buildings. In residential buildings, chances that an EV load is shed using demand response management (DRM) are minimal while using appropriate scheduling algorithms.

2. Related work

EV charging algorithms presented in literature consider the

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Nomentclature

i	EV ID
j	time interval (j = 1,2,3…48)
α_i	priority parameter based on state of charge(SOC)
SOC_i	SOC of i^{th} EV
β_i	priority parameter based on slack time
$N_{dep,i}$	departure interval of i^{th} EV
$N_{req,i}$	actual number of time intervals (30 min) necessary to reach the desired SOC level
$t_{c,i}$	overall number of time intervals (30 min) required for charging i^{th} EV on a given day
δ_i	priority parameter based on allotted time
$N_{com,i}$	actual number of time intervals for which the i^{th} EV was charging before the current interval
$SOC_{initial,\ i}$	initial SOC of i^{th} EV
$SOC_{final\ previous\ day,\ i}$	final SOC required for the i^{th} EV on the previous day
μ_i	mean of the distance travelled by the i^{th} EV
σ_i^2	variance of the distance travelled by the i^{th} EV
P_n	load demand for any given day
P_i	load demand for j^{th} interval
$\overline{p_j}$	mean from load demands
$\overline{\sigma_j^2}$	variance from load demands
N	number of samples generated
p_j^k	k^{th} iid
σ_j^2	variance of generated samples
$p_{\mathrm{n}}^{\mathrm{limit}}$	power limits representing all intervals
$p_{\mathrm{j}}^{\mathrm{limit}}$	power limit of j^{th} interval
$PN(EV_i)$	overall probability that i^{th} EV is not charged to its desired SOC
$N(EV_i)$	number of events during which the i^{th} EV did not reach its desired SOC
N(S)	total number of charging events/days
$I(EV_i)$	number of events during which the charging of i^{th} EV will be stopped charging if DRM is invoked
$I(S)$	total number of interruptions.
$x_{i,j}$	charging command parameter
$p_j^{b,i}$	maximum power at which the i^{th} EV can be charged
Cd_n	chargeability matrix for ‘n’ EVs
cd_i	chargeability value for i^{th} EV

individual EVs parked in a residential building either as interruptible load (time coordinated charging) or as flexible load (power coordinated charging). The authors in Ref. [9] classify the residential loads as manageable and non-manageable, and EVs can be considered as manageable loads as their charging process is adjustable. Furthermore, the priority value assigned to the EV is pooled along with the priority of other residential loads [10–12]. However, in case of highly urbanized cities such as Singapore, most of the EVs will be charged together (in groups) in parking lots. Such a charging pattern is highly suitable for using EVs in DRM as flexible loads and offers a wide range for load demand control.

In Ref. [13], investigation for DRM using various charging methods in a car park environment was carried out. Statistical data was used to obtain arrival times and durations for which the EVs are parked. The charging of individual EVs is assumed to be controlled by the car park operator. With the above conditions, the effect of DRM on the total charging cost of the system was analyzed. In Ref. [14], a methodology for managing quasi-time EV charging was presented. The authors considered the participation of EV aggregators in electricity markets as well as the technical restrictions of the electricity grid components. In Ref. [10], a DR strategy was proposed to minimize the impact of EV charging on a distribution circuit of a smart distribution network. Severity indices were used for executing the demand response of EVs. In Ref. [15], a new model of DRM for the future integration of EVs and renewable distributed generators into a smart grid network was proposed. In Ref. [16], a DR strategy to increase the potential for adding new load with minimal infrastructure investments was proposed. It also served as a load-shaping tool for improving the usage of the distribution transformer. The consumers' preferences, load priorities, and privacy were also taken into account.

In Ref. [17], two DR programs were presented, namely the trip reduce DR and trip shifting DR. The DR models were activated whenever the energy price reaches the cutoff value set by users. In Ref. [18], the authors investigated dynamic DR for intelligent EV charging. A detailed hybrid model was proposed to handle problems that cannot be properly handled by traditional tools. In Ref. [11], a distributed framework for DR and user adaptation in smart grid networks was proposed. The authors applied the concept of congestion pricing developed for internet traffic control to regulate the user demand and balance the load of a network. The authors of [19] demonstrated the applicability of a novel ‘pool market mechanism’ for re-schedulable demands such as EVs having flexible charging capability. In Ref. [3], a novel scheduling driven DRM utilizing time coordinated scheduling was proposed. Group of EVs were combined to form a load demand which is both flexible and interruptible. The degree of fairness obtained using the above method is better owing to the fact that the EV with highest probability to charge before departure is shed first while invoking the DRM for EV load demand. The DRM was implemented as a part of the Building Energy Management System.

In Ref. [20], the authors carried out an analysis on the influence of various priority parameters on the chargeability of EVs and fairness accorded to all EV users. In this paper, the impact of interruption due to DRM on the chargeability of the EVs is examined for various priority criteria. Subsequently, the proportion of interruption for each EV (when various priority criteria are employed for DRM) and the need for determining the chargeability of EVs before shedding them are studied. A novel scheduling driven algorithm is also proposed for determining the chargeability of EVs before shedding them using DRM. The major contributions of the paper are the analyses on the impact of DRM on chargeability and the proposed novel scheduling driven chargeability algorithm for determining the suitability of the EVs for DRM in any given interval.

3. Impact of DRM on EV chargeability

In commercial/office buildings when the DRM is invoked, various priority criteria as proposed in Refs. [3,7,20–25] can be used to determine which EV's charging has to be interrupted for managing the load demand. All the above priority criteria can be consolidated into state of charge (SOC) of the EV battery [22–24], slack time available [22,24,25] and time allotted [3,7] for charging, and can be represented by Equations (1)–(3) given below,

$$\alpha_i = 1 - \left(\frac{SOC_i}{100}\right) \tag{1}$$