Optimal scheduling of EV charging system

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Abstract: -

In this paper optimal scheduling of EV charging system by using various methods are studied. Uncoordinated charging of large-scale electric vehicles (EVs) will have a negative impact on the secure and economic operation of the power system, especially at the distribution level. Given that the charging load of EVs can be controlled to some extent, research on the optimal charging control of EVs has been extensively carried out. In this paper, two possible smart charging scenarios are studied: centralized optimal charging operated by an aggregator and decentralized optimal charging managed by individual users. Under the assumption that the aggregators and individual users only concern the economic benefits, new load peaks will arise under time of use (TOU) pricing which is extensively employed To solve this problem, a simple incentive mechanism is proposed for centralized optimal charging while a rolling-update pricing scheme is devised for decentralized optimal charging. The original optimal charging models are modified to account for the developed schemes. Simulated tests corroborate the efficacy of optimal scheduling for charging EVs in various scenarios. [1]

Aggregators, optimal, overloading, electric vehicles

Introduction:

An electric vehicle charging station, also called EV charging station, electric recharging point, charging point, charge point, ECS (electronic charging station), and EVSE (electric vehicle supply equipment), is an element in an infrastructure that supplies electric energy for the recharging of electric vehicles, such as plug-in electric vehicles, including electric cars, neighborhood electric vehicles and plug-in hybrids. At home or work, some electric vehicles have onboard converters that can plug into a standard electrical outlet or a high-capacity appliance outlet. Others either require or can use a charging station that provides electrical conversion, monitoring, or safety functionality. These stations are also needed when traveling, and many support faster charging at higher voltages and currents than are available from residential EVSEs. Public charging stations are typically on-street facilities provided by electric utility companies or located at retail shopping centers, restaurants and parkings, and operated by many private companies.

Fig.1 EV charging station

Electric vehicles can provide several distinct benefits compared to their conventional counterparts such as reduced emissions of air pollutants and reduced cost of energy consumption. Apart from the energy cost reduction, electric vehicles can provide additional cost benefits by offering ancillary services to the grid, e.g. regulation services [3]. In order to enable this possibility, an aggregator which represents smart interface between electric vehicle fleet and the grid should be introduced [4, 5].

The risk of overloading local transformers is particularly high during peak hours. Imagine what will happen when all-electric vehicles owners in the neighborhood decide to recharge them at the same time, in the early evening, after returning from work, which is more or less the same time households turn their cooking, cooling and other appliances on.

And this is not just a theoretical problem. The study conducted on electric cars users in Austin, Texas has confirmed this exact pattern. The most severe impacts of charging when arriving home occur in June, July, August, and September. Local transformers may not be able to withstand such extra pressure.

With large numbers of EVs plugged-in, the overall load profile will be greatly affected. Uncoordinated charging of large-scale EVs will ineluctably have a negative influence on the secure and economic operation of power system, especially at the distribution level. Supposing that the charging load of EVs can be controlled to some extent, different optimal charging methods have been proposed.

Centralized control strategies are developed in [6-10]. Random numbers are generated to characterize the EV plug-in time [6].Yet the specific charging requests of individual EV users are neglected. The charging rate is optimized to maximize the total charging capacity within network limits [7]. An improved two-stage optimization model is proposed to increase the economic benefit of charging station and reduce the peak-valley difference [8].An optimal charging scheduling scheme is reported to minimize the total charging cost under TOU price[9].Nonetheless, new load peaks will arise in the valley price period. Global and local optimal scheduling schemes for charging of EVs are studied in [10]. In aforementioned optimal charging approaches, the number of control variables increase drastically with the number of EVs. To address the dimensional problem, decentralized control strategies receive more and more attention.

In [11-17], different decentralized control strategies are discussed. The scheduling of EV charging is optimized to maximize benefits of consumers[11-15]. Iterative decentralized optimization schemes based on Lagrange relaxation method are proposed in [11-13]. Decentralized mechanisms are devised based on congestion pricing that is used in IP networks, but the optimality cannot be guaranteed [14]. Distribution locational prices are leveraged to guide the charging of EVs [15]. This method does not require an iterative communication and computation process, but the dc optimal power flow model used in attaining locational price may cause trouble given that line resistances in distribution networks are relatively large. A decentralized algorithm is developed to iteratively solve the valley-filling problem with provable convergence to the optimality. But to ensure the optimality, an additional term is essential in the end user's response function, i.e., the end user's objective is no longer purely maximum economic benefits oriented. The additive increase and multiplicative decrease charging algorithm are enhanced to take local voltage constraints into account [16]. Yet in this scheme, the charging requests of end users (such as charging me requests) are overlooked and the charging process is still under the grid cooperation control.

Centralized and decentralized optimal charging of EVs are both considered in this paper. In centralized optimal charging, charging of EVs is managed by aggregators (EV charging station can also be viewed as a special aggregator), while in decentralized charging it is managed by individual users. Without loss of generality, we assume that the aggregators and individual EV users only care about charging revenues. Therefore, under the current TOU pricing framework, a new load peak will occur at the very beginning of the valley price period 0. With high penetration of EVs, this new load peak can be even higher than the original one.

The present work targets the aforementioned new load peak problem, which can happen in the TOU pricing based optimal charging. The contributions of this paper are-

Two fold:

1) A simple peak-valley difference related incentive mechanism is proposed for centralized charging management. This mechanism is free of bi-directional communication and complex computation.

2) A rolling-update pricing mechanism is devised for decentralized charging management. The proposed method only requires solving the optimization once while the existing decentralized valley-filling one requires iterative computation for both gird coordinator and individual users [17]. The remaining sections are organized as follows. Section 3presents the centralized and decentralized charging architectures. Centralized optimal charging is detailed in Section 4while decentralized optimal charging is specified in

Section 5. Section 6shows simulation results in different charging scenarios. Finally, Section 7draws the conclusion.

Optimal Charging Control Architectures

In general, two optimal charging control architectures can be deployed, i.e., centralized and decentralized control0.Thedifferencebetween the two architectures mainly lies in locations where optimization decisions are made. In centralized control, there is a control center at the aggregator level, and in decentralized control, the optimal scheduling is performed by individual EV users.

The two architectures also differ with respect to computational complexity, implementation flexibility and information exchange requirements. In this paper, the two charging control architectures are detailed in section 4and section 5, respectively. The charging scenario

considered in this paper is set in the low-voltage distribution network. The following customary assumptions are made: 1) for centralized optimal scheduling, charging spots of EVs under one distribution transformer are owned by one aggregator. The aggregator can get the profile of the base load day-ahead. 2) The spatial variation of the electricity price is neglected, which means the electricity price is the same at all locations at a given time instant. 3) The charging control method is the on-off method while the lithium-ion battery charging characteristic is applied to simulate the charging behavior

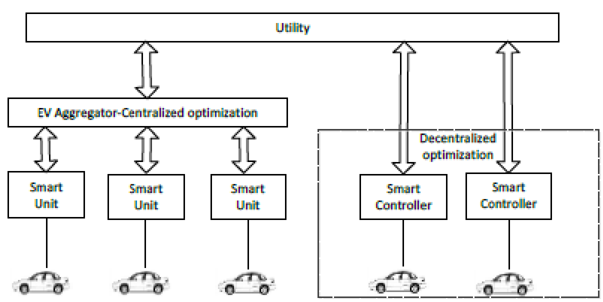

Fig. 2 EV Chrging architecture

Centralized Optimal Charging

Centralized optimal scheduling: The EV aggregator collects the charging requests of EV users to make the optimal charging schedules. When an EV is connected to the charger and requests charging, the smart unit uploads the current state of charge (SOC), battery type and total capacity of the battery to the aggregator. Meanwhile, the EV user should set the plug-off time and the expected SOC. Under the premise of satisfying the charging request of EVs, the aggregator determines the optimal charging schedule to maximize its total benefits.

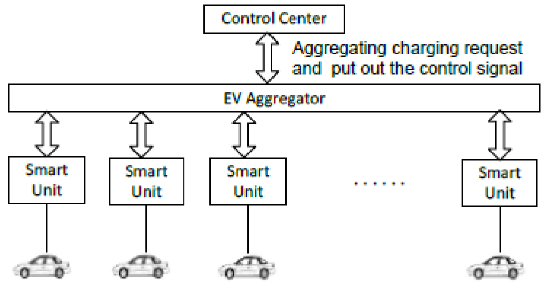

Fig.3 Centralized Optimal Charging

The ideal solution requires perfect knowledge of EV plug-in, plug-out, SOC information and also base load over the scheduling period, which is infeasible in practice. A kin to the local optimal scheduling in 0, our method dividesone day into 96 optimization time intervals, and calculates the optimal charging schedule at the end of each interval for EVs arriving in that interval.

Decentralized Optimal Charging

In decentralized optimal scheduling, each EV owner is postulated to have a smart controller which can receive the price signal issued by the aggregator or the utility. The smart controller performs local optimal scheduling.

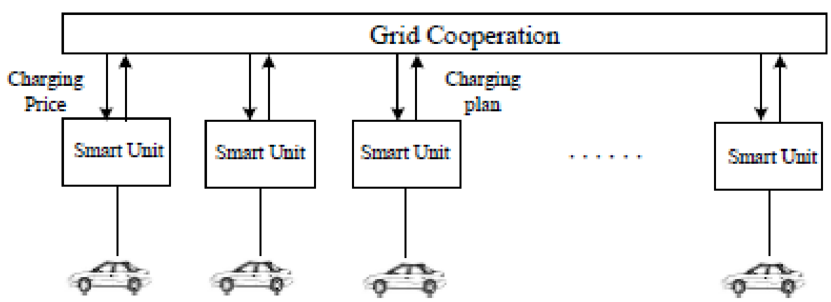

Fig.4 decentralized optimal scheduling

Figure 4depicts the decentralized optimal charging scenario. When an EV is connected to the charger, the smart controller collects battery information. At the same time, the EV user is required to set its plug-out time and minimum expected SOC. With the received charging price, each individual smart controller schedules the EV charging to minimize the charging cost.

Conclusion

The uncoordinated charging of EVs will increase the load peak tremendously since the using habits of EV owners. To mitigate the negative influence; this paper proposes two charging scenarios of optimal scheduling in China, which are centralized optimal charging deployed by the aggregator and decentralized optimal charging managed by individual users. However, with TOU price, maximizing the benefits of the aggregator and minimizing the cost of individual users will cause new peak loads in the valley price. Hence, this paper devises two scheduling methods which can be correspondingly applied to the centralized optimal charging by an aggregator and decentralized optimal charging managed by individual users. Ones is giving the aggregator the economic incentive with respect to the peak-valley difference and the other one is the rolling-update pricing method for individual users. The simulation results corroborate that for centralized management scenario, the proposed incentive mechanism is effective in further reducing the peak-valley difference and smoothing load curve; for decentralized management, the developed rolling-update pricing can achieve desirable efficiency in valley-filling. Further study will be focused on the incentive mechanism or pricing method taking V2G into consideration.

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