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Innovative appraisement of smart grid operation considering large-scale integration of electric vehicles enabling V2G and G2V systems

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ABSTRACT

Upgrading the internal combustion engine (ICE) driven cars to the electric vehicles (EVs) offers the opportunity to reduce the fossil fuel consumption, emission rates and total driving costs. However, the large scale utilization of the EVs introduces a stochastic load demand to the power grid. The effect of EVs charging demand on the distribution network operation should be investigated properly. This paper proposed a novel model to study the effects of power exchange between the grid and EVs on the power system demand profile, the operation stability index, and the reliability indices. To this end, the operation instability indices are introduced by the range and standard deviation of the load factor of the network components to evaluate the system stability. Further, the CAIFI,[1] SAIDI,[2] SAIFI,[3] and ASAI[4] reliability indices are calculated for various vehicle-to-grid (V2G) and grid-to-vehicle (G2V) power level to estimate the impact of different level of power exchange on system reliability. We introduced an EV charging scheduling approach which considers the specification of Li-Ion battery and the limitations for increasing battery life. The power exchange profile for V2G is also calculated using the constant power method to discharge the energy at different levels for times which cars are parked at the workplace. Due to the stochastic nature of EVs, the minimal path method is used to compute the stability and reliability parameters and the backward–forward algorithm is used to load flow analysis. The proposed model is evaluated via modified IEEE 33-bus test system.

1. Introduction

In the conventional transportation network, a large number of cars have created a tremendous amount of demand for fossil fuels to meet their required energy. Internal combustion vehicles with the low energy efficiency of 20% constitute a major share of the transport sector [1]. According to [2], demand in the transport sector will experience growth of 54% till 2035. This increased demand will lead to further contamination of the environment and rising costs, so the planners sought to use energy efficient cars with a lower gas emission rate. Electric vehicles with clean energy consumption can be counted as a major alternative for conventional vehicles to electrification of the transport sector. High energy efficiency of EVs in converting electrical energy into kinetic energy approximately 80–90% causes a diminution in fuel consumption and thereby reducing costs and pollutions. Furthermore,the performance of the EVs depend heavily on the energy utilization efficiency of it's battery pack [33,34]. In recent years, Battery-only electric vehicles (BEVs) and plug-in hybrid EVs (PHEV) that are powered by a combination of battery and ICE are two main types of EVs on the market [3,4]. These types of vehicles can be classified based on their energy consumption and electric range (ER).

High penetration of EVs into the network can bring challenges such as increasing losses and damage to the power system equipment and network performance degradation, especially at the time of peak demand. In order to control the overload caused by the

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[1] Homepage: www.hadiamini.com.

[1] Customer Average Interruption Frequency Index.

[2] System Average Interruption Duration Index.

[3] System Average Interruption Frequency Index.

[4] Average Service Availability Index.

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Nomenclature

Symbol	Description
$\text{Demand}_{\text{ch}}^{t}$	energy required for EVs charging at time t
$\text{Demand}_{\text{avg}}^{R,M,F,T}$	average amount of energy consumed by EVs in different driving condition
n_i^t	number of EVs in ith mileage group at time interval t
N	total number of EVs in the system
$\text{dist}_i^{R,M,F,T}$	traveled distance of ith mileage group which occurred in different driving condition
dist_{tot}	total EVs daily travel distance
$\text{ER}_{\text{avg}}^{R,M,F,T}$	average amount of ER related to the different driving condition
LF_i	load factor of ith component
$\overline{\text{LF}}$	mean value of load factor
$\text{load}_{\max}$	maximum amount of network demand
$\overline{\text{load}}$	average amount of network demand
OS'	operation instability based on the difference between the amount of two equip
OS''	operation instability based on standard deviation
α_{c_i}	average rate of ith component failure
τ_{c_i}	average time required for ith component repairing
τ_s	time of switching operation when there is backup power
τ_{iso}	time required for network isolation
$\alpha_{c_j}^{c_i}$, $\tau_{c_j}^{c_i}$, $\beta_{c_j}^{c_i}$	impact of short route leading to ith component reliability on jth part reliability parameters
$\widehat{\alpha}_{c_j}^{c_i}$, $\widehat{\tau}_{c_j}^{c_i}$, $\widehat{\beta}_{c_j}^{c_i}$	impact of non-short rout leading to ith component on jth part reliability parameters
mp	short path
α_{lp_i}, τ_{lp_i}, β_{lp_i}	reliability parameters related to ith load point

charging demand and protect the network from potential risks, the EVs charging and discharging should be scheduled with an appropriate optimal planning and management strategy. To this end, in [5] a dynamic method for vehicle charging management is provided. In this method, vehicles are prioritized based on the amount of energy stored in the battery, battery capacity, maximum charge rate and departure time of charging station for their charging process. In this paper, the stochastic behavior of EVs is ignored. In [6] an optimization problem based on the limitations of the vehicle and the power grid is defined to control the charging and discharging of vehicles and maximizing consumer and operator benefit. In this work, EVs and driver habits specifications have not been investigated in details and charging/discharging power rate are not intended in calculations. National household travel survey data in [7] and the impact of V2G and G2V process on the network using different strategies are provided in [8]. This report has shown that the use of different methods of charging at different times by different incentives can be effective in preventing the occurrence of operational and economic challenges. In [9] the new pricing method to control the vehicle charging process is introduced and the behavioral effects of the vehicle on the parking operator's profit are studied. This paper shows that if the driver's behavior pattern is more similar then profits will be greater. Authors in [10] defined a function based on electricity price, fuel price, charging rate, and charging control to model the EVs behavior. In this study, the impact of changing in energy tariffs and demand response programs on EVs behavior has been studied and the result shows that the electricity pricing method would affect the EVs charging schedule.

In [11] the simultaneous allocation of EV charging stations and distributed renewable resources and its effect on system losses is investigated. In this work, the demand for vehicle charging has been modeled considering their mileage and the duration to fully charged. EV parking also used as vehicle aggregator and renewable resources were considered as stochastic generation resources. In [12] a framework is developed to specify the EVs charging load in the distribution network. In this work, a fuzzy logic decision model is proposed in order to study the affected system demand due to additional load. The authors in [13] have examined the impact of vehicle charging load on transformers and feeders at different levels of vehicle penetration that led to the construction of new infrastructure in the low voltage distribution network. In this study, the control method according to thermal and voltage limitations of the network has been introduced for vehicle charging. In [14] an optimal simultaneous siting and sizing of renewable energy sources and EVs charging stations are done. The authors have proposed an improved hybrid Genetic Algorithm-Particle Swarm Optimization (GA-PSO) optimization algorithm to solve the objective function with the goal of minimizing losses, voltage fluctuations, and costs. The results confirm the robustness of the proposed method to deal with this issue. In [15] a bi-level method is proposed to allocate the EVs parking lots based on probabilistic modeling of EVs behavior and reliability constraint. In this paper, the genetic algorithm is used to solve the objective problem and obtained results show the effectiveness of EVs to enhance the system operation reliability. In [16] an optimal determination of location and capacity of EVs public charging stations considering power system reliability and traffic constraints of the city is accomplished. Also, an objective function is developed to minimize the energy not supplied and charging related costs. In [17] a real data based model is given to predict EVs demand profile. Authors have compared the estimation process in two cases using personal information and stations data. In [18] vehicles are used through V2G and V2H[5] to supply power for network subscriber in the event of a power failure and island mode operation. The results confirm the effectiveness of this method to improve the network reliability. In [19] a new method for frequency regulation, using V2G energy is given. Results show the effectiveness of this approach to satisfy the both EV owners and V2G aggregator simultaneously. A recent study [20] is addressed the different ways to recharge the vehicle from the point of view of impact on reliability, economic and environmental parameters. In this study, the vehicle's specifications and impact of external factors on the EV consumption are not considered. Random behavior of statistical data related to transport sector on the basis of driving pattern and mileage to estimate the power required to recharge the vehicle which is discussed in [21]. In this way, by minimizing the prediction error, profit increased due to the accurate prediction. In [22] a method for instantaneous power pricing considering the accidental grid information is provided that can be used to optimize vehicle charge and discharge planning. Ref. [23] introduced a SOC and temperature based experimental model for system simulation to assess the battery's life time and cost efficiency in the different operating situation.

By reviewing the previous studies, many of them have assumed specified amount or continuous uniform random numbers as battery capacity of EVs. Since there are different types of EVs with different battery capacity this kind of assumption cannot be practical. Furthermore, it seems very unlikely that people of a region own the same model of EVs. So, it is essential to consider of different types of EVs in the simulations. Also, some authors have defined DOD = 1 for EVs which arrived at the end of a day. However, SOC at that time should be calculated based on daily mileage, EV model, and different driving condition. So different types of EVs and driving

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[5] Vehicle-to-Home.