Research on the Optimization Plan Method based on Electric Vehicles' Scheduling Strategy in Active Distribution Network with Wind/Photovoltaic/Energy Storage Hybrid Distribution System

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Abstract: The rapid development of electric vehicles (EVs) and distributed generations (DGs) has brought new challenges to the safe and economical operation of power system. This paper mainly works on how to optimize the management of plug-in EVs in the distribution system with fixed DGs, in order to achieve the economic and stability in power grid. Firstly, the management characteristic of EV is discussed and classified to obtain the access probability model. Secondly, being in distribution network investors' shoes and considering the constraints of distribution network, DG, ESS and EV, the economic management of EV optimization bi-level model is established with the objective function of maximum annual income and minimum fluctuation of output power of equivalent load. Then the genetic algorithm(GA) is used to solve this model. Finally, the experimental results of 33-bus system with DGs and EVs verifies the effectiveness of the proposed method, and the influence of different penetration of EV on the annual income of distribution network is also analysed to provide a new idea for the future development of distribution network.

1. Introduction

Recent years, with the environmental pollution and energy shortage problems become increasingly serious, clean energy including wind and solar and the zero carbon emissions of EVs get more attention in the distribution network. However, with the higher penetration of DGs and the large popularity of EVs, their uncertainty will have a serious impact on the safe and economical operation of the distribution network [1-3].

Energy storage system (ESS) can quickly adjust power flow. It can store energy or release the excess power, which is the key to adjust network's operation state[4-5]. But it is difficult to configuration on a large scale because of the expensive price[6]. Because of the characteristics of EVs' battery, EV is not only the load in power system, but also can be as a mobile energy storage device. Under the control strategy, EV can use V2G technology undertake the task of smooth power fluctuation of load in network with traditional ESS[7-8]. Therefore, the reasonable guidance and configuration of the plug-in EV will directly affect the operation and management level and economy of the distribution network, which is the key in future development.

In [9], a stochastic economic scheduling model was constructed, which took the uncertainly of EV and wind power output into account. And the expectation expression of wind turbine and EV in V2G state were derived. [10] established the EVs and wind power co-scheduling model in multi-time scale with the aim of smoothing the system load fluctuation. However, only the charging mode is considered in this model, and V2G technology is not involved. [11-12] proposed a multi-objective optimization model to decrease the fluctuation caused by DG by using different algorithms respectively. Through dynamically adjusting the charging and discharging power of EV to match the demand of system. But both of them changed EV into ESS directly, which didn't consider the uncertainty and randomness of plug-in EV in actual situation.

This paper is in distribution network investors' shoes and considers the constraints of distribution network, DG, ESS and EV, proposes the economic management of EV optimization bi-level model. Objective of the model is maximum annual income and minimum power fluctuation of equivalent load. The GA is used to solve the algorithm.

2. Dispatchable model of electric vehicle

2.1. The status classification of electric vehicle
According to the purpose, EV can be divided into two types including public and private. According to the mode connection to grid, EV can be divided into three types including slow charge, fast charge and replacing battery. This paper mainly focuses on the private EV with mode of slow charge. Statistics show that about 90% time of private cars are in a state of suspension during one day [13]. Excluding some of the EVs may be in the state of unconnected to grid, the remaining EVs will connect into grid to charge power according to their need without guide incentives. From the grid point of view, these charging vehicles constitute a disordered load.

However, the more attractive research is the large size of storage resource provided by EVs. Through incentive strategies, EVs users can management their charge action to meet the need of grid[14]. As long as the user is willing to access the EV to the grid and follow the grid's dispatch, EV can fully realize the energy storage function.

Here the following assumptions are made for the control of dispatchable EVs:

(1)The dispatchable EVs connected into the same node will be management by the aggregator[15];

(2)The EVs that have registered into dispatchable will automatically been identified, and obey the management of grid;

(3)The charge and discharge function is achieved by DC/AC converter of aggregator and EV battery.

2.2. Access probability analysis of dispatchable EVs
To analyze the dispatchable EVs, it is necessary to master the access probability at any time in typical day. In this paper, the Monte-Carlo simulation method is used to study the probability model. By simulating it, the access probability result is shown in Figure.1.
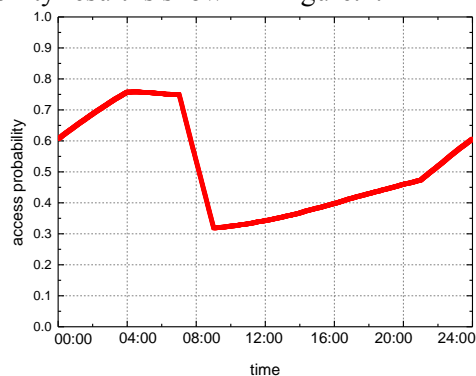

Figure 1. access probability of EV

2.3. Analysis of influencing factors of dispatchable EVs

At present stage, managers mainly use the way of price compensation to guide EVs to participate in the scheduling. Considering the big difference of EVs' usage during the day and night, and in different times their reaction are also vary greatly. Reasonable subsidy price at different times can guide the users to make more favorable choice for the operation of the grid. However, [16] pointed that the frequent changes in the price will lose the guiding role. So this paper set the subsidy price into two time periods to consider:6:00—20:00 and 20:00—6:00 of the next day. Using different mathematical formulas to fit the relationship between subsidy price and EV number[17-18], the expression is as follows:

$$n = \begin{cases} 0.013\ln(x)N & 6:00-20:00 \\ \dfrac{1}{10+57e^{-0.01x}}N & 0:00-6:00, 20:00-24:00 \end{cases} \quad (1)$$

Where, x is subsidy price. N is the total number of plug-in EVs. n is the total number of dispatchable EVs in the corresponding periods.

3. Optimization model of EV scheduling strategy

3.1. Objective function

The outer optimization is mainly from the perspective of the distribution network investment manager, taking into account the part of the profit part and the cost part, analyze the economic benefits brought about by the dispatchable EVs. The objective function for outer optimization is as follows, and all costs are converted into one-year calculations:

$$\max F_{total} = f_{pur} + f_{save} + f_{loss} + f_{sale} - f_{cons} - f_{main} - f_{V2G} \quad (2)$$

Where, f_{pur} is the saved purchasing cost after the DG connected to network; f_{save} is the saved expansion investment; f_{loss} is saved network loss; f_{sale} is the profit from sale power to the EVs which don't participate in dispatch; f_{cons} is the total investment; f_{main} is the total operation and maintenance cost; f_{V2G} is the total subsidy cost for dispatchable EVs.

The target of inner optimization is mainly smoothing the fluctuation of equivalent load. The function is as follows:

$$\min F_{flu} = \sum_{i=1}^{T-M+1} \sum_{t=i}^{i+M-1} (P_l(t) - P_{DG}(t) - P_{ESS}(t) + P_{EVl}(t) - P_{av}(i))^2 \quad (3)$$

Where, T is the number of sampling data in the period; M is the number of sampling data in one time window; $P_l(t)$ is the load power at time t; $P_{DG}(t)$ is output power of DG at time t; $P_{ESS}(t)$ is the total power of dispatchable EVs and ESS at time t; $P_{EVl}(t)$ is the EVs load at time t; $P_{av}(i)$ is the mean value of the equivalent load during this time window.

3.2. Constraints

- Power flow constrains: The state of distributed network should always satisfy the power flow formulas.
- The constrain of voltages: The newly-allocated DGs will change the voltages. While the voltages should always follow the constrains as

$$U_N(1-\varepsilon_1) \le U_i \le U_N(1+\varepsilon_2) \quad (4)$$

Where, U_i is the voltages of the nodes; ε_1 and ε_2 is the allowed deviation of voltages.

- The constrain of DGs: The output of DGs has its own maximum limits and is limited by the real-time weather condition.

$$\begin{cases} 0 \le P_{DG} \le P_{DG\max} \\ Q_{DG} \to 0 \end{cases} \quad (5)$$

Where, P_{DGmax} is the maximum output of DGs. Assume that DGs generate no inactive power.

- The constrain of DESS: All the DESS should meet the constrains about SOC, charging and discharging power[19].

$$\begin{cases} SOC_{min} \le SOC_t \le SOC_{max} \\ 0 \le \left| P_{DESS,t} \right| \le P_{DESS,max} \end{cases} \tag{6}$$

Where, SOC_{max} and SOC_{min} is the upper and lower limits of the SOC of each distributed energy storage; $P_{DESS,max}$ is the maximum power of each DESS; SOC_t and $P_{DESS,t}$ is SOC and power of each distributed energy storage at time t.

- The constrain of EV: All the EVs should meet the constrains about charging and discharging power.

$$0 \le \left| P_{EV,t} \right| \le P_{EV,max} \tag{7}$$

Where, $P_{EV,max}$ is the maximum power of each EV; $P_{EV,t}$ is power of each electric vehicle at time t.

3.3. Solution and algorithm
GA is a randomized search method based on the evolution of biological evolution, which is suitable for solving the mathematic problem of incentive strategy in this paper.

3.4. Model and parameter settings
In this paper, IEEE 33 nodes distribution network is selected as the test system. The topology of its structure is shown in Figure.2. Set node 19 and 31 connect to wind generation(WG), node 20 and 32 connect to photovoltaic(PV). The rated power of them are all 100kW.And the output data of WG and PV is selected from the typical day in a certain area, the sampling period is 15min. Their output power curves are shown in Figure.3. The load data of the typical day refers to [20]. Capacity lithium-ion battery is used in ESS which has 92.74 percent efficiency.

It is assumed that the total number of EVs in this network is 400, and the corresponding node of DG is connected to 100 electric vehicles, the maximum charging and discharging power of EVs is 3kW, and the discharge efficiency is 95%.At the same time, the scheduling priority of the EV is higher than the ESS.
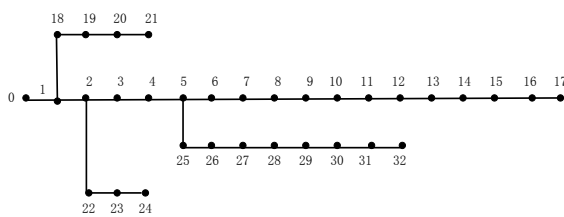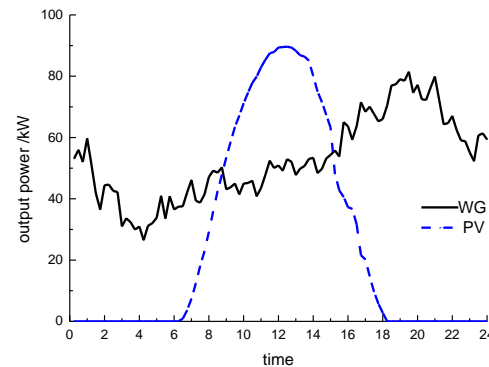

Figure 2. IEEE 33-bus system

Figure 3. Curves of WG and PV output power in typical day

3.5. Results and analysis
The optimization of the EV management strategy is carried out in the network with wind/photovoltaic/energy storage hybrid system. And the GA has evolved to the 14th generation convergence through the method mentioned in this paper. The optimal configuration scheme of dispatchable EVs subsidy price is shown in Table 1. The subsidy price means that each dispatchable EV can get the corresponding subsidy when they plug-in grid one hour.

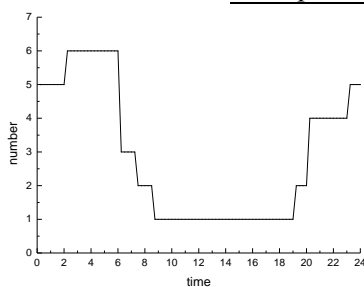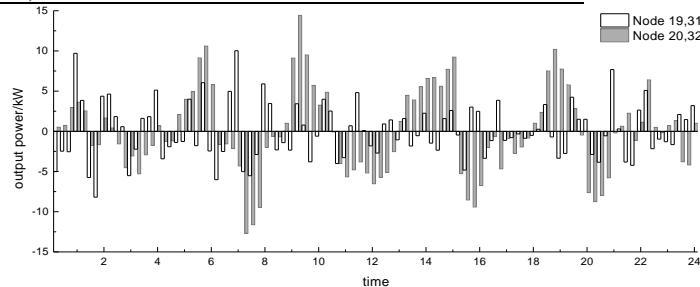**Table 1.** The optimal configuration scheme of subsidy price

Time interval	6:00—20:00	20:00—6:00
subsidy price(yuan/h)	2.51	1.32
Upper limit of EV	3	6

In this scheme, the optimized strategy of the time-sharing subsidy price is adopted to control the EVs subject to power grid dispatch to make the maximum annual profit, about 353,828 yuan. And the access situation of dispatchable EVs in one node can be seen in Figure.4.
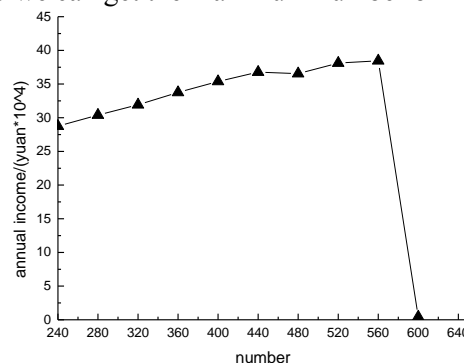
In the process of smooth the fluctuation of equivalent load, due to the dispatchable EVs can't guarantee meeting the demand of grid all the time in one day. So it's necessary to use traditional ESS to auxiliary dispatchable EVs in the shortage period. The rated power of ESS scheme is shown in Table.2. And the output power change of the joint system is shown in Figure.5. We can see it clearly that the effective reduction of ESS configuration with the EVs' participation.

Table 2. The optimal configuration scheme of ESS capacity

Node	19/31	20/32
Rated power/(kW)	7.03	14.42

Figure 4. The change state of dispatchable EVs

Figure 5. The change state of joint system output power

To study the variation of annual income of distribution network with the number of EVs. It can be found that with the increase of EVs, the overall income is on the rise. But to one certain point, the income stop increasing and even falling fast as shown in Figure.6. Analysis of this phenomenon, when the rated power connected into grid of DGs is fixed, it will bring much disorder load with the huge number of EVs to the grid which can't be balanced by the dispatchable EVs. So the income is published by the algorithm. Also we can get the maximum number of EVs is 480 in this system.

Figure 6. The curve of annual income varies with the number of EVs

4. Conclusions

In this paper, the study of the optimization of EVs scheduling strategy in the background of distribution network with wind/photovoltaic/energy storage hybrid system is studied.

The article from the perspective of power distribution network investment managers, in order to improve the annual income and decrease the fluctuation of equivalent load as the objective function, establishing the bi-level optimization model to seek the optimal scheduling strategy of dispatchable EVs subsidy price. The proposed model of is solved by the GA with good searching ability and convergence. The results of the example analysis show that the proposed model method can be considered as a more reasonable configuration scheme considering economy and power grid security.

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