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Research on Planning Method of Microgrid Energy Unit in Intelligent Districts Containing Electric Vehicles Considering CO_2 Emission

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The coordinated planning operation of electric vehicles and microgrid considering CO_2 emission is a key issue to promote the development of electric vehicle and microgrid. The flexible charging and discharging characteristics of electric vehicles will affect the planning and operation of microgrid when it is integrated to the microgrid. In order to study the influence of electric vehicles on microgrid energy unit planning, the coordinated planning model of electric vehicles and intelligent districts onsidering CO_2 emission is established, and the PSO-SA mixed algorithm is used to solve the model. And then, the energy unit planning result of intelligent districts based on the optimal total economic and environmental cost is obtained. Example analysis shows that the electric vehicle is regarded as a mobile storage device with high economic efficiency in microgrid energy unit planning. With the increase of the environmental cost's weight, the stationary energy storage device will have a greater advantage when compared to the electric vehicle.

1. Introduction

At present, in China and abroad, there are two aspects of researches on the coordination of electric vehicles and microgrid, namely, theoretical study and simulation optimization. In the aspect of theoretical research, literature (Hu et al., 2012) reviewed the influence of electric vehicle's integration on the planning of power supply, power grid and distribution network; literature (Ma et al., 2013) and literature (Han et al., 2011) analyzed the effects of charging and discharging behaviors of electric vehicles on the power flow of distribution network; based on literature (Hu et al., 2012; Ma et al., 2013; Han et al., 2011) the impact assessment method and relevant solutions are put forward; Few studies have considered the effects of the electric vehicle's charging and discharging characteristics on the planning of other energy units in microgrid, which is not conducive to realizing the optimal coordinated planning of power grid under the background of large-scale integration of electric vehicles. Based on the analysis of the effects on microgrid after the integration of electric vehicles, this paper establishes the total cost minimization mathematical model of microgrid's planning and operation, which is on a year cycle and considers the integration of electric vehicles. The PSO-SA mixed algorithm and examples are used to simulate the optimal planning and decision-making of each energy unit in the microgrid after the integration of electric vehicles, in order to provide decision-making basis for planning of microgrid. At the same time, this paper compares the performance of the single intelligent algorithm and PSO-SA mixed algorithm when used to solve the coordinated planning problem of electric vehicles and microgrid, in order to provide reference when solving these problems in the future.

2. Coordinated planning model of electric vehicles and intelligent districts

2.1 Model introduction

The assumptions of the coordinated planning model of electric vehicles and intelligent districts are as follows:
(1) Electric vehicles belong to all individuals. The owner affords the purchase cost and the investment cost of

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energy storage device won't be occupied.
(2) The government controls the carbon dioxide emissions through the carbon tax on enterprises, and sets the carbon tax in a constant level at 10 yuan /tCO_2 (Zhang, 2014).

2.2 Objective function

The total costs of the system consist of two parts: one part is the economic costs of the system after the integration of electric vehicles, including the purchase cost of electricity that intelligent districts purchase from grid, the purchase cost in the building, operation and maintenance cost and the battery loss cost of electric vehicles; the other part is the environmental cost. It equals to the amount of total carbon dioxide emissions multiplied by the carbon tax. As shown in formula (1):

$$\min C_{total} = (1-w)\cdot(C_{elec} + C_E + C_O + C_M + C_{bat}) + w\cdot\left(CO_{2elec} + CO_{2fuel} + CO_{2EV}\right) \quad (1)$$

Where, C_{total} is total costs of the system, which consist of intelligent districts and electric vehicles, ten thousand yuan/year; C_{elec} is the purchase cost of electricity purchased from grid, ten thousand yuan/year; C_E, C_O, C_M are the purchase cost of equipment in the building, operating cost and maintenance cost, respectively, ten thousand yuan/year; C_{bat} is the battery loss cost of electric vehicles, ten thousand yuan/year; CO_{2elec} is the carbon emission caused by the electricity consumption of intelligent districts, kg/year; CO_{2fuel} is the carbon emission from the fuel of distributed generation burning, kg/year; CO_{2EV} is the carbon emission from the use of electric vehicles, kg/year; c is the price of carbon tax, yuan/t CO_2; w is weight factor, $w \in [0,1]$.

2.3 Auxiliary equations

The battery loss cost of electric vehicles is shown in formula (2):

$$C_{bat} = E_{EV} \times CL \times RC_{bat} \quad (2)$$

Where, E_{EV} is power exchange capacity of electric vehicle's battery, kWh/year; CL is the attenuation coefficient of capacity; RC_{bat} is the replacement cost of electric vehicle's battery, yuan/kWh.
Carbon emission from the use of electric vehicles is shown in formula (3):

$$CO_{2EV} = \left(\frac{E_{c\to e}}{\eta_{EVc}} + E_{e\to c} \times \eta_{EVdc}\right) \times co_{2,EV} \quad (3)$$

Where, $E_{c\to e}$ is the electricity that flows from intelligent districts to electric vehicles, kWh/year; $E_{e\to c}$ is the electricity that flows from electric vehicles to intelligent districts, kWh/year; η_{EVc} is the charge efficiency of electric vehicles; η_{EVdc} is the discharge efficiency of electric vehicles; $co_{2,EV}$ is the unit carbon emission from the electric power exchange of electric vehicless, kg/kWh.

2.4 Constraint conditions

(1) Equilibrium constraint

$$S_{U,t} + S_{DER,t} + S_{ST,t} + S_{EV,t} = D_{B,t} + D_{ST,t} + D_{EV,t} \quad (4)$$

Where, $S_{U,t}$, $S_{DER,t}$, $S_{ST,t}$, $S_{EV,t}$ are the electricity supplied by internal and external power grid, distributed energy, stationary energy storage devices and electric vehicles in time period t, kWh; $D_{B,t}$, $D_{ST,t}$, $D_{EV,t}$ are the electricity demanded by intelligent districts, stationary energy storage devices and electric vehicles in time period t, kWh.
(2) Power constraints

$$ES_{EV,t} = ES_{EV,t-1} \times (1-\varphi_{EV}) + i_{EV,t} - o_{EV,t} \quad (5)$$

$$ES_{ST,t} = ES_{ST,t-1} \times (1-\varphi_{ST}) + i_{ST,t} - o_{ST,t} \quad (6)$$

Where, $ES_{EV,t}$, $ES_{ST,t}$ are the stored electricity of electric vehicles and stationary energy storage devices in time period t, respectively, kWh; φ_{EV}, φ_{ST} are the loss rate of electric vehicle's battery and stationary energy storage devices; $i_{EV,t}, o_{EV,t}, i_{ST,t}, o_{ST,t}$ are the charging and discharging capacity of electric vehicles and stationary energy storage devices in time period t, kWh.
(3) Current constraints

$$D_{EV,t} = \frac{i_{EV,t}}{\eta_{EVc}} \tag{7}$$

$$S_{EV,t} = o_{EV,t} \times \eta_{EVdc} \tag{8}$$

$$D_{ST,t} = \frac{i_{ST,t}}{\eta_{STc}} \tag{9}$$

$$S_{ST,t} = o_{ST,t} \times \eta_{STdc} \tag{10}$$

Where, $\eta_{EVc}, \eta_{STc}, \eta_{EVdc}$ respectively indicate the charging and discharging efficiency of the stationary energy storage devices.
(4) Capacity constraints

$$ES_{EV,t} \le c_{EV} \tag{11}$$

$$c_{ST} \times soc_{\min} \le ES_{Stm,h} \le c_{ST} \times soc_{\max} \tag{12}$$

Where, c_{EV}, c_{ST} are the capacity of electric vehicle's battery and stationary energy storage devices, respectively; soc_{max}, soc_{min} are the maximum and minimum charing states of the stationary energy storage device, respectively.
(5) Rate constraints

$$i_{ST,t} \le c_{ST} \times cr \tag{13}$$

$$o_{ST,t} \le c_{ST} \times dr \tag{14}$$

Where, cr, dr are the maximum charging and discharging rate of stationary energy storage devices, respectively.

3. Model solutions-PSO-SA mixed algorithm

Considering the characteristics of the coordinated planning model of electric vehicles and intelligent districts established in this paper, and the advantages and disadvantages of the PSO algorithm and SA algorithm, PSO-SA mixed algorithm is used to solve the model, so as to play the advantages of the two algorithms at the same time. PSO-SA algorithm will use SA algorithm to disturb and optimize the optimal solution in the convergence of PSO algorithm, in order to jump out of the local optimal to search for a better solution. At the same time, compared to SA algorithm's optimal solution, the optimal solution of PSO algorithm is a better initial solution than the randomly generated solution, so it is helpful to improve the efficiency of SA algorithm (Chen, 2013). In summary, the processes of PSO-SA algorithm are as follows:
Step 1: Initialize the position and velocity of each particle. Setting the current iteration number of PSO to $t_{PSO} = 1$, the maximum iteration number of PSO stage is $T_{PSO,max}$the algorithm stagnation parameter is ε. And determine the group size N and particle dimension D;
Step 2: Evaluate the fitness value of each particle, and then obtain the optimal particle in history and the global optimum of the group;
Step 3: Determine whether the global optimum satisfies the termination condition (the algorithm stagnation or the maximum number of iterations has been reached). If the condition is met, then going to the sixth step; or else, returning to the fourth step;
Step 4: The position and velocity of each particle are updated according to the formula (15) and (16);

$$v_i^d = v_i^d + a_1 k_1 (h_i^d - x_i^d) + a_2 k_2 (A_d - x_i^d) \tag{15}$$

$$x_i^d = x_i^d + v_i^d \tag{16}$$

Where, $i = 1,2,\cdots,N$, $d = 1,2,\cdots,D$, a_1, a_2 are the acceleration constant. k_1, k_2 are random numbers which are independent to each other and subject to $U(0,1)$. h_i^d is the best position in history of particle i. A_d is the position of particle i in the global optimum.
Step 5: Make $t_{PSO} = t_{PSO} + 1$, and turn to step 2;

Step 6: Set the initial temperature, end temperature and cooling function. Setting the current iteration number of SA stage at $t_{SA} = 1$, and the maximum iteration number of SA stage is $t_{SA,max}$. The number of initial disturbance at each temperature is $T = 0$, and the maximum number of disturbance is T_{max}.
Step 7: Select a new solution randomly in the scope of existing solutions, calculate the fitness value of two solutions, and then, update solutions according to the Metropolis criterion.
Step 8: Make $t_{SA} = t_{SA} + 1$, if t_{SA} reaches $t_{SA,max}$, turn to step 10. If not, then make $T = T + 1$. If $T = T_{max}$, then turn to step 9, otherwise, turn to step 7;
Step 9: The cooling function is used to cool down. If it reaches the end temperature, then turn to step 10, otherwise, make T=0, and turn to step 7;
Step 10: The output at this time is the global optimal solution. The cumulative iteration number of PSO-SA algorithm is $t = t_{PSO} + t_{SA}$.

4. Case analysis

Taking some intelligent districts in area A as an example, this paper uses the PSO-SA mixed algorithm, and combines the coordinated planning model of electric vehicle and intelligent district mentioned above to simulate the device's capacity decision of the intelligent district after the integration of electric vehicles. This intelligent district covers an area of 19200 square meters, and the maximum electric load is 32000kw, so it is typical in the area A.

4.1 Basic data

(1) Cost data
The existing electric sources in the system are divided into two types: the first category is represented by the combined heat and power generation, and the unit cost of technology investment is characterized by strictly increasing staircase function; the second category is represented by photovoltaic power generation, solar collector, absorption refrigeration and others, and the unit cost of the technology investment is fixed and constant. The total cost and device capacity are linear relationship.
There are two forms of combined heat and power generation: internal-combustion engine and fuel cell. The related cost of the first and second of kind of power in the intelligent district is shown in table 1 and table 2:

Table 1: Related Cost of the First of Kind of Power

	internal-combustion engine			fuel cell		
specification of equipment	small	medium	large	small	medium	large
installed capacity (kW)	65	260	500	105	260	500
purchase cost of equipment (yuan/kW)	16000	9500	8300	14000	11000	9500
maintenance cost (yuan/kWh)	0.12	0.09	0.06	0.21	0.19	0.18

Table 2: Related Cost of the Second of Kind of Power

	stationary energy storage device	thermal energy storage device	Absorption refrigeration	Solar collector	PV
Purchase cost of device (yuan)	1800	62000	59000	2200	25000
operation cost (yuan/kW or yuan/kWh)	1200	630	4250	3050	20100
maintenance cost (yuan/kWh)	0	0	11	3.5	2

(2) The parameter of stationary energy storage devices
The stationary energy storage devices of the intelligent district comprise electric energy storage device and heat energy storage device. The performance is affected by charging and discharging efficiency, loss rate of the storage system and other technical indicators. The specific parameters are shown in Table 3.
(3) The parameter of electric vehicles
Electric vehicle's power batteries used in the system are lithium-ion batteries with the capacity of 16kWh. The parameters of battery are shown in table 4.
In addition, the example also makes the following assumptions:
(1) The electricity price is fixed, for 0.55 yuan /kWh;

(2) The maximum absorption areas of photovoltaic and solar collectors, as well as the area of parking spaces that can be used by electric vehicles are fixed, at 15000m^2;
(3) In the specific time interval, electric vehicles are only connected to the intelligent district. Its connection time is 06:00-18:00.
(4) Set the algorithm's parameters
The relevant parameters of the PSO-SA algorithm are set up. The number of particles in the PSO stage is 40. The stagnation parameter ε equals to 0.001, that is, when the difference of the maximum and minimum of the fitness function is less than 0.001 in ten successive iterations, the algorithm stagnates. The acceleration constants a_1 and a_2 equal to 1.49445. The maximum number of iterations in PSO stage $T_{PSO,max}$ is 200. The maximum number of iterations in SA stage $T_{SA,max}$ is 400. The maximum number of disturbance at each temperature T_{max} is D, and D is particle dimension, randomly disturbing in the range of 0 to σ along each dimension of particle in turn, and$\sigma \sim U(0,1)$. In order to avoid randomness, PSO-SA algorithm is repeated 10 times in each scenario, and then, the optimal value is taken as the result.

Table 3: Stationary energy storage device parameters

	electric energy storage device	thermal energy storage device
charging efficiency	0.9	0.9
discharging efficiency	0.9	0.9
loss rate	0.001	0.01
the maximum charging rate	0.1	0.25
the minimum charging rate	0.25	0.25
the minimum charging state	0.3	0

Table 4: Electric vehicles battery parameters

Parameters	values
charging efficiency	0.95
discharging efficiency	0.95
loss rate of battery	0.001

4.2 Results of example

Adjusting the proportion of economic cost and environmental cost in decision-making, six weight factors are taken to form scenarios, that is $w_1 = 0, w_1 = 0\ w_2 = 15\%, w_3 = 25\%, w_4 = 35\%, w_5 = 45\%, w_6 = 1$. The PSO-SA algorithm is used to solve the coordinated model of electric vehicles and intelligent districts, and then, the lowest total cost of the system can be obtained as the optimal result. The obtained optimal planning of each device in each scenario is shown in table 5.

Table 5: Optimal Planning of Energy Units in the Intelligent District

	w_1	w_2	w_3	w_4	w_5	w_6
capacity of internal combustion engine of combined heat and power generation (kW)		1326	986	772	402	63
capacity of fuel cell of combined heat and power generation combined heat and power generation (kW)		1512	1861	2108	2402	2758
capacity of absorption refrigerator (kW)			765	752	731	744
capacity of solar collector (kW)	518	1602	5151	5013	5078	5067
capacity of PV (kW)		1014	1683	2873	2676	2742
capacity of stationary energy storage device (kWh)		4233	7471	12152	15823	18733
capacity of mobile energy storage device (kWh)	20502	19079	13422	8124	4512	287
capacity of thermal energy storage device (kWh)		4105.5	16402	16287	16373	16289
total cost of the system (ten thousand yuan)	347	325	310	397	368	202

It can be seen from table 5 that when the system only considers economic cost, compared to the stationary energy storage device, the mobile energy storage device has a stronger competitive power, and there is no investment in other devices. This is because the power battery regarded as a mobile energy storage device can provide a variety of ancillary services. Moreover, the power battery has a second life. That is, when the battery is not suitable for the use of electric vehicles, it can be recycled as the stationary energy storage device.

The fuel cell's investment of combined heat and power generation is increasing with the weight factors. On the one hand, because of the restriction of thermal energy demand and area, the solar collectors and photovoltaic power generation can't be used; on the other hand, because the fuel cell's efficiency is higher, compared to the internal combustion engine of combined heat and power generation, the fuel cell is used to replace the internal combustion engine, which can improve the total efficiency of the system, and then decrease the environmental cost. At the same time, the number of electric vehicles in the intelligent district will reduce with the increase of weight factors. When the system only considers economic cost, the growth of stationary energy storage device's operating capacity is obvious, far greater than the mobile energy storage device (that is electric vehicles). Because in the residential area, the stationary energy storage device is easy to manage and plan for the storage and use of energy, the power consumption of the external power grid can be reduced and environmental efficiency can be improved.

5. Conclusions

Considering the economic cost and environmental cost of the system under the condition of large-scale integration of electric vehicles and other mobile energy storage devices in microgrid, this paper establishes the coordinated planning model of electric vehicles and intelligent districts based on the intelligent district microgrid. And PSO-SA mixed algorithm is used to solve the model. This paper takes an intelligent district in area A as an example and simulates the coordinated planning model of electric vehicles and intelligent districts, in the cases of different weights of economic cost and environmental cost.

The results of the example show that electric vehicles regarded as mobile energy storage devices have a stronger competiveness than the stationary energy storage device, when mainly considering the economic cost. However, with the ever-increasing consideration of environmental cost, the competiveness will gradually weaken and disappear. Therefore, under the background of the national strategies of energy-saving and emission reduction, the market prospect and development space of electric vehicles regarded as a means of transportation should be more deeply analyzed, and the economic and environmental benefits should be compared with other traditional means of transportation. The electric vehicle should not be simply regarded as a mobile energy storage device.

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