OPTIMAL ALLOCATION OF GENERALIZED HEAT STORAGE IN DISTRIBUTION NETWORK OF RENEWABLE ENERGY

by

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In order to solve the problem of optimal allocation of general heat resources in high permeability renewable energy distribution network, an optimal allocation scheme of general heat resources in renewable energy distribution network is proposed. The optimal allocation scheme in renewable energy distribution network is proposed. In this paper, the internal and external two-layer structure is designed. The outer layer uses genetic algorithm to search the structural parameters of general energy system, and the inner layer uses dynamic programming method to get the optimal performance of general energy system. The internal and external alternate adjustment methods are used to optimize the general-purpose power distribution capability of the continuous-wave power supply network with different permeability and controllability, and the proposed method is verified in IEEE 33 node distribution network. The experimental results show that the general strength storage capacity is 26.6% and 45.7% higher than that of the process with a continuous strength renewable permeability of 30% and 40%, respectively. The utility rates were increased by 18.4% and 27.8%, respectively. Under the condition of high permeability renewable energy, the proposed method can increase the efficiency of resource management of distribution network by regulating load, decrease the distribution capacity of energy stability, and reduce the operation cost of the system.

Key words*: high permeability renewable energy, generalized energy storage, two level optimization, controllable load*

Introduction

The high input power amplifier will be connected to the power supply system, which will make the power supply temperature standby, frequency adjustment, power control and other auxiliary transmitting devices less. The stable and easy control system will face serious challenges, which leads to the decline of power consumption continuously. In order to find out the proportion of the renewable energy, new requirements are put forward for energy storage. Considering the future electric vehicles' participation in power system regulation, demand side response and other factors, it is estimated that China's energy storage demand will reach 400-600 GW [1].

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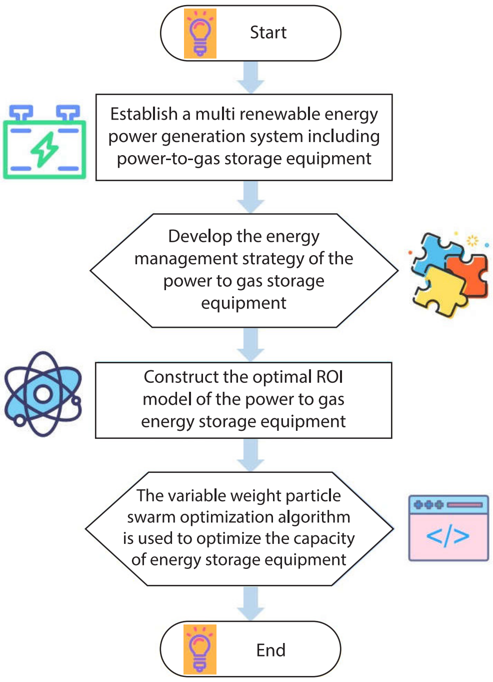

Figure 1. capacity optimization method of energy storage equipment for multi renewable energy power generation system

With the development of smart grid, load that retains heat, energy capacity and electrical power, such as air conditioners, refrigeration, heating, water tower, water heater, electric vehicle*, etc.*, have the potential to aggregate into new energy storage systems with large capacity. Figure 1 shows a scalability optimization for the electrical equipment storage of various power generating units. However, the increase in the popularity of renewable energy distribution and the extensive use of electric vehicles loaded in distribution networks make the operation of distribution areas more efficient.The traditional demand side response technology connotation (control method and response speed), which takes price based or incentive based as the response mechanism, cannot meet the rapid regulation and control needs of the new distribution network. Therefore, the demand side response technology, which takes hours/days as the time scale for regulation, is now taking seconds/hours as the time scale for regulation, and is evolving towards a tradable energy (TE) system characterized by decentralization and independent decision-making [2].

In order to adapt to the development trend of the future smart grid and facilitate the effective implementation of the practical operation of the distributed load control system in the dynamic grid system, this paper divides a new energy-saving scheme designed by the aforementioned control mode based on the virtual power storage system and call for the traditional power storage system design of battery energy storage power plant based on the power stable storage [3].

Literature review

In addition the advanced technology, the industrial application of energy storage system cannot be separated from mature electricity market. In the future, China can adopt energy market policies in reforming electricity market: the power suppliers sign contracts with traditional power generators to determine the contract electricity through forward trading and futures trading. There is a deviation between the actual load demand and the contract electricity, which requires the spot market and the balanced market to balance. Unbalanced electricity is quoted in the form of stepped electricity price. The more deviating from the planned output, the higher the quotation [4].

Methods

Generalized energy storage model

The general energy consumption considered in this paper includes: transfer load (TL), impact load (IL), electric vehicle and power stability [5].

Transferable load

It can be turned into a certain amount of time. When the load moves forward, it is proportional to the charge and then out of the energy storage, and vice versa. The collection of electrical equipment with transferable load is represented by, its feature description is shown in eq. (1), and the aggregation model is shown in eq. (2):

$$\begin{gathered} P_a^t = P_{a,\mathrm{e}},\ t \in \left[t_a^{\mathrm{s}}, t_a^{\mathrm{e}}\right] \\ P_a^t = 0,\ t \notin \left[t_a^{\mathrm{s}}, t_a^{\mathrm{e}}\right] \\ t_a^{\mathrm{s}}, t_a^{\mathrm{e}} \in \left[t_a^-, t_a^+\right] \\ t_a^{\mathrm{e}} - t_a^{\mathrm{s}} = T_a \end{gathered} \tag{1}$$

where $a \in A_{\mathrm{TL}}$; P_a^t and $P_{a,\mathrm{e}}$ the strength and average strength of the material in normal use, t_a^{s} and t_a^{e} is the start and stop time of part equipment, and [t^-_{a}, t^+_{a}] time interval constituting load change:

$$\begin{gathered} P_{\mathrm{TL,cmax}}^t = \sum_{a \in A_{\mathrm{TL}}} P_{a,\mathrm{e}},\ t \in \left[t_a^-, t_a^{\mathrm{s}}\right) \cup \left(t_a^{\mathrm{e}}, t_a^+\right] \\ P_{\mathrm{TL,d}max}^t = \sum_{a \in A_{\mathrm{TL}}} P_{a,\mathrm{e}},\ t \in \left[t_a^{\mathrm{s}}, t_a^{\mathrm{e}}\right] \end{gathered} \tag{2}$$

where $P^t_{\mathrm{TL,cmax}}$ and $P^t_{\mathrm{TL,dmax}}$ are the maximum charging power and the output power of the virtual storage power are equal to each load variable at any given time [6].

Interruptible load

The interrupt load can be closed at any time, but the time of the interrupt load is limited by the user's comfort. In this paper, mainly used air conditioner and water heater. The power can be adjusted by adjusting the temperature value or changing the operation time directly. When temperature control load reduces energy, it is considered as virtual energy storage. At first increased the cooling capacity (heating) of the output power storage part, decided to compensate the virtual storage power. The collection of interruptible load electrical equipment is represented by AIL, and its feature description is shown in eq. (3), and the aggregation model is shown in eq. (4):

$$\begin{gathered} P_{a,\mathrm{e}} \le P_a^t < P_{a,\max},\ t \in \left[t_a^{\mathrm{s}}, t_a^{\mathrm{e}}\right], \theta_a^t < \theta_{a,\min} \\ 0 \le P_a^t < P_{a,\mathrm{e}},\ t \in \left[t_a^{\mathrm{s}}, t_a^{\mathrm{e}}\right], \theta_a^t \ge \theta_{a,\min} \\ P_a^t = 0,\ t \notin \left[t_a^{\mathrm{s}}, t_a^{\mathrm{e}}\right] \end{gathered} \tag{3}$$

where $a \in A_{\mathrm{IL}}$; $P_{a,\max}$ is the highest working strength of the material and θ^t_a is the user's electrical comfort at the moment:

$$\begin{gathered} P_{\mathrm{IL,max}}^t = \sum_{a \in A_{\mathrm{IL}}} \left(P_{a,\max} - P_a^t\right) \\ P_{\mathrm{IL,dmax}}^t = \sum_{a \in A_{\mathrm{IL}}} P_a^t \theta_a^t \geqslant \theta_{a,\min} \\ t \in \left[t_a^{\mathrm{s}}, t_a^{\mathrm{e}}\right] \end{gathered} \tag{4}$$

Electric vehicle

Using hybrid vehicle (V2G) technology, electric vehicle can interact with power grid and become a stable power grid. This paper assumes that the space and time for the passage of the electric vehicle are specified after the signing of the contract between the electric vehicle and the electric vehicle. The power of each electric vehicle does not change when charging and discharging, and the power of each electric vehicle is the same. Self discharge of battery and energy loss of discharge system are ignored [7]. When an electric vehicle is charged, the quantity of electric vehicle at time t can be expressed:

$$E_{\mathrm{EV},i}^{t} = E_{\mathrm{EV},i}^{t-1} + P_{\mathrm{EV,c}}\Delta t \tag{5}$$

When an electric vehicle is discharged, its value at the time, t, may be expressed:

$$E_{\mathrm{EV},i}^{t} = E_{\mathrm{EV},i}^{t-1} - P_{\mathrm{EV,d}}\Delta t \tag{6}$$

where $P_{\mathrm{EV,d}}$ is the electric vehicle discharge power.

Fixed energy storage system

For a fixed power storage system composed of a storage battery, the compensation of the E_B^t time is related to the residual power of the last storage system and the charging and discharging problems in this part. When the jth power storage station is charged, its charging at the time t can be expressed:

$$E_{\mathrm{B},j}^{t} = E_{\mathrm{B},j}^{t-1} + P_{\mathrm{B},j,\mathrm{c}}^{t}\Delta t \tag{7}$$

When an electric station is discharged, its value at the time t may be expressed:

$$E_{\mathrm{B},j}^{t} = E_{\mathrm{B},j}^{t-1} - P_{\mathrm{B},j,\mathrm{d}}^{t}\Delta t \tag{8}$$

where $P_{\mathrm{B},j,\mathrm{d}}^{t}$ is the power out of jth's power storage station at time, t.

Generalized energy storage optimal allocation model

In this paper, a two-stage optimization model of multi-objective function is established on the basis of comprehensively analyzing cost allocation and operational benefit of general utility.

Selection of optimization variables

The general energy storage equivalent output power P_{BR}^{t} satisfies the relationships:

$$P_{\mathrm{BR}}^{t} = P_{\mathrm{TL}}^{t} + P_{\mathrm{IL}}^{t} + P_{\mathrm{EV}}^{t} + P_{\mathrm{B}}^{t} \tag{9}$$

Objective function of generalized energy storage configuration

In eq. (10), the expression of annual fixed input cost $f_1(X_1)$:

$$f_1\left(X_1\right) = C_{\mathrm{CAP}} + C_{\mathrm{REP}} \tag{10}$$

This paper considers that virtual energy storage is to integrate existing available resources, and the initial investment cost is not included.

Among them, the expression of the average annual development rate of energy stability:

$$C_{\mathrm{CAP}}=\left(c_{\mathrm{P}}P_{\mathrm{B}}+c_{\mathrm{E}}E_{\mathrm{B}}\right)\frac{\gamma(1+\gamma)^{L_{\mathrm{B}}}}{(1+\gamma)^{L_{\mathrm{B}}}-1} \tag{11}$$

where c_{p} and c_{E} are the unit voltage value and unit capacity value of power accumulator. The replacement cost expression:

$$C_{\mathrm{REP}}=\left(c_{\mathrm{P,\,rep}}P_{\mathrm{B}}+c_{\mathrm{E,\,rep}}E_{\mathrm{B}}\right)F_{\mathrm{B}}S_{\mathrm{FF}}\left(\gamma,L_{\mathrm{B}}\right)-S_{\mathrm{B}}S_{\mathrm{FF}}\left(\gamma,L_{\mathrm{B}}\right) \tag{12}$$

The expression of variable net income $f_2(X_2)$ of annual operation:

$$f_2\left(X_2\right)=C_{\mathrm{N}}+C_{\mathrm{E}}-C_{\mathrm{OM}}-C_{\mathrm{D}} \tag{13}$$

where C_{N} is the sum of the average annual upgrading and reconstruction costs saved by generalized energy storage and the grid crossing costs saved by reducing the transmission capacity of the distribution network and C_{E} – the refers to the income obtained by generalized energy storage through providing services for power suppliers in the spot market of electricity every year.

Optimization solution of generalized energy storage configuration

Optimization process of generalized energy storage configuration

Because of the interaction between structural problems and operational problems, a two-phase optimization method is adopted in this paper. Defining issues should be addressed for key issues of setting out effective external mechanisms and sub-issues of internal mechanisms.

In the literature that generally uses two-layer optimization method to configure energy storage, the power capacity value of fixed energy storage is used as the decision variable of the outer model, so the calculation of annual fixed investment cost $f_1(X_1)$ it will not be influenced by the internal optimization strategy. In this paper, the discrete variable external model is a set of general utility model. Considering the real-time change of the scheduling capability of the power storage system to build a virtual storage system.

Outer layer optimization method

In this paper, the genetic algorithm is used to optimize the outlier lay-out and set up the power and capacity of the general utility. The flow chart is shown in fig. 2 [8].

Inner layer optimization method

In the process of inner layer optimization, a power factor programming method is selected to optimize the compensation and output power of general electronic components in each cycle. Each adjustment cycle is divided into two-stages. The first state and the end of each cycle are, respectively, $E_{\mathrm{low}}=E_{\mathrm{min}}$.

In the process of internal model optimization, namely, annual variable net operating income $f_2(X_2)$, is divided into two parts: the sum of C_{N} and C_{E} represents operating income, and the sum of C_{OM} and C_{D} represents operating cost. The internal optimization process is divided into two steps [9].

First of all, in the case of the generalized energy storage configuration scheme given by the outer model, with the maximum operating income as the optimization objective, an optimal path from the initial time to the end time is obtained through the dynamic programming

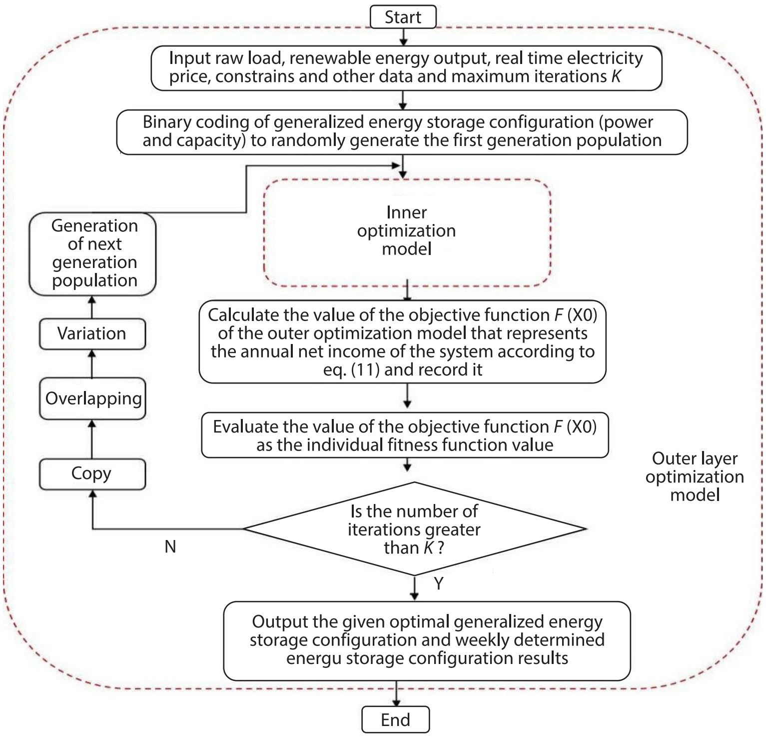

Figure 2. Flow chart of genetic algorithm

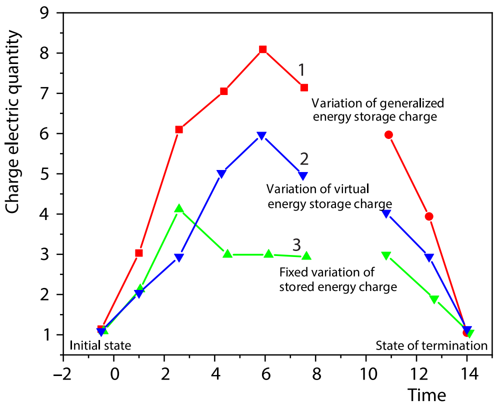

Figure 3. Schematic diagram of optimizing virtual energy storage by dynamic planning

algorithm in each 24 hours optimization cycle as the charge variation curve of the generalized energy storage, as shown by the red line – 1 in fig. 3. Secondly, in order to reduce the total call cost of controllable load and improve the operation income, the maximum net income of virtual energy storage operation is taken as the optimization objective, and the change curve of virtual energy storage capacity is obtained through dynamic programming algorithm, as shown by the green line – 3 in fig. 3. The value represented by the red curve and the green curve are subtracted to obtain the change curve of fixed energy storage charge, as shown in the blue line – 2 in fig. 3.

Controllable load control strategy

The change curve of virtual energy storage charge is obtained through inner optimization, and the aggregate value of all controllable load increases or decreases in power in each period can be calculated. Therefore, we need to decompose to obtain the power value that needs to be increased or reduced for various controllable loads. According to the principle of preferentially calling the load with small power but strong timeliness, and finally calling the electric vehicle with electric energy loss, we need to call the virtual energy storage resources in the order of transferable load > interruptible load > electric vehicle.

The dispatching strategies of various controllable loads are as follows.

Switch load: A load that can change the time of a window is called a preference.

Load disturbance: Only temperature control of disturbance load is considered in this paper, and controllable load electrical equipment is sorted according to user satisfaction. When virtual energy storage charging is required, electrical equipment with low satisfaction is preferred, otherwise, equipment with high satisfaction is preferred. The user's satisfaction with the temperature control load is defined:

$$\theta'_a = \begin{cases} \left|\dfrac{T_\mathrm{R}-T_0}{T_\mathrm{S}-T_0}\right| & \left|\dfrac{T_\mathrm{R}-T_0}{T_\mathrm{S}-T_0}\right| \in (0,1) \\ 1 & \dfrac{T_\mathrm{R}-T_0}{T_\mathrm{S}-T_0} \geq 1 \\ 0 & \dfrac{T_\mathrm{R}-T_0}{T_\mathrm{S}-T_0} \leq 0 \end{cases} \tag{14}$$

Electric vehicles: Classified as residual energy. When emission is required, the greater the intensity, the higher the priority. On the contrary, the lower the price, the higher the price.

At the same time, in order to improve the resolution speed, this paper also simplifies the temperature control model: calculates the change of customer satisfaction after the load joining schedule process according to various pre-process parameters. When scheduling deal with temperature control group, customer satisfaction can be adjusted directly according to eq. (15), without further solving by equivalent thermal parameter model:

$$\theta_a^t = \theta_a^{t-1} + k\Delta t \tag{15}$$

where k is the change in customer satisfaction after the utility responds to the dispatch command.

Experiment

In order to verify the effectiveness of this method, IEEE33 bus distribution network model is analyzed as an example. See fig. 4 for the IEEE33 distribution network model. Among them, if the nodes 13, 23, and 30 are, respectively connected with photovoltaic power station and wind power station, the power station is installed on the side of the power station continuously. The main benefit of charging and discharging in this paper is to stabilize the total capacity of energy storage and the total power of charging and discharging in each cycle. The capacity of each power station and the charging and discharging power of each cycle are determined by the ratio of the installed capacity of the next power station the total installed capacity.

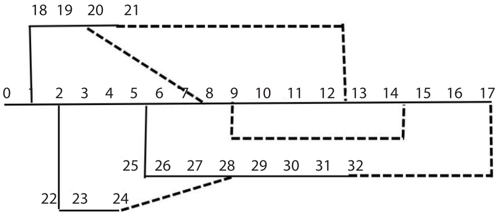

Figure 4. The IEEE 33 node distribution network structure

This paper needs to carry out power flow to check whether the node voltage is connected with the power supply and the storage power supply exceeds the limit, and whether the network distributes power supply to the grid better. To ensure the effectiveness of the resolution,the generalized energy storage operation strategy for the whole day is obtained according to the optimization objectives and other constraints, and then the power flow calculation is carried out to modify the renewable energy and the optimized generalized energy storage operation strategy:

If the voltage of the node connected to the renewable energy exceeds the limit or the power is reversed to the superior grid, the output value of the renewable energy at the node shall be reduced to the generalized energy storage charging power at the node. If the node voltage connected with the renewable energy is lower than the limit and the general power supply is compensated, the charging power of the general power supply is set to zero and the planned output power is reduced in the coming period. If energy is released in this cycle, the discharge power in this period will be increased. Finally, the value of the income function is modified according to the actual operation strategy.

Results and discussion

The unit cost of the power storage battery is 1.5 yuan per W. In addition, three schemes are also considered, that is, the generating capacity of the power amplifier is extended to 20%, 30% and 40% of the total load demand, respectively. The output capacity of the power supply system is improved. Table 1 lists the plan's optimization and profitability criteria based on renewable energy costs.

Table 1. Configuration and benefits of energy storage system

Renewable energy penetration rate [%]	Generalized energy storage capacity [MWh]	Generalized energy storage power [MW]	Fixed energy storage capacity [MWh]	Fixed energy storage power [MW]	Annual net income of energy storage 10000 yuan	Configuration cost without virtual energy storage 10000 yuan	Configuration cost of using virtual energy storage 10000 yuan
20	0.94	0.76	0.62	0.55	2.47	208.0	144.5
30	1.19	0.90	0.79	0.68	2.79	254.0	181.0
40	1.37	1.15	1.01	0.92	4.02	309.5	239.0

It can also be seen from the results in tab. 1 that with the increase of the power consumption, the capacity and power of the general power supply will also increase. In the process of renewable energy utilization between 30% and 40%, the general energy consumption is 26.6% and 45.7% higher than that of the projects with renewable energy consumption of 20%, respectively. Water and electricity prices rose 18.4% and 27.8%, respectively. If the system does not use virtual storage power, the general storage capacity and power of external structure are provided by the stable storage power. Table 1 lists the comparison of initial investment results when virtual energy storage is not used and when virtual energy storage is used [10].

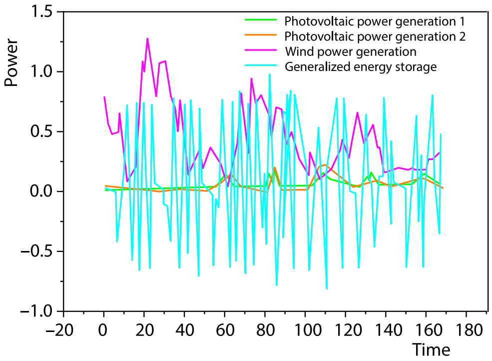

Figure 5. Generalized energy storage output power curve when renewable energy penetration rate is 20%

Figure 5 shows the weekly renewable energy and the renewable energy curve when the renewable energy is 20%. When the renewable energy is 30% and 40%, the weekly renewable energy curve and the renewable energy curve are improved.

Conclusion

This paper presents an optimum method for general energy consumption in renewable energy systems. On the premise of emphasizing the acceptance of renewable energy, the increase of renewable energy will lead to the increase of the uneven energy in power grid. In order to reduce the operation cost, the demand for storage power supplies has been increased. The optimization method adopted in this paper can reduce the conversion cost of unbalanced energy, and the application of virtual energy storage can also reduce the export demand and initial investment of the stable energy.

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