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Research Article

Distributed Energy Storage Cluster Control Method for DC Microgrid Considering Flexibility

Peng Tao, Yangrui Zhang, and Junpeng Zhao

State Grid Hebei Marketing Service Center, Shijiazhuang 050000, China

Correspondence should be addressed to Yangrui Zhang; 2016120272@jou.edu.cn

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As the core support, when we develop some new energies, the energy storage industry and energy storage technology cover both the power supply, grid and the user side, residential side, and socialized functional store of the energy facilities. If we can implement the storage of energy by the distributed unit, we can save the time and space translation of energy in function and has the characteristics of flexible layout and installation at the equipment level. It is important to promote the production and consumption of renewable energy and improve the operational reliability of alternating current or direct current AC/DC hybrid power grids. It is a virtual form and develops a tendency for energy storage resources in the power grid in the future. However, as an emerging technology and resource, the use of distributed energy storage still has problems such as low efficiency, high idle rate, and single functional scenarios. Distributed energy storage systems can be used almost everywhere around the system of power, have broad application prospects and huge application potential, and will become more and more significant for the power grid in the near future. In general, the distributed energy storage system now is at a primary level of engineering application, and deep study about it still exists various key technologies which needed to lay the foundation for its popularization and application. In this paper, by constructing a microgrid experimental system containing a variety of distributed energy storage systems, research is carried out around the modeling, control, efficiency analysis, and energy management of distributed energy storage systems.

1. Introduction

As an energy microgrid based on electric energy, the microgrid is the current research hotspot and difficulty of new energy power generation technology [1–5]. The USA, Japan, the European Union, my country, and many other countries have made lots of fundamental work about microgrids, and have also constructed a variety of demonstration projects to verify and display-related technologies and research results, which are briefly described below [6].

The United States first put forward the concept of "microgrid," which is in the leading position in the research and practice of microgrid, and it has the world's more demonstration projects of the microgrid. According to the definition of a microgrid by the Consortium for Electric Reliability Technology Solutions (CERTS), it is composed of loads, energy storage, and distributed power generation systems; energy storage and distributed power are mainly composed of The power electronic device is responsible for the conversion of energy and provides the necessary control; compared to the external grid, the microgrid behaves as a single controlled unit; the microgrid needs to meet user requirements for power quality and other requirements [7–9], CERTS is still in the United States. The company's Dolan Technology Center's Walnut microgrid experimental platform has systematically verified its overall control algorithm and achieved good results [10]. The plan for developing the US's future microgrid strategy, which has a great influence in advancing the research and developing the microgrid of the USA [11]. The department of energy launched the RDSI (renewable and distributed systems integration) project in 2009 and established it in 8 states. Nine micro-grid demonstration engineering projects were implemented, which reduced the peak load in the power system through integrated management of distributed power sources [12]. At the same time, the Mad River microgrid demonstration engineering system undertaken by the Northern Power System in the United States was tested. The modeling and protection algorithms of the microgrid are presented, and the economic benefits brought by the operation of the microgrid are evaluated experimentally. In addition, a large number of microgrid demonstration projects such as SPIDERS1 [12] and NREL Microgrid [13] have been completed and put into operation research.

The capacity of existing power distribution and transformation equipment in the power grid cannot meet the increasing demand for electricity, and the progressive growth in load peak-to-valley difference also leads to low comprehensive utilization of power grid equipment, resulting in investment expenses. The growth [14]. And more and more high-tech and digital enterprises have also listed much higher demand for the reliability and quality of power [15]. In response to the above problems, distributed access to energy storage equipment in the grid is an effective solution, which can promote the grid's ability to accept distributed energy, advance the reliability and the quality of the system power, and optimize the management of grid resources. Therefore, developing and applying distributed energy storage technology and related system integration technology will become more and more important and influential in future development.

With the rapid development of smart grids, the energy that can be replicated for the production of electricity, distributed generation methods of power and micro-grids, and electric vehicles, the research and application of energy storage has received increasing attention from countries around the world and has advanced rapidly. As of 2010, the total installed capacity of global electric energy storage exceeded 125 GW, which takes about 3% of the global capacity of electricity, of which pumped storage was about 123 GW, which takes about 98% of the established capacity of electric energy storage, and ice-storage energy storage 1002 MW (megawatt), there are 440 MW in the compressed air energy storage, while the energy storage of battery is 451 MW, flywheel energy storage and other energy storage are 237 MW [16]. Almost all of the projects described above are still demonstration projects, with the exception of large energy storage power plants.

The research is organized as follows: the introduction and literature review are presented in Section 1. Section 2 analyzes the distributed energy storage's classification basic control methods. Section 3 discusses the research on the partition method of the distributed energy storage cluster. In Section 4, the energy storage cluster partition method of a distribution network is based on a genetic algorithm. Section 5 proposed the design of a voltage regulation control strategy for cluster energy storage. Section 6 discusses the experiment and results of the proposed methods. Finally, in Section 7, the research work is concluded.

2. Distributed Energy Storage's Classification Basic Control Methods

The power of distributed energy storage equipment ranges from a few kW (kilowatt) to a few MW. The available capacity of the energy storage is generally less than 10 MWh (Megawatt Hours), and it is often connected to the medium and the distribution network with low voltage or the customers. Since there are many different types of energy, we can classify it as follows:

(1) The basic fuels storage
(2) The intermediate fuels storage
(3) Electric energy
(4) Store the energy after consumption (such as phase change energy storage, etc.)

In this article, we focus on how to store electric energy efficiently. From the perspective of electrical energy storage's method, distributed energy storage technology is very analogously with the extensive centralized energy accumulation technology, which could be roughly divided into two types, they are physical energy storage and chemical energy storage, of which physical energy storage includes mechanical energy storage and electromagnetic energy storage. For the energy storage method, we can see that they can be commonly classified as two different types, which are battery storing method and hydrogen storage storing method [11]. The specific classification is shown in Figure 1:

If we classify the technologies used in distributed electric energy storage, there are two different types in that field, which are power form and energy form. For the power form, it is a good choice for occasions which has a high demand of power in a very short period of time, it includes improving the quality of power and providing fast support of the power; the energy type is appropriate for satisfying the much higher energy demand, which requiring energy storage equipment to provide long period power support. Energy storage has a high energy storage density and longer charge and discharge time. The classification of distributed electric energy storage technology is shown in Figure 2.

Because of its advantages in size and technological maturity, electrochemical energy storage devices are the majority in the current grid engineering practice and demonstration of DES and are represented by lithium batteries, lead-acid batteries, and supercapacitors [12], so this article also chooses electricity chemical energy storage as our final study object. According to the different application scenarios of the power grid, we can connect the single chemical cell in series or parallel so as to form a large-scale system for energy storing with the required capacity of the system, and are connected with the power grid by a DC/DC converter or an AC/DC converter. By the grid-connected converter contained in it, we can control the system easily. Specifically, in the DC grid usage scenario, we can build a connection between the energy storage system and the DC grid by a two-way DC/DC converter, and in practice, it can be treated as a balance node to make the voltage of the DC stable, so as to become the main power source for the grid. At this time, the energy storage converter should be the DC voltage tracking or DC voltage droop control state. It can also be used as a constant power control node. At this time, the controller design only needs to consider the energy storage output current tracking [11, 12]. In AC grid usage

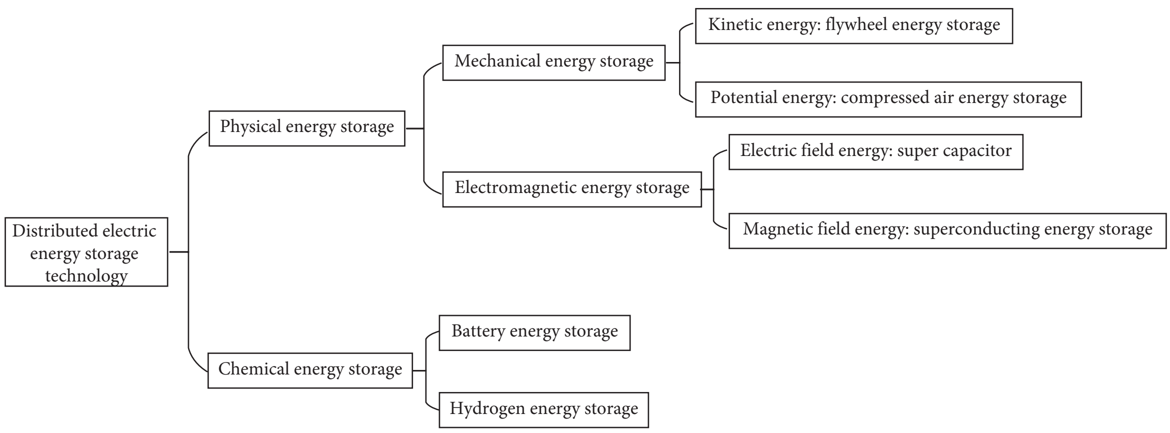

Figure 1: The different types of energy-storing technologies.

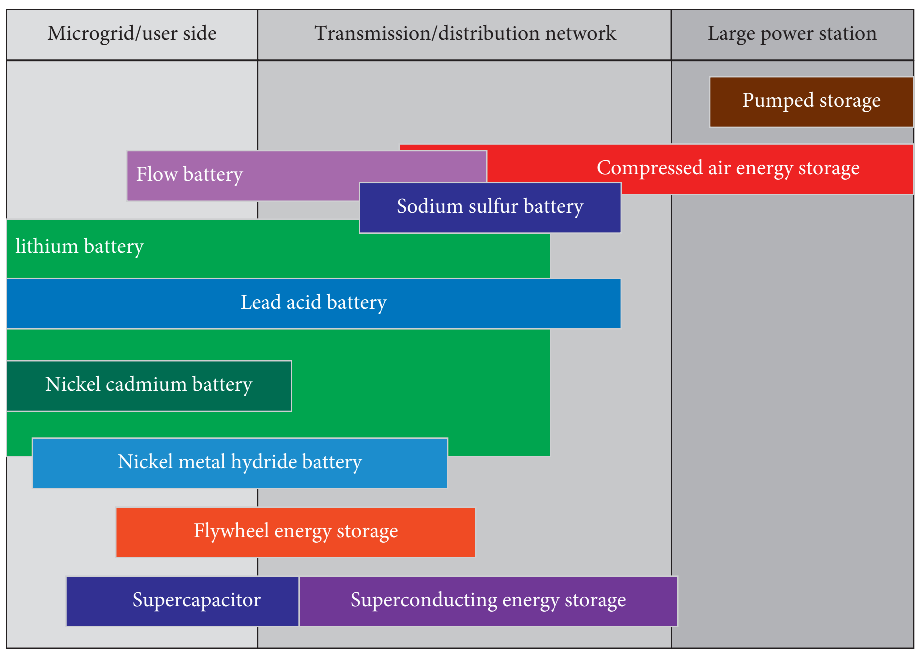

Figure 2: Schematic diagram of different types of energy-storing method.

scenarios, energy storage is connected to the grid through a two-way AC/DC converter. Passive control can be selected as needed to build an isolated AC microgrid to become a balanced node of the AC grid; or use active control to perform frequency Or tracking of a given power, at this time energy storage can participate in peak clipping and valley filling or frequency adjustment [8–10].

3. Research on Partition Method of the Distributed Energy Storage Cluster

At present, there are some urgent problems to be solved in the AC/DC power grid, such as difficult cross section energy coordinated control, low inertia characteristics of power electronics, and intermittent output of renewable energy, which bring challenges to its power coordinated control and the system's stability operation. As core support for new energy development, energy-storing industry and energy-storing technology cover various needs such as power supply side, power grid side, user side, residential side, and socialized functional energy-storing facilities. The system, which can be used to store the energy and is consists of energy storage elements and a power conversion system, can realize the time-space translation of energy in function, and has the characteristics of flexible layout and installation at the equipment level. It is a critical factor in promoting the production and consumption of renewable energy and improving the operation reliability of AC/DC hybrid power grid However, most of the existing applications use energy storage as a standby power supply or simply meet the purpose of local power balance. There are some problems, such as low efficiency, high idle rate, single-function scenario, and so on. In short, for the operational requirements of the AC/DC hybrid power grid, a series of problems still need to be solved, while energy storage, as an excellent solution, is in a state of low efficiency and idle resources.

How to build a bridge between the problems faced by AC/DC hybrid power grid and the high-quality solution of energy storage, study the collaborative control method of distributed energy storage based on power grid demand, and then tap the potential of efficient utilization of energy storage resources is of great research significance and engineering value.

3.1. Energy Storage Cluster Control Structure. In order to take the impact of distributed power generation and electric vehicle access on the distribution network into account, we propose a distributed network-based structure diagram of distributed energy storage in this paper and Figure 3 displays the architecture of the framework. In the figure, we illustrate the photovoltaic power generation, distributed wind power generation and conventional load. Here, PS refers to the power provided by the superior grid. If $PS \geq 0$, then the power flow direction is the reference direction in the figure, and if $PS < 0$, the guaranteed power is transmitted back to the upper-level grid.

Based on the demand for a hybrid power grid, this paper studies the distributed energy storage collaborative control method, and its necessity is mainly reflected by the demand of power grid and energy storage. In the future, the development trend of the smart grid is AC/DC hybrid. However, the fluctuation of a high proportion of renewable energy and the access of different loads makes it difficult to balance the net power of the system, which brings challenges to its stable operation. Firstly, for AC/DC hybrid microgrid, the flexible interconnection between subnets and the coordinated control of active energy are important issues to make sure that the system can provide a stable operation for hybrid microgrid system. The existence of the AC/DC section makes there a natural barrier for the two-way power flow between AC/DC subnets, which hinders the energy regulation between different types of power consumption areas. Energy storage resources are needed to assist IC converters to realize the flexible interconnection between subnets; In addition, the low inertia problem of power electronic systems is more prominent in AC/DC hybrid microgrid. It is urgent to establish a unified inertia evaluation index of the AC/DC hybrid system, and make full use of various flexible and adjustable resources to respond to the inertia demand of the system.

Secondly, for AC/DC hybrid distribution network, needs to meet the stable operation requirements of frequency and voltage under the background of increasing penetration of clean energy, realize renewable energy consumption and reliable power supply, and provide a stable platform for source network load intelligent interactive operation under the background of energy Internet. The flexible and reliable operation of such multiple scenarios also needs to rely on the energy storage system with the ability of energy space-time transfer and allocation, and the collaborative control method of energy storage to meet the needs of multiple types of power grid needs to be studied. Finally, electrochemical energy storage is the main energy storage resource that can be flexibly allocated in the power system, but at present, chemical energy storage resources are still relatively expensive. Examination of transmission and distribution pricing costs made it clear that "the electric energy storage facilities invested by power grid enterprises are clearly not included in the transmission and distribution pricing costs." It means that the construction of power grid side projects is lack profit channel support in the short term, and the development of power grid energy storage is restricted. Hence, besides innovating at the level of energy storage materials to reduce costs, optimizing collaborative control methods at the application level, improving their own utilization rate, increasing net benefits as much as possible, and offsetting cost disadvantages are the practical needs of the marketization of energy storage industry and the development of the whole energy industry. The feasibility of distributed energy storage collaborative control research is mainly reflected by the current situation of energy storage application and industrial development trends. Firstly, thanks to the fast response characteristics and mature control technology of power electronic converter, we can easily realize the multi quadrant operation of energy-storing system and the coordinated control between different energy storage components. Therefore, the cooperative operation and control of distributed energy storage is technically feasible at the bottom control level.

3.2. Cluster Division Principles and Indicators. The structural characteristics of community network classification generally include time-domain characteristics, coupling strength characteristics, overlapping characteristics, and hierarchical characteristics. The cluster is the refinement of the complex network community in the computer field. Power network clustering is an extension of the theory of the complicated structure of the community in the power network, in which the vertices and their connections which has certain characteristics in the power grid can be distinguished, and it aims to find out the extensive power network located in different areas to facilitate control and scheduling. The "Guidelines for the Safety and Stability of Power Systems" pointed out that the grid structure and power supply structure should meet the principle of "layering and partitioning." The cluster structure is shown in Figure 4. Characteristics of cluster division are shown in Figure 5.

As the proportion of distributed power sources and electric vehicles connected to the distribution network continues to rise at this stage, it has brought a series of impacts on the local network. Conventional solutions directly adjust from the perspective of the power grid and nodes, with limited effects and low efficiency. Carrying out regulation and control work on the basis of the cluster division of the distribution network can further improve the source-load matching ability and realize the hierarchical and zoned control of the power grid. Distribution network cluster division mostly takes nodes as basic units and categorizes nodes with similar electrical distances and electrical characteristics according to electrical characteristics between nodes. The principles generally followed in the division process are:

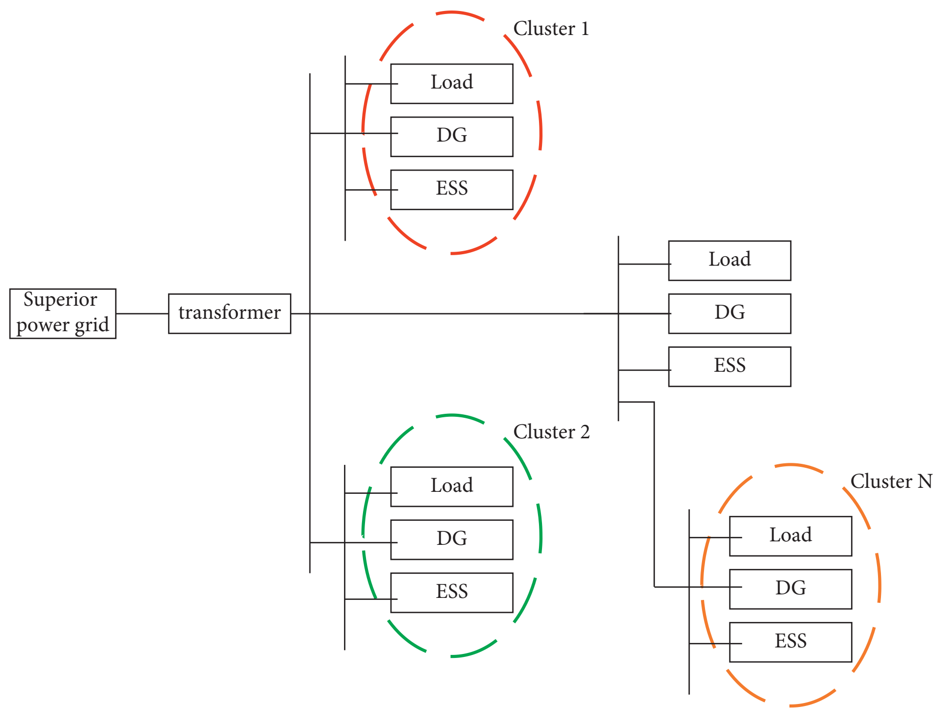

Figure 3: Cluster-based distribution network architecture.

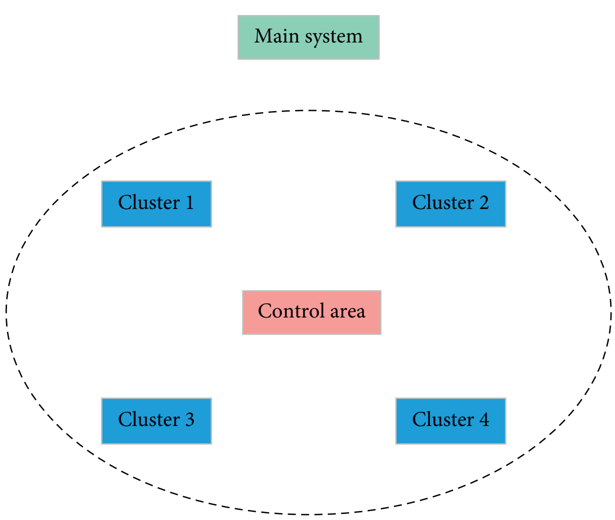

Figure 4: Cluster structure.

(1) Logic principle

(2) Functional principle

The cluster division indicators are as follows:

(1) Modularity based on electrical distance

Modularity is an indicator to measure the structural strength of the network community. By quantifying the structural strength of the cluster, the degree of division is measured and the optimal division method is determined. The degree of network modularity is usually determined by the network connection and the edge weights between nodes. In the power network, the edge weights between nodes are mainly represented by reactance weights, spatial distance weights, and electrical distance weights, among which electrical distance weights can more effectively reflect the electrical connections between nodes in the power network.

$$\begin{gathered}\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix}=\begin{bmatrix}H & N\\ M & L\end{bmatrix}\begin{bmatrix}\Delta\delta\\ \Delta V\end{bmatrix},\\ \begin{bmatrix}\Delta\delta\\ \Delta V\end{bmatrix}=\begin{bmatrix}H & N\\ M & L\end{bmatrix}^{-1}\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix}=\begin{bmatrix}S_{P\delta} & S_{Q\delta}\\ S_{PV} & S_{QV}\end{bmatrix}\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix},\\ \Delta V=S_{PV}*\Delta P+S_{QV}*\Delta Q,\end{gathered}\tag{1}$$

where S_{PV} is the node active voltage sensitivity matrix.

$$\begin{gathered}d_{ij}=\frac{1}{2}\sum_{k=1}^{N-1}\left(X_{ik}-X_{jk}\right)^2,\\ X_{ij}=-\lg\left|\frac{S_{ij}}{\max_j S_{ij}}\right|,\end{gathered}\tag{2}$$

where d_{ij} is the electrical distance between node i and node j, S_{ij} is the element of row i and column j in the sensitivity matrix, $\max\{|S_{ij}|\}$ represents the maximum value of the element in column j of the active voltage sensitivity matrix, N is the number of network nodes.

In order to describe the degree of electrical coupling between two nodes, the definition of modularity based on electrical distance weight is adopted to

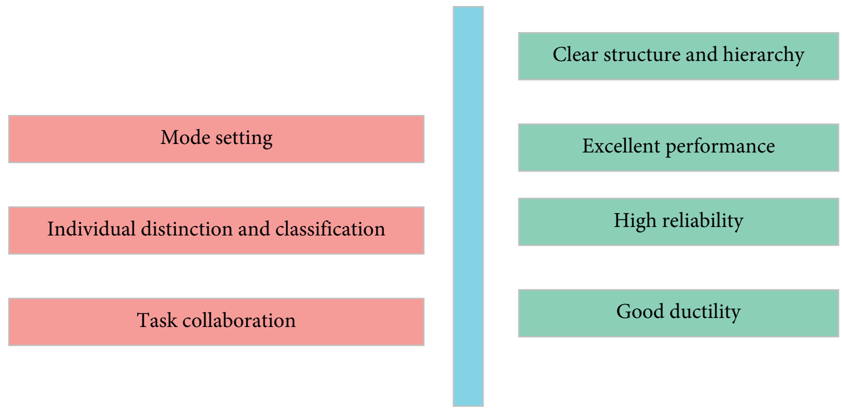

Figure 5: Characteristics of cluster division.

determine the optimal division of the system by measuring the overall modularity of the system.

$$f_1 = \rho = \frac{1}{2m}\sum_i \sum_j \left[d_{ij} - \frac{k_i k_j}{2m}\right]\delta(i, j),$$
$$\delta(i, j) = \begin{cases} 1, & i, j \text{ belongs to same partition}, \\ 0, & \text{otherwise}, \end{cases} \quad (3)$$

where ρ Is the system modularity, m is the sum of all edge weights in the network, D_{ij} is the electrical distance between node i and node j, and k_i and k_j are the sum of all edge weights connected to node i and node j respectively.

(2) Power balance

Active power balance degree is an index reflecting the self-absorption ability of distributed generation in a certain period.

$$f_2 = P_{\mathrm{ck}} = 1 - \frac{1}{T}\sum_{t=1}^{T}\left|\frac{P_{\mathrm{clu}}(t)}{\max\left(P_{\mathrm{clu}}(t)_{\mathrm{ck}}\right)}\right|,$$
$$\varphi_P = \frac{1}{c}\sum_{c_k \in c} P_{c_k}, \quad (4)$$

where ϕ_p is the active power balance index of the divided cluster; P_{ck} is the active power balance index of the c_k cluster, and T is the time scale of the scene. $P_{\mathrm{clu}}(t)_{\mathrm{ck}}$ is the net power value of the c_k th cluster at time T (understood as the surplus power in the region). Under the T time scale, the net power of node i is $Pi = [Pi(1), Pi(2)m, \ldots, Pi(T)]$, and the net power of cluster c_k is the sum of all nodes in the cluster; max is the maximum value.

4. Energy Storage Cluster Partition Method of a Distribution Network Based on Genetic Algorithm

4.1. Principle of Genetic Algorithm. A genetic algorithm (GA) is an automatic search and optimization method based on Darwin's biological evolution law and simulated natural selection and genetic mechanism.

As shown in Figure 6 Compared with conventional optimization methods, genetic algorithms have the following main differences:

(1) In each optimization step, GA always retains the population size of a certain individual, and each individual in the population is a solution to the problem, and a certain high-quality population individual is retained in each process; while the conventional method always retains the population size of a certain individual. There is usually only one optimal solution for each iteration.

(2) GA expresses the solution of the problem by encoding the individual, and the individual is driven by a certain probability factor (hybridization, mutation, etc.) in the process of optimizing; conventional methods generally have more certainty in the process of solving.

(3) In the optimization of individual solutions, GA usually measures the pros and cons of the solution according to the fitness function (that is, the degree of fitness of the individual solution in the optimization process); conventional methods are generally measured by the reciprocal or second derivative.

4.2. Cluster Partition Method considering Comprehensive Performance Index

4.2.1. Objective Function. Integrating the overall system modularity and regional active power balance, and taking the system division mode as the variable, the following distribution network cluster division model is established.

$$\max F_c = \lambda_1 f_1 + \lambda_2 f_2, \quad (5)$$

where λ_1 and λ_2 are the variables and f_1 is the modularity index, f_2 is the active power balance index, and F_c is the comprehensive performance index of cluster division.

4.2.2. Solution Flow. In order to represent the cluster division of the distribution network, the roads connecting the

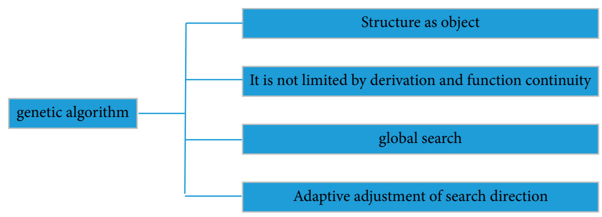

FIGURE 6: Features of genetic algorithm.

nodes of the distribution network are numbered, and the binary coding form is used to represent the connection of each branch, where 0 represents the connection of the branch and 1 represents the division of the branch. Taking IEEE33 power distribution system as an example, each gene locus of a chromosome is defined as 00001000 00000000 00000000 10000000, indicating that branch 5 is disconnected from branch 25, as shown in Figure 7.

On the basis of encoding the chromosomes, the solution is solved based on the genetic algorithm solving process. The specific steps are as follows: first, automatically generate the initial population, calculate the initial fitness, and adopt the elite retention method to retain the best individuals of each generation, and the rest of the individuals participate During the cross-mutation process, algebraic updates are continuously performed until the fitness meets the requirements or the maximum number of iterations is reached. In order to eliminate the influence of the randomness of the solution process in the process of using the genetic algorithm, the following settings are made when dividing the distribution network cluster:

(1) Increase the number of populations in each generation and set up multiple sets of initial samples for experimentation
(2) Crossover points are randomly generated during each generation of crossover
(3) Properly increase the probability of chromosome mutation during the solution process

5. Design of Voltage Regulation Control Strategy for Cluster Energy Storage

The voltage deviation of the distribution network includes overvoltage and undervoltage, which are mainly caused by load growth, a high proportion of new energy grid connection, and unreasonable grid structure. The distribution network is directly connected to various electrical loads, and various voltage deviations will directly affect the system's power quality. As we described in Section 1, with the promotion of supportive policies, distributed power generation technology and the market are becoming more mature. While the proportion of DGs is linked with the network is still getting more and more, we also need much more power with high quality to feed in the network. In this chapter, based on the voltage limit phenomenon caused by DG, we use the electric vehicles to build connections between the network based on the analysis of traditional energy storage participating in the voltage regulation of the distribution network, through the establishment of cluster division indicators, the distribution network distributed cluster storage is proposed. It can adjust the voltage control strategy, and the effectiveness of the strategy is verified through the simulation of the IEEE33 node.

5.1. *The Formalization of the Optimization Problem.*

In this paper, we need to realize the optimal daily operation benefit of an energy storage system based on eliminating node voltage out of the limit.

$$\max F = F_T + F_{\text{loss}}, \tag{6}$$

where, F stands for the benefit obtained by the daily operation in energy storage; F_{loss} benefits from reducing the cost of network loss within days after the energy storage is linked to the distribution network; F_T is the peak shaving and valley filling arbitrage income within the energy storage day. The ways we compute each component can be seen in the following sections.

5.1.1. *Arbitrage Income F_T.*

The arbitrage income is defined as the difference between the power sales income obtained by energy storage discharge and the power purchase cost paid by charging.

$$\begin{aligned} F_T &= F_{\text{sale}} - F_{\text{buy}}, \\ F_{\text{sale}} &= \sum_{l=1}^{N_{\text{ESS}}} \sum_{t=1}^{T} \left(M(t) P_{\text{ess},J,\text{dis}}(t) \Delta t \right), \\ F_{\text{buy}} &= \sum_{l=1}^{N_{\text{ESS}}} \sum_{t=1}^{T} \left(-M(t) P_{\text{css},l,\text{char}}(t) \Delta t \right), \end{aligned} \tag{7}$$

where, F_{sale} is the power sales revenue brought by the release of electric energy when we check the peak load period; the real power purchase cost F_{buy} of energy is the cost caused by the superior power grid. $P_{\text{ess},l,c}$, $P_{\text{ess},l,\text{dis}}$ Are the charging and discharging power of the first energy storage at time t, N_{ESS} is the number of energy storage.

5.1.2. *Loss Income F_{loss}.*

The network loss revenue is defined as the difference between the system network loss cost F_{loss1} before energy storage access and the network loss cost F_{loss2} after access.

$$\begin{aligned} F_{\text{loss}} &= F_{\text{LOSS1}} - F_{\text{LOSS2}}, \\ F_{\text{LOSS1}} &= \sum_{t=1}^{96} M(t) \left(\sum_{n=1}^{N_L} P_{(\text{loss},n)}(t) \right) \Delta t, \\ F_{\text{LOSS2}} &= \sum_{t=1}^{96} M(t) \left(\sum_{n=1}^{N_L} P_{\text{loss}-\text{ESS},n}(t) \right) \Delta t. \end{aligned} \tag{8}$$

The value 96 is upper value of the summation where $t = 1$ $M(t)$ the time of use price of electricity is purchased from the main network at time t; $P_{\text{loss},n}(t)$, $P_{\text{loss}-\text{ESS},n}(t)$ are the active line loss of the n^{th} branch at time t before and after

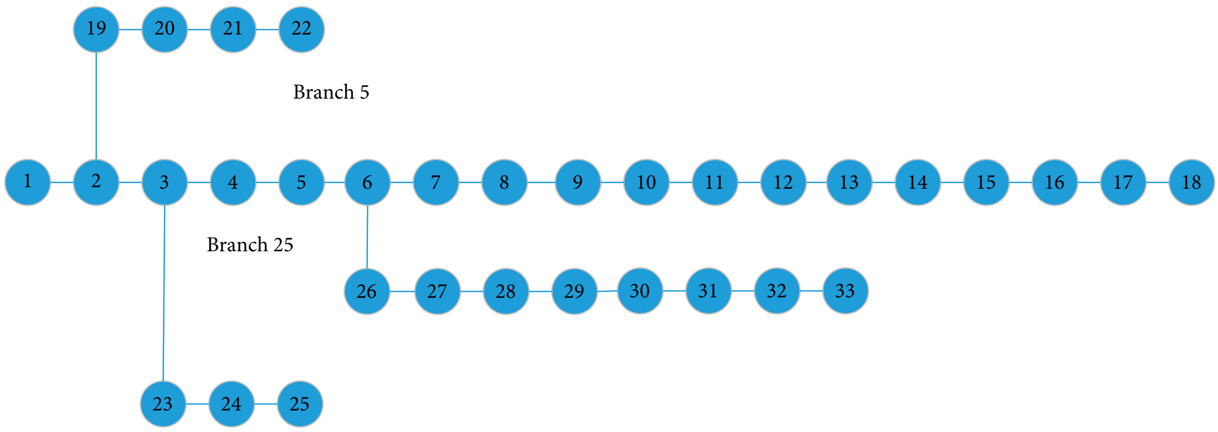

FIGURE 7: IEEE33 node system diagram.

energy storage access; N_L is the total number of distribution network branches.

Divide the distribution network into different clusters with the system modularity as an indicator, set the voltage regulation ratio as the initial value; select the most severe node in the cluster with the most severe voltage overrun as the priority regulation object, and calculate the upper and lower limits of the voltage regulation corresponding to the regulation ratio. Use the internal energy storage charging and discharging of the cluster to adjust the voltage, and cyclically detect and adjust the voltage of each overlimit cluster node until the voltage of the whole network is restored to a reasonable range; then continuously update the voltage adjustment ratio and output the energy storage operation under different adjustment ratios Income; Finally, determine the optimal voltage regulation ratio and energy storage timing output. Specific steps are as follows.

Step 1. Input the parameters used in the system, and the parameters typically included daily load, EV, DG data, and so on, construct a modularity index based on electrical distance, and substitute the proposed genetic algorithm-based distribution network cluster method for a solution to form a distribution network node cluster.

Step 2. Count the time and amplitude of the internal node voltage overrun in each cluster; if there is a node voltage overrun, filter the cluster with the largest overrun cluster amplitude (take the maximum time under the same amplitude), set the voltage adjustment ratio λ_{ad} to 0, and set the iteration The number of times $h = 1$, otherwise no action.

Step 3. Select cluster K with the most severe over-limit voltage as the adjustment object, count the voltage over-limit amplitude of each node in K, select the most severely over-limit node L as the adjustment object, and calculate the voltage sensitivity of node L is: $S_{LL} = \partial E_L / \partial P_L$.

Step 4. Calculate the upper bound and the lower bound of the adjustment voltage corresponding to the adjustment ratio (U_u and U_d)

Step 5. Output $P_{ESS,h}(t) = P_{char}(t) + P_{dis}(t) + P_{bl}(t)$,

Step 6. Determine whether the voltage adjustment ratio is less than the maximum value. If the condition is met, increase the voltage adjustment ratio, the number of iterations $h = h + 1$, return to Step 3 and re-enter the loop until the condition is not met.

Step 7. Determine the corresponding energy storage operating income set within the adjustable range, get the maximum income $F = \max(A)$, and then output the timing output $P_{ESS}(m)$ corresponding to the optimal energy storage operating income F_m.

6. Experiment and Results

6.1. The Parameters. Using the IEEE 33-node distribution network example system, the system's baseline capacity is SB = 10 MVA, and the voltage level is 10.5 kV; nodes 12, 15, 30, and 32 are connected to distributed photovoltaic, and nodes 8, 21, 24, and 28 Connecting to distributed wind power, nodes 8, 15, 28, and 32 are connected to EVs; nodes 13, 18, 20, 24, 28, and 32 are connected to DES, and different energy storage clusters are formed according to the results of cluster division. Cluster 1 contains nodes 20 and 24 energy storage, cluster 2 includes nodes 28 and 32 energy storage, cluster 3 includes nodes 13 and 18 energy storage, the state of charge ranges from 0.05 to 0.95, and the initial state of charge is 0.2. The allowable voltage deviation range is ±5%. With the purpose of optimizing the modularity index, the suggested cluster division method is employed to divide the IEEE33-node power distribution system into clusters [11, 12]. The time-sharing voltage used in this paper is shown in Table 1.

6.2. Comparison of Different Energy Storing Control Strategies' Effects. In this paper's experiment, we want to verify the advantages of the strategy proposed in this article, under the premise of the same capacity configuration, the technical and economic effects of this article and the traditional solution are compared.

Table 1: Time of use tariff.

Time interval	Electricity price
Peak period	1.00
Peacetime segment	0.70
Valley period	0.39

(1) Scheme 1:

Traditional control method. Count the voltage limit violations of each node, calculate the node voltage influence factor of each energy storage installation point; select the energy storage where the influence factor accounts for the largest proportion to participate in the voltage adjustment, and determine the energy storage timing output according to the severely overlimit node overlimit amplitude and the two-node voltage sensitivity; Calculate system network loss income before and after adjustment and energy storage operation arbitrage income.

(2) Option 2:

Cluster voltage regulation control. Using the control strategy proposed in this paper, we spited the distributed network and energy-storing cluster, and the cluster energy storing power is calculated according to the results of the division. Since our goal is to maximize the overall income of energy storage, it is determined that the energy-storing is charged and discharged at the optimal power. So, we adopt two different schemes with the same adjustment ratio to strengthen the contrast.

Since the objective function proposed in our paper contains the information about the effectiveness of the control strategy proposed in this paper, two scenarios containing only the lower limit of voltage and the scenario of both lower limit and upper limit of voltage are constructed.

(a) Scenario 1: the voltage exceeds the lower limit

When the EV access ratio is high and the DG access ratio is low, the voltage of distribution network nodes exceeds the lower limit. [14] Photovoltaic access points are connected to 0.3 MW, wind power access points to 0.2 MW, and electric vehicle access points to 0.1 MW. Table 2 shows the energy access node and installed capacity.

With the continuous improvement of regulation ratio, the revenue of energy storage operation increases continuously until the maximum value of voltage regulation standard is obtained. In our opinion, there are three different reasons which can explain this phenomena, they are:

(1) The amount of electric energy released for energy storage is increasing, and the out-of-limits periods are generally during peak price periods, resulting in an increase in energy storage arbitrage income.

(2) The network loss benefit is related to the reduction of network loss during the regulation voltage out of limit period and the increase of network loss during energy storage and charging. The network loss reduction tends to be saturated as the regulation ratio grows, whereas the network loss caused by energy storage and charging gradually increases. At the same time, the power flow also brings a certain network loss, resulting in the change of network loss benefit in the form of a convex function.

(3) As the model aims to maximize the comprehensive income of energy storage, there are more low storage and high-power generation in this scenario, and the reduction of network loss is relatively small, so the income of energy storage mainly comes from arbitrage income.

Table 2: Equipment parameters.

Time interval	Node	Capacity (MW/MWh)
PV	12	0.3
	15	0.3
	30	0.3
	32	0.3
PW	8	0.2
	21	0.2
	24	0.2
	28	0.2
EV	8	0.1
	15	0.1
	28	0.1
	32	0.1
DES	13	1.5/2
	18	1.5/2
	28	1.5/2
	32	1.5/4.6

7. Conclusion

The large-scale connection of DG and EV to the distribution network brings voltage problems and new energy consumption problems. The conventional energy storage control directly uses the energy storage of each node to regulate the whole distribution network. The energy storage system has low operation efficiency, relatively insufficient economy, and is difficult to meet the hierarchical and zoning control of the power grid. After having a detailed analysis of the traditional energy storage control strategy and the meaning of "cluster" in the computer field, this paper puts forward the cluster division method of distribution network. On this basis, the cluster energy-storing control method is proposed for the voltage out of the limit problem and new energy consumption problem respectively, and the simulation and analysis are carried out through the IEEE-33 node distribution network simulation example, the conclusions are as follows:

(1) We proposed a distribution network cluster partition model based on genetic algorithm. Based on the establishment of a typical distribution network structure, the reference indexes for cluster division are determined from two aspects: one is the logic

principle, mainly including the modularity index based on electrical distance; The second is the functional principle, mainly including the regional active power balance index. The disconnection of distribution network branches is expressed in the form of binary code and taken as an individual solution. The optimization is carried out by genetic algorithm with the maximum objective function, so as to achieve the purpose of optimal cluster division of distribution network.

(2) Aiming at the node voltage out of limit caused by the large-scale access of DG and EV to the distribution network: (a) two typical voltages out of limit scenarios are constructed: one is that the voltage exceeds the lower limit only, and the other is that the voltage exceeds the lower limit and the upper limit at the same time. (b) Based on the division of distribution network clusters, a cluster energy storage and voltage regulation control strategy is proposed. By analyzing the influence of DG access on node voltage of distribution network and the mechanism of energy storage participating in distribution network voltage regulation, a method of cluster voltage regulation is proposed to realize the purpose of distribution network voltage regulation.

(3) For the sake of getting the new energy consumption caused by power reverse transmission of distribution network:

  (a) An energy storage power determination method based on cluster net power load characteristics is proposed, and we compared it with the traditional control strategy based on capacity allocation, the determination method of energy storage timing power is improved.

  (b) On the basis of considering the cluster division of comprehensive performance, a new energy storage and consumption control strategy based on cluster division is proposed. By analyzing the mechanism of energy storage participating in the new energy consumption of distribution network, the determination methods of cluster energy storage and node energy storage power under different new energy consumption ratios are proposed.

  (c) Under the same energy storage configuration, the consumption proportion of new energy can be increased by 15%. (d) At this stage, the energy storage cost is still at a relatively high price. Considering the energy storage investment cost, the profit range of energy storage operation is relatively small, and the income from additional consumption of new energy is still insignificant compared with the energy storage investment cost. When the reverse transmission power is fully absorbed, the arbitrage and network loss income brought by low storage and the high incidence is not enough to balance the cost of energy storage investment.

Combined with the operational requirements of AC/DC hybrid power grid scenario, this paper makes an in-depth analysis and research on the collaborative control model for distributed energy storing, but the application of energy-storing in power grid involves the comprehensive control among multiple subjects in the system, and with the change of operation scenario requirements and the increasing complexity of market development, combined with the current development trend, The collaborative control of distributed energy storage still has many contents worthy of further research.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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