Distributed Reactive Energy Storage Structure Voltage Reactive Power Control Algorithm Based on Big Data Analysis

Yang Xu[1(✉)], Jie Gao[1], Yong-biao Yang[2], and Hai-hong Bian[3]

[1] State Grid Jiangsu Electric Power Company Yangzhou Power Supply
Company, Yangzhou 225000, China
zxg560020@Sina.com
[2] Southeast University, Nanjing 210096, China
[3] Nanjing Institute of Technology, Nanjing 210000, China

Abstract. In the traditional distributed hybrid energy storage structure, there are security, island operation and capacity blocking. For this reason, a distributed hybrid energy storage structure voltage reactive power control algorithm is proposed based on big data analysis. First, establish a voltage reactive power control model, using the control or manual operation of the communication system to achieve automatic operation of the transformer tap or capacitor input capacity. Secondly, the Nash theorem is used to calculate the physical quantity obtained by the secondary user under certain transmission power conditions. Based on the game theory, the operating data of the power grid is obtained, and then the voltage reactive power control algorithm is realized. Finally, experiments show that the distributed reactive energy storage structure voltage reactive power control algorithm based on big data analysis has certain advantages compared with the traditional voltage reactive power control algorithm.

Keywords: Active power · Equilibrium node · Control variable · Nash theorem

1 Introduction

The AC-DC relay protection of the traditional distributed hybrid energy storage structure already has a large amount of tuning. Among them, the calculation index and formula are based on years of operation experience. Now, the distributed hybrid energy storage structure under big data analysis is connected to adjust the voltage, but there are still new problems in relay protection. In order to adapt to a variety of operation modes, each device in the voltage needs communication and corresponding control strategies, especially when the operation mode is converted or isolated network, the control mode determines whether the voltage frequency of the whole system can be stable. At present, there are two main control modes of voltage and reactive power control algorithm:

S. Liu and L. Xia (Eds.): ADHIP 2020, LNICST 348, pp. 91–102, 2021.
https://doi.org/10.1007/978-3-030-67874-6_9

1) The master-slave control mode refers to that there is a master controller in the voltage, which is responsible for maintaining the voltage frequency stability of the whole micro-grid during the operation of the isolated grid, and therefore adopts Vf control. As for other DGs, PQ control can be used. For those that can not be controlled, such as wind power without energy storage, photovoltaic maximum power tracking, these DGs are collectively known as the slave controller. In the voltage of master-slave control structure, some slave control units output constant power according to instructions, some slave control units have intermittent fluctuations, so once the load changes, it can only be tracked through the master control units, only when the power achieves a balance, the voltage and frequency can be stable, so the energy storage system that can achieve two-way rapid power flow is the best choice for the master controller. The master-slave control mode can realize the no-difference control of voltage and frequency. At present, there are corresponding demonstration projects in Holland, Greece and Japan. In this structure, the MU is not always controlled by Vf. When the MU is connected to the grid, the large power grid is responsible for maintaining the frequency stability. Otherwise, the system will be disturbed. That is to say, the main control unit has two control loops. When the voltage enters the isolated operation mode, the control loop switches quickly from PQ to Vf.
2) In the peer-to-peer control mode, all DG and energy storage systems have no master-slave relationship, they have the same status, and generally adopt droop control. The so-called droop control refers to the real-time acquisition of the output voltage and frequency, and the difference with the reference value, control feedback, local power compensation. In this structure, all the peer-to-peer control units are responsible for maintaining power balance, voltage stability and frequency stability, and work together to reach a new balance point when the load changes. Different from the master-slave control, even when the voltage operation mode changes, the control loop is still unchanged, which can realize the fast switching between grid connected and isolated network. In droop control, the coefficient directly affects the stability of the whole voltage. If the coefficient is not reasonable, it may cause voltage and frequency oscillation. Otherwise, each DG can automatically distribute power according to its own droop coefficient.

Due to the limitations of the traditional algorithm control device, once the grid has a large fault, it can not continue to provide support to the grid as much as the traditional thermal power. Considering the constraints of the branch flow, voltage access may cause other loads on the same line to be cut off, and frequent switching on the other hand will also affect the quality of the power supply. Due to the intermittent and forecasting errors of wind power, photovoltaic and other energy sources, the distributed hybrid energy storage structure may not be put into operation on time according to the requirements of the local main network controllers, which may result in high economic losses. To this end, based on big data analysis, the distributed hybrid energy storage structure voltage reactive power control algorithm is proposed to solve the problem of security, island operation and capacity blocking in the traditional distributed hybrid energy storage structure [1].

2 Distributed Hybrid Energy Storage Structure Voltage Reactive Power Control Algorithm

2.1 Establish Voltage Reactive Power Control Model

The voltage reactive power optimization compensation is to optimize the reactive power flow of the computing system and optimize the distribution of the reactive power compensation position and size in the system. Its real intention is to use the results of the reactive power calculation of the power system to achieve reactive power [2]. In fact, the optimal control of reactive power can be understood as a sub-process in the reactive power optimization process of the power system. That is to say, the control or manual operation of the communication system is used to achieve automatic operation of the transformer tap or capacitor input capacity. This is the most practical, simple, fast and safe operation method, which is also a direction for the development of power system control in the future [3]. In the process of research, the voltage reactive power control model is established based on this, and the voltage reactive power model structure is as follows:

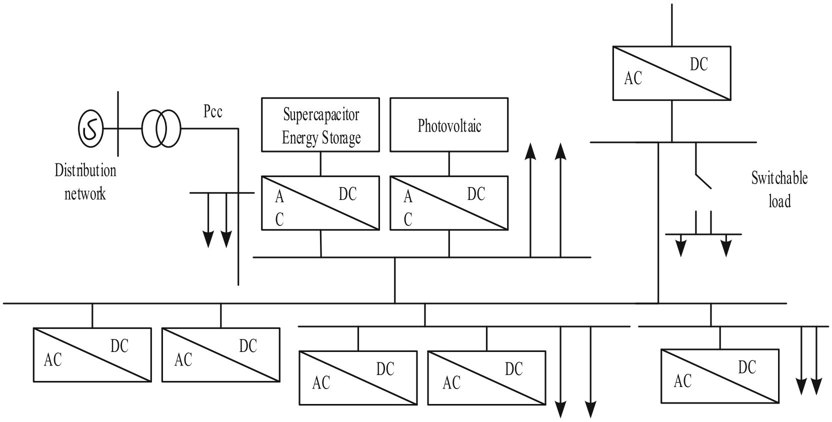

Fig. 1. Voltage reactive model structure

Figure 1 shows the voltage reactive power model structure. The voltage reactive power optimization of the distributed hybrid energy storage structure can be defined as the voltage reactive power control model that minimizes the active power network loss at a certain moment in the system operation. In the entire power grid, except for the balance node, the active power of the generator sets on all remaining nodes has been given. Moreover, the power level of the given node is always kept constant, so if you want to minimize the loss of the active power network of the system, you can turn this problem into the minimum active power injected by the balanced node. The objective function can also be written as the problem of the least active injection of the balanced nodes of the system [4]. The specific expression is as follows:

$$\begin{cases} m_e = b\sum_{ei} b_e(k_e\cos\theta + k_e) \\ n_e = b\sum_{ei} b_e(k_e\sin\theta - k_e) \end{cases} \tag{1}$$

In formula (1), m denotes the active voltage injected by the node, b denotes the reactive voltage injected by the node, k denotes conductance, n denotes susceptance, and e denotes phase angle difference [5]. The above is a node power equation expressed in polar coordinates. The constraint equation is also a mathematical model mainly used in the load flow calculation method such as Newton method.

Because the operation of the power system needs to meet certain economic and technical requirements, this requires certain constraints to be met in the calculation process. The constraints in the voltage reactive optimization problem contain state variable constraints and control variable constraints. The control variable constraint is divided into reactive power compensation capacity, the ratio of the load regulating transformer and the terminal voltage of the generator; the reactive power injected by the generator ensures that the voltage of each node is a state variable [6]. The constraint formula for all control variables in the system is as follows:

$$\begin{cases} F_{i\min} < F_i \\ B_{i\min} < B_i \\ T_{i\min} < T_i \end{cases} \tag{2}$$

In formula (2), F denotes that the control variable constraint is divided into reactive power compensation capacity, B denotes the terminal voltage of the generator, and T denotes the on-load voltage regulating transformer, $F_{i\min}$ is the lower limit and upper limit of the transformer ratio, $B_{i\min}$ is the lower limit and upper limit of the compensation capacity of the shunt compensation capacitor, and $T_{i\min}$ is the lower limit and upper limit of the generator terminal voltage [7]. When the result is negative, it follows the regular arrangement from small to large, and then sees whether the input of the corresponding bus shunt capacitor can be increased to change the amount of reactive compensation of the node.

Distributed hybrid energy storage structure voltage reactive power control has its own characteristics: the three-level coordinated control system can be compatible with a variety of communication protocols, and its data acquisition program has multiple acquisition methods [8]. This is because the three-level coordinated control is performed between different levels, which inevitably has the problem that the data interface of different voltage reactive devices is incompatible. In addition, the communication protocol and acquisition method are different for voltage reactive devices produced by different manufacturers or different types of device models produced by the same manufacturer. So far, the construction of the voltage reactive power control model is completed.

2.2 Realizing Voltage Reactive Power Control Algorithm

The voltage qualification rate is the most important quality indicator of the power grid, and the grid line loss rate is the most important economic indicator of the power grid. Effective voltage control and reasonable reactive power compensation can not only ensure voltage quality, but also improve the stability and safety of power system operation, reduce power loss of power grids, improve transmission capacity of power grid equipment, and give full play to the economic benefits of power grid operation. Unqualified voltage will bring huge losses to the safe operation and social and economic benefits of electrical equipment. Reducing the power loss of the grid will greatly reduce the current shortage of power, which is of great significance [9]. With the development of technology, energy storage types are divided into three categories according to the energy storage form, namely mechanical energy storage, electromagnetic energy storage and battery energy storage. Table 1 shows the performance comparison results of various energy storage technologies. Among them, pumped storage has been widely used because of its mature technology and large capacity, while super capacitor, superconducting magnet, liquid flow battery, flywheel energy storage and other technologies are more convenient to use and have their own advantages, but they are still in the development stage.

Table 1. Comparison of advantages and disadvantages of various energy storage technologies

Energy storage type		Advantage	Inferiority
Mechanical energy storage	Pumped storage	High power, large capacity and low operation cost	Special geographical environment
	Flywheel energy storage	High-capacity	Low energy density
	Compressed air energy storage	High power, large capacity and low operation cost	High environmental requirements
Electromagnetic energy storage	Superconducting magnetic energy storage	High-capacity	High investment cost, low energy density
	Super capacitor energy storage	Long life, high efficiency, fast charging and discharging	High investment cost, low energy density
Battery energy storage	Lead acid battery	Low investment	Short life
	Ni MH, Ni Cd batteries	Large capacity, long life	Low energy density
	All vanadium flow battery	High capacity, high energy density	Low power density

Energy storage technology can directly and effectively solve the problem of unbalanced power supply and demand. At present, the role of energy storage system in the power grid can be summarized as four points: first, it can be used to cut peak and fill valley in the power system; second, energy storage technology can improve the reliability of power supply, and play a role of temporary power supply in case of power failure due to system failure, that is, the role of uninterruptible power supply (UPS) to reduce Accident and economic loss caused by sudden power failure; once again, the energy storage device can charge and discharge instantaneously, with similar functions as SVC, statecom and other devices, and has an auxiliary supporting role in maintaining the stability of the power grid, which is helpful for the system to reach a new balance point under the large disturbance state such as short circuit fault of the power grid; finally, it is a necessary device for intermittent energy generation such as wind power, photovoltaic and other energy storage devices It can not only suppress the power fluctuation, but also maintain the voltage and frequency stability of microgrid as the main control element under the operation condition of isolated network. In one cycle, the change curve of battery state of charge is shown in Fig. 2.

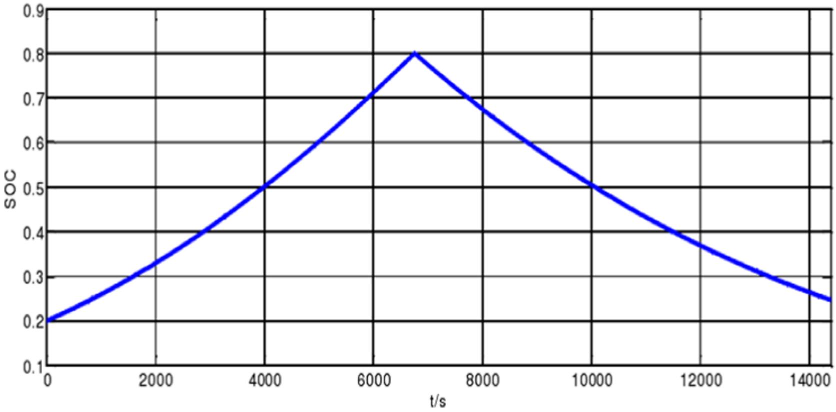

Fig. 2. Change curve of state of charge

The traditional voltage reactive power control strategy is that the control devices at each level first collect the local voltage value and the reactive power value, and then take corresponding control measures according to the control principles of the equipment at all levels. It can only implement voltage and reactive power control for this level, but it does not affect each other and is not related to each other. In the case where there is no mutual communication between the equipments at all levels, the regulation strategy of the distribution station area has been exhausted, the voltage at the end of the user is still low, and the substation side and the line part are regulated but cannot participate in the regulation. This causes a waste of resources used by the equipment. Therefore, the traditional voltage reactive power control method only relies on the independent voltage and reactive power control performed by the devices at all levels, and cannot realize the synchronous adjustment of the operating states of the devices at all levels. This makes the substation, line, and station equipment unable to complement each other effectively, and the equipment control margins of all levels are not fully utilized.

In order to effectively control the voltage and reactive power of the distribution network, according to the voltage reactive power control model, a voltage reactive power control algorithm is proposed for the distributed hybrid energy storage structure. The distributed reactive energy storage structure voltage reactive power control algorithm mainly relies on reactive power compensation devices at all levels. Through the wireless communication public data exchange platform to realize the data exchange between the control center and each reactive compensation control device, not only the operation data of the power grid is obtained, but also provides the analysis basis for the control [10, 11]. At the same time, it can also provide a good solution for remote control of the compensation device, greatly reducing the number of equipment actions and extending the life of the equipment.

Based on the voltage reactive power control model, the research of voltage reactive power control algorithm is realized. In the voltage reactive power control algorithm, the Nash theorem is used to optimize the voltage reactive power control algorithm, and the calculation formula is as follows;

$$h = \arg\max \eta(j_i - j_{i\min}) \tag{3}$$

In formula (3), h represents the utility function, j represents the maximum utility in the cooperative game, and i represents the cognitive user. Where $\arg\max$ represents the minimum utility function value of user i. The utility function is the physical quantity obtained by the secondary user under certain transmit power conditions. In the voltage reactive control model, the utility function definition formula is as follows:

$$u_i(p_i, y_i) = \eta(y_i - y_i^{\min}) \tag{4}$$

In formula (4), u denotes a cognitive user, y denotes a maximum utility function, and p denotes a policy space. In the process of calculation, the initial transmission power of a group of users needs to be selected, the power meets the minimum normal communication condition, and the initial interference power of the primary user is set to zero. The transmission power is obtained by using the Nash theorem.

Nash equilibrium is an important term in game theory. Nash equilibrium means that in a strategy combination, there are n participants. Under certain circumstances, if any player participant changes the strategy alone, then all users participating in the game will not increase the revenue [12, 13]. Before giving the definition of Nash equilibrium, we first need to give a mathematical description of the three elements of the game. We usually use $S_1, S_2.S_3, \ldots\ldots, S_N$ to represent the set of strategies that all participants can choose in a game with n participants. The i-th strategy of game participant j is denoted by $S_{ij} \in S_i$. $u_i, u_2.u_3, \ldots\ldots, u_N$ represents the revenue of each game participant, and u is the income of the i-th participant. The parameter setting values of the Nash theorem optimized voltage reactive power control algorithm are as follows (Table 2):

Table 1 is the parameter setting value of the Nash theorem optimized voltage reactive power control algorithm. At the same time, in the voltage control reactive power optimization, the high and low voltage reactive power compensation is planned,

Table 2. Parameter setting of Nash theorem optimization voltage reactive power control algorithm

Node 1	Node 2	Resistance	Reactance
1	2	0.2344	0.6578
2	3	0.3244	0.7654
3	4	0.2565	0.4356
4	5	0.3454	0.6458
5	6	0.3455	0.6238
6	7	0.7678	0.4738
7	8	0.8788	0.7939
8	9	0.5467	0.2375
9	10	0.4566	0.3896
10	11	0.7864	0.3893
11	12	0.4676	0.9046
12	13	0.1256	0.5693
13	14	0.1266	0.5486
14	15	0.2652	0.5623
15	16	0.1653	0.2653

mainly including two types. First, a fixed capacitor bank with a corresponding capacity of 15% capacity is configured. The high voltage network is arranged on the voltage load bus, and the low voltage network is arranged on the distribution side. The second is to install a fixed compensation capacitor bank at the voltage feeder load center or somewhere according to the reactive demand at low load. The qualified voltage values of the power grid are not only one, but the range of the upper and lower limits. If the three-level joint control is not carried out, there is no mutual communication between the distribution transformer and the user. This will cause the voltage value of the low-voltage user side to be smaller than the minimum value of the voltage interval, and the regulation side has the regulation margin but does not participate in the regulation. The reason why the transformer control device does not operate is because its own voltage value is normal, so it will not adjust and control the low voltage of the low voltage user. This results in a low voltage user side voltage deviation from the normal range of voltage is not improved.

If the voltage reactive three-level joint control is adopted, when the above situation occurs, if there is a control margin on the distribution side, the voltage reactive power control device at the distribution will immediately take effective measures to adjust. This is based on the analysis of the voltage on the distribution side. If the transformer, the line, and the distribution side are combined for analysis, the control strategy is more complicated and contains more levels of logic [14, 15]. This kind of coordinated control is a comprehensive consideration of the coordinated control of various voltage levels and various types of voltage regulation and reactive power equipment in rural power grids. It includes “adjacent coordination” and “neighborhood coordination” based on “adjacent coordination”. “Adjacent coordination” is divided into three situations: mutual control of “feeder” and “substation”, mutual control of “user” and “distribution”, mutual control of “distribution” and “feeder”; “Neighboring coordination” refers to fully digging the control capabilities of equipment at all levels on the basis of the adjustment control of “adjacent coordination” to achieve comprehensive control of cross-level assisted voltage regulation [16].

After configuring the appropriate reactive power compensation capacity, the distribution network has a certain reactive power compensation capability. However, the non-intelligent and uncontrollable fixed compensation method cannot adapt to the dynamic requirements of the system load change, and the compensation effect is poor. At present, the power sector mainly uses a variety of reactive power compensation intelligent control components to perform a certain degree of intelligent control on the capacitor bank, so that the control effect has been correspondingly improved, and the power grid has a certain optimization ability. However, for a large-scale distribution network system, it is impossible to achieve the optimization goal of the system or even a distribution network feeder by relying on local optimization control alone. Therefore, based on the voltage reactive power control model, a distributed reactive energy storage structure voltage reactive power control algorithm based on big data analysis is proposed.

3 Experimental Results

In order to verify the validity of the distributed reactive energy storage structure voltage reactive power control algorithm based on big data analysis, the traditional voltage reactive power control algorithm and the distributed hybrid energy storage structure voltage reactive power control algorithm based on big data analysis are respectively carried out. In the experiment, the PI parameters of the voltage outer loop PI controller of the two algorithms are consistent. The test parameters are as follows:

Table 3 is the test environment. The comparison results of the two algorithms are as follows:

Table 3. Test environment

Experimental parameters	Numerical value
Net side power supply voltage	34
Given voltage on DC side	35
DC side resistance load	36
AC side equivalent inductance	63
DC side support capacitor	24
Control cycle	2
Switching period	2.3

As can be seen from Fig. 3, in the steady-state state, the sinusoidal current obtained by the distributed reactive energy storage structure voltage reactive power control

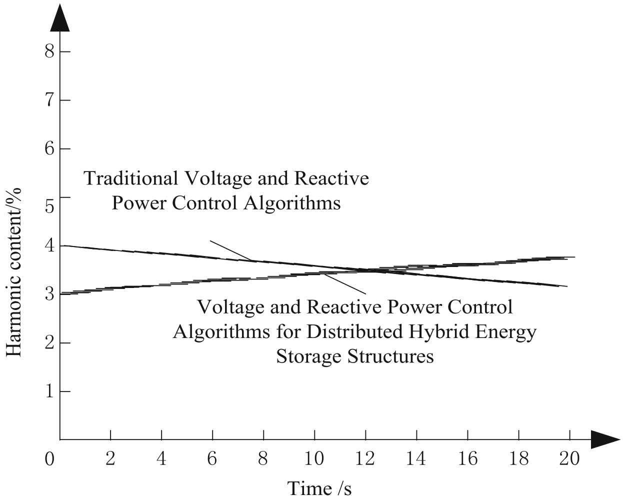

Fig. 3. Comparison of experimental results

algorithm is relatively large, while the sinusoidal current obtained by the conventional voltage reactive power control algorithm is relatively small. The analysis results of the power grid side current show that the harmonic content of the traditional voltage reactive power control algorithm is relatively high, which is 8.70%. Moreover, harmonics are mainly distributed in the low frequency band, and the switching frequency is not fixed. The current harmonic content on the network side of the distributed reactive energy storage structure voltage reactive power control algorithm is small, and the harmonic content is 3.38%. The high frequency harmonic components are mainly distributed around 2 times of the switching frequency, and the switching frequency is fixed. Compared with the traditional voltage control algorithm, the harmonic content of the distributed harmonic storage structure voltage reactive power control algorithm is between the two, the harmonic content is 4.25%. The harmonic high frequency component is mainly distributed around 2 times of the switching frequency, while the harmonic low frequency component is distributed between the two, which is a great improvement compared with the traditional voltage control algorithm.

4 Conclusion

With the development of distributed power technology, voltage and reactive power control is a new type of voltage structure. It can not only connect the traditional voltage, but also operate in isolation. Because of the intermittent energy access, the safe and stable operation of voltage and reactive power control can not be separated from the energy storage system. The hybrid energy storage system of liquid flow battery and super capacitor can give full play to their advantages, increase the growth space of their own advantages, and significantly extend the cycle life of energy storage elements. In the safe and reliable operation of distributed hybrid energy storage structure under big data, energy storage technology is the key, which plays an important role in uninterrupted power supply, improvement of power quality and improvement of photovoltaic power supply performance. The voltage reactive power control algorithm combines the characteristics of energy and power storage, which reduces operating costs and greatly improves the utilization of energy storage. In this paper, the distributed hybrid energy storage structure is used and its characteristics are analyzed, and the voltage reactive power control model is established. On this basis, the voltage reactive power control algorithm is implemented. The shift of voltage and frequency is also regarded as the key point of optimization. Taking the minimum square sum of shift as the objective function, on the basis of stability optimization results, the droop coefficients KPF and kqv are updated through multiple simulation calculations, and finally an optimization program with internal and external cycles is formed. The intermittent energy such as fan can be regarded as the load with negative power, and its transient characteristics are ignored and replaced by load. Then the small signal model is derived in the simplified microgrid. In the future research, in order to get more accurate parameter optimization results, we should study the small signal model derivation method for complex networks, and then expand the application scope of this method.

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