A centralized coordinated control strategy for distributed generation when microgrid on grid

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Abstract. This paper presents a centralized and coordinated control strategy for microgrid, whose control strategy includes the coordinated control of renewable energy sources (RESs) and energy storage systems (ESSs). To solve the schedulability of distributed generation in a microgrid, when it operates in grid-connected, a multiple operation mode is adopted, through switching the operation mode, the charge/discharge and state of charge (SOC) of ESSs can be maintained, and the loads will be shared by RESs first when microgrid occurs power deficiency, it reduces loss of ESSs. In this paper, a secondary control strategy for the microgrid model by simulated in MATLAB/Simulink, it through switched three modes, improves schedulability of microgrid and realizes SOC balance smoothly. The results show centralized and coordinated control strategy is accurate and useful.

1. Introduction
Energy is an essential material basis for economic and social development. In recent years, energy demand has continued growth, fossil energy becomes increasingly depleted, and nuclear energy been restrictive development, energy issues a severe challenge for countries around the world [1] frequently. Also, the aging of the traditional power system structure and the increasing requirements of users for power quality made the development and utilization of renewable energy become the perfect way for sustainable development of society. Distributed generation (DG) has received more and more attention in the 21st century because of its environmental protection, high efficiency, flexibility, and low investment. The American Electric Power Research Institute (EPRI) pointed out the cumulative power generation of photovoltaics in the United States will reach 20 million megawatts by 2020, occupy about 15% for the total amount of new power generation [2]. The European Union formulated the White Paper on Renewable Energy Development in 1997, which requires wind power as the primary alternative energy source, and wind power will reach 22% in total European electricity supply by 2030. The accesses of DG will improve the distributed generation capacity of the distribution network to a certain extent, alleviate the distributed generation pressure. However, the output of DG is random, and their massive accesses will bring a series of uncertainty impacts on the distribution network [3]. The main effects are as follows:

- There are a lot of distributed generators (fans, photovoltaics and energy storage) with converters as interfaces in the microgrid, but the converter lacks mechanical parts similar to the synchronous generator rotor, which leads to the lack of inertia in the microgrid. When disturbances such as abrupt load change occur in the microgrid, the voltage and frequency of the microgrid will change rapidly, requiring that the distributed power supply can respond quickly, which poses a challenge to the coordinated control of the distributed power supply.
The out of new energy generating units has volatility and randomness, to make the microgrid become a controllable unit, it needs other distributed generators to suppress the fluctuation of the output of new energy generators [4].

The microgrid is one of the valid ways to settle the problem of DG and grid-connected problems. It both run on the grid and remote island operation, improves the flexibility and reliability of the load distributed generation [5]. However, DG makes up the microgrid are diverse and have different performances. For instance, new energy generation has problems of uncertainty and volatility, energy storage can regulate the power of charge and discharge quickly, it stabilizes the fluctuation of the output power belong to new energy generator [6]. For economic reasons, the capacity of the energy storage configured in the microgrid limited by the proportion of the installed capacity. In the situation of finite volume of energy storage, a problem which is SOC must consider in operation. If the SOC has too high value or too low value, it will influence the regular operation of ESSs. Also, when there are multiple energy storages in the microgrid, it is necessary to balance the SOC of the energy storage to avoid some grave charge of the energy storage [7]. Other deep discharge situation will affect operation and energy storage life of the microgrid. Therefore, how to coordinate the control of the DG in the micro-network according to the various types of characteristics, take advantage of various distributed power sources and make better achieve the microgrid control objectives is an issue that needs research genuinely.

In the research aspect, the literature [8] proposed Maximum Power Point Tracking (MPPT) mode when Microgrid runs on power grid; energy storage only participates in peak-cutting and valley-filling of power grid during a peak-valley period of load. The literature [9] proposed that new energy generators operate in MPPT mode when the levy grid connected to power grid. Storage energy participates in peak load reduction while charging to SOC upper limit with continuous power during non-peak load period. The literature [10] pointed out that when the microgrid connected to the grid, the stored energy is charged or discharged at constant power, according to SOC. Based on the above literature, this paper proposed a centralized and coordinated control strategy for energy storage and other distributed generations connected to power grid.

2. Design of microgrids operation mode and switch strategy for mode on-grid
The surplus power of the stored energy can be expressed by the SOC so that the SOC can use as the basis for the judgment of the energy storage and discharge. Equation (1) is one of the methods for calculating the energy storage SOC [11].

\[
SOC = SOC(0) - \int_0^t \frac{I_{ESS}(\tau)}{S_{ESS}(\tau)} d\tau 
\]

Where \(soc(0)\) is the initial value of the energy storage SOC, \(I_{ESS}\) is output current of the energy storage, and \(S_{ESS}\) is capacity of the energy storage. This paper comprehensively considers the characteristics of each distributed generation and the objectives of control for microgrid. Moreover, designs the following microgrid operation mode and mode switching strategy.

When the microgrid connected to the grid, the three operation modes, and mode switching strategy shown in figure 1, let microgrid have a schedulable function while maintaining the SOC of energy storage in the suitable space [12]. Mode 1: energy storage and new energy generator units respectively operated in combination modes of Automatic Generation Control (AGC) and MPPT; Mode 2: Energy storage and new energy generator units are respectively operated in combination modes of hot standby and AGC; Mode 3: New energy generators and the energy storage manipulated in AGC mode. The MPPT mode: the new energy generator moves along the MPPT bight; the hot standby mode: the energy storage compensates the shortfall power only when the sum of the utmost output of the new energy generator is smaller than the amount of the dispatching commands of the microgrid load and the main microgrid interaction power. AGC mode: Microgrid Central Control (MGCC) distributes the
system load to the distributed generation operation in AGC mode in the light of the tenet of maximum output power, each distributed generation adjusts the output according to the power command of MGCC. The following details of the microgrid connected to the operation mode and mode switching strategy.

![Diagram of control strategy for microgrids on-grid.](image)

**Figure 1.** The diagram of control strategy for microgrids on-grid.

- When the microgrid works in mode 2 (connect to grid), the load is first assigned by the new energy generating units in proportion to the maximum output power. When the maximum output of the new energy generating set is less than the sum of the dispatching instructions of the reciprocation power amid the microgrid load and the main microgrid, the energy storage can compensate for the lack of power, so that the interactive power amid the power grid and the microgrid can track the dispatching instructions. Between them, energy storage is homologous to the thermal standby units in the conventional power grid. The sum of maximum output and minimum output of new energy generating units set as follows: $P_{\text{RES, max}}, P_{\text{RES, min}}$; the sum of maximum charge and discharge power of energy storage are $P_{\text{ESS, max}}$ and $P_{\text{ESS, max}}$ respectively; interactive power dispatching instructions $P_{\text{linecmd}}$ between microgrid and power grid should meet the conditions (2) and (3) independently in normal situation and short time (such as peak load shifting time slot) [12].

\[
P_{\text{linecmd}} \geq P_{\text{RES, min}} - P_{\text{load}} \\
P_{\text{linecmd}} \leq P_{\text{RES, max}} - P_{\text{load}}
\]  

(2)

\[
P_{\text{linecmd}} \geq P_{\text{RES, min}} - P_{\text{ESS, max}} - P_{\text{load}} \\
P_{\text{linecmd}} \leq P_{\text{RES, min}} + P_{\text{ESS, max}} - P_{\text{load}}
\]  

(3)

In this expression, $P_{\text{load}}$ is active power load of microgrid.

- When the energy storage discharges to $SOC \leq SOC_{\text{low1}}$, the microgrid switches from operation mode 2 to operation mode 1 and charges the energy storage, it avoids deep discharge of energy storage and maintains a large discharge leeway. In mode 1, energy storage and new energy generators operate in AGC mode and MPPT mode separately, in which energy storage is accountable for dominating the interaction power between microgrid and power grid to track dispatching instructions. When $SOC \geq SOC_{\text{norm1}}$, the microgrid operation mode from mode 1 switches to the mode 2.

- When the energy storage is charged to $SOC \geq SOC_{\text{high1}}$, the microgrid alters from operation mode 2 to operation mode 3, discharging the energy storage, to avoid deep charging of energy storage and keep a more significant charging margin. All of New energy generators and energy storage operated in AGC mode to dominate the interaction power between microgrid and power grid thus they can trace dispatching instructions. When energy storage discharged
to SOC, the microgrid is switched from mode 3 to mode 2. When $SOC \leq SOC_{\text{norm}1}$, the microgrid operation mode from mode 3 switches to the mode 2.

In summary, the microgrid can accept the dispatch of the power grid when it operates in the above three modes. The proposed switching strategy can maintain the SOC of energy storage in a reasonable range, make the energy storage have a more significant charge and discharge margin, and improve the flexibility of power grid dispatching so that it can provide peak load shifting service for power grid during the peak-valley period. When the microgrid runs in the mode 2 of grid-connected regular operation, the load is first allocated by the new energy generating units in proportion to the maximum output power. When the maximum output belongs to the new energy generating set less than the dispatching instructions of the interaction power between the microgrid load and main microgrid, the energy storage can be used to compensate for the lack of power, thus reducing the energy storage loss and prolonging its service life.

3. Multiple energy storage operation mode for switch strategy
When there is multiple energy storage in the microgrid, using the highest and lowest SOC of all energy storage as the decision condition of mode switching may lead to confusion in mode switching judgment and unreasonable mode switching. To avoid the above situation, this paper uses the average value of SOC of all energy storage as the criterion for mode switching, as shown in equation (4). Others are similar to the case of single energy storage. This section is not covered.

$$SOC = \frac{\sum_{i=1}^{n} S_{ESS_i} \cdot SOC_i}{\sum_{i=1}^{n} S_{ESS_i}}$$

(4)

In the equation (4), $S_{ESS_i}$ is the capacity of energy storage $i (i = 1, \cdots, n)$, $SOC_i$ is charged state of energy storage.

4. Coordination control of new energy generators and energy storage
A proposed coordinated control belongs to energy storage and new energy generating units uses a typical centralized, hierarchical control structure, including first control and secondary control, as shown in figure 2 [13]. The local controller (LC) of the distributed generation is responsible for the central regulation of the microgrid frequency, while the MGCC is responsible for the secondary control, which takes into account the interactive power control of the main microgrid, the secondary regulation of the microgrid frequency, the distribution of active load, and the switching of operation mode. This paper simulations used the secondary control based on MGCC mode in MATLAB software.

![Figure 2. The block diagram of secondary control strategy for microgrid.](image)

The traditional droop control is used in the primary control of distributed power generation, as shown in formula (5).
\begin{equation}
    f = f_{\text{ref}} + k_p (p_{\text{ref}} - p)
\end{equation}

Above the formula, \( f \) and \( f_{\text{ref}} \) are the frequency and frequency reference of the distributed generation, \( p \) and \( p_{\text{ref}} \) are the active power and active power reference of the distributed generation output respectively. Secondary control can change the output of distributed generation by changing the rated operating point \( p_{\text{ref}} \) or the slope of the sag curve. However, changing the slope of the sag curve will affect the dynamic characteristics of the closed-loop system, which may lead to some unpredictable problems of small signal stability. Therefore, this paper chooses the way to change the rated operating point \( p_{\text{ref}} \) and shift the sag curve to change the output of distributed generation.

The secondary control in MGCC shown in figure 2. Accord to this diagram, it can see AGC, REGi and ESSi these three components clearly, and used PI controller in each component. The input \( P_{\text{line cmd}} \) and \( f_{\text{cmd}} \) of the secondary control can be given by EMS/SCADA of the third control. The AGC reference values for new energy generating units and energy storage active power allocation modules obtained by feedforward and feedback control technology.

\begin{equation}
    AGC = AGC_{\text{feedback}} + AGC_{\text{feedforward}}
\end{equation}

Above the formula, \( AGC_{\text{feedforward}} \) is the feedforward component of AGC, \( AGC_{\text{feedback}} \) is the feedback component of AGC. The following section is an introduction to the active power allocation module of new energy generating units and energy storage based on the three operation modes.

Firstly, the total active power demand in the microgrid is estimated: the user-accessible mode when the microgrid on grid can be calculated by equation (7).

\begin{equation}
    P_{\text{sys}} = \sum P_{\text{RESi}} + \sum P_{\text{ESSi}} - P_{\text{line}} + P_{\text{line cmd}}
\end{equation}

Above the formula, \( P_{\text{RESi}} \) and \( P_{\text{ESSi}} \) are the active power output of new energy generating units and the active power output of energy storage units respectively.

- When the microgrid runs in mode 1, the new energy generating unit runs along the MPPT curve, and the energy storage unit runs in AGC mode. The output power of the two units shown in equation (8).

\begin{equation}
    P_{\text{RESi,des}} = 1
    P_{\text{ESS,des}} = AGC_{\text{feedforward1}} + AGC_{\text{feedback}}
\end{equation}

In this equation, \( P_{\text{RESi, max}} \) is a maximum output power of the new energy generating sets, \( P_{\text{RESi,des}} \) is the standard unit of the utmost output power of the new energy generating sets, \( P_{\text{ESS,des}} \) is the standard unit of the energy storage capacity. AGC1 and AGC2 are the feedforward and feedback component of the AGC respectively, which shown in formula (9).

\begin{equation}
    AGC_{\text{feedforward1}} = \frac{P_{\text{sys}} - \sum P_{\text{REGi}}}{\sum S_{\text{ESSi}}}
    AGC_{\text{feedback}} = K_{fp} \Delta P_{\text{line}} + K_{LPI} \int \Delta P_{\text{line}} \, dt
\end{equation}

In the equation (9), \( \Delta P_{\text{line}} \) is the deviation between the active power \( P_{\text{line}} \) and the power dispatching instruction \( P_{\text{line cmd}} \), \( K_{fp} \) and \( K_{LPI} \) are the proportional and integral coefficients of the AGC control.
When the microgrid runs in mode 2, the new energy generating unit runs in AGC mode, and the energy storage unit runs in hot standby mode. The output power of the two modes shown in equation (10).

\[
P_{\text{RES,des}} = \frac{P_{\text{sys}}}{\sum P_{\text{RESi,max}}} \\
P_{\text{ESS,des}} = AGC_{\text{feedback}2} + AGC_{\text{feedforward}2}
\]

In this equation, the feedforward component \(AGC_{\text{feedforward}2}\) and the feedback component \(AGC_{\text{feedback}2}\) of AGC are equal to \(AGC_{\text{feedforward}1}\) and \(AGC_{\text{feedback}1}\) respectively. It can be seen from formula (10), when the microgrid operates in mode 2, the principle of power allocation among new energy generating units expressed in formula (11), in the light of the tenet of equal proportion of utmost output power.

\[
P_{\text{RES}} = \frac{P_{\text{RES1}}}{P_{\text{RES1,max}}} = \frac{P_{\text{RES2}}}{P_{\text{RES2,max}}} = \cdots = \frac{P_{\text{RESn}}}{P_{\text{RESn,max}}}
\]

When the microgrid runs in mode 3, both the generating unit and the energy storage unit run in AGC mode and their output power shown in equation (12).

\[
P_{\text{ESS,des}} = P_{\text{RES,des}} = AGC_{\text{feedforward}3} + AGC_{\text{feedback}3}
\]

In this formula, the feedforward and feedback components of AGC shown in equation (13).

\[
AGC_{\text{feedforward}3} = \frac{P_{\text{sys}}}{\sum S_{\text{ESSi}} + \sum P_{\text{RESi,max}}} \\
AGC_{\text{feedback}3} = K_f \Delta P_{\text{line}} + K_{LPI} \int \Delta P_{\text{line}} dt
\]

According to the equation (12), when microgrid runs in mode 3, new energy generator and energy storage allocate active power load in equal proportion of maximum output power.

5. Simulations
In figure 3, the MGCC mode controls the whole microgrid, when the interactive instructions transfer to network, wind turbine controller, photovoltaic controller and energy storage controller accept instructions to work. Finally, the input and output power through converters trans to AC bus, then the power of grid and load get a balance.

To verify the effectiveness of the proposed coordinated control strategy for distributed generation. Using MATLAB/Simulink modify the microgrid (one photovoltaic, two wind turbines and three energy storages) shown in figure 3. The reciprocation power amid the microgrid and the grid is positive in the outflow microgrid, and the energy storage output power is positive. The SOC value of the mode switching criterion can be determined according to the actual situation of the microgrid. The main parameters of the simulation system are shown in table 1.
Figure 3. The Schematic diagram of microgrid structure.

Table 1. The main parameters of the simulation system.

| Parameter of System                          | Value | Parameter of SOC       | Value |
|---------------------------------------------|-------|------------------------|-------|
| The capacity (MW) of wind turbine 1,2       | 1     | SOC_{norm}             | 60%   |
| The capacity (MW) of photovoltaic           | 1     | SOC_{norm2}            | 60%   |
| The capacity (MW) of energy storage 1,2,3   | 15    | SOC_{low1}             | 40%   |
| Maximum charge and discharge power (MW) of energy storage 1,2,3 | 1 | SOC_{low2} | 40% |
|                                             |       | SOC_{high1}            | 80%   |
|                                             |       | SOC_{high2}            | 80%   |

- The simulation of mode 2 change to mode 1

Initial simulation conditions: a load of this microgrid is 1 MW, the interaction power of power grid and Microgrid is 1 MW, and the SOC of energy storage 1, 2 and 3 is 70%, 53% and 35% respectively. Consider the following operating conditions: when t=20 s, the interacting power dispatching order of the microgrid and power grid will step from 1 MW to 2 MW, the SOC of three energy storage decreased at the same time; when t=70 s, the interacting power step from 2 MW to 1 MW, the SOC of three energy storage increased at the same point. The simulation results show in figure 4. Among them, the change of SOC for energy storage shown in figure 4(a); the interaction power between microgrid and power grid are shown in figure 4(b); the MPPT curve of new energy generating set is shown in figure 4(c); and the active output of distributed generation is shown in figure 4(d).

From figure 4(a), it can be seen that during discharge, energy storage can tend to SOC equilibrium smoothly. From figure 4(b), it can be seen the microgrid can accurately and quickly track the dispatching order of the power reciprocation amid the power grid and the microgrid, and the control effect of the power interaction between the power grid and the microgrid is almost not affected when the energy storage tends to be SOC balanced. As can be seen from figures 4(a) and 4(d), when the
microgrid works in mode 2, the load is distributed preferentially by the new energy generator in proportion to the maximum output power, and the energy storage cannot do it. When the interaction power between the power grid and the microgrid rises to 2 MW, the maximum output power of the new energy generator set is smaller than the active power demand of the power grid; the energy storage can recompense the deficiency power. When \( t = 45 \) s, the energy storage discharges to chemical SOC \( \leq 40\% \), and the operation mode of the microgrid is changed from mode 2 to mode 1. Figure 4(b) shows that the switching process does not cause fluctuations in the interaction power amid the power grid and the microgrid, that means the microgrid is switched from mode 2 to mode 1 smoothly. When the microgrid runs in mode 1, it can be seen in figure 4(d) that the new energy generating unit runs along the MPPT curve and charges the energy storage.

**Figure 4.** The simulation results of mode 2 change to mode 1.
In summary, when the microgrid runs in mode 1 or mode 2, it can accept power grid dispatch and smoothly switch from mode 2 to mode 1. When the microgrid works in mode 2, the load is first assigned by the new energy generating units in proportion to the utmost output power. When the maximum output of the new energy generating units is smaller than the load, the energy storage will compensate for the deficiency power.

- The simulation of mode 2 change to mode 3

![Simulation results](image)

**Figure 5.** The simulation results of mode 2 change to mode 3.

Initial simulation conditions: the load of the microgrid is 0.5 MW, the reciprocation power amid the microgrid and the grid is -0.75 MW, and the SOC of energy storage 1, 2 and 3 is 65%, 75%, 85%, respectively. Consider the following operating conditions: when t=60 s, the interacting power dispatching order of the micro-grid and power grid changes from -0.75 MW to 0.25 MW, the SOC of three energy storage decreased at the same time; figure 5 shows the simulation results. Among them, the evolution of SOC for energy storage shown in figure 5(a); the interaction power between microgrid and power grid shown in figure 5(b); the MPPT curve of new energy generator paper shown in figure 5(c); and the active output of distributed power is shown in figure 5(d).

From figure 5(a), although the SOC of energy storage 3 has reached 85%, the average value of
SOC of all energy storage is less than 80%, and the microgrid still operates in mode 2. From figure 5 (b), it can be seen the microgrid can accurately and quickly track the dispatching order of the interaction power between power grid and the microgrid. The interaction power amid the microgrid and the power grid does not fluctuate in the process of energy storage tending to SOC equilibrium, that means during the charge process, the energy storage tends to SOC equilibrium smoothly. Figure 5(d) shows when the load of the microgrid is negative, the export of the new energy generating unit decreases to 0, and the energy storage absorbs the remaining active power in the microgrid. This situation may occur during the low load period. The microgrid is used to fill the valley of power grid. When t=41 s, the storage charge is SOC≥80%. The operation mode of the microgrid is switched from mode 2 to mode 3. As shown in figure 5(b), the switching process does not cause the fluctuation of the interaction power amid the power grid and the microgrid, that means the smooth switching of the microgrid from mode 2 to mode 3. Figure 5(d) shows that when the microgrid runs in mode 3 and the load of the microgrid is positive, the new energy generators and energy storage units distribute the load in proportion to the maximum output power to discharge the stored energy.

In summary, when the microgrid runs in Mode 2 or Mode 3, it can accept power grid dispatch and smoothly switch from Mode 2 to Mode 3. In the process of energy storage and charging, the multi-storage switching strategy can dynamically adjust the charging power of energy storage with the change of SOC deviation, to achieve the balance of SOC smoothly and meet the requirements of coordinated control belong to energy storage and new energy generators.

6. Conclusions
This paper adopts the coordinated control of the energy storage and new energy generating units, the microgrid can accept the dispatch of the grid when it connected to the grid, it also can operate in multi-mode when it connected to the grid. Through the switching strategy of operation mode, the energy storage cooperative control strategy can adjust the charging power of energy storage with the change of SOC deviation in the process of energy storage and charging dynamically. It achieves the balance of SOC smoothly, maintain the energy storage SOC in a suitable range, and improves the schedulability of microgrid operation when the microgrid operates in the normal mode, the load first allocated by the new energy generator group. When the maximum output of new energy generating units is less than the load, the power imbalance occurs in the microgrid; the energy storage will compensate for the lack of power.

The secondary control strategy of microgrid used in MATLAB/Simulink, it based on MGCC mode, achieved three modes switching with each other. When a microgrid has change of load, secondary control can compensation for frequency and voltage deviation, the primary control cannot do it and third control will waste more time.

In future, further research on coordinated control strategy and its practical application is needed. Based on the centralized and coordinated control strategy of distributed generation proposed in this paper, the energy management function and economic dispatch of microgrid can realize by combining the generation forecasting and load forecasting of new energy generating units.

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References
[1] Zhou C N, Zhao Q, Zhang G S et al 2016 Energy revolution: From fossil energy to new energy Natural Gas Industry 36 1-10
[2] Lipp J 2007 Lessons for effective renewable electricity policy from Denmark, Germany and the United Kingdom Energy Policy 35 5481-95
[3] Du Z G and Zhang X D 2005 Some Thoughts on accelerating the development of urban power
grid Power Grid Technol. 29 7-10
[4] Chen Y Z, Zhang B H, Wang J H et al 2011 Active control strategy of microgrid energy storage system based on short-term load forecasting Power Grid Technol. 35 35-40
[5] Chen J, Chen X, Feng Z Y et al 2014 Seamless switching control strategy for microgrid system grid/island operation mode Chinese J. Electr. Engin. 34 3089-97
[6] Tang X S, Deng W and QI Z P 2011 Energy storage based microgrid grid/off-network seamless switching technology J. Electrotechnics 26(S1) 279-84
[7] Zhang Y, Jia H J and Guo L 2012 Energy management strategy of islanded microgrid based on power flow control IEEE PES in Innovative Smart Grid Technologies (washington) chapter 1 pp 1-8
[8] Tan K T, Peng X Y, So P L et al 2012 Centralized control for parallel operation of distributed generation inverters in microgrids IEEE T. Smart Grid 3 1977-87
[9] Tan K T, So P L, Chu Y C et al 2013 Coordinated control and energy management of distributed generation inverters in a microgrid IEEE T. Power Delivery 28 704-13
[10] Miao Z, Xu L, Disfani V R et al 2014 An SOC-based battery management system for microgrids IEEE T. Smart Grid 5 966-73
[11] Urtasun A, Sanchis P and Marroyo L 2015 State-of-charge-based droop control for stand-alone AC supply systems with distributed energy storage Energy Convers. Manage. 106 709-20
[12] He X L, Zhang L Q, Tan H Y et al 2016 Coordination control strategy of distributed power supply and multi-storage energy in microgrid Power Journal 14 103-11
[13] Zhang L, He X, Xin H et al 2016 Hierarchical control design and verification of a multi-mode microgrid on the zhairuoshan island IEEE Power and Energy Society General Meeting (Boston) chapter 1 pp 1-5