Application of Superconducting Magnetic Energy Storage in Microgrid Containing New Energy

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Abstract. Superconducting magnetic energy storage (SMES) system can be long-term, efficient, non-destructive electric energy storage, the decoupling control can run in four quadrant, can achieve power active power and wattless power real-time fast independent adjustment. It is applied to the microgrid implemented through the SMES dynamic power compensation so as to greatly increase the initiative control of power grid operation. In this paper, the current source type SMES as the research object, the SMES system based on microgrid operation research. A microgrid PSCAD model including SMES system, SMES respectively provide short-term electricity, fault time buffer, improve microgrid power quality, micro smoothing grid and main network switching, optimization of DG improve the operation of microgrid operation economy of simulation study, provide a reference for SMES application in microgrid.

1. INTRODUCTION

To co-ordinate the power grid to enable it to better accommodate distributed power and take full advantage of the value and benefits that distributed energy generates for power grids and users, the concept of micro-grid (MG) has emerged. Through the micro-grid, various forms of energy supply system can be conveniently completed. Combining the relevant energy storage technologies, the power grid peak voltage can be relieved and the smoothly dispatched power can be used to complete peak load shaving and valley filling. Microgrid optimizes energy distribution and grid operating efficiencies and protects the environment, making microgrid an integral part of the future smart grid[1-3].

In practice, the micro-grid faces the issue of how to efficiently receive the energy with different characteristics, how to operate more safely and steadily and how to provide excellent energy. At the same time, it should also consider the main grid connected microgrid grid to withstand the impact of external failures, smooth switching between grid-connected operation and islanding and other special technical problems. Applying the energy storage technology to the microgrid can improve its capability of receiving intermittent renewable energy, the stability and reliability of the power of the power system and power quality. This has been echoed by more and more countries around the world.

The technical advantages of SMES are not only the higher energy storage density and energy storage efficiency but more importantly, the individually controllable dynamic power compensation with response time less than 10ms. In this paper, the SMES system based on microgrid is studied, and the PSCAD model of microgrid containing SMES system is established. The simulation and research on SMES to provide short-term power supply, fault time buffering, improving the power quality of microgrid, smooth switching between micro-grid and main power grid, optimizing the operation of DG and improving the economy of micro-grid are carried out.
2. STRUCTURE AND PRINCIPLE OF SUPERCONDUCTIVE MAGNETIC ENERGY STORAGE SYSTEM

Figure 1 is a schematic diagram of the specific structure of SMES device. The structure is first proposed by the Los Alamo Laboratory [4]. SMES device consists of several main parts: superconducting coil, cryogenic vessel, refrigeration device, power conversion device, quench protection system and monitoring system.

![Figure 1 SMES device structure diagram](image)

The SMES system uses superconducting coils to store electrical energy directly in the magnet. Depending on the needs, the stored electromagnetic energy can be returned to the grid or supplied to other loads. The energy \( W \) and power \( P \) stored in the superconducting coil can be expressed by (1) and (2):

\[
W = \frac{1}{2} LI^2
\]

\[
P = \frac{dW}{dt} = LI\frac{dI}{dt} = LV
\]

DC current is stored in the superconducting coils. Because of its zero resistance and zero energy loss, the average current density in superconducting coils is 1-2 orders of magnitude higher than normal coils. Thus the energy density in superconducting coils is very high, about \(10^6 \text{ J/m}^3\). Due to the DC power is stored in superconducting coil, the current must be through the current inverter and control system to complete the power exchange with the AC power grid in order to participate in power regulation.

3. MODELING OF CURRENT SOURCE SMES SYSTEM

3.1. Mathematical Model Of Current Source SMES

![Figure 2 6-pulse wave current source type SMES topology](image)

![Figure 3 The waveform of pulse modulation](image)

Figure 2 shows the basic topology of a six-pulse current source SMES. As shown in the figure, the current source type SMES mainly includes a six-pulse IGBT current inverter, a transformer for matching
the grid voltage with the AC input voltage of the current inverter, a superconducting magnet \( L_d \) for storing electric energy and a capacitor \( C \) for filtering out the high-order harmonic in \( i_{ca}, i_{cb} \) and \( i_{cc} \). Where \( R_T \) and \( L_T \) represent the equivalent resistance and reactance of the connecting transformer. \( R_d \) represents the sum of the equivalent resistance of the superconducting magnet and the normal-joint connector and the IGBT switch. According to Kirchhoff's law, the mathematical model of SMES with six pulse current sources can be derived as follows:

\[
\begin{align*}
\begin{bmatrix}
i_{sa} \\
i_{sb} \\
i_{sc}
\end{bmatrix} &= C \frac{d}{dt} 
\begin{bmatrix}
u_{ca} \\
u_{cb} \\
u_{cc}
\end{bmatrix} + \begin{bmatrix}
i_{ca} \\
i_{cb} \\
i_{cc}
\end{bmatrix} \\
\end{align*}
\]

\( \text{(3)} \)

\[
\begin{align*}
L_T \frac{d}{dt} 
\begin{bmatrix}
i_{sa} \\
i_{sb} \\
i_{sc}
\end{bmatrix} + R_T 
\begin{bmatrix}
i_{sa} \\
i_{sb} \\
i_{sc}
\end{bmatrix} + \begin{bmatrix}
u_{ca} \\
u_{cb} \\
u_{cc}
\end{bmatrix} &= \begin{bmatrix}
u_{sa}
\end{bmatrix}
\end{align*}
\]

\( \text{(4)} \)

\[
\begin{align*}
L_d \frac{dL_d}{dt} + R_d I_{dc} = u_{sa}v_a + u_{sb}v_b + u_{sc}v_c
\end{align*}
\]

\( \text{(5)} \)

In equation (3), the switching states of a total of six switching elements of the three-phase bridge in the inverter are respectively represented as \( v_k (k = a, b, c) \). The working principle of the current source inverter and the voltage source inverter is different. Under normal operating conditions, it is necessary to ensure that the upper and lower arms of the current inverter have one and only one switch in an on state at any time. It can be drawn: There will be one phase bridge whose upper and lower switch remain off under normal operating condition. It is represented as \( v_k = 0 (k = a, b, c) \). The equation (5) shows that when calculating the phase voltage on the right, the state of each switch needs to be considered. Thus, the on-state of the upper half of the three-phase bridge arm in FIG. 3-7 can be marked as \( v_k = 1 \), the on-state of the lower half can be marked as \( v_k = -1 \). According to this definition and reference [5], the PWM switching trigger pulse can be obtained.

### 3.2. Control of current source SMES power

The SMES system is divided into two parts when regulating the power exchange with the power grid, that is, the outer loop control and the inner loop control. The main function of outer loop control is to analyze the demand of reactive power and active power in the system. Based on this, the set values of active and reactive power required for inner loop control are calculated. The inner loop control system is mainly composed of two parts. First of all, based on the real-time reactive and active power parameters given by the outer loop control system, the control variables such as amplitude \( M \) and phase \( \theta \) of the modulation signal needed for PWM control of the current inverter are determined. Secondly, according to the different control modes of the inverter, the trigger pulse signal of each switching device in the corresponding mode is modulated to ensure that the amplitude and phase of the alternating current of the inverter are consistent with the given reference value of the outer loop control. To facilitate the analysis, ignore the power loss of the inverter, the transformer and the filter shown in Figure 1. According to the instantaneous power theory, the adjustment of SMES’s active and reactive power can be expressed by Eqs. (6) and (7):

\[
P_{\text{SMES}} = u_{sa}i_{sa} + u_{sb}i_{sb} + u_{sc}i_{sc}
\]

\( \text{(6)} \)

\[
Q_{\text{SMES}} = \frac{1}{\sqrt{3}} (u_{bc}i_{sa} + u_{ca}i_{sb} + u_{ab}i_{sc})
\]

\( \text{(7)} \)
Since the three-phase voltage in the grid is symmetrical, that is, the sum of the three-phase current and the three-phase voltage is zero:
\[ i_{sa} + i_{sb} + i_{sc} = 0, \quad u_{sa} + u_{sb} + u_{sc} = 0. \]
Assuming that the phase difference between voltage and current is \( \alpha \) and that the current at the SMES and grid access point is the filtered fundamental current of the inverter:
\[ i_k(t) = i_{k1}(t) \quad (k = a, b, c). \]

Substituting the above conditions into Eqs. (6) and (7) can obtain:
\[ P_{SMES} = \frac{3}{2} U_s I_s \cos \alpha = \frac{3\sqrt{3}}{4} U_s M_{dc} \cos \alpha \]
\[ Q_{SMES} = \frac{3}{2} U_s I_s \sin \alpha = \frac{3\sqrt{3}}{4} U_s M_{dc} \sin \alpha \]

Where \( U_s, I_s \) are voltage and current amplitude of the inverter at the access point of SMES. The ultimate goal of SMES inner loop adjustment is to follow the real and reactive power reference values calculated by the outer loop control in real time. Therefore, the power adjustment reference values \( r_P \) and \( r_Q \) can be substituted into Eqs. (8) and (9):
\[ \alpha = f(P_r, Q_r) = \tan^{-1}(Q_r / P_r) \]
\[ M = g(P_r, Q_r) = \frac{4\sqrt{P_r^2 + Q_r^2}}{3U_s I_{dc}} \]

From Eqs. (10) and (11), it can be seen that by adjusting the sizes of \( M \) and \( \alpha \), real-time exchange of active and reactive power between SMES and the power grid can be realized according to the given power reference value. Figure 4 is the SMES power controller schematic. The figure is designed with two PI regulators. One of them is responsible for active power feedback control, and the other is responsible for reactive power feedback regulation. The two regulators cooperate to compensate the error caused by the power loss of inverter, filter, and transformer. In order to reduce the drastic change caused by regulating power error, PI parameters should be set properly. In other words, choosing better parameters can reduce the fluctuation of SMES output current and power, at the same time, SMES can output power with a better quality and response [6-10].

4. MICRO-GRID SIMULATION ANALYSIS WITH SMES
According to the EU definition of microgrid structure to build the PSCAD simulation model shown in Figure 5. Where microgrid voltage \( U_s = 400V \). DG and load parameters are shown in Table 1. In the following, the SMES to provide short-term power supply, fault time buffering, improve the power quality of micro-grid, smooth switching between micro-grid and main power grid, optimize DG operation are simulated.
Figure 5 microgrid with SEMS simulation circuit

| Device               | Quantity | Capacity | control method     | Remarks                          |
|----------------------|----------|----------|--------------------|----------------------------------|
| Wind farm            | 2        | 300kW    | Constant voltage control | Direct drive PMSG                |
| PV                   | 4        | 320kW    | MPPT               | Affected by external conditions  |
| Micro gas turbine    | 1        | 200kW    | PQ/VF              | Cold standby or main power supply |
| SMES                 | 4        | 100kW    | PQ/VF              | Capacity is set according to the use of SMES |
| Load                 | 3        | 800kVA   |                    | Contains non-linear load         |
| Reactive power       | 1        | 160kVar  |                    | Adjustable capacity              |

Table 1. DG and load parameters in microgrids

4.1. Short-Term Power Supply

Because micro-grid contains a variety of distributed power supply, the structure is more complicated than the general distribution network. When a fault occurs in the micro-grid system and some areas cannot supply power in time, the SMES system can provide short-time power supply for the microgrid, ensuring uninterrupted power supply to important loads and gaining time for recovery after a breakdown. As shown in FIG. 6, load1: 83.5 kW, 23.5 kVar, load2: 55.7 kW, 22.86 kVar; tbk1 and bk2 trip at $t = 3s$. SMES is in PQ control before the line switch is opened. $P_{SMES} = 0, Q_{SMES} = 0$. When the switches of line 1 and line 2 in the microgrid system are disconnected respectively, the power supply in the microgrid will no longer supply power to load1 and load2, and load1 in line 1 will have to be powered down. However, due to the installation of SMES in line 2, the load2 can be supplied by the stored energy in SMES.

As shown in Figure 7, the micro-grid is powered by two power lines respectively before 3s. At this time, the SMES system is in a closed-loop freewheeling state and does not supply power. $P_{SMES} = 0, Q_{SMES} = 0$. System frequency $f = 50Hz$, $U=400V$. When $t = 3s$, the switch is tripped: load1 is powered off, $P_1$ and $Q_1$ are changed to 0. Although load2 is disconnected from the microgrid power supply, SMES timely supplies power to load2 to ensure short-term power consumption since SMES equipment is installed in line 2. $P_2 = P_{SMES} = 54kW$, $Q_2 = Q_{SMES} = 28.6kVar$. 
Knowing from Fig. 6 that load1 and load2 are disconnected from the power supply, the voltage of load1 drops rapidly from 400V to 0V. Because SMES device provides reactive power support the voltage of load2 can still be kept at about 400V. According to the previous analysis of current source SMES rely on the current inverter for power exchange, resulting in harmonic effects, so Load2 voltage fluctuates.

Similarly, as shown in Figure 7, SMES provides active power to load2 to ensure that it can run continuously for a certain period of time, and due to the influence of SMES current inverter and its control strategy, the active fluctuations provided by SMES changes correspondingly.

4.2. Fault Buffering

The structure and operating status of a microgrid differ from that of a high-voltage power grid. According to the operation rules of the power grid, it can be known that for a low-current grounding system, the healthy phase is allowed to continue operating for a period of time when the line has a single-phase to ground fault. When a branch connected to the same bus fails, the bus voltage is pulled down and the load on the other branches connected to the bus powered by the micro-power supply is also reduced.

As shown in FIG. 8: micro-power supply $U_s = 400V$ with a capacity of 100kVA, the SMES power is 400kW and capacity is 1.5MJ; load1: 20.5kW, 15.5kVar; load2: 25.7kW, 8.86kVar. The transition resistance is 0.5Ω. After 1 second, the fault line resumes normal operation. When the micro-grid is powered by the micro-power supply, the SMES needs to use the $v_f$ control to provide voltage support for the bus M when the voltage drops, until the fault is recovered.
As shown in Fig. 9 (a), when the bus is not equipped with SMES device, the voltage of line 1 drops to 300V after single-phase grounding short-circuit, the voltage drops to 150V after the two-phase ground short circuit, and drops to 10V after the three-phase ground short circuit. But when the bus is equipped with SMES device, as shown in Figure 9(b), voltage drop were 388V, 378V, 363V. Thus, SMES has obvious support for the voltage sag caused by the fault. Of course, the extent and timing of support depends on the level of SMES capacity and voltage sag.

![Figure 8 SMES fault buffer simulation circuit](image)

Due to the small micro-power capacity in the microgrid and its obvious influence from the external environment, short-circuit current to the short-circuit point may be small (typically less than 2 times the rated current) when a short circuit occurs in the system. The relay protection in the distribution network is current protection. When the short-circuit current is too small, the current protection may be refuse to move, posing a serious safety hazard to the system operation. When fitted with a SMES device, SMES provides a large short-circuit current to the short-circuit point in the event of a short circuit to ensure reliable operation of the current protection.

4.3. Smooth Switching Between Microgrid And Main Network

There are two basic modes of operation of a microgrid: Under normal conditions, the microgrid and the main grid are connected to operate in the grid, that is, the grid-connected operation mode. When the grid fails or the power quality is not satisfied, the microgrid will be disconnected from the grid in time to run independently, known as island operation mode. At present, there are many microgrid demonstration projects all over the world and great achievements have been made in the research on the microgrid energy management system. Considering the operation mode of microgrid and the influence of system stability, the control methods and strategies of power supply that need to be controlled by micro-grid during different operation modes also change. However, the disturbance caused by the adjustment of this control strategy should be within the acceptable range of the system and the voltage and frequency inside the microgrid should still be maintained after switching. The SMES system can serve as a smooth switch between the microgrid and the main network.
As can be seen from Figure 10, when the micro-grid operates in the grid-connected mode, the micro-grid and the main grid supply power to the load together and satisfy the following relationship:

\[ P_{\text{Load}} = P + \Delta P, \ Q_{\text{Load}} = Q + \Delta Q \]  

(12)

\[ P_{\text{Load}} = \frac{V_{\text{PCC}}^2}{R} \]  

(13)

\[ Q_{\text{Load}} = V_{\text{PCC}}^2 \left( \frac{1}{\omega L} - \omega C \right) \]  

(14)

Where: \( V_{\text{PCC}} \) is the voltage at the point of common coupling (PCC); \( P, Q \) is the active and reactive output of the micro-power supply; and \( P_{\text{Load}}, Q_{\text{Load}} \) is the active and reactive power consumed by the load. From (4-3) and (4-2) can be obtained:

\[ \omega = \frac{1}{2\sqrt{LC}} \left( \frac{Q_{\text{Load}}}{Q_{\text{Load}}} + 4 - \frac{Q_{\text{Load}}}{Q_{\text{Load}}} P_{\text{Load}} \right) \]  

(15)

Where: \( Q_f = R\sqrt{C} \) is the quality factor of the load. When the microgrid is in an isolated state, the main network no longer injects energy into the microgrid and the power output of the microgrid generally does not change immediately. Therefore, there will be a power shortfall \( (\Delta P, \Delta Q) \) when the microgrid is in island operation.

- The voltage changes when there is a change in the active power:

  \[ P > P_{\text{Load}} \rightarrow P_{\text{Load}} \uparrow \rightarrow V_{\text{PCC}} \uparrow \]  
  \[ P < P_{\text{Load}} \rightarrow P_{\text{Load}} \downarrow \rightarrow V_{\text{PCC}} \downarrow \]  

Changes in active and reactive power will affect the changes of frequency. It will be divided into three cases:

- When the reactive power does not change but the active changes:

  \[ P > P_{\text{Load}} \rightarrow P_{\text{Load}} \uparrow \rightarrow V_{\text{PCC}} \uparrow \rightarrow f \uparrow, \quad P < P_{\text{Load}} \rightarrow P_{\text{Load}} \downarrow \rightarrow V_{\text{PCC}} \downarrow \rightarrow f \downarrow \]  

- When the active power is constant but reactive power changes:

  \[ Q > Q_{\text{Load}} \rightarrow Q_{\text{Load}} \uparrow \rightarrow f \downarrow, \quad Q < Q_{\text{Load}} \rightarrow Q_{\text{Load}} \downarrow \rightarrow f \uparrow \]  

- When the reactive power and active power both changes, depends on the amount of the respective changes to decide.

The main factor that affects the switching smoothness of the microgrid and the main network is the transmission power of the public connection point (PCC) between the microgrid and the main network, that is, the exchange power between the main network and the microgrid during switching. In general, when the power sent by the DG in the microgrid can not only meet the load of the microgrid but also return the remaining power to the primary network, if the microgrid is disconnected from the primary network at this moment, the microgrid system will be over-powered Resulting in increased voltage and...
frequency can make the load in the microgrid cannot operate normally. On the other hand, if the main network is in the condition of providing power to the micro-grid when the micro-grid is switched on, disconnecting the micro-grid from the main network may result in insufficient power of the micro-grid, which causes the voltage and frequency of the micro-grid to drop. In addition, if the switching power of the main grid and the microgrid is very high, the two systems will also exert a severe impact during the grid-connecting process, which is extremely unfavorable to the operation of the grid.

When power exchange at the PCC point is not the same, the voltage, frequency and grid current of the microgrid are as follows:

![Figure 11 (a)](attachment:image1)

(a)

![Figure 11 (b)](attachment:image2)

(b)

![Figure 11 (c)](attachment:image3)

(c)

Figure 11 (a) 10% power shortage (b) 10% power surplus (c) Islanding voltage, frequency, and grid side current of microgrid with SMES (power difference ~5%)

As shown in Figure 11 (a), when the power from the power supply in the micro-grid can not satisfy all the loads in the micro-grid, an islanding operation occurs at 3s, the microgrid voltage will drop and the frequency will not be maintained at 50Hz and down to 48.5-50Hz due to the lack of reactive power and active power. Islanding ends at 4s and the maximum inrush current caused by closing the PCC is about 450A. As shown in Figure 11 (b), when the power in the microgrid is sufficient, in addition to providing all the load requirements in the microgrid, the excess power is also backtracked to the grid. In this case, an islanding operation occurs at 3s. The voltage of the microgrid will rise higher than 400V,
and the frequency will fluctuate in the range of 48.5-51Hz due to the lack of reactive power and active power. Islanding ends at 4s and the maximum inrush current caused by closing the PCC is about 1000A. As shown in Figure 11 (c), when the SMES system ensures that the power exchange between the microgrid and the main network is within a certain range (<5%) through PQ control. In this case, an islanding operation occurs at 3s and the SMES uses the VF control to keep the voltage slightly fluctuating at 400V when the micro-grid islanding occurs. The frequency is also maintained at about 50 Hz due to the reactive and active regulation. In addition, due to VF control, SMES's voltage and frequency support also results in a smaller voltage harmonic content in the microgrid than in the case of without SMES. The maximum inrush current at 4s is about 400A. In summary, microgrid equipped with SMES has a smoother switching between islanding and grid connection. That is, the adjustment of SMES equipment makes the micro-grid islanding more stable and restrains the inrush current when the micro-grid is connected to the network. The simulation results are consistent with the theoretical analysis. It should be pointed out that the above control strategy of SMES can improve the utilization of energy provided by renewable energy in the microgrid and at the same time ensure the security when the mode of microgrid operation is changed.

4.4. Improving The Economic Benefits Of Micro-Grid By Optimizing The Dg Operation

Micro-grid contains a large number of distributed generation (DG). However, most of the distributed power sources are generally provided by renewable energy sources such as photovoltaic power generation, wind power generation, tidal power generation and geothermal power generation. The operating conditions of these renewable energy power generation devices are constrained by the inherent characteristics of their respective energy sources. For example, wind power generation and photovoltaic power generation systems are greatly affected by the weather. Therefore, in order to make full use of renewable energy, the SMES system can be utilized to balance the power changes so as to optimize each DG operation and maximize the acceptance of these renewable energies.

Calculate the wind power, photovoltaic power generation curve and daily load curve through the generation characteristics of a micro-grid. As shown in Figure 15 and Figure 16 below:

As can be seen from Figure 12, the power generated by the photovoltaic system is related to the sunshine intensity and the light's angle of incidence. The peak of power generation is generally around 10:00 to 14:00 and almost no power is emitted from 18:30 to 5:30 the next day. The wind turbine power is mainly affected by the wind speed. The figure shows the wind turbine power output variation has a strong volatility. It can be seen from the figure that the wind power generation system has good complementarity with the photovoltaic power generation system. From the microgrid load curve in Fig. 13, the peak load power is concentrated between 8:30-18:00, which is different from that of the micro-power supply. It is necessary to rationally allocate the power to achieve the load-supply balance.
Fig. 14 shows the daily power change of the transmission line when the energy storage device is not involved in the regulation. From the figure: main grid supply power to the microgrid from t = 9:00 to 19:00. From t = 19:30 to 8:30 the next day, power in the microgrid meets the load of the microgrid and feeds back the power to the main network. According to the region's peak valley price shown in Figure 15: The region's electricity prices can be divided into the following four forms: Peak period (1.1643 yuan/kWh), high period (1.0676 yuan/kWh), flat period (0.6695 yuan/kWh) and low period (0.2942 yuan/kWh). The specific arrangements for each session are as follows: The peak hours are 10:30, 11:30, 16:00, 17:00, 19:00, 20:00; high period are 8:30, 10:30, 18:00, 19:00, 20:00, 23:00; flat period are 7:00, 8:30, 11:30, 16:00, 17:00, 18:00; low period are 23:00, 7:00 of the next day.

Calculate the electricity costs in this microgrid without SMES as shown in Figure 16. The daily fee is 96.89 yuan. As shown in Fig. 13, the difference between the peak value and the trough value of microgrid daily electricity consumption is obvious. And the total amount of electricity fed to the main grid in one day of the microgrid is similar to that of the main grid. We can optimize the operation of this microgrid by using SMES energy storage devices. Referring to [11], SMES deployment strategy as shown in Figure 17 is proposed based on minimizing the daily power bill and setting the SMES device to avoid peak-hour charging.

If operated according to this strategy, the daily electricity bill is 0.882 yuan, which is lower than 1% when SMES is not installed.

5. CONCLUSION

In this paper, the principle and structure of SMES are studied, and the control strategy and power output characteristics of SMES are analyzed. By establishing a time-domain SMES simulation model of PSCAD/EMTDC, the simulation and analysis of SMES system's role in the microgrid shows the following conclusions:

1) SMES devices store DC energy in superconducting coils as electromagnetic energy. Due to the characteristics of the superconducting material, its energy storage loss is very low. The output and absorption of active power and reactive power can be timely controlled by the current inverter and the corresponding control strategy.
2) When the microgrid is disconnected from the grid, the SMES system can provide short-term power supply for the devices in the microgrid, ensuring uninterrupted power supply to important loads and gaining time for recovery after a microgrid system failure.

3) The power shortage caused by the conversion from grid-connected mode to island mode will lead to the inability of the island-based microgrid to transition smoothly to a new stable state. The installation of energy storage devices can provide short-term power supply in the case of power shortage to make the micro-grid switch smoothly to island operation.

4) Microgrids contain a large number of distributed power sources (DGs). The operational status of these renewable energy generation units is constrained by the inherent characteristics of their own energy sources. SMES system can be used to balance the power changes to optimize the operation of DG and maximize the acceptance of these renewable energy sources.

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