Stability coordination control of multi-resource integrated microgrid considering demand response

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Abstract. Fully exploit the demand-side resources to build a multi-energy complementary microgrid system, which can improve the stability control of multiple indicators and save system operating costs. Based on the microgrid architecture including gas turbine generator set, energy storage system and central air-condition, each part of the system model is constructed to study the complementarity between resources, and a multi-resource integration multi-user regulation configuration method is proposed. Based on the principle of reverse thrust control, the multi-objective stability coordination control strategy of the microgrid system in off-grid mode is proposed, and the stability of the controller is proved theoretically. The control algorithm is verified by a simulation example. The result shows that the coordinated controller can ensure the tracking and adjustment of multiple controlled quantities such as power angle and frequency of the microgrid system during control, and the system can be quickly pulled back to stable operating state after the control is over. The participation of demand response resources in micro-network regulation can effectively improve the dynamic response of each state quantity of the system, and improve system stability, and reduce system control expenditure.

1. Introduction

With the establishment of strong smart grid construction, multi-energy complementary microgrid with "complementary" characteristics emerged as the times require. It overcomes the randomness and intermittent impact of distributed power supply on the grid, and increases the reliability of power supply, and enhances the overall efficiency of the energy system and promotes the transformation and development of energy structure [1]. However, while multi-energy complementary microgrid inherits the advantages of flexible operation of microgrid and local consumption, it brings power imbalance, power angle and frequency fluctuation caused by the combination of micro-source output intermittent and load fluctuation. Demand response (DR) resources, represented by central aircon system/refrigerators in commercial buildings, air conditioners(ACs)/water heaters for residential users, and some industrial large users can respond quickly to scheduling commands, and is a high-quality and valuable demand-side schedulable resource on a short time scale. And The fluctuation of power consumption during the minute time has little impact on the user experience [2]. In North China, DR resource scheduling response potential can reach 1.4%-13.3% [3], In the US it is 4%-20% [4]. It is of great practical significance to fully participate in the regulation of microgrid system by exploiting the response of DR resource scheduling.

Multi-energy complementarity and stability control of microgrids is one of the current research hotspots. In document [5], an energy-connected microgrid multi-energy complementary system for gas-electric heat integrated load terminals is established, and the optimal economic control under gas-electric-thermal hybrid energy storage mode is studied; In document [6], a diesel-light storage microgrid...
system is introduced, in which photovoltaic and energy storage is the main power source in the whole power grid system, and diesel generators provide backup power. It can operate both on-grid and off-grid, and can adapt to multiple common loads. In the document [7], a multi-energy complementary DC microgrid model is constructed. The DC bus voltage variation factor is used to determine the working state of each converter under different control layers by improving the hierarchical control strategy to solve the voltage stability and energy optimization of the DC microgrid bus. In document [8], the characteristics of multi-energy complementary microgrid, such as photovoltaic, wind power and hydropower, in the Zhaqin County microgrid demonstration power station in Tibet are studied. The virtual synchronous generator (VSG) control strategy that can flexibly realize the microgrid networking is proposed, and improve the power supply quality and stable operation ability of microgrid and can also meet seamless switching between different operating modes of the microgrid. In document [9], taking the grid-connected multi-energy complementary microgrid including photovoltaic power generation, cogeneration unit, ground source heat pump, battery and load as the research object, the robust operation optimization model of microgrid with supply and demand coordination is constructed to effectively utilize the demand, and respond to optimize economic and environmental goals and reduce pressure on the supply side in dealing with uncertainty. It can be seen that the current research on the multi-complementation of microgrid mostly focuses on the consumption of intermittent power supply, but the consideration of DR resources is insufficient; Its stability control is only for load tracking or single regulation of frequency and voltage, It is rare to coordinate multi-objective stability control of microgrid power angle and frequency.

The innovation of this paper is mainly reflected in the following two points: Firstly, the model of each part of the microgrid system considering the demand side response resources is constructed. The characteristics of response rate, response capacity and control characteristics among various resources are analyzed and a multi-user control configuration method based on Fourier decomposition is proposed; Secondly, based on the principle of reverse thrust control, the multi-objective stability coordination control strategy of the microgrid is designed. The stability of power angle and frequency is guaranteed in the fluctuation of system regulation, and the system is quickly stabilized at the new operating point after the end of regulation. The simulation results show that the multi-energy configuration method and coordinated control strategy proposed in this paper achieves the stable control of power angle and frequency, and the stability of the system can be better improved and the operation cost can be greatly reduced with the participation of DR resources.

2. System Model Construction

Design the commercial park microgrid system shown in Fig.1, which mainly includes gas turbines, energy storage systems (ESS) and flexible loads (mainly central air con system). The microgrid can be connected to the grid by the circuit breaker and this paper mainly considers its off-grid operation mode.

![Figure 1. Business park microgrid architecture](image)

2.1. Gas turbine generator set model
The gas turbine generator system (Fig. 2) includes a gas turbine control system, a gas turbine model and a generator model. The gas turbine control system includes a speed/power controller and a temperature controller that minimizes the speed/power controller output under normal conditions; The temperature controller is primarily protective to ensure that the gas turbine is not overheated to ensure its service life.

2.1.1. Gas turbine model. The gas turbine control model (Fig. 3) includes an input fuel quantity command, an output exhaust temperature, and an output mechanical power. In Fig.2: $k_{nf}$ is the ratio of fuel consumption to rated fuel consumption $T_{cr}$ at no load; $T_b$ is the control valve time constant, $s$; $T_f$ is the fuel system time constant, $s$; $T_d$ is the combustion delay, $s$; $T_{tg}$ is the transmission delay of the gas turbine and the exhaust system, $s$; $T_{cd}$ is the compressor discharge delay time constant, $s$; $A$, $B$ and $C$ are the gas turbine torque calculation module parameters; $E$ and $F$ is the gas turbine exhaust temperature calculation module parameters, $^\circ$C; $G_{sh}$ is the radiation protection screen parameter; $T_{sh}$ is the radiation shield time constant, $s$; $T_{tr}$ is the thermocouple time constant, $s$; $T_r$ is a given temperature, $^\circ$C.
2.1.2. **Generator model.** Generator model is

\[
\begin{aligned}
\dot{\delta} &= \omega_0 (\omega - 1) \\
\dot{\omega} &= \frac{1}{H} (P_m - P_e) - \frac{D}{H} (\omega - 1)
\end{aligned}
\]

where \(\delta\) is the power angle of the generator, rad; \(\omega_0\) is the standard angular velocity, rad/s; \(\omega\) is the relative angular speed of the generator, p.u.; \(D\) is the damping coefficient of generator; \(H\) is inertia constant of generator, s; \(P_m\) is the input mechanical power of generators, p.u.; \(P_e\) is the output power of the generator, p.u.;

2.1.3. **Gas turbine generator set model.** The gas turbine model contains multiple first-order inertia links with small inertia time constants, and the excessive number of inertia links increases the difficulty of backstepping design. Therefore, approximate simplification is required. The proportional valve, control valve, volume effect and pure delay of the combustion chamber in the gas turbine model are equivalently reduced to a first-order transfer function. Then the system's state space expression is converted to:

\[
\begin{aligned}
\dot{\delta} &= \omega_0 (\omega - 1) \\
\dot{\omega} &= \frac{1}{H} (P_m - P_e) - \frac{D}{H} (\omega - 1) \\
\dot{m}_f &= \frac{1}{T_{cd}} (\omega_f - m_f) \\
\dot{\omega_f} &= -c_1 \omega_f + c_2 (u - b)
\end{aligned}
\]

where \(P_m = B \left( m_f - \frac{A}{B} \right) - C (\omega - 1)\), \(c_1\), \(c_2\) and \(b\) are the correlation coefficient of the equivalent post-transfer function, \(m_f\), \(\omega_f\) are shown above.

2.2. **Air conditioner model**
Compared with fixed-frequency AC, the advantage of inverter AC is that inverters of inverter AC can achieve infinite adjustment of AC's load. There is no minimum frequency-modulation time limit under the start-stop control of fixed-frequency AC, and the power factor of new national standard inverter AC is higher. The negative impact of changing the load on the power grid is further reduced, and the effect of participating in system regulation is also more significant. For centralized AC (central air con system), the cooling capacity is not only related to the compressor, but also involves multiple heat exchange modules such as the chilled water circulation system, the cooling water circulation system, and the fresh air system. In general, central air con system has large power consumption and is relatively concentrated. Compared with split AC, it has greater adjustment potential and is a high-quality demand response resource. The power saving potential of the air conditioning load varies with the control time, and adjusting the set temperature in a very short time (seconds) which has little effect on the user. But as control time increases, this approach does not allow the air-conditioned room to maintain the appropriate comfort. For multiple ACs, the heat storage characteristics of the building to which the air conditioning load belongs can be utilized, and the power saving potential is controlled by the coordination of the group within a suitable room temperature adjustment range. The power saving potential is the power demand that the AC can reduce under the premise of ensuring the comfort of a given temperature within a certain period of time.

The main power consumption of the central air con system is generated by the air conditioning and cooling main engine, the chilled water system, the cooling water system, and the terminal system. The working principle is shown in Fig. 4.

Figure 4. Schematic diagram of central air con system working principle

The chilled water return temperature signal automatically adjusts the speed and power consumption of the chilled water pump after the corresponding instruction is calculated by the built-in PID of the frequency converter. The cooling water return water temperature difference signal affects the cooling water pump flow and power consumption, and the room temperature and indoor set temperature difference The signal affects the operating state and energy consumption of the end system. Therefore, by installing a frequency converter to control the working state of the central air con system refrigeration host, the chilled water outlet temperature is changed to affect the energy consumption of the entire...
central air con system. The chiller performance data shows that the chilled water effluent temperature is increased by 1 °C on average, and the energy consumption is reduced by 2% to 3%. In this paper, the chilled water temperature is increased 1° C with the energy consumption is reduced 2.5%, namely:

$$P_{air} = 2.5\% \times \Delta T_{wat}$$

(3)

The air conditioning load has the characteristics of thermal inertia, which can be scheduled under the premise of less affecting the user's comfort. Therefore, it is necessary to establish a room temperature time-varying model during air conditioning operation to analyze user comfort. According to the principle of energy conservation, the amount of heat change in the air-conditioned room during a certain period of time causes a change in temperature. Using this principle, we can get the room temperature variation equation as shown below:

$$T_{in}(t) = \lambda_1 + \frac{\Delta T_{wat}}{\lambda_2} (e^{-at} - e^{-bt}) + \left( \lambda_1 - T_{in}(0) \right) e^{-bt}$$

(4)

Where $T_{in}(t)$ is room temperature at room time $t$. $a$ is the chilled water temperature changing parameter and can be taken as 1. $\Delta T_{wat}$ is the temperature difference between the chilled water inlet and outlet water. Parameters $\lambda_1, \lambda_2, b$ are determined by building parameters:

$$\begin{align*}
\lambda_1 &= \frac{Q_{er}}{1.8(k_{top}S_{top} + k_{wall}S_{wall})} \\
\lambda_2 &= \frac{a(p_v c_a + k_s S_{in}) - 1.8(k_{top}S_{top} + k_{wall}S_{wall})}{am c_w} \\
b &= \frac{1.8(k_{top}S_{top} + k_{wall}S_{wall})}{\rho_a V c_a + k_s S_{wall}}
\end{align*}$$

(5)

The grid frequency modulation signal period is short which usually in the order of seconds. To adjust the central air con system working state too frequently can cause fatigue damage to compressors, pumps, bearings, valves, etc., and shorten the service life. Refer to the air conditioning operating status and the traditional FM unit, we can set the upper frequency limit and the dead zone, and avoid frequent movements. This paper is taken as 0.1Hz.

For ACs, operating the AC in a high power (or low power) state for a long time will affect user’s comfort. Using the above model, the sinusoidal signal can be used to simulate the dispatching of the FM signal, and the lower limit of the frequency that the central air con system can bear is obtained:

$$\begin{align*}
&\min w \\
&\text{s.t.} \\
&P_{air} = 2.5\% \times \Delta T_{wat} = \sin wt \\
&T_{in}(t) = \lambda_1 + \frac{\Delta T_{wat}}{\lambda_2} (e^{-at} - e^{-bt}) + \left( \lambda_1 - T_{in}(0) \right) e^{-bt} \\
&T_{set} - \delta \leq T_{in} \leq T_{set} + \delta \\
&\Delta T_{wat}^{\min} \leq \Delta T_{wat} \leq \Delta T_{wat}^{\max}
\end{align*}$$

(6)

Where $w$ is the scheduling signal frequency. $T_{set}$ is the indoor temperature setting. $T_{set} \pm \delta$ is the human comfort zone. $\Delta T_{wat}^{\min}$ and $\Delta T_{wat}^{\max}$ are the extreme value of chilled water temperature adjustment. By solving the above optimization problem, the frequency response interval of the central air con system FM signal is obtained.

2.3. Energy storage system model
The frequency regulation of electric vehicles participating in the system is the use of the two-way fluidity of the energy of the car battery. When the system frequency rises, the electric vehicle absorbs electric energy from the power grid; When the system frequency drops, power is released to the grid. And charge and discharge have extremely fast response speed which can meet the millisecond power adjustment, and are suitable for high frequency components in the FM signal. The energy storage systems (ESS) can be divided into three types: charging, idle and discharging. It is described according to the energy storage model which is constructed in the previous section:

\[
C(t) = P_{ch}(t)\eta_{ch} - \frac{P_{dis}(t)}{\eta_{dis}}
\]

Where \( C(t) \) is the energy storage system; \( P_{ch}(t) \) and \( P_{dis}(t) \) are the charging power and discharge power of the energy storage system at time \( t \), respectively. \( \eta_{ch} \) and \( \eta_{dis} \) are the charging efficiency and discharge efficiency of the energy storage system, respectively. The expressions of electric quantity \( C(t) \) and output \( P(t) \) of energy storage system can be obtained.

\[
\begin{align*}
C(t) &= \int_{t_0}^{t} \left( P_{ch}(\tau)\eta_{ch} - \frac{P_{dis}(\tau)}{\eta_{dis}} \right) d\tau \\
P(t) &= \frac{dC(t)}{dt} = P_{ch}(t)\eta_{ch} - \frac{P_{dis}(t)}{\eta_{dis}}
\end{align*}
\]

In addition, the energy storage system operation constraints are expressed as follows:

\[
C_{sto} S_{soc, min} \leq C(t) \leq C_{sto} S_{soc, max}
\]

\[
0 \leq P_{ch}(t) \leq P_{sto} B_{ch}(t)
\]

\[
0 \leq P_{dis}(t) \leq P_{sto} B_{dis}(t)
\]

\[
B_{ch}(t) + B_{dis}(t) \leq 1
\]

where \( S_{soc, min} \) and \( S_{soc, max} \) are the minimum and maximum values of the state of charge of the energy storage system, respectively; \( C_{sto} \) is the rated capacity of the energy storage system; \( P_{sto} \) is the rated power of the energy storage system; \( B_{ch}(t) \) and \( B_{dis}(t) \) are the variable between 0-1 and represent the working state of the energy storage system.

3. Coordinated control strategy design

3.1. Fourier decomposition of regulatory signal

Since the frequency of the control signals suitable for each component in the microgrid is different, the discrete Fourier transform is used to perform frequency domain analysis on the scheduling signal. The discrete Fourier transform converts the time-domain discrete scheduling signal \( \{x(t)\} \) of length \( N \) into representation \( \{X(k)\} \) of the discrete frequency domain, and equation (12) represents the Fourier transform:

\[
X(k) = \sum_{t=0}^{N-1} x(t)e^{-j2\pi kt/N}, k = 0, 1, 2, ..., N-1
\]

Where \( e^{\pm j\phi} = \cos\phi \pm j\sin\phi \).

When microgrid control center receives the regulate signal, the frequency components of the signal are separated by the Fourier transform, and the signal component \( P_{DR,ref} \) in the appropriate frequency band is sent to the central air con system on the demand response side, and the low-frequency component
$P_{G, \text{ref}}$ is sent to the gas turbine unit, energy storage system is responsible for the high-frequency component $P_{\text{ESS}, \text{ref}}$.

3.2. Multi-objective system stability control based on backstepping

The basic idea of the backstepping control method is to decompose the complex nonlinear system into several subsystems that do not exceed the order of the system, and then design the Lyapunov function and the intermediate virtual control quantity for each subsystem, and then "backstepping" to the whole control system, and integrate them to complete the design of the overall control strategy. The basic steps of its design start from the kernel of a higher-order system, (usually a dynamic equation that satisfies the output of the system), design a virtual control law to ensure certain performance of the kernel system, such as stability; then the algorithm of virtual control algorithm is modified step by step, but the stability requirement must be guaranteed; a real stabilization controller is finally designed to realize the global control or tracking of the system and make the system achieve the expected control indicators. The backstepping control is applicable to nonlinear systems that can be state linearized or have strict feedback characteristics.

3.2.1. Design of fuel quantity instruction controller. Let $e_\delta = \delta_{\text{ref}} - \delta$, where $\delta_{\text{ref}}$ is the reference value of the power angle and $e_\delta$ is the error variable of the power angle. According to the backstepping control principle. By taking the derivative of $e_\delta$, we can get:

$$\dot{e}_\delta = \delta_{\text{ref}} - \dot{\delta} = \delta_{\text{ref}} - \omega - 1$$

(13)

Design the virtual control quantity $\omega_{\text{ref}}$ as follows:

$$\omega_{\text{ref}} = \delta_{\text{ref}} + k_\delta e_\delta + 1$$

(14)

Where the adjustable power angle control parameter $k_\delta > 0$. Substitute equation (14) into equation (13) yields:

$$e_\delta = -k_\delta e_\delta$$

(15)

Let $e_{\omega} = \omega_{\text{ref}} - \omega$, where $e_{\omega}$ is error variable of the angular velocity. Deriving $e_{\omega}$ and substituting equation (14):

$$\dot{e}_{\omega} = \frac{\delta_{\text{ref}} - k_\omega e_\omega}{\omega_0} - \frac{1}{H} \left[ B \left( m_f - \frac{A}{B} \right) - C(\omega - 1) - P_e \right] + \frac{D}{H}(\omega - 1)$$

(16)

Where $P_e = P_{G, \text{ref}}$. Design the virtual control quantity $m_{f, \text{ref}}$ as follows:

$$m_{f, \text{ref}} = \frac{B \left( \delta_{\text{ref}} - k_\delta e_\delta + k_\omega e_\omega \right) + (D + C)(\omega - 1) + P_e + A}{\omega_0}$$

(17)

In the formula, the adjustable angular velocity control parameter $k_\omega > 0$. Substitute equation (17) into equation (16), we can get:

$$e_{\omega} = -k_\omega e_\omega$$

(18)

Let $e_{mf} = m_{f, \text{ref}} - m_f$, where $e_{mf}$ is the error variable. Deriving $e_{mf}$ and substituting equation (17):
Design the virtual control quantity $\omega_{j, ref}$ as follows:

$$
\dot{\omega}_{j, ref} = \frac{T_{ed}}{B} \left[ H \left( \frac{\ddot{\delta}_{ref} + k_\delta \dot{\delta} \delta}{\alpha_0} - k_{\omega_0} \dot{\omega}_0 \right) + (D + C) \dot{\omega} + \dot{P}_e \right] + T_{cd} k_{mf} \dot{e}_{mf} + m_f
$$

(19)

Where the controllable parameter $k_{mf} > 0$. Substitute equation (20) into equation (19), and get:

$$
\dot{e}_{mf} = -k_{mf} e_{mf}
$$

(21)

Let $e_{af} = \omega_{j, ref} - \omega_j$, where $e_{af}$ is the load power error variable. Deriving $e_{af}$ and substitute equation (20) into it:

$$
\dot{e}_{af} = \frac{T_{ed}}{B} \left[ H \left( \frac{\dddot{\delta}_{ref} - k_\delta \dot{\delta} \delta}{\alpha_0} + k_{\omega_0} \dot{\omega}_0 \right) + (D + C) \dot{\omega} + \dot{P}_e \right] - T_{cd} k_{mf} \dot{e}_{mf} + m_f + c_1 \omega_f - c_2 (u - b)
$$

(22)

Design the actual fuel quantity command controller $u$ as

$$
u = \frac{T_{ed}}{\alpha_0} \left[ H \left( \frac{\dddot{\delta}_{ref} - k_\delta \dot{\delta} \delta}{\alpha_0} + k_{\omega_0} \dot{\omega}_0 \right) + (D + C) \dot{\omega} + \dot{P}_e \right] - T_{cd} k_{mf} \dot{e}_{mf} + m_f + c_1 \omega_f + k_{af} e_{af} + b
$$

(23)

Where the controllable gas quantity parameter $k_{af} > 0$. Substitute the formula (23) into the formula (22), one can obtain:

$$
\dot{e}_{af} = -k_{af} e_{af}
$$

(24)

3.2.2. Stability proof of the backstepping controller. Firstly, take the constructing of Lyapunov function $V_1 = \frac{1}{2} e_{\delta}^2$ in the first step of the backstepping control as an example, $\dot{V}_1 = -k_\delta \leq 0$, $V_1$ is consistent and continuous, if both sides of the inequality integrate simultaneously, we can get obtain: $\int_0^\infty \dot{V}_1 dt \leq 0$, that is, $-V_1(0) \leq V_1(\infty) - V_1(0) \leq 0$. The inequality above can be reduced to: $0 \leq V_1 \leq V_1(0)$. $V_1$ is bounded, that is, $-V_1(0) \leq \int_0^\infty \dot{V}_1 dt \leq 0$, so $\int_0^\infty \dot{V}_1 dt$ exists and is bounded, according to Barbalat's rule, it can be concluded: $\int_0^\infty \dot{V}_1 dt = 0$, that is, $\lim_{x \to \infty} e_{\delta} = 0$, so $V_1$ is bounded, and $V_1$ progressively tends to zero. Similarly, $\lim_{x \to \infty} e_{af} = 0$, $\lim_{x \to \infty} e_{mf} = 0$ and $\lim_{x \to \infty} e_{af} = 0$ can be introduced. It can be seen that the reverse thrust control can gradually reduce the tracking error to zero for the purpose of accurate tracking. It can be seen that the backstepping control can make the tracking error asymptotic to zero to achieve the purpose of accurate tracking.

Then for the entire control system, take the Lyapunov function $L_y$ as:
\[ L_y = \frac{1}{2} \dot{e}_d^2 + \frac{1}{2} \dot{e}_\omega^2 + \frac{1}{2} \dot{e}_{mf}^2 + \frac{1}{2} \dot{e}_{of}^2 \]  

(25)

By taking the derivative of equation (25) and substituting equation (15), (18), (21) and (24), we get:

\[ \dot{L}_y = -k_\delta \dot{e}_d^2 - k_\omega \dot{e}_\omega^2 - k_{mf} \dot{e}_{mf}^2 - k_{of} \dot{e}_{of}^2 \leq 0 \]  

(26)

Consider Ly is bounded, according to Barbalat's rule, there is

\[ \lim_{t \to \infty} L_y(t) = 0 \]  

(27)

Therefore, it is proved that the backstepping controller is asymptotically stable. That is to say, as time goes by, under the action of controller u, the error system will converge asymptotically to (0,0,0,0), and the system state quantity will also converge to the set reference value.

4. Simulation verification

The joint micronetwork system of the commercial park is built as shown in figure 1, and the proposed control strategy is simulated and verified. The relevant parameters of the system are as follows.

Gas turbine parameters:

| Parameter | Value | Parameter | Value |
|-----------|-------|-----------|-------|
| \( K_{nl} \) | 0.24  | \( T_b / s \) | 0.04  |
| \( T_f / s \) | 0.26  | \( T_{cd} / s \) | 0.16  |
| \( T_d / s \) | 0.04  | \( T_{sh} / s \) | 12.2  |
| A         | 0.158 | B         | 1.158 |
| C         | 0.5   | E         | 413   |
| F         | 313   | \( G_{sh} \) | 0.85  |
| \( T_{sh} / s \) | 12.2  | \( T_{ui} / s \) | 1.7   |
| \( T_f / ^\circ C \) | 522   | \( \omega_0 / p.u. \) | 1     |

Take the initial operating point of the system as \( \delta = 50^\circ, \omega = 1, m_f = 0.5, \omega_f = 0.511 \), the backstepping control parameters are set as: \( k_\delta = 0.199, k_\omega = 0.27, k_{mf} = 0.5, k_{of} = 0.96 \).

The park is designed with 50 commercial buildings, each with a set of central air con systems with the same parameters. Each commercial building is 45m long, 27m wide, 4.5m high, and 15 floors above ground, the remaining thermal parameters of the building are shown in Table 2. The rated power of each central air con system is 0.0012, and the overall energy consumption increases by 2.5% for every 1^\circ C rise in the outlet temperature of chilled water. The acceptable temperature range for users is 2^\circ C fluctuation in the set temperature, that is, \( T_{\text{acceptable}} = T_{\text{set}} \pm 2^\circ C \).
Table 2 Thermal parameters of the building

| Parameter                                           | Value |
|-----------------------------------------------------|-------|
| Wall thermal conductivity / W / (m² • °C)            | 0.6   |
| Roof thermal conductivity / W / (m² • °C)            | 1.2   |
| Cooling load factor of electrical equipment         | 0.88  |
| Cooling load factor of lighting equipment           | 0.95  |
| Heat loss per unit area of electrical equipment / W / m² | 17.75 |
| Lighting unit heat dissipation per unit area / W / m² | 42.5  |
| Sensible heat dissipation and cooling load coefficient of human body | 0.9   |
| Sensible heat dissipation of human body / W         | 69.78 |
| Latent heat dissipation of human body / W           | 111.65|
| Cluster coefficient                                 | 0.89  |

An energy storage system with rated power of 0.1 and maximum capacity of 0.1 is configured in the microgrid system.

The simulation period is within 2h in a summer time. According to the historical data stored and the predicted rolling model, the dispatching center can directly obtain the current power generation plan value of the unit and load in the time period, the ESS power and load prediction of the system. Then the microgrid power shortage information is formed as shown in Figure 5. After the power fluctuation prediction signal is decomposed, the gas turbine completes the $0.1 Hz \leq f < 0.1 Hz$ component, the central air con systems handle the $0.01 Hz \leq f \leq 0.1 Hz$ component, and the $f \leq 0.01 Hz$ component is completed by the ESS, see the blue curve in Figure 6~ Figure 8. In order to better verify the effectiveness of the proposed control strategy, a comparative simulation experiment in which the central air con system does not participate in the system adjustment is set, at this time, the gas turbine completes the $f \geq 0.05 Hz$ component, and the energy storage system completes the $f \leq 0.05 Hz$ component, As shown in the red curves in Figure 6 and Figure 8.

![Figure 5 power fluctuation prediction signal of microgrid](image1)

![Figure 6 Gas turbine output fluctuation component](image2)
In order to verify the dynamic and static regulation performance of the control strategy at the same time, the simulation system is designed to receive the above power adjustment signal at 10th minute, and the tracking control is ended at the 130th minute. That is, the dynamic monitoring performance of the controller is checked from the 10th to the 130th minute, after the 130th minute, what is simulated is the controller's ability to return the system to a stable state at a new operating level. The simulation results are shown in Figure 9~ Figure 13.

Figure 7 Central air con system output fluctuation component

Figure 8 ESS output fluctuation component

Figure 9 Power angle fluctuations of the microgrid

Figure 10 Frequency fluctuations of the microgrid

Figure 11 Fuel quantity command fluctuations of the gas turbine

Figure 12 Indoor temperature fluctuations of central air con system
Figure 13 Energy fluctuations of the ESS

It can be seen from Figure 9- Figure 11 that the backstepping controller can guarantee the stability of the microgrid’s power angle \( \delta \) and angular frequency \( \omega \) under different working conditions, and the gas turbine intake is quickly adjusted to enable the generator set to accurately track the power adjustment, and after the end of the tracking regulation, the system is quickly stabilized at the new operating point.

According to the comparison between Figure 9- Figure 11 and Figure 13, the participation of DR (central air con system) in system regulation can significantly suppress the fluctuation of system parameters in regulation, which is conducive to the smooth operation of the system. In particular, it can be seen from Figure 11 and Figure 13 that the DR resource can reduce the adjustment of the intake valve of the gas turbine unit and the charge/discharge of the ESS, which is of great significance for saving the system control cost and prolonging the service life of the equipment. And as can be seen from Figure 12, the regulation of the central air con system does not cause the indoor temperature to fluctuate drastically, \( T_{in} \) is within an acceptable range.

5. Conclusion
In this paper, a multi-resource integrated commercial park microgrid system model including gas turbine, central air con system and ESS is constructed; comprehensively considering about the response rate, response capacity and control characteristics of multi-resource, a tracking matching method for different resources in system regulation is proposed; a multi-index coordinated control strategy based on backstepping control principle is designed to fully utilize DR resources in system control and improve system stability. The research results are as follows:

- The multi-objective coordinated backstepping controller can effectively adjust the state of the system under different working conditions, enable multiple control targets, such as power angle and frequency, to track their reference values quickly, which indicates the correctness and robustness of the coordinated control strategy.
- The participation of DR resources can effectively improve the dynamic and static regulation characteristics of the system, save the cost of system regulation and prolong the service life of the equipment.

In this paper, only the typical central air con system model with cooling characteristics and homogenization is selected when considering DR resources of microgrid. In further research, models of different types of DR resources can be built separately, and control strategies can be further optimized by combining intermittent power supply.

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