APPENDIX

Appendix A: Different node inertia coefficients and SCR calculation process

For each scenario $S = S_{typ} \bigcup S_{ext}$, the multi-site short-circuit ratio (MRSCR) for renewable energy stations is calculated by Equation (A1):

$$MRSCR_i = \left| \frac{\dot{U}_i^* \dot{U}_{Ni}}{\dot{Z}_{eqii}} \right| / \left| \dot{S}_{REi} + \sum_{j=1, j \neq i}^{n} \dot{\Pi}_{ij} \dot{S}_{REj} \right| \tag{A1}$$

where $\dot{U}_i$ is the actual operating voltage at the i-th renewable bus, and $\dot{U}_{Ni}$ denotes the rated voltage at the same bus. $\dot{Z}_{eqii}$ is the i-th diagonal element of the equivalent impedance matrix $\dot{Z}_{eq}$, representing the self-impedance at the point of common coupling. $\dot{S}_{REi}$ refers to the complex apparent power injected by the renewable resource at i-th bus. The coupling coefficient $\dot{\Pi}_{ij}$ between i-th and j-th buses is defined as $\dot{\Pi}_{ij} = \dot{Z}_{eqij} \dot{U}_i^* / \dot{Z}_{eqii} \dot{U}_j^*$, where $\dot{Z}_{eqii}$ represents the mutual impedance between the two buses.

The spatial variation of system inertia is reflected in the fact that, following a disturbance in the power system, different nodes exhibit significantly different frequency responses. To characterize this phenomenon, a system nodal inertia matrix H is defined, representing the observed inertia at various nodes when a specific node experiences a disturbance. The matrix is expressed by Equation (A2):

$$H = \begin{bmatrix} H_{i1} & H_{i2} & \cdot & \cdot & \cdot & H_{iN} \end{bmatrix}^T \tag{A2}$$

Where H_{ij} denotes the system inertia observed at j-th node when a disturbance is applied at i-th node. Specifically, H_{ii} represents the self-inertia coefficient of i-th node, while H_{ij} (for $i \neq j$) quantifies the mutual inertia observed at j-th node due to a disturbance at i-th node. These coefficients are calculated by Equations (A3)-(A4):

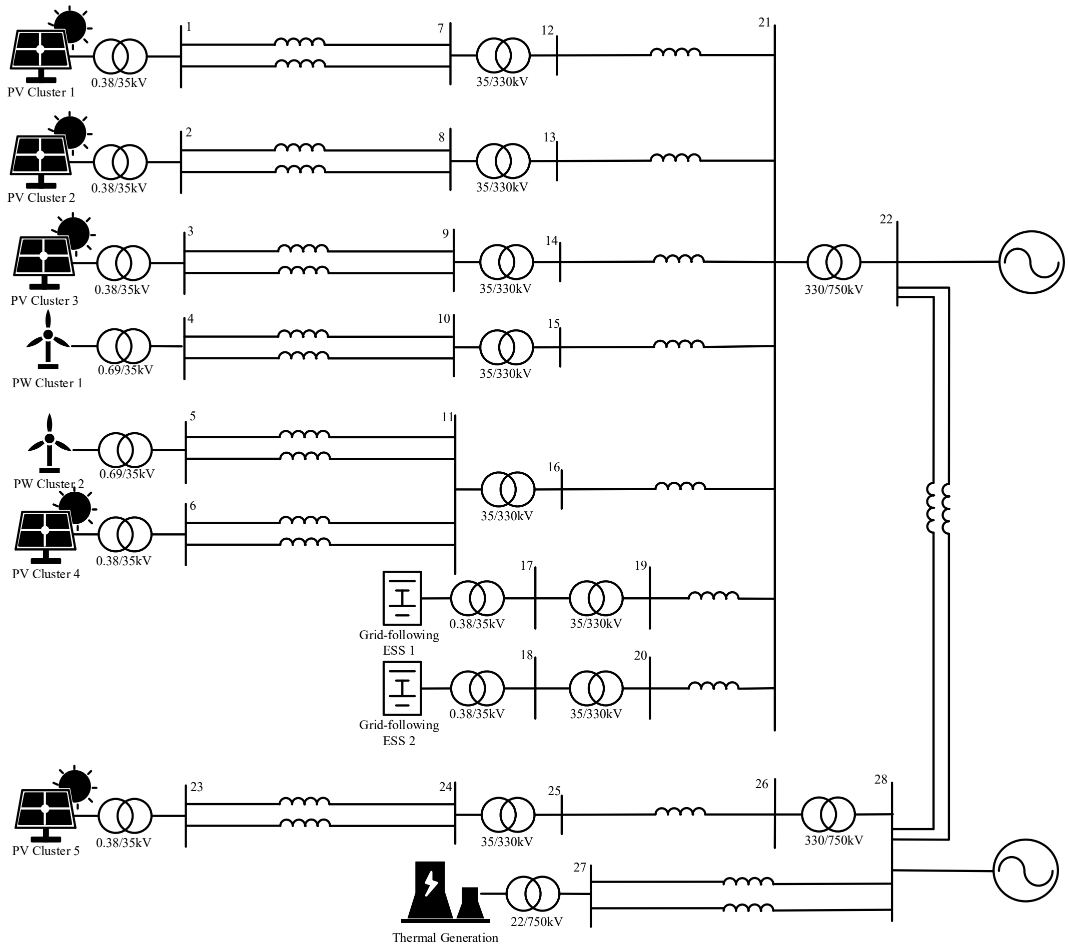
$$H_{ii} = -\Delta P_{e-i} / (2df_i / dt) \tag{A3}$$

$$H_{ij} = -\Delta P_{e-i} / (2df_j / dt) \tag{A4}$$

Where ΔP_{e-i} denotes the change in total system active power caused by a disturbance at i-th node, and f_i、f_j represent the frequency measured at i-th and j-th nodes, respectively. These expressions quantitatively capture the coupling between frequency dynamics and the spatial distribution of system inertia across different nodes.

For each operational scenario, the maximum value of $MRSCR_i$ and the mutual inertia coefficient H_{ij} are identified for each node. The normalized node inertia coefficient Hi and the normalized short-circuit ratio SCRi are then computed for each node individually.

Appendix B: Topology of the Power Grid System



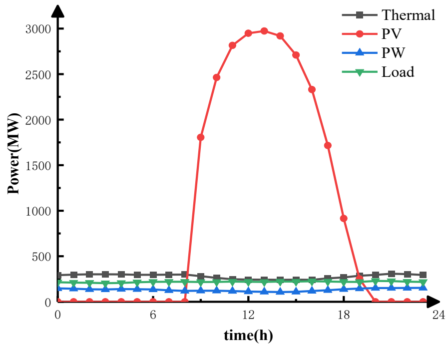
Appendix Figure 1. Topology of the Power Grid System

Appendix C: Solving Parameters for GFMES Optimization

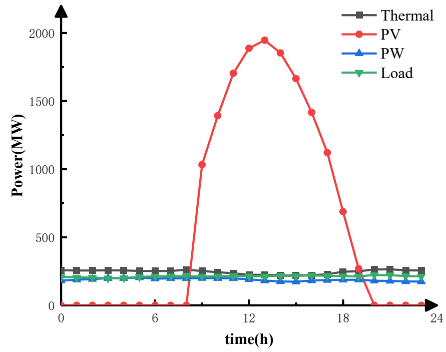
Appendix Table 1. Solving Parameters for GFMES Optimization

Parameter Type	**Value**
Unit power investment cost C_p (10^4 CNY/MW)	100
Unit energy capacity investment cost C_{cap} (10^4 CNY/MWh)	150
Discount rate r (%)	8
Lifetime N_y (years)	20
Unit Power Maintenance Cost C_o (10^4 CNY/MW)	25
Unit Power Decommissioning Cost C_{pd} (10^4 CNY/MW)	8
Unit Energy Decommissioning Cost C_{sd} (10^4 CNY /MWh)	0
Contract Electricity Price of Power Plant e （10^4 CNY/MWh）	0.05
Number of Peak-Shaving Operation Days per Year for Energy Storage N_p (days)	360
Number of frequency regulation operation days per year N_f （days）	360
Average Frequency Regulation Mileage Coefficient ω	2.75
Comprehensive Frequency Regulation Performance Index K_{Ap}	1.5
Frequency mileage settlement price λ_1 (10^4 CNY/MW)	0.0015
Coal-fired unit annual operating hours T (h)	5000
Thermal Unit Lifetime M (years)	30
Thermal Installation Cost per Capacity Unit $P_{thermal}$ (10^4 CNY/MW)	370
Basic Peak Regulation Ratio of Thermal Units q	0.3
Thermal Unit Maintenance Coefficient λ_2	0.1
Unit Fuel Cost of Thermal Power W_{fuel} (t/MWh)	0.35
Fuel Price of Thermal Power C_{fuel} （10^4 CNY/t）	0.04
NO_x Emission Cost per Unit Generation c_{NO_X} (10^4 CNY/MWh)	0.0010074
SO_2 Emission Cost per Unit Generation c_{SO_2} (10^4 CNY/MWh)	0.0002671
CO_2 Emission Cost per Unit Generation c_{CO_2} (10^4 CNY/MWh)	0.0018669

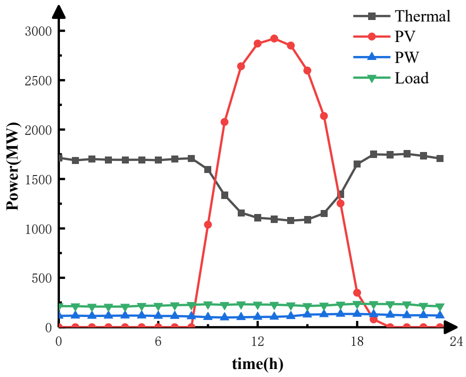
Appendix D: The corresponding 24-hour power output of each scenario



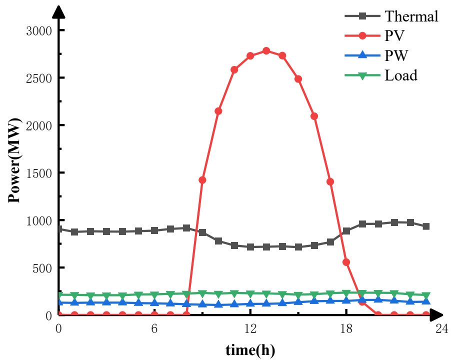
Appendix Figure 3(a) Summer Typical Scenario 1



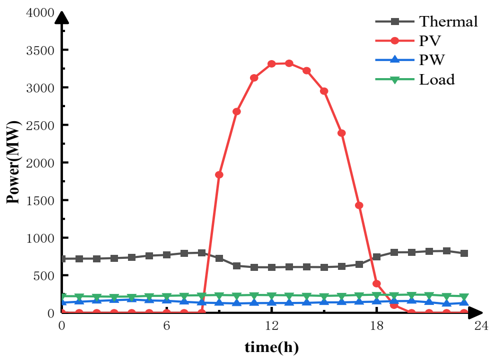
Appendix Figure 3(b) Summer Typical Scenario 2



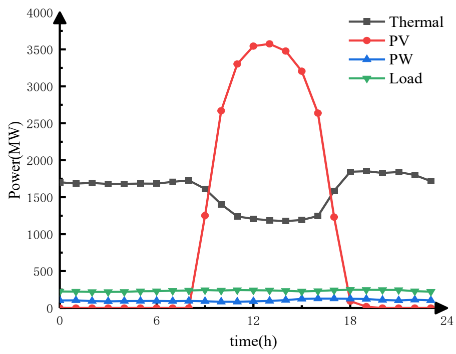
Appendix Figure 3(c) Winter Typical Scenario 1



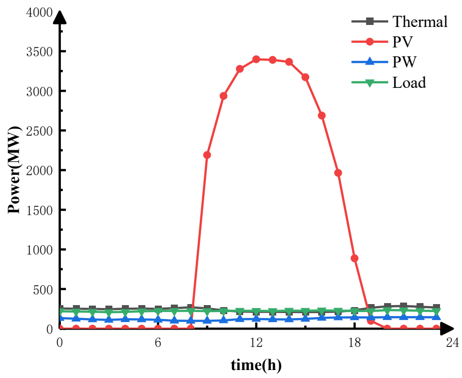
Appendix Figure 3(d) Winter Typical Scenario 2



Appendix Figure 3(e) Extreme Scenario 1



Appendix Figure 3(f) Extreme Scenario 2



Appendix Figure 3(g) Extreme Scenario 3