Research Article

Research on the Evaluation of Multi-Energy Microgrid under the Background of New Power System

Wenxin Du, Tianbo Han, and Shizhao Hu

Guangdong Power Grid Co., Ltd., Guangzhou 510699, China

Correspondence should be addressed to Tianbo Han; 458948526@qq.com

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As a key means to elevate low-carbon energy transformation in China, multi-energy microgrid accelerates the construction of new power systems. In order to scientifically evaluate the benefits of multi-energy microgrids, we proposed a benefit evaluation index system from the dimensions of economy, reliability, low carbonization, and intelligence. Considering the relationship between the evaluation indicators, this paper innovatively proposed a multi-energy microgrid benefit evaluation model based on AHP-VWT-MEEM. In addition, this paper selected different multi-energy microgrid demonstration projects in the China Southern Power Grid Company Limited’s region for example analysis. In the example analysis, through the comparison of the comprehensive benefits of the three projects, the comprehensive benefit of the project 3 is the best. On this basis, from the specific configuration plan of Project 3, it can be concluded that the configuration of larger capacity thermal storage can realize the "thermal decoupling" of cogeneration, thereby improving the flexible adjustment capability of the demonstration area, promoting the consumption of renewable energy, and obtaining more considerable comprehensive benefits. At the same time, it is pointed out that the comprehensive benefit evaluation result can be improved by appropriately reducing the investment cost of project 3.

1. Introduction

The construction of a new power system with new energy as an important source can be an important means to achieve the goal of “double carbon.” As installed renewable energy in China continues to grow, how to ensure the safe and stable operation of new energy systems and achieve clean, low-carbon, and smart digital development is a significant issue in the current industry [1–4].

In the context of comprehensively promoting the construction of a new power system and effectively serving the “dual carbon” goal, in November 2021, China Southern Power Grid Limited issued the “14th five-year plan” of China Southern Power Grid. During the 14th five-year plan period, China Southern Power Grid will invest about 670 billion yuan to promote the construction of digital power grid and modern power grid and new power system with new energy as the main body [5]. In addition, the “big base, big power grid” development model still plays a crucial part in absorbing renewable energy power generation and delivery in Guangxi, Yunnan, and other provinces. The development of distributed renewable energy in economically developed load centers such as the Pearl River Delta is an important way to increase the proportion of installed renewable energy in recipient regions. The multi-energy microgrid can coordinate the allocation of various types of resources, such as electricity, gas, heat, and cold, and improve the flexibility of system energy supply and ability to meet users’ energy demand. It is an important method for the development on a large scale and application of distributed renewable energy in the future [6, 7].

At present, local and international experts have conducted in-depth research studies on the comprehensive benefits of integrated energy systems or multi-energy microgrids. In the literature [8], an optimization model of a combined electricity and gas system configured with electricity-to-gas equipment was proposed, and the combined system by setting corresponding indicators was modeled to analyze the impacts of the application of electricity-to-gas equipment on the load supply rate and the renewable energy
surplus rate. Ning and Fang [9] explored multi-energy coordination and interaction evaluation method for campus microgrids and constructed a multiple decision-making model for integrated energy systems by VIKOR and fitted the index calculation to the system operation, which lacked the analysis of the impacts of individual indexes on the final evaluation results. According to the literature [10], universally adaptable indicators were extracted from aspects of source-network-load and equipment, respectively, and then an overall evaluation of the integrated regional energy system was developed. The value evaluation method of integrated energy system based on the green house economy was proposed in the literature [11], but mostly the value evaluation of integrated energy system was done through the indexes of the efficiency and energy consumption. In the literature [12], energy efficiency evaluation indexes for integrated energy systems in parks were proposed, and a discrete energy flow calculation method and energy efficiency evaluation method were established based on a weighted directed graph to establish a system equivalence model. Zhang et al. [13] proposed a comprehensive evaluation of regional integrated energy system on the basis of the material meta-topologic model with coordinated interests of multiple entities, but its evaluation indexes for project investors were too simple and lacked the consideration of energy efficiency indicators such as comprehensive energy utilization rate.

To sum up, the current evaluation of multienergy microgrid mainly has problems such as imperfect construction of the index system, insufficient connection between the index calculation and the actual operation of the new power system, too macroscopic indicators and evaluation methods, and emphasis on the final evaluation results. At the same time, the current evaluation takes less consideration of clean and low carbon, and does not take into account the development of intelligent digitalization of the multienergy microgrid system.

In order to solve the problems of randomness and uncertainty in performance evaluation and grasp the key indicators, matter-element extension model is adopted to improve the multi-level fuzzy comprehensive evaluation method. This paper constructed a multi-energy microgrid benefit evaluation index system and established a benefit evaluation model based on AHP-VWT-MEEM, considering the evaluation attributes of realizing "energy triangle" and intelligent advanced in many aspects. The comprehensive evaluation model can realize both the ranking analysis of single indicators and the feasibility of the program or project as a whole, so that the decision makers of power grid enterprises can analyze the advantages and disadvantages of different programs from the bottom up and improve the effectiveness of scientific decision making.

2. Multi-Energy Microgrid Evaluation Index System

According to traditional active distribution grids or microgrids, multi-energy microgrids can realize the coordination and optimization between a great diversity of energy systems and utilize the complementary features of different energy species and energy systems to enhance the efficiency of end-use energy, the capacity of renewable energy consumption, the energy supply reliability, and system operation economy in the region. In terms of this, this paper constructed a multi-energy microgrid efficiency evaluation index system, including energy consumption, economy, reliability, and decarbonization and intelligence.

2.1. Energy Consumption Indicators

2.1.1. Comprehensive Energy Utilization. The comprehensive energy utilization is the ratio of effectively utilized energy to the actual energy consumed [14]. The index is a comprehensive indicator reflecting the level and effect of energy consumption and utilization, that is, the degree of effective utilization of energy, as shown in formulas (1) and (2).

\[
\eta_{\text{utili}}^{\text{zh-energy}} = \frac{\lambda_1 P_{\text{electric}}^{\text{ann-buy}} - \lambda_2 V_{\text{gas}}^{\text{ann-buy}} + \lambda_3 P_{\text{boiler}}^{\text{ann-buy}}}{\lambda_1 P_{\text{CHP}}^{\text{ann-supply}} + \lambda_4 Q_{\text{ann-supply}}} \tag{1}
\]

\[
V_{\text{gas}}^{\text{ann-buy}} = \lambda_3 P_{\text{CHP}}^{\text{ann-supply}} + \lambda_4 Q_{\text{ann-supply}} \tag{2}
\]

where \(\eta_{\text{utili}}^{\text{zh-energy}}\) represents the system energy utilization rate; \(P_{\text{electric}}^{\text{ann-cons}}, Q_{\text{ann-cons}}\), and \(Q_{\text{ann-cons}}\) mark the annual electricity consumption, annual heat consumption, and annual cooling capacity in the integrated energy system, respectively; \(V_{\text{gas}}^{\text{ann-buy}}\) and \(P_{\text{electric}}^{\text{ann-buy}}\) refer to annual natural gas purchases and annual purchased electricity for the integrated energy system, respectively; \(\lambda_1\) stands for the conversion factor for kWh and KJ units; \(\lambda_2\) is the calorific conversion factor of natural gas; \(\lambda_3\) and \(\lambda_4\) represent the natural gas consumption factor per unit of output for combined heat and power unit (CHP) and gas boilers, respectively; \(P_{\text{CHP}}^{\text{ann-supply}}\) stands for the annual power generation of CHP, and \(Q_{\text{ann-supply}}\) denotes the annual heat supply of gas boiler.

2.1.2. Renewable Energy Utilization. Renewable energy utilization rate is the proportion of renewable energy consumption including hydropower, wind power, and solar power to the total energy consumption, as shown in the following formula:

\[
k_{\text{ke-zs}}^{\text{utili}} = \frac{P_{\text{cons}}^{\text{tot}}}{P_{\text{cons}}^{\text{tot}}} + \frac{P_{\text{cons}}^{\text{tot}}}{P_{\text{cap}}^{\text{tot}}} \tag{3}
\]

where \(k_{\text{ke-zs}}^{\text{utili}}\) is the utilization rate of renewable energy in the multi-energy microgrid; \(P_{\text{cons}}^{\text{tot}}\) and \(P_{\text{cap}}^{\text{tot}}\) represent the renewable energy consumption, respectively; \(B_{\text{cap}}^{\text{v}}\) is distributed photovoltaic construction capacity; \(B_{\text{cap}}^{\text{v}}\) indicates the construction capacity of distributed wind power; and \(T_{\text{cap}}^{\text{v}}\) and \(T_{\text{cap}}^{\text{w}}\) represent the annual working hours of photovoltaic and wind power, respectively.

2.1.3. Exergy Efficiency. Exergy efficiency is the ratio of the revenue or utilization exergy to the exergy of payment or
consumption, and it can quantitatively calculate the various revenue and expenditure, utilization, and loss of energy exergy[15], as shown in the following formula:

$$
\eta^{\text{zh-yong}}_{\text{utili}} = \frac{\lambda_{1}P_{\text{electric, ann-cons}} + K_{\text{xunh}}Q_{\text{xunh-cons}} + K_{\text{xunh}}Q_{\text{cold-cons}}}{\lambda_{1}V_{\text{gas, ann-buy}}K_{\text{xunh}} + \lambda_{1}P_{\text{electric, ann-buy}}}
$$

where $\eta^{\text{zh-yong}}_{\text{utili}}$ represents the system exergy efficiency; $K_{\text{xunh}}$ and $K_{\text{cold-cons}}$ represent the Carnot cycle efficiency of annual heat supply and annual cooling supply, respectively (the efficiency is only related to the thermodynamic temperature of the two heat sources); and $K_{\text{xunh}}$ marks the energy quality coefficient of natural gas.

### 2.2. Economic Indicators

#### 2.2.1. Investment Cost

The investment cost of multi-energy microgrid is the sum of the capital expenditures brought by the materials and labor consumed by the fixed asset investment project. This section also gives the equivalent annual value of the system’s investment, as shown in formulas (5) and (6).

$$
C_{\text{sys-cost}} = c_{\text{CHP}} + B_{\text{CHP}}(N_{\text{cap}}) + B_{\text{cap}}(c_{\text{cap}}^\text{ch} \cdot Q_{\text{cold}}^\text{ch}) + Y_{\text{sq}}(c_{\text{cap}}^\text{ch} \cdot Q_{\text{cold}}^\text{ch}) + \delta_{\text{PV}}(c_{\text{cap}}^\text{PV})
$$

$$
C_{\text{equal, annu}} = C_{\text{sys-cost}} \cdot \left(1 + \frac{r_{\text{ate}}}{1 - \left(1 + r_{\text{ate}}\right)^{-T_{i}}}ight)
$$

where $c_{\text{sys-cost}}$ represents the total investment cost of multi-energy microgrid; $c_{\text{CHP}}$ is the fixed investment cost of CHP; $B_{\text{CHP}}$, $B_{\text{cap}}$, $c_{\text{cap}}$, $Q_{\text{cold}}$, and $Y_{\text{sq}}$, respectively, mark the unit capacity/area cost of CHP, absorption chiller, heat pump, photovoltaic, fan, gas boiler, electric energy storage, thermal energy storage, and solar thermal equipment; $B$ represents the construction capacity of different kinds of energy units in the multi-energy microgrid; $Y_{\text{sq}}$ refers to the effective area of the photovoltaic panel; $C_{\text{equal, annu}}$ stands for the equivalent annual value of the multi-energy microgrid investment; $r_{\text{ate}}$ denotes the discount rate; and $T_{i}$ indicates the operating life of the multi-energy microgrid.

#### 2.2.2. Operation and Maintenance Cost

The operation and maintenance cost of the multi-energy microgrid is shown in the following formula:

$$
C_{\text{opera}} = \delta_{\text{CHP}}(c_{\text{CHP}} + c_{\text{cap}}^\text{ch} Q_{\text{cold}}^\text{ch}) + \delta_{\text{bo}}(c_{\text{bo}} Q_{\text{bo}}) + \delta_{\text{PV}}(c_{\text{PV}})
$$

$$
+ \delta_{\text{cap}}(c_{\text{cap}}^\text{ch} Y_{\text{sq}} + c_{\text{cap}}^\text{ch} Q_{\text{cold}}^\text{ch} + c_{\text{cap}}^\text{PV} Y_{\text{sq}} + c_{\text{cap}}^\text{cap}) + \delta_{\text{cap}}(c_{\text{cap}}^\text{cap})
$$

$$
+ \delta_{\text{cap}}(c_{\text{cap}}^\text{cap}) + \delta_{\text{cap}}(c_{\text{cap}}^\text{cap}) + \delta_{\text{cap}}(c_{\text{cap}}^\text{cap})
$$

where $C_{\text{opera}}$ represents the annual operation and maintenance cost of the system; $\delta$ represents the unit operation and maintenance cost of different kinds of energy units in the multi-energy microgrid; $c_{\text{CHP}}$, $c_{\text{cap}}$, and $c_{\text{bo}}$ indicate the average annual power generation of CHP, distributed wind power, and photovoltaic power; $Q_{\text{bo}}^\text{ch}$ is the average annual cooling capacity of the absorption chiller; and $T_{\text{ch}}$, $T_{\text{cap}}$, and $T_{\text{bo}}$ mark the average annual operating hours of the electric energy storage, heat storage tank, and heat pump, respectively.

#### 2.2.3. Outsourced Energy Cost

The cost of outsourcing energy in the multi-energy microgrid mainly comes from the outsourcing of natural gas and electricity, as shown in the following formula:

$$
C_{\text{buy}} = \lambda_{3}P_{\text{CHP}} + \lambda_{4}Q_{\text{boiler}},
$$

where $\lambda_{3}$ and $\lambda_{4}$ represent the annual natural gas and electricity price.

#### 2.2.4. Reduce Grid Investment Cost

The operation of the multienergy microgrid system can reduce the operating cost of the power grid, so the indicator “reduce grid investment cost” is established.

$$
C_{\text{equal, redu-inves}} = \frac{c_{\text{CHP}}}{\chi} \cdot \left(1 + r_{\text{ate}}\right)^{-T_{i}} - 1
$$

where $C_{\text{equal, redu-inves}}$ means the equivalent annual value of reducing the system investment cost; $P_{\text{CHP}}$ indicates the maximum load in the microgrid area; $P_{\text{cap}}$ marks the maximum off-grid load of the system; $\chi$ is the load rate of the transformers configured in the grid-connected place; and $c$ denotes the investment cost of transformers per unit capacity.

### 2.3. Reliability Indicators

#### 2.3.1. Expected Energy Not Supplied

Expected energy not supplied (EENS) is a significant evaluation indicator in reliability analysis of traditional power systems. EENS refers to the electricity supply gap in the system for a time [16]. Since the multi-energy microgrid needs to satisfy the energy needs of users in the future, including cold, heat, and electricity, we need to analyze its ability to supply different energy demands. In this paper, the generalized EENS was used to analyze the reliability of the multi-energy microgrid, as shown in the following formula:

$$
\text{EENS} = \sum_{k=1}^{K} \left(\theta_{\text{electric}, \text{EENS}} + \theta_{\text{hot}, \text{EENS}} + \theta_{\text{cold}, \text{EENS}}\right),
$$

where $\text{EENS}$ represents the generalized expected energy supply shortage; $K$ represents the calculation time period; and $\theta_{\text{electric}, \text{EENS}}$, $\theta_{\text{hot}, \text{EENS}}$, and $\theta_{\text{cold}, \text{EENS}}$ denote the expected energy supply shortage of electric energy, heat energy, and cold energy, respectively; due to the different influences of different energy supply shortages, this section sets three weighting coefficients $\theta_{\text{electric}}$, $\theta_{\text{hot}}$, and $\theta_{\text{cold}}$, which,
respectively, indicate the degree of influence of different types of energy supply shortages on the system energy supply reliability index. In the calculation, the above weights can be represented by the normalized loss costs caused by different types of energy outages.

2.3.2. Frequency Safety Margin. In a new power system that incorporates new sources of energy, renewable energy power sources and grid-connected multi-energy microgrids need to have a certain frequency stability capability, which can adjust their active power output according to frequency changes [17]. The frequency stability index needs to consider the moment of inertia and primary frequency modulation, that is, the ability to respond to the frequency change rate and frequency deviation.

In the multi-energy microgrid, we need virtual synchronizers equipped with conventional power sources, as well as renewable energy sources such as wind and photovoltaic, to provide the necessary moment of inertia and primary frequency modulation capability. This section quantitatively analyzes the transient frequency stability of the multi-energy microgrid through the frequency safety margin ##\text{RoCoF}##, as displayed in formulas (11)–(14).

\[
\text{RoCoF}_{\text{frequ}} = \sqrt{f_{\text{rate}}^2 + z_{\text{frequ}}^2}, \quad (11)
\]

\[
f_1 = \frac{\text{RoCoF}_{\text{frequ}} \cdot |\text{RoCoF}_{\text{max}}|}{\text{RoCoF}_{\text{sup}}}, \quad (12)
\]

\[
f_2 = \frac{\Delta f_{\text{sup}} - |\Delta f_{\text{max}}|}{\Delta f_{\text{sup}}}, \quad (13)
\]

\[
\text{RoCoF} = \frac{\Delta P_{\text{loss}} - f_{\text{cap}}}{2E_{\text{sys}}}, \quad (14)
\]

where ##\text{RoCoF}_{\text{sup}}## represents the upper limit of the allowable frequency change rate; ##f_{\text{rate}}## and ##z_{\text{frequ}}##, respectively, refer to the frequency change rate and the weight of the frequency change, which were both taken as 0.5 in this paper; ##\text{RoCoF}_{\text{max}}## means the maximum frequency change rate in the multi-energy microgrid; ##\Delta f_{\text{sup}}## is the upper limit of the frequency change allowed by the system; ##\Delta f_{\text{max}}## denotes the maximum frequency change in the multi-energy microgrid; ##\Delta P_{\text{loss}}## represents the maximum active power deficit; ##f_{\text{cap}}## is the rated power; and ##E_{\text{sys}}## indicates the total rotational kinetic energy in the system, including the rotational kinetic energy of the traditional units and the rotational inertia provided by the virtual synchronous machines of wind power and photovoltaic units.

2.3.3. Grid Connection Point Voltage Offset Ratio. Since the multi-energy microgrid belongs to an active power distribution system, the access of the distributed voltage may cause power flow back, thus causing the voltage of the grid-connected nodes to rise or fluctuate [18]. In this paper, the voltage offset situation ##U_{\text{devi}}## was used to quantitatively analyze the voltage control capability of the multi-energy microgrid, as shown in the following formula:

\[
U_{\text{devi}} = \max \left( \frac{U_{\text{sys}}^{\text{max}} - U_{\text{sys}}^{N}}{U_{\text{sys}}^{N}} \times 100\% \right)
\]

where ##U_{\text{sys}}^{N}## represents the rated voltage at the grid-connected location and ##U_{\text{sys}}^{\text{max}}## and ##U_{\text{sys}}^{\text{min}}## mark the maximum and minimum voltages at the grid-connected location, respectively.

2.4. Low Carbonization Indicators

2.4.1. Proportion of Renewable Energy Delivered. Renewable energy delivery refers to the ratio of photovoltaic, wind power, and other renewable energy to the capacity of the delivery channel [19], as shown in formulas (16) and (17).

\[
h_{\text{pv}}^{\text{prop}} = \frac{P_{\text{pv}}^{\text{cap}}}{P_{\text{cap}}^{\text{cap}}}, \quad (16)
\]

\[
h_{\text{wt}}^{\text{prop}} = \frac{P_{\text{wt}}^{\text{cap}}}{P_{\text{cap}}^{\text{cap}}}, \quad (17)
\]

where ##h_{\text{pv}}^{\text{prop}}## and ##h_{\text{wt}}^{\text{prop}}##, respectively, refer to the proportion of renewable energy such as photovoltaic and wind power delivered to the outside world and ##P_{\text{cap}}^{\text{cap}}## denotes the capacity of the delivery channel.

2.4.2. Proportion of Renewable Energy Generation. The proportion of renewable energy power generation refers to the proportion of renewable energy power generation, including hydropower, wind power, and solar power in the total energy power generation, as shown in the following formula:

\[
\alpha_{\text{ke}}^{\text{zs}} = \frac{a_{\text{el}}^{\text{elec}} + a_{\text{el}}^{\text{hot}} + a_{\text{el}}^{\text{old}}}{a_{\text{el}}^{\text{ann-cons}} + a_{\text{el}}^{\text{ann-cons}} + a_{\text{el}}^{\text{ann-cons}}}, \quad (18)
\]

where ##\alpha_{\text{ke}}^{\text{zs}}## is the proportion of renewable energy supply, which is the ratio of annual renewable power generation to the total energy supply of the system.

2.4.3. Carbon Emission Intensity. Carbon emission intensity is the amount of carbon dioxide emitted per unit of GDP growth. Economic scale, energy intensity, energy structure, and industrial structure are the main factors affecting carbon emission intensity, as shown in the following formula:

\[
C_{\text{em}} = f_{\text{gas}}^{\text{ann-buy}} + f_{\text{elec}}^{\text{ann-buy}}, \quad (19)
\]

where ##C_{\text{em}}## is the carbon emission intensity; ##f_{\text{gas}}^{\text{ann-buy}}## is the carbon emission intensity of natural gas per cubic meter; and
f_{electric} is the carbon emission intensity of purchased electricity per kilowatt-hour.

2.5. Intelligent Indicators

2.5.1. Distribution Automation Coverage Rate. The multi-energy microgrid distribution automation coverage rate refers to the ratio of distribution lines and distribution transformers with automation functions to their total number, as shown in the following formula:

\[
h_{\text{line-tran}}^{\text{prop}} = \frac{p_{\text{line-tran}}^{\text{auto-dist}}}{p_{\text{line-tran}}^{\text{distribution}}},
\]

where \( h_{\text{line-tran}}^{\text{prop}} \) represents the coverage rate of distribution automation; \( p_{\text{line-tran}}^{\text{auto-dist}} \) denotes the number of distribution lines and distribution transformers with automation functions; and \( p_{\text{line-tran}}^{\text{distribution}} \) marks the total number of distribution lines and distribution transformers.

2.5.2. Distribution Network Intelligent Terminal Penetration Rate. The penetration rate of intelligent terminals in the distribution network refers to the proportion of intelligent terminals in distribution transformers, lines, and reactive power compensation devices, as shown in the following formula:

\[
h_{\text{Inte-terminal}}^{\text{prop}} = \frac{D_{\text{终端}}}{{D}^{\text{all}}_{\text{终端}}},
\]

where \( h_{\text{Inte-terminal}}^{\text{prop}} \) represents the penetration rate of intelligent terminals in the distribution network; \( D_{\text{终端}}^{\text{Inte}} \) stands for the number of intelligent terminals in distribution transformers, lines, reactive power compensation, and other devices; and \( D_{\text{终端}}^{\text{all}} \) marks the number of end users.

2.5.3. Coverage Rate of Electricity Consumption Information Acquisition System. The coverage rate of the electricity consumption information acquisition system denotes the ratio of metering devices connected to the electricity consumption information acquisition system, as shown in the following formula:

\[
h_{\text{sn-system}}^{\text{prop}} = \frac{D_{\text{device}}^{\text{sn-system}}}{D_{\text{device}}^{\text{all}}},
\]

where \( h_{\text{sn-system}}^{\text{prop}} \) represents the coverage rate of the electricity consumption information acquisition system; \( D_{\text{device}}^{\text{sn-system}} \) is the number of metering devices connected to the electricity consumption information acquisition system; and \( D_{\text{device}}^{\text{all}} \) indicates the number of end-user metering devices.

2.6. Comprehensive Benefit Evaluation Index System. According to the above research, the multi-energy microgrid benefit evaluation index system is divided into 5 evaluation attributes and 16 evaluation indicators. It is pointed out that the indicators such as comprehensive energy utilization rate, exergy efficiency, reduction of grid investment cost, renewable energy utilization efficiency, and renewable energy power generation ratio are benefit indicators, that is larger indicator value, are better. The indicators such as investment cost, operation and maintenance cost, external energy purchase cost, insufficient expected energy supply, frequency stability, voltage offset at the grid connection point of the system, and carbon emission intensity are cost-based indicators, that is, smaller indicator value is better.

In view of this, the multi-energy microgrid benefit evaluation index system is shown in Table 1.

### 3. AHP-VWT-MEEM Evaluation Model

The basic concept of matter-element extension model (MEEM) is to express the thing \( N \) to be evaluated with an ordered triple \( R, \) and \( R \subseteq N. \) Among them, \( R \) represents the matter-element, \( \partial = [\alpha_1, \alpha_2, \ldots, \alpha_n] \) is the characteristic index vector of the thing, and \( V = [v_1, v_2, \ldots, v_n] \) refers to the magnitude of the corresponding characteristic index \([20].\) It is assumed that the matter-element \( R \) has \( m \) levels to be evaluated, and \( R \) is represented in the form of a matrix, as shown in the following formula:

\[
R = \begin{bmatrix}
R_1 \\
R_2 \\
\vdots \\
R_m
\end{bmatrix}.
\]

Based on the traditional matter-element extension theory, this paper constructed a multi-energy microgrid benefit evaluation model by using AHP-VWT-MEEM method \([21].\) The specific evaluation steps are as follows.

3.1. Determining the Classical Domain Level. The classical domain level of the matter-element \( R_j \) of the grade to be evaluated:

\[
R_j = (N_j, \alpha, d) = \left[ \begin{array}{c}
N_j \\
\alpha_1 (v_{j_1}, q_{j_1}) \\
\alpha_2 (v_{j_2}, q_{j_2}) \\
\vdots \\
\vdots \\
\alpha_n (v_{j_n}, q_{j_n})
\end{array} \right],
\]

where \( \alpha_i \) is the eigenvector index of the level to be evaluated and \( i \leq n, j \leq m; d_{ji} = (v_{ji}, q_{ji}) \) denotes the magnitude range of \( \alpha_i, \) which is the classical domain level of the matter-element \( R_j \) of the level to be evaluated.

3.2. Determining the Nodal Level. The determined node domain level of the matter-element \( A \) of the grade to be evaluated is specifically illustrated in the following formula:

\[
R_j = (\rho, \alpha, d_m) = \left[ \begin{array}{c}
\rho \\
\alpha_1 (v_{p_1}, q_{p_1}) \\
\alpha_2 (v_{p_2}, q_{p_2}) \\
\vdots \\
\vdots \\
\alpha_n (v_{pm}, q_{pm})
\end{array} \right],
\]
where $p$ is the complete evaluation grade and $d_{pi} = (v_{p1}, q_{pi})$ means the range of magnitudes taken by $p$ with respect to the feature index vector $a_i$.

### 3.3. Building a Matter-Element Model to Be Evaluated.

Based on the original data or actual situation of the feature vector of $R$ to be evaluated, $R_0$ is expressed by MEEM as

$$R_0 = (p_0, a_i, d_o)$$

$$= \begin{bmatrix} p_0 & a_1 & v_1 \\ a_2 & v_2 \\ \cdots \\ a_n & v_n \end{bmatrix}, \quad (26)$$

where $R_0$ represents the matter element to be evaluated $p_0$ refers to the thing to be evaluated; and $v_1, v_2, \ldots, v_n$ represent the actual data of $p_0$ on the eigenvector index, respectively.

### 3.4. Establishing an Evaluation Correlation Function and Determining the Correlation Degree.

Based on the correlation function in MEEM theory, calculate the correlation degree of each evaluation index for each level to be evaluated, which is shown in the following formula:

$$h_{ij}(v_i) = \begin{cases} \frac{\zeta(v_i, d_{ji})}{\zeta(v_i, d_{pi}) - \zeta(v_i, d_{ji})} & \zeta(v_i, d_{ji}) \neq \zeta(v_i, d_{pi}) \\ \frac{-\zeta(v_i, d_{ji})}{\|d_{ji}\|} & \zeta(v_i, d_{pi}) = \zeta(v_i, d_{ji}) \end{cases},$$

$$\quad (27)$$

where $h_{ij}(v_i)$ represents the correlation function value of the $i$-th index with respect to the $j$-th evaluation level; $\zeta(v_i, d_{ji})$ marks the distance from the $i$-th index and its corresponding classical field; and $\zeta(v_i, d_{pi})$ indicates the distance from the $i$-th index and its corresponding node field. The specific calculation method of $\zeta(v_i, d_{ji})$ and $\zeta(v_i, d_{pi})$ is shown in the following formula:

$$\zeta(v_i, d_{ji}) = v_i - \frac{v_{pi} + q_{ji}}{2} - \left( \frac{q_{ji} - v_{ji}}{2} \right),$$

$$\zeta(v_i, d_{pi}) = v_i - \frac{v_{pi} + q_{pi}}{2} - \left( \frac{q_{pi} - v_{pi}}{2} \right).$$

### 3.5. Indicator Weight Determination.

We use analytic hierarchy process (AHP)-variable weight theory (VWT) combination weighting method to calculate the weight value of each indicator.

AHP is a commonly used subjective weighting method. According to the stratification of every index factor, two index factors of each level are compared in pairs to form an importance relationship matrix, and then the weight of each index is obtained through the consistency test. The weights of indicators formed by this method belong to static constant weights, and the obtained weights are highly subjective and do not consider the differences between the groups of different evaluation objects, and the balance of indicators is insufficient.

VWT can more comprehensively consider the differences between groups in the evaluation index data, take the characteristics of the index data itself into account, reflect the changes in weights between different evaluation objects, and avoid affecting the overall judgment of the evaluation index due to the pros and cons of an evaluation index [22].

It is assumed that the weight vector of the matter element $R_0$ to be evaluated based on AHP is $u_{\text{AHP}}$ and the state variable weight vector is $S_{\text{variation}}$. Then, the variable weight vector $H_{\text{AHP-vari}}$ can be represented by the product of the subjective weight vector obtained by AHP and the state variable weight vector Hadamard, as shown in the following formula:

### Table 1: Multi-energy microgrid benefit evaluation index system.

| Evaluation attribute       | Evaluation indicators                                                                 | Unit       |
|---------------------------|---------------------------------------------------------------------------------------|------------|
| Energy consumption indicators | Comprehensive energy utilization                                                   | %          |
|                           | Renewable energy utilization                                                          | %          |
|                           | Exergy efficiency                                                                    | %          |
| Economic indicators       | Investment cost                                                                      | Ten thousand yuan |
|                           | Operation and maintenance cost                                                       | Ten thousand yuan |
|                           | Outsourced energy cost                                                               | Ten thousand yuan |
|                           | Reduce grid investment cost                                                          | Ten thousand yuan |
| Reliability indicators    | Expected energy not supplied                                                         | MWh/year   |
|                           | Frequency safety margin                                                              | Pu         |
|                           | Grid connection point voltage offset ratio                                          | %          |
| Low carbonization indicators | Proportion of renewable energy delivered                                            | %          |
|                           | Proportion of renewable energy generation                                            | %          |
|                           | Carbon emission intensity                                                            | Ton        |
| Intelligent indicators    | Distribution automation coverage rate                                               | %          |
|                           | Distribution network intelligent terminal penetration rate                            | %          |
|                           | Coverage rate of electricity consumption information collection system               | %          |
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\[ h_{i,\text{AHP-vari}} = \sum_{j=1}^{m} \frac{y_i^\text{factor variation}}{s_j^\text{factor variation}} \]

\[ s_i^\text{variation} = e(y_i^\text{factor variation}) \cdot (s_{i,\text{max}} - s_{i,\text{min}}) \quad (29) \]

where \( s_i^\text{variation} \) represents the normalized index value of the \( i \)-th index \( R_0 \) to be evaluated; \( s_{i,\text{max}} \) and \( s_{i,\text{min}} \), respectively, mark the normalized lower and upper values of the \( i \)-th index section domain; and \( y_i^\text{factor variation} \) is the variable weight factor, which takes values in the range of \([0, 1]\), and its numerical magnitude indicates the requirement for indicator balance. When \( y_i^\text{factor variation} = 1 \), the variable weight vector is equal to the weight vector derived from hierarchical analysis; when \( y_i^\text{factor variation} < 1 \), it indicates a certain requirement for indicator balance; when \( y_i^\text{factor variation} > 1 \), it indicates a low requirement for indicator balance.

3.6. Determining the Final Evaluation Level. By weighting the correlation between each evaluation index and different evaluation levels, the weighted correlation for the object to-be-evaluated is obtained, as shown in the following formula:

\[ g_j^\text{corr}(R_0) = \sum_{i=1}^{n} h_{i,\text{AHP-vari}} \cdot g_{ij}^\text{corr}(v_i). \quad (30) \]

Using the principle of maximum membership degree, the specific evaluation level \( R_0 \) to be evaluated can be finally obtained, as shown in the following formula:

\[ \mathbb{N}_0 = j, \quad \exists g_{\mathbb{N}_0}^\text{corr}(R_0) = \max(g_j^\text{corr}(R_0)), \forall j \in \mathbb{N}, \quad (31) \]

where \( \mathbb{N}_0 \) represents the level \( R_0 \) to be evaluated. In addition, the variable eigenvalues of the evaluation level can also be obtained according to MEEM, as shown in formulas (32) and (33).

\[ \bar{g}_j^\text{corr}(R_0) = \frac{g_j^\text{corr}(R_0) - \min(g_j^\text{corr}(R_0)), \forall j}{\max(g_j^\text{corr}(R_0), \forall j) - \min(g_j^\text{corr}(R_0), \forall j)}, \quad (32) \]

\[ j^* = \frac{\sum_{j=1}^{m} \bar{g}_j^\text{corr}(R_0)}{\sum_{j=1}^{m} \bar{g}_j^\text{corr}(R_0)}, \quad (33) \]

where \( j^* \) represents the variable feature value of the matter-element to be evaluated. It is used to analyze the development trend of the matter-element to be evaluated as the degree of the matter-element to be evaluated toward the adjacent grades.

4. Example Analysis of Comprehensive Evaluation of Integrated Energy Microgrid

4.1. Model Parameters. To better analyze the comprehensive benefits of different multi-energy microgrid projects and verify the validity and practicability of the proposed multi-energy microgrid benefit evaluation model based on AHP-VWT-MEEM method, this paper selected three multi-energy microgrid demonstration projects in different regions of China Southern Power Grid as the objects to be evaluated. The three demonstration projects were connected to the 110 kV substation of the main network with 10 kV, and the electricity and heat load levels are basically the same. The load composition is mainly industrial load, with a low proportion of residential load and industrial and commercial load. The specific configuration scheme of the demonstration project to be evaluated is shown in Table 2, and the equipment cost parameters in the microgrid demonstration area are demonstrated in Table 3.

It is supposed that the operation period of the multi-energy microgrid demonstration project is 20 years, and the bank’s long-term loan interest rate is 4.9%. The average price of outsourced electricity is 0.5 yuan/kWh. The average price of natural gas is 2.63 yuan/m³. The upper limit of frequency change rate allowed by the system is 1 Hz/S, and the upper limit of frequency change allowed by the system is 0.8 Hz.

According to the actual operation of the microgrid demonstration item, the average values of the maximum frequency fluctuation and voltage fluctuation measured in each month are determined by \(|\text{RoCoF}_{\text{max}}|, |\Delta f_{\text{max}}|, U_{\text{max}}^\text{sync}, \) and \( U_{\text{min}}^\text{sync} \), respectively.

As the demonstration project is located in Southern China, it has high requirements on cooling load. In the generalized EENS calculation, the weight coefficients of \( \theta_{\text{electric}}, \theta_{\text{hot}}, \) and \( \theta_{\text{cold}} \) are, respectively, 0.6, 0.1, and 0.3.

In this paper, generalized EENS was calculated based on Monte Carlo algorithm, and the operating states of different types of equipment were sampled. It is assumed that the forced outage rate of all equipment is 4%. As the demonstration projects to be evaluated are located in the same region and the load scale and composition are basically the same, the typical scenarios and corresponding probabilities are formed based on the existing output data and load of renewable energy, as shown in Table 4.

The evaluation set of comprehensive energy microgrid evaluation index system was constructed, and the score set was divided into five rating levels, namely, very poor = \( E_1^{\text{py}}, \) poor = \( E_2^{\text{py}}, \) general = \( E_3^{\text{py}}, \) better = \( E_4^{\text{py}}, \) and very good = \( E_5^{\text{py}}. \)

According to the power distribution and heating system index values and other microgrid operation data in the multi-energy microgrid demonstration project, the classical domain and section domain of each evaluation indicator are determined, and the specific results are shown in Table 5.
4.2. **Weight Value Solution.** According to the constructed AHP-VWT variable weight method, the weight value of evaluation index was determined. Considering that the multi-energymicrogridevaluationindexsystemconstructed in this paper needs to consider the balance between indicators, the value was set to be 0, and the variable weight of each evaluation object is obtained as shown in Table 6 and Figure 1.

4.3. **Comprehensive Evaluation Results.** Based on the index weight and basic data of the multi-energy microgrid benefit evaluation model, the microgrid demonstration project was comprehensively evaluated, and the correlation degree between different project evaluation indexes and evaluation grades was obtained. The X-axis represents different project evaluation indexes (index 1–index 16), the Y-axis represents different evaluation levels (E1–E5), the Z-axis represents the correlation between evaluation indicators and evaluation levels, and different colors represent different correlation ranges. Thus, a three-dimensional view is obtained, as shown in Figures 2–4.

The evaluation results of the multi-energy microgrid demonstration project to be evaluated are shown in Table 7. According to the evaluation results of each demonstration project in Table 7, the evaluation grade of project 1 is $E_{1}^{p-yu}$, that of project 2 is $E_{2}^{p-yu}$, and that of project 3 is $E_{3}^{p-yu}$.

According to formula (29), the characteristic values of variables of each demonstration project are $j_{1}^{*} = 1.941$, $j_{2}^{*} = 1.803$, and $j_{3}^{*} = 2.673$, respectively. From the evaluation results of multi-energy microgrid benefits, the evaluation results of demonstration project 3 are the best, while the comprehensive benefits of project 1 and project 2 are poor.

As can be seen from the eigenvalues of project 1 and project 2, there is a small gap between the evaluation results of the two. The evaluation results of demonstration projects 1 and 2 are not ideal, mainly due to the poor evaluation results of some evaluation indexes in both projects.

Based on the results of calculation examples, the benefit evaluation of three multi-energy microgrid demonstration projects is analyzed in depth.

1. Demonstration project 1 has a high proportion of renewable energy access, but a small capacity of CHP and electric energy storage configuration, thus resulting in the unsatisfactory evaluation results of its generalized EENS, system frequency safety margin, and system voltage offset ratio. This is mainly because the power supply in project 1 region is mostly dependent on renewable energy with uncertain output, thereby leading to small rotational inertia, insufficient primary frequency modulation and other capabilities, and large fluctuation of internal frequency of the system. When the installed capacity of renewable energy is relatively large and the configuration capacity of energy storage equipment is limited, power flow backflow often occurs in project 1, which causes the voltage at the connection point to rise and approach the voltage deviation threshold of 5%. At the same time, due to the lack of flexible heat/electricity load conversion device and energy storage equipment, although the system installed capacity of renewable energy is the biggest among the three projects to be evaluated, the

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### Table 2: The specific configuration scheme of the demonstration project to be evaluated.

| Capacity | Heat pump (kW) | Gas boiler (kW) | Heat (kW) | Absorption refrigerator (kW) | Distributed fan (kW) | Distributed photovoltaic (kW) | CHP (kW) | Thermal energy storage (kW) | Electrical energy storage (kW) |
|----------|----------------|-----------------|-----------|------------------------------|---------------------|-----------------------------|---------|-----------------------------|-----------------------------|
| Demonstration project 1 | 4500 | 450 | 415 | 500 | 550 | 5700 | 300 | 1230 | 340 |
| Demonstration project 2 | 3000 | 750 | 555 | 400 | 380 | 2400 | 400 | 50 | 500 |
| Demonstration project 3 | 3250 | 600 | 305 | 600 | 770 | 4700 | 200 | 3200 | 300 |

### Table 3: Equipment cost parameter index.

| Equipment parameter | Fixed acquisition cost (yuan) | Acquisition cost per capacity (yuan/kW) | Operational cost per capacity (yuan/kWh) |
|---------------------|--------------------------------|-----------------------------------------|----------------------------------------|
| Heat pump           | —                              | 3000                                    | 0.1                                    |
| Heat pump           | —                              | 1000                                    | 0.15                                   |
| Heat                | —                              | 300 yuan/m$^2$                          | 230 yuan/m$^2$                         |
| Absorption refrigerator | —                          | 4500                                    | 0.1                                    |
| Distributed fan     | —                              | 7000                                    | 0.07                                   |
| Distributed photovoltaic | —                          | 6000                                    | 0.005                                  |
| CHP                 | —                              | 3500                                    | 0.15                                   |
| Thermal energy      | —                              | 500 yuan/kWh                            | 0.1                                    |
| Electrical energy storage | —                          | 3000 yuan/kWh                           | 0.05                                   |
| 110kV main transformer | 25000000                    | —                                       | —                                      |
Table 4: Typical scenario parameters of renewable energy output and load.

| Parameter scenario               | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | Scenario 6 | Scenario 7 | Scenario 8 | Scenario 9 | Scenario 10 | Scenario 11 | Scenario 12 |
|----------------------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| Average power load of the system (kW) | 2761       | 2781       | 2987       | 2178       | 32051      | 2603       | 3592       | 2730       | 2473       | 2692       | 2451       | 2468       |
| Average heat load of the system (kW) | 4169       | 5180       | 5861       | 3693       | 3531       | 3884       | 3089       | 4468       | 4080       | 4831       | 5621       | 3293       |
| Average cooling load used by the system (kW) | 2108       | 1569       | 1083       | 1356       | 2508       | 2114       | 3204       | 1508       | 1782       | 2682       | 2460       | 1731       |
| Mean wind speed (m/s)            | 7.94       | 5.13       | 7.05       | 6.63       | 5.16       | 6.98       | 4.86       | 10.42      | 8.14       | 8.77       | 6.94       | 7.18       |
| Mean radiation intensity (kW/m²)  | 0.63       | 0.85       | 0.23       | 0.75       | 0.97       | 0.56       | 0.70       | 0.50       | 0.83       | 0.75       | 0.41       | 0.53       |
| Scene probability                | 0.17       | 0.09       | 0.14       | 0.08       | 0.07       | 0.07       | 0.07       | 0.05       | 0.11       | 0.12       | 0.11       | 0.08       |
The utilization of renewable energy is limited, and the advantage in the two indicators of renewable energy efficiency and the proportion of renewable energy supply is not obvious. Follow-up project 1 can configure certain thermal energy storage equipment or increase the electric energy storage capacity to improve the energy supply capacity in the item. Simultaneously, certain virtual synchronizers can be configured in the wind power and photovoltaic projects to improve the frequency response capacity of windpower and photovoltaic items.

(2) The main problems in demonstration project 2 are that the way of resource allocation is too simple, the installed proportion of renewable energy in the project is insufficient, and power supply in the demonstration area mainly depends on CHP output, which is highly dependent on the main network. This results in poor evaluation results of renewable energy utilization rate, proportion of renewable energy supply, carbon emission intensity, and other indicators, which ultimately affects the overall evaluation results of the project.

(3) The overall evaluation result of demonstration project 3 is good. Through the configuration of large capacity thermal energy storage, CHP realizes “thermoelectric decoupling,” which improves the flexible adjustment ability in the demonstration area and realizes more efficient absorption and utilization of renewable energy. As can be seen from Figure 4, most evaluation indexes of demonstration project 3 have satisfactory performance. However, due to the configuration of more thermal power conversion and energy storage equipment, the overall

| Table 5: The level of matter element classical domain and section domain of each evaluation grade. |
|-------------------------------------------------|
| The average index comment grade | E_{1}^{y_{1}} | E_{2}^{y_{2}} | E_{3}^{y_{3}} | E_{4}^{y_{4}} | E_{5}^{y_{5}} | d_{pa} |
|---------------------------------|-------------|-------------|-------------|-------------|-------------|----------|
| Comprehensive energy efficiency | [40, 60)    | [60, 80)    | [80, 100)   | [100, 120)  | [120, 140)  | [30, 150) |
| Renewable energy efficiency    | [40, 60)    | [60, 80)    | [80, 100)   | [100, 120)  | [120, 140)  | [30, 150) |
| Exergic efficiency             | [20, 40)    | [40, 60)    | [60, 80)    | [80, 100)   | [100, 120)  | [20, 120] |
| Investment cost                | [400, 500)  | [320, 400)  | [220, 320)  | [100, 220)  | [0, 100)    | [0, 510]  |
| Operational costs              | [100, 120]  | [80, 100]   | [60, 80]    | [40, 60]    | [20, 40]    | [20, 510]  |
| Outsourcing energy costs       | [330, 400)  | [250, 330)  | [190, 250)  | [140, 190]  | [0, 140]    | [0, 410]   |
| Cost of reducing grid investment | [90, 100)   | [100, 110)  | [110, 120)  | [120, 150]  | [150, 190]  | [90, 200]  |
| Expect energy in short supply  | [300, 420]  | [240, 300]  | [200, 240]  | [170, 200]  | [0, 170]    | [0, 450]   |
| Frequency safety margin        | [0, 0.2]    | [0.2, 0.4]  | [0.4, 0.6]  | [0.6, 0.8]  | [0.8, 1]    | [0, 1]     |
| Voltage offset ratio of connection point | (4, 5) | (3, 4) | (2, 3) | (1, 2) | [0, 1] | [0, 8] |
| Proportion of renewable energy sent out | [0, 60] | [60, 70] | [70, 80] | [80, 90] | [90, 100] | [0, 100] |
| Proportion of renewable energy generation | [0, 20] | [20, 40) | [40, 60] | [60, 80] | [80, 100] | [0, 100] |
| Carbon intensity               | [400, 500]  | [300, 400]  | [200, 300]  | [100, 200]  | [0, 100]    | [0, 520]   |
| Distribution automation coverage | [0, 20] | [20, 40) | [40, 60] | [60, 80] | [80, 100] | [0, 100] |
| Distribution network intelligent terminal penetration rate | [0, 20] | [20, 40) | [40, 60] | [60, 80] | [80, 100] | [0, 100] |
| Coverage of electricity information acquisition system | [0, 20] | [20, 40] | [40, 60] | [60, 80] | [80, 100] | [0, 100] |

| Table 6: Weight comparison of different weighting methods. |
|-----------------------------------------------------------|
| Serial number | Indicator weight | The weight of standing power | The weight of the variable power |
|---------------|------------------|-----------------------------|---------------------------------|
| 1             | Comprehensive energy efficiency | 0.081                        | 0.073  | 0.083  | 0.075  |
| 2             | Renewable energy efficiency | 0.073                        | 0.077  | 0.07   | 0.071  |
| 3             | Exergic efficiency | 0.052                        | 0.056  | 0.05   | 0.051  |
| 4             | Investment cost | 0.091                        | 0.087  | 0.091  | 0.092  |
| 5             | Operational costs | 0.063                        | 0.065  | 0.067  | 0.059  |
| 6             | Outsourcing energy costs | 0.056                        | 0.06   | 0.061  | 0.058  |
| 7             | Cost of reducing grid investment | 0.042                      | 0.041  | 0.041  | 0.045  |
| 8             | Expect energy in short supply | 0.083                        | 0.085  | 0.087  | 0.079  |
| 9             | Frequency safety margin | 0.071                        | 0.072  | 0.073  | 0.069  |
| 10            | Voltage offset ratio of connection point | 0.056                     | 0.059  | 0.056  | 0.054  |
| 11            | Proportion of renewable energy sent out | 0.063                      | 0.064  | 0.057  | 0.061  |
| 12            | Proportion of renewable energy generation | 0.046                      | 0.046  | 0.049  | 0.05   |
| 13            | Carbon intensity | 0.065                        | 0.063  | 0.062  | 0.064  |
| 14            | Distribution automation coverage | 0.053                      | 0.056  | 0.054  | 0.055  |
| 15            | Distribution network intelligent terminal penetration rate | 0.058                      | 0.053  | 0.061  | 0.054  |
| 16            | Coverage of electricity information acquisition system | 0.047                      | 0.043  | 0.038  | 0.063  |

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investment cost is high, and the project investment cost has great impacts on the evaluation results of comprehensive benefit.

On this basis, this paper conducted sensitivity analysis on the investment cost index of demonstration project 3, and the specific results are shown in Table 8.
Table 8: System investment cost index analysis in project 3.

| Proportion of investment cost reduction in project 3 (%) | Rating | Characteristic value |
|---------------------------------------------------------|--------|----------------------|
| 10                                                      | $E_{1}^{y_{u}}$ | 3.105                |
| 20                                                      | $E_{2}^{y_{u}}$ | 3.278                |
| 30                                                      | $E_{3}^{y_{u}}$ | 3.517                |
| 40                                                      | $E_{4}^{y_{u}}$ | 4.032                |
From the analysis of system investment cost index in Table 8, it is obvious that the decrease of investment cost has significant impacts on the comprehensive benefit evaluation results of demonstration project 3. When the investment cost decreases by 40%, the multienergy microgrid benefit evaluation is better when the evaluation grade is $E^{p}_{4-75}$

5. Conclusion

The evaluation model proposed in this paper is mainly applicable to the multi-energy microgrid system in the pursuit of economic, safe, and green power system, which is characterized by the interaction of multi-subsystem and multi-equipment, and has a strong demand for reliability. In the evaluation process of low-carbon and intelligent indicators of the system, indicators, including the proportion of renewable energy sent out, carbon emission intensity, penetration rate of intelligent terminals in the distribution network, and coverage rate of electricity information acquisition system, were introduced. In addition to considering the energy supply capacity of the multi-energy microgrid, the important influence of renewable energy on the integrated energy microgrid is also considered, which makes the evaluation index system more comprehensive and scientific. The efficiency evaluation model of multi-energy microgrid based on the AHP-VWT-MEEM method was established, and the effectiveness and applicability of the proposed model were verified by an example. Also, it is pointed out that AHP uses the subjective method to construct the weight of evaluation level, which cannot fully capture the characteristics of the evaluation object. If there is no significant difference between the two schemes, the improved AHP-VWT-MEEM will make the evaluation results reflect the difference between them enough to provide more scientific and reasonable evaluation results.

By comparing the evaluation results of demonstration projects to be evaluated, it is concluded that the evaluation result of project 3 is better than projects 1 and 2. It is necessary to better coordinate the mutual relations among economy, reliability, low carbonization, and intelligence of system construction under the background of "dual carbon" goal and new power system construction. While providing the proportion of renewable energy installed, it could effectively solve the problems of renewable energy consumption and system security and stable operation. Most importantly, power grid enterprises should promote the implementation of more multi-energy microgrid demonstration projects, truly realize the commercial operation of demonstration projects, further reduce related equipment and system investment cost, and give full play to the efficiency and multi-energy microgrid benefit.

Data Availability

The data were obtained from Songshan Lake Park, Dongguan city, Guangdong Province.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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