OPTIMAL DESIGN OF DISTRIBUTED GENERATOR CAPACITY IN MICROGRIDS CONSIDERING LIFE CYCLE COST

Haoming Liu, Fengqin Kang, Shanshan Li, Xiaoling Yuan
College of Energy and Electrical Engineering
Hohai University
Nanjing, China
liuhaom@hhu.edu.cn; kangfengqin@126.com; kelen-lss@163.com; lingx@hhu.edu.cn

ABSTRACT
For the optimal sizing of distributed generators in a stand-alone microgrid, the minimum annual life cycle cost (LCC) of the microgrid, which includes equipment investment cost, equipment replacement cost, microgrid operation cost (contains equipment operation and maintenance cost, fuel cost and environment-pollution penalty), failure cost (payment to customers due to outages), and equipment discard cost after the life cycle, is taken as the objective to establish the optimization mathematical model. A hybrid optimization algorithm, in which particle swarm optimization (PSO) is main and genetic algorithm (GA) is auxiliary, is proposed to solve the optimization mathematical model for escaping from the local optimum and ensuring the accuracy of the global optimum. For an example microgrid, the optimal sizing scheme of distributed generators is found among a range of configurations that meet certain system constraints to validate the correctness and effectiveness of the model and hybrid algorithm proposed.

KEY WORDS
Microgrid, stand-alone system, distributed generators, optimal sizing, life cycle cost (LCC), hybrid optimization algorithm

1. Introduction
Microgrid is a small-scale power system that consists of distributed generators, loads, energy storage devices, and controllers. In recent years, with the development of microgrid technologies, the research and application of microgrid have obtained more and more attention, which makes microgrid gradually become an important means to solve many problems that exist in traditional power systems. Microgrid can operate at two modes, one is the connection mode with traditional power system, and the other is the stand-alone mode with no connection. Stand-alone microgrid is suitable for providing power supply at remote areas where traditional power systems hardly reach to.

Optimal sizing of distributed generators in microgrid is one of important and complex planning issues. Reasonable distributed generator capacities can delay the construction of traditional transmission and distribution networks, improve power supply reliability, and meet consumers’ requirements for power qualities and environment protection. Many papers have studied the optimal planning of microgrid. Reference [1] described typical microgrid architectures and planning benchmarks for improving reliability and integration. Reference [2] proposed a formula for optimal design and operation of a grid-connected microgrid. Reference [3] carried out an economic and operational case study on a hybrid system of renewable and conventional energies, analyzing the optimal combination of renewable and conventional energies by HOMER simulation. Reference [4] illustrated a dynamic programming based method to determine the optimal combination and location of different kinds of distributed generators with considering the impacts of combined heat and power (CHP). Reference [5] also proposed a methodology for economic design and optimal operation of microgrid with CHP system.

Considering the characteristics of different kinds of distributed generators, this paper develops an optimal sizing model for distributed generators in stand-alone microgrid with the minimum life cycle cost as the objective. A hybrid optimization algorithm of particle swarm optimization (PSO) and genetic algorithm (GA) is constructed to search the global optimum of the optimal sizing model under a series of system constraints.

2. Microgrid Architecture and Distributed Generator Models

2.1 Microgrid Architecture
The common microgrid architecture is shown in Figure 1. The power sources include renewable energy generators, such as wind generators and photovoltaic cells, non-renewable energy generators, such as diesel generators, fuel cells, and micro-turbines, and battery bank. Feeder 1 and 2 are connected with sensitive loads (important loads), and Feeder 3 is connected with non-sensitive loads (common loads). When electricity in the microgrid is insufficient, loads on Feeder 3 can be cut off selectively, and when electricity in the microgrid is redundant, the excess can be stored in the battery bank. The electricity stored in the battery bank can also be released to meet the loads timely.
2.2 Distributed generator models

2.2.1 Wind power

The output power of wind generator (WG) $P_{WG}$ can be calculated as follows:

$$P_{WG} = \begin{cases} 0, & v \leq v_{ci} \\ a v^3 - b P_r, & v_{ci} \leq v \leq v_r \\ P_r, & v_r \leq v \leq v_{co} \\ 0, & v \geq v_{co} \end{cases}$$

(1)

where $a = P_r / (v_c^3 - v_{co}^3)$; $b = v_c^3 / (v_c^3 - v_{co}^3)$; $P_r$ is the rated power of WG; $v_{ci}$, $v_{co}$, $v_r$ are the cut-in, cut-out and rated wind speeds of WG, respectively; $v$ is the wind speed at WG’s hub height.

2.2.2 Photovoltaic system

The output power of photovoltaic (PV) array $P_{PV}$ can be calculated as follows:

$$P_{PV} = \eta_g N_{PV} A_m G_t$$

(2)

where $\eta_g$ is the instantaneous efficiency of PV array; $N_{PV}$ is the number of PV modules in the array; $A_m$ is the area of a single PV module; $G_t$ is the light intensity.

The instantaneous efficiency $\eta_g$ is represented by the following equation:

$$\eta_g = \eta_i \eta_{pt} \left[ 1 - \beta_i (T_e - T_r) \right]$$

(3)

where $\eta_i$ is the referenced efficiency of PV array; $\eta_{pt}$ is the efficiency of power tracking equipment; $\beta_i$ is the temperature coefficient; $T_e$ is the temperature of PV array; $T_r$ is the referenced temperature of PV array.

The temperature of PV array $T_e$ can be represented by the following equation:

$$T_e = T_a + G_1 \left( \frac{NOCT - 20}{800} \right)$$

(4)

where $T_a$ is the ambient temperature; $NOCT$ is the nominal operating temperature of PV array.

2.2.3 Battery bank

The battery bank is usually composed of lead-acid batteries. The status of battery bank at hour $t$ is related to its status at hour $t-1$, the total output power of PV and WG, and the load demand at hour $t$. When the total output power of PV and WG is greater than the load demand, the battery bank is charged, and the available battery bank capacity can be described as:

$$C_{Bat}(t) = C_{Bat}(t-1)(1-\sigma) + \left[ \left( E_{WG}(t) + E_{PV}(t) \right) - \frac{E_{load}(t)}{\eta_{inv}} \right] \eta_{Bat}$$

(5)

On the other hand, when the load demand is greater than the total output power of WG and PV, the battery is discharged. Taking the battery discharging efficiency as 1, the available battery bank capacity can be expressed as:

$$C_{Bat}(t) = C_{Bat}(t-1)(1-\sigma) - \left[ \frac{E_{load}(t)}{\eta_{inv}} - \left( E_{WG}(t) + E_{PV}(t) \right) \right]$$

(6)

where $C_{Bat}(t)$ and $C_{Bat}(t-1)$ are battery bank capacity at hours $t$ and $t-1$, respectively; $\sigma$ is the self-discharging rate of battery bank; $E_{WG}(t)$ and $E_{PV}(t)$ are the output powers of WG and PV at hour $t$, respectively; $E_{load}(t)$ is the load demand at hour $t$; $\eta_{inv}$ and $\eta_{Bat}$ are the converting efficiency and charging efficiency, respectively.

3. Optimal Sizing Model for Distributed Generators in Stand-Alone Microgrid

The main goal of the optimal sizing of distributed generators in a microgrid is to ensure the power supply safe and stable and to minimize the total cost of the microgrid while satisfying the performance indices. In this paper, we use life cycle cost (LCC) theory to determine the optimal sizing scheme for a stand-alone microgrid. The distributed generators in the microgrid include WG, PV, diesel engine (DE), fuel cell (FC), micro-turbine (MT), and battery bank.

3.1 Objective function

The life cycle cost of the microgrid refers to all different kinds of life cycle costs of distributed generators that involves in the microgrid, including equipment investment cost (IC), equipment replacement cost (RC), microgrid operation cost (OC), failure cost (FC) due to electricity shortages in microgrid, and equipment discard costs (DC). Therefore LCC can be expressed as:
The microgrid operation cost refers to all different kinds of costs that occur when the microgrid operates, including equipment operation and maintenance cost, fuel cost, and environment-pollution penalty. \(OC\) can be expressed as:

\[
OC = \sum_{i=1}^{n} \left( K_{\text{o&m,i}} \sum_{t=1}^{8760} P_i(t) \Delta t \right) + \\
\sum_{j=1}^{M} \sum_{t=1}^{8760} \left( \alpha_j \beta_j \sum_{i=1}^{n} P_i(t) \Delta t + C_d K_{\text{DE}} \sum_{t=1}^{8760} P_{\text{DE}}(t) \Delta t \right) + \\
C_{H_i} K_{\text{FC}} \sum_{t=1}^{8760} P_{\text{FC}}(t) \Delta t + C_{NG} \frac{8760}{LHV_{\text{NG}}} \sum_{t=1}^{8760} P_{\text{MT}}(t) \Delta t \frac{\eta_{\text{MT}}(t)}{}\tag{10}
\]

where \(K_{\text{o&m,i}}\) is the operation and maintenance cost of distributed generator \(i\) per kWh of electricity; \(P_i(t)\) is the actual output power of distributed generator \(i\); \(M\) is the pollution gases such as NO\(_x\), SO\(_2\), CO\(_2\), produced by DE and MT because of fossil fuels they burn; \(\alpha_j\) is the penalty to per kilogram of pollution \(j\); \(\beta_j\) is the emission coefficient of pollution \(j\) produced by distributed generator \(i\) (kg/kW-h); \(C_d\) is the fuel price of DE; \(K_{\text{DE}}\) is the fuel consumption rate of DE (g/kW-h); \(C_{H_i}\) is the hydrogen price; \(K_{\text{FC}}\) is the hydrogen consumption rate of FC under standard conditions (L/kW-h); \(C_{NG}\) is the natural gas price; \(LHV_{\text{NG}}\) is the low heat value of natural gas (9.7 kW-h/m\(^3\)); \(\eta_{\text{MT}}(t)\) is the efficiency of MT over the time interval \(t\); \(\Delta t = 1\text{h} \). In this paper, the emissions of hydrogen FC are only pure water, so the environment-pollution penalty to FC is 0.

### 3.1.4 Failure cost

The failure cost mainly refers to the outage costs caused by electricity shortages and power interruptions in the microgrid. In this paper, outage costs caused by power interruptions such as equipment failure and maintenance outage are not considered, that is, only outage costs caused by electricity shortages are considered in view of non-important loads in microgrid can be cut off to ensure the power supply to important loads when the electricity from distributed generators and the available battery bank is not enough to meet the load demand.

The failure cost \(FC\) in the planning year can be expressed as:

\[
FC = C_{\text{we}} \sum_{t=1}^{8760} LPS(t) \tag{11}
\]

where \(C_{\text{we}}\) is the cost coefficient of electricity shortages per kWh, \(LPS(t)\) is the power supply loss at hour \(t\),

\[
LPS(t) = P_{\text{load}}(t) \Delta t - \left( \sum_{i=1}^{n} P_i(t) \Delta t + C_{\text{bat}} (t-1) - C_{\text{bat min}} \right) \eta_{\text{ev}} \tag{12}
\]

The probability of power supply loss \(LPSP\) over a certain period \(T = 8760\text{ h}\) can be defined as the ratio of all to the total load demand during that period,

\[
LPSP = \frac{\sum_{t=1}^{T} LPS(t)}{\sum_{t=1}^{T} P_{\text{load}}(t) \Delta t} \tag{13}
\]

### 3.1.5 Discard cost

The discard cost refers to the fees required to pay for the clean-up and destruction of the microgrid project after the entire life cycle and equipment salvage value. Different equipments have different discard costs. Some equipment discard cost is negative because they can be sold for other uses to get some amount of income before they are completely scrapped, while some equipments’ discard cost is positive because they cannot produce any salvage value, but need money for their clean-up and destruction.

Based on the statistics of practical projects, the discard cost \(DC\) can be approximately equivalent to a ratio of the initial investment cost,

\[
DC = k \cdot IC \tag{14}
\]

where \(k\) is the discard conversion coefficient.
3.2 Constraints

The optimal sizing scheme of distributed generators in the microgrid should satisfy a series of constraints.

3.2.1 The amount of DGs

\[ 0 \leq N_i \leq N_i^{\text{max}} \tag{15} \]

where \( N_i^{\text{max}} \) is the allowable maximum quantity of distributed generator \( i \) due to the objective conditions.

3.2.2 The output power of DGs

In order to ensure the security and stability of power supply in the microgrid, the output power of distributed generator \( i \) must be within the upper and lower limits,

\[ P_{i}^{\text{min}} \leq P_i \leq P_{i}^{\text{max}} \tag{16} \]

where \( P_{i}^{\text{min}} \) and \( P_{i}^{\text{max}} \) are the minimum and maximum output powers of distributed generator \( i \), respectively.

3.2.3 The capacity of the battery bank

Whenever it is, the capacity of the battery bank must satisfy the following constraint:

\[ C_{\text{Bat}}^{\text{min}} \leq C_{\text{Bat}}(t) \leq C_{\text{Bat}}^{\text{max}} \tag{17} \]

where \( C_{\text{Bat}}^{\text{min}} \) and \( C_{\text{Bat}}^{\text{max}} \) are the allowable minimum and maximum capacities of the battery bank, respectively. \( C_{\text{Bat}}^{\text{max}} \) can be set to be the rated capacity of the battery bank \( C_R \), and \( C_{\text{Bat}}^{\text{min}} \) can be expressed as:

\[ C_{\text{Bat}}^{\text{min}} = (1-DOD) \times C_R \tag{18} \]

where \( DOD \) is the allowable maximum discharging depth of the battery bank.

3.2.4 The load-shedding capacity of the microgrid

In order to ensure the reliability of power supply in the microgrid, the load-shedding capacity cannot exceed the allowable maximum value \( P_{ul}^{\text{max}} \), i.e.

\[ P_{ul} \leq P_{ul}^{\text{max}} \tag{19} \]

3.2.5 The probability of power supply loss

The probability of power supply loss \( LPSP \) in the microgrid cannot exceed the allowable maximum value \( LPSP_{\text{max}} \), i.e.

\[ LPSP \leq LPSP_{\text{max}} \tag{20} \]

4. Hybrid Optimization Algorithm of PSO and GA

Since GA and PSO are complementary, a hybrid optimization algorithm of combining the two is proposed here, in which PSO is main and GA is auxiliary. The GA-PSO hybrid optimization algorithm assembles the advantages of GA and PSO, therefore can minimize the probability of searching a local optimum and at the same time guarantee the accuracy of the global optimum.

The optimization principle of GA-PSO is illustrated as following: PSO performs the search during the early period, but when an optimum is got, we define it to be a suspected optimum rather than a global optimum; the suspected optimum is directly copied into the next generation of the group using the GA theory in order to guarantee the suspected optimum is not lost at the later search period; then use the mutation in GA to vary the particles in the group which have already been gathered up to ensure the diversity of the population, and diffuse all the particles in the group except the suspected optimum into the entire search space, and search again; if a better solution than the suspected optimum is found after the variation, abandoning the suspected optimum and perform PSO until gathering up again to find another suspected optimum; if after \( N \) times of continuous replication and mutation, no better solution is found, then the current suspected optimum is taken as the final global optimum. The flowchart of GA-PSO is shown in Figure 2.
5. Case Study

In the stand-alone microgrid for case study, power comes from WG, PV, DE, FC, MT, and battery bank. The optimal sizing model considers the characteristics of local climate conditions, energy resources, and load demands. Since wind energy and solar energy have strong randomness and uncertainty, in order to estimate the annual output powers of WG and PV as accurately as possible, the hourly average historical data of wind speed, temperature and light intensity of the region in 8760 hours is collected to make the estimation. The performance parameters of WG, PV, DE, FC, MT and battery bank are shown in Table A1 to Table A6 of the Appendix. MATLAB is used here to implement the optimal sizing model and GA-PSO to optimize the distributed generators’ capacities, the result is shown in Table 1.

MATLAB is used here to implement the optimal sizing model and GA-PSO to optimize the distributed generators’ capacities, the result is shown in Table 1.

<table>
<thead>
<tr>
<th>DG</th>
<th>Unit type</th>
<th>Amount</th>
<th>IC</th>
<th>OC</th>
<th>RC</th>
<th>DC</th>
</tr>
</thead>
<tbody>
<tr>
<td>WG</td>
<td>HF15.0-50kW</td>
<td>23</td>
<td>84.334</td>
<td>41.400</td>
<td>0</td>
<td>-0.843</td>
</tr>
<tr>
<td>PV</td>
<td>STP255-20Wd</td>
<td>1551</td>
<td>28.198</td>
<td>2.769</td>
<td>0</td>
<td>-5.640</td>
</tr>
<tr>
<td>DE</td>
<td>QSC-50GF</td>
<td>11</td>
<td>5.131</td>
<td>61.585</td>
<td>0</td>
<td>-1.026</td>
</tr>
<tr>
<td>FC</td>
<td>SLHP-50k</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MT</td>
<td>C65</td>
<td>1</td>
<td>9.676</td>
<td>12.693</td>
<td>0</td>
<td>-0.968</td>
</tr>
<tr>
<td>Bat</td>
<td>PM3000-2</td>
<td>204</td>
<td>12.467</td>
<td>1.224</td>
<td>15.179</td>
<td>-0.277</td>
</tr>
</tbody>
</table>

Table 1 Optimal sizing scheme (unit: yuan rmb)

The LCC of the microgrid is 2.668 million yuan, of which the failure cost is 571 yuan. It can be seen from Table 1 that the installed capacities of WG, PV and DE in the planning year are relatively big, while the installed capacity of MT is relatively small and the installed capacity of FC is 0. Calculation results show that compared with other distributed generators, DE has an obvious advantage of small equipment investment cost at present, while WG and PV do not burn fossil fuels, their fuel costs and environment-pollution penalties are 0, so they three make up a majority of the total installed capacity; the fuel cost of MT is much lower than other controllable distributed generators, but its equipment investment cost is relatively high, so its input proportion is relatively small; FC has dear costs of equipment investment, fuel and replacement, etc., so not be used in this microgrid. It also can be seen that battery bank is an important supplement device.

Since the actual wind speed, light intensity and load demand are changeable, the output powers of WG and PV will be unstable, causing power shortage in the microgrid, as shown in Figure 3.

The total power shortage capacity in Figure 3 is 475.820 kW, which accounts for 0.013% of the total load. It can be seen that the power shortage mainly occurs in July, August and September. The main reason is that the output powers of WG and PV are greatly influenced by climate factors, that is, wind energy is not sufficient in July, August and September while the total load is greater in these months, thus the power cannot meet the load, and the output powers of DE and MT have to increase significantly in these months to balance the power shortage. Therefore, DE, MT and battery bank can help to overcome the impacts of climate factors on WG and PV, improving the reliability of the microgrid.

Figure 3. Power shortage capacity in microgrid.

Both PSO and GA-PSO proposed are used to optimize the distributed generators’ capacities, and the results are listed in Table 2. It can be seen that the results of GA-PSO are better than those of PSO in the aspects of reducing the probability of searching for a local optimum and ensuring the accuracy of the global optimum.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>GA-PSO</td>
<td>291.24</td>
<td>286.79</td>
<td>266.83</td>
<td>307.23</td>
<td>287.30</td>
<td>287.88</td>
</tr>
<tr>
<td>PSO</td>
<td>334.59</td>
<td>293.04</td>
<td>300.31</td>
<td>352.33</td>
<td>325.18</td>
<td>321.09</td>
</tr>
</tbody>
</table>

Table 2 Performance comparison of GA-PSO and PSO (unit: yuan rmb)

The factors and uncertainties affecting the optimal sizing of distributed generators in the microgrid are analyzed as follows.

5.1 Installation cost of distributed generators

At present, the high installation cost of distributed generators is still an important factor affecting its economy compared with traditional power generators. But taking the technical progress into account, the installation cost of distributed generators will decline gradually. Assuming the other costs are constant, if the investment cost of each distributed generator in the microgrid decreases by 30% averagely, then the LCC of the microgrid will drop to 2.303 million yuan from 2.668 million yuan, saving 365,580 yuan.

5.2 Fuel price

The fuel price is mostly related to the balance between supply and demand, and greatly affects the economy of the microgrid. The rise of the fuel price would worsen the economy of the microgrid. For example, if the diesel price increases from 5600 to 6600 yuan/t, the LCC of the microgrid will increase by 3.26%.

As can be seen the high installation cost of distributed generators and the rise of traditional fossil fuel price will weaken the economy of the microgrid, therefore
promoting the technical progress and the development of clean renewable energy, CHP or CCHP to improve the operating efficiency is an important means to enhance the economy of the microgrid.

5.3 Penalty to CO2 emission

The environment-pollution penalty of regions is distinctly different since the economy level, the population density and the pollution emission are different. CO2 is not only one of the main emissions, but also the most important greenhouse gas. The pollution penalty charging standard is currently mainly referring to carbon emission. Optimization results for different penalties to CO2 emission are shown in Table 3.

<table>
<thead>
<tr>
<th>Penalty to CO2 emission (/yuan·kg⁻¹)</th>
<th>NWG</th>
<th>N_DG</th>
<th>N_FC</th>
<th>N_MT</th>
<th>NBat</th>
<th>CO2 emission (/t·a⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02</td>
<td>23</td>
<td>1551</td>
<td>11</td>
<td>0</td>
<td>204</td>
<td>383.158</td>
</tr>
<tr>
<td>0.07</td>
<td>24</td>
<td>2014</td>
<td>11</td>
<td>0</td>
<td>281</td>
<td>265.585</td>
</tr>
<tr>
<td>0.12</td>
<td>22</td>
<td>3099</td>
<td>9</td>
<td>0</td>
<td>333</td>
<td>198.105</td>
</tr>
<tr>
<td>0.17</td>
<td>23</td>
<td>3310</td>
<td>2</td>
<td>1</td>
<td>337</td>
<td>158.156</td>
</tr>
</tbody>
</table>

It can be seen from Table 3 that with the increasing penalty to CO2 emission, the total capacity of DE and MT, which are CO2 emission sources, decreases, while the total capacity of WG, PV and FC increases. Different pollution charging standards illustrate the governments’ different recognition. If the penalty is very high, then the government must attach great importance to strictly controlling emissions and reducing pollutions, which will benefit the development of microgrid and reflect its environment-protection value.

- Discount
  
  The LCC of the microgrid will increase gradually along with the increasing discount, as shown in Figure 4.

![Figure 4. Optimization results for different discounts](image)

6. Conclusion

Based on the characteristics of distributed generators and loads in a stand-alone microgrid, an optimal sizing model for distributed generators that takes the minimum LCC of the microgrid as the objective is developed. A hybrid optimization algorithm of PSO and GA is proposed. In addition, factors that affect the optimal sizing are analyzed. Case study shows that the optimal sizing of distributed generators can significantly reduce the cost of the microgrid and pollutions in the microgrid, and improve the power supply reliability. The proposed GA-PSO hybrid optimization algorithm has fast convergence speed and can search for a global optimum with high probability and accuracy simultaneously.

Acknowledgement

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References

### Appendix: Example data

#### Table A1
**WG parameters**

<table>
<thead>
<tr>
<th>Type</th>
<th>Rated Power</th>
<th>Cut-in Speed</th>
<th>Cut-out Speed</th>
<th>Rated Speed</th>
<th>Life</th>
<th>One-machine Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF15.0-50kW</td>
<td>50 kW</td>
<td>3.5 m/s</td>
<td>35 m/s</td>
<td>12 m/s</td>
<td>20 years</td>
<td>360,000 yuan</td>
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</tbody>
</table>

#### Table A2
**PV parameters**

<table>
<thead>
<tr>
<th>Type</th>
<th>Conversion Efficiency</th>
<th>NOCT</th>
<th>Temperature Coefficient</th>
<th>Area of a Single Module</th>
<th>Life</th>
<th>One-machine Cost</th>
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</thead>
<tbody>
<tr>
<td>STP255-20/Wd</td>
<td>15.7%</td>
<td>45±20C</td>
<td>-0.44%/0C</td>
<td>1640*992 mm</td>
<td>25 years</td>
<td>7*255 yuan</td>
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</tbody>
</table>

#### Table A3
**DE parameters**

<table>
<thead>
<tr>
<th>Type</th>
<th>Rated Power</th>
<th>Diesel Consumption Rate</th>
<th>Diesel Price</th>
<th>Life</th>
<th>One-machine Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>QSC-50GF</td>
<td>50kW</td>
<td>210g/kW·h</td>
<td>6500 yuan /t</td>
<td>25 years</td>
<td>45,800 yuan</td>
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</table>

#### Table A4
**FC parameters**

<table>
<thead>
<tr>
<th>Type</th>
<th>Rated Power</th>
<th>Hydrogen Consumption Rate under Standard Conditions</th>
<th>Hydrogen Price</th>
<th>Life</th>
<th>One-machine Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLHP-50K</td>
<td>50kW</td>
<td>720L/kW·h</td>
<td>0.0022 yuan /L</td>
<td>5 years</td>
<td>1,800,000 yuan</td>
</tr>
</tbody>
</table>

#### Table A5
**MT parameters**

<table>
<thead>
<tr>
<th>Type</th>
<th>Rated Power</th>
<th>Power Generation Efficiency</th>
<th>Natural Gas Price</th>
<th>Life</th>
<th>One-machine Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>C65</td>
<td>65kW</td>
<td>29%(±2)</td>
<td>1.9 yuan /m3</td>
<td>20 years</td>
<td>950,000 yuan</td>
</tr>
</tbody>
</table>

#### Table A6
**Battery parameters**

<table>
<thead>
<tr>
<th>Type</th>
<th>Rated voltage</th>
<th>Rated capacity</th>
<th>Charge efficiency</th>
<th>Self-discharge rate per hour</th>
<th>Allowable Maximum Discharge Depth</th>
<th>Life</th>
<th>One-machine Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM3000-2</td>
<td>2V</td>
<td>3000Ah</td>
<td>0.87</td>
<td>0.0001</td>
<td>80%</td>
<td>5 years</td>
<td>6000 yuan</td>
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