IOP Conference Series: Earth and Environmental Science

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To cite this article: Zicong Yu *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **227** 032041

Research on capacity optimization configuration of AC/DC hybrid microgrid interconnect converter

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Abstract. Interconnected converters are an important part of AC/DC hybrid microgrids. This paper fully considers various factors affecting the capacity configuration of interconnected converters, and proposes the principle of optimal capacity allocation to meet the power exchange requirements between AC and DC hybrid microgrids and meet the requirements of reliable power supply for important loads. According to the operation requirements of AC/DC hybrid microgrid under different scenarios, two optimal capacity allocation methods for power supply continuity and economy are given. Finally, the AC/DC hybrid microgrid project with island operation is taken as an example to verify the effectiveness of the proposed method, and the influence of important parameters is discussed in depth. The optimal configuration of interconnected converter capacity is given.

1. Introduction

With the development of microgrid technology, AC-DC hybrid microgrid has attracted people's attention [1-6]. The AC-DC hybrid microgrid consists of an AC microgrid, a DC microgrid and an interconnected converter that connects the two microgrids. Among them, the interconnected converter is a key device in the AC-DC microgrid, plays an important role in the coordinated distribution and stable operation of the system, and has the function of transmitting power and acting as a reactive power compensation device.

At present, the research on interconnected converters is still in its infancy, mainly focusing on the design of operation control methods and the lack of relevant discussions on capacity optimization configuration. For example, in literature [1-2], the mathematical model was established for the grid-connected operation and island operation mode of AC/DC hybrid microgrid, and two sets of control methods were designed based on different control objectives. The literature [5] comprehensively reviewed Typical topology of AC/DC hybrid microgrid, switching between interconnected converter control and control mode. The literature [6] proposed a new AC/DC hybrid microgrid structure design, multi-layer, single-ring and complementary ring structures are designed according to the division, stratification, resource utilization maximization and power quality assurance principles of microgrid. In literature [7-8], Aiming at a series of problems existed when the interconnected converters are switched between the grid-connected/islanding modes, the unitized and power-based mathematical processing methods are used to improve the droop control of the interconnected converter. The method also increases the wait mode and reduces the frequent actions of the interconnected converter.

The reasonable configuration of the interconnected converter capacity is directly related to the safe, reliable and stable operation of the AC-DC hybrid microgrid, and will also affect the economic indicators such as the initial investment cost of the system and the post-operation and maintenance costs [9-13]. How to optimize the configuration of interconnected converter capacity and coordinate the two conflicting parameters of reliability and economy to achieve system optimality is a problem worth studying.

According to the role of interconnected converters in AC/DC hybrid microgrid, this paper proposes to configure the capacity of interconnected converters with the minimum capacity method based on power supply continuity and economical optimality. The effects of different parameters on the capacity configuration results are compared and analyzed. The optimal configuration of interconnected converter capacity in AC/DC hybrid microgrid is given.

2. Capacity configuration principle

2.1. Meet the power exchange requirements

As a bridge for power exchange between AC and DC microgrids, interconnected converters should meet the power exchange requirements between the AC and DC sides at each moment.

When the AC/DC hybrid microgrid is operating in an island, the supply and demand power difference of the AC-DC microgrid is coordinated by the interconnected converter. In this paper, the interconnection of microgrid 1 and microgrid 2 is taken as an example to illustrate the power transmission of interconnected converter under various supply and demand power differential conditions. In order to avoid repetitive content, only the case where the supply and demand power difference of the microgrid 1 is positive is analyzed here[5].

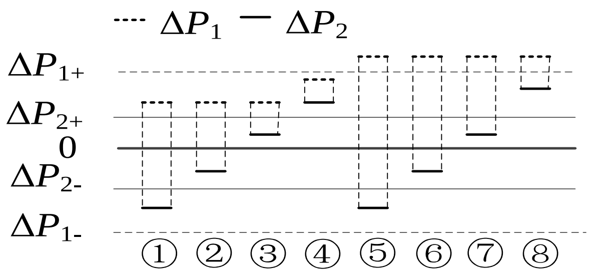

Figure 1. Operating condition of the power supply and demand difference for microgrid 1 and 2.

In Figure 1, ΔP_1 and ΔP_2 represent the supply and demand power difference of the microgrid 1, 2, respectively, ΔP_{1-} and ΔP_{1+}, ΔP_{2-} and ΔP_{2+} are negative and positive safety limits for ΔP_1 and ΔP_2 respectively. The line marked with "0" represents the zero supply and demand power difference line, above which is the positive supply and demand power difference area, and below it is the negative supply and demand power difference area. P_{12} is the transmission power of the interconnected converter, and the positive power direction is set by the micro grid 1 to the micro grid 2. ①~⑧ represents 8 working conditions:

Case ① indicates that ΔP_1 is within the positive safety margin and ΔP_2 exceeds the negative safety limit, ie $\Delta P_1 \in [0, \Delta P_{1+}]$, $\Delta P_2 < \Delta P_{2-}$. In order to reduce the power shortage of the microgrid 2, the microgrid 1 transmits excess power to the microgrid 2 while ensuring its own supply and demand balance, $P_{12}=\min\{|(\Delta P_2 - \Delta P_{2-})|, \Delta P_1\}$.

Case ② indicates that both ΔP_1 and ΔP_2 are within the safety margin, and $\Delta P_1 \in [0, \Delta P_{1+}]$, $\Delta P_2 \in [\Delta P_{2-}, 0]$. At this time, the microgrids 1, 2 are each responsible for the power balance inside the grid, and the interconnect converter is in an idle state, $P_{12}=0$.

Case ③ indicates that ΔP_1 and ΔP_2 are both within the positive safety margin, ie $\Delta P_1 \in [0, \Delta P_{1+}]$, $\Delta P_2 \in [0, \Delta P_{2+}]$. Similar to Case 2, the two microgrids perform their duties, $P_{12}=0$.

Case ④ indicates that ΔP_1 is within the positive safety margin and ΔP_2 exceeds the positive safety limit, ie $\Delta P_1 \in [0, \Delta P_{1+}]$, $\Delta P_2 > \Delta P_{2+}$. The microgrid 1 absorbs part of the excess power of the microgrid 2 under the premise of ensuring that the supply and demand power difference is within the safety margin, $P_{12}=-\min\{(\Delta P_2-\Delta P_{2+}), (\Delta P_{1+}-\Delta P_1)\}$.

Case ⑤ indicates that both ΔP_1 and ΔP_2 exceeded the safety margin range, and $\Delta P_1 > \Delta P_{1+}$, $\Delta P_2 < \Delta P_{2-}$. The remaining power of the microgrid 1 can be input to the microgrid 2, and the transmission power of the interconnected converter is the larger of the following two ways: the first method is to ensure that the supply and demand power difference of the microgrid 1 and 2 is within the safe range. $P_{12}=\max\{\min\{(\Delta P_1-\Delta P_{1+}), (\Delta P_{2+}-\Delta P_2)\}, \min\{(\Delta P_{2-}-\Delta P_2), (\Delta P_1-\Delta P_{1-})\}\}$.

Case ⑥ indicates that ΔP_1 exceeds the positive safety margin, and ΔP_2 is within the negative safety margin, ie $\Delta P_1 > \Delta P_{1+}$, $\Delta P_2 \in [\Delta P_{2-}, 0]$. In order to reduce the supply and demand power difference of the microgrid 1 to a safe range, the microgrid 2 absorbs part of the remaining power of the microgrid 1 under the premise of ensuring that the supply and demand power difference is within the normal range, at this time $P_{12}=\min\{(\Delta P_1-\Delta P_{1+}), (\Delta P_{2+}-\Delta P_2)\}$.

Case ⑦ indicates that ΔP_1 exceeds the positive safety margin range, and ΔP_2 is within the positive safety margin, ie $\Delta P_1 > \Delta P_{1+}$, $\Delta P_2 \in [0, \Delta P_{2+}]$. The microgrid 2 shares part of the remaining power of the microgrid 1, $P_{12}=\min\{(\Delta P_1-\Delta P_{1+}), (\Delta P_{2+}-\Delta P_2)\}$.

Case ⑧ indicates that both ΔP_1 and ΔP_2 exceed the positive safety margin range, that is, $\Delta P_1 > \Delta P_{1+}$, $\Delta P_2 > \Delta P_{2+}$. The microgrids 1, 2 each take measures to maintain their supply and demand power balance, and the interconnected converter does not transmit power between the two microgrid networks, $P_{12}=0$.

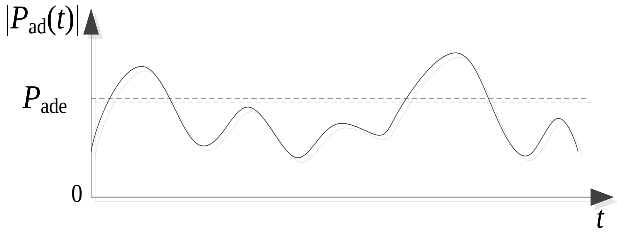

Figure 2. Maximum power transfer curve of interconnected converter.

According to the supply and demand power difference of AC/DC hybrid microgrid in one year, the annual maximum power transmission curve of the interconnected converter can be obtained by comparing the above eight working conditions, as shown in Figure 2. P_{ade} is the capacity of the interconnected converter, and $P_{ad}(t)$ is the interconnected converter transmission power at time t.

Constructor $T_{ad}(t)$: When $|P_{ad}(t)| \le P_{ade}$, let $T_{ad}(t)=1$; when $|P_{ad}(t)| > P_{ade}$, let $T_{ad}(t)=0$. Then, in 8760 hours a year, $|P_{ad}(t)|$The probability λ_{ad} not exceeding P_{ade} can be expressed as

$$\lambda_{ad} = \frac{\sum_{t=1}^{8760} T_{ad}(t)}{8760} \quad (1)$$

Similarly, if the system requires at least one year a_{ad} hours of AC-DC hybrid microgrid power transmission requirements, the capacity of the interconnect converter should meet:

$$P_{inv} \ge P_{ade}(\lambda_{ad} = a_{ad} / 8760) \quad (2)$$

2.2. Reliable power supply requirements for critical loads

When the output power of the microgrid is severely limited and the critical load is insufficient, the power shortage can be input via the interconnected converter[14].

When the AC/DC hybrid microgrid is operating in an island: when the power supply of the important load in the microgrid is insufficient, the backup power supply in the AC/DC hybrid microgrid is preferentially activated. The insufficient part is supplied by the interconnected microgrid, and the interconnected converter capacity should be satisfied.

$$P_{\text{inv}} \geq \max\left\{(c_{\text{a}}P_{\text{iloada}} - P_{\text{rsa}}),(c_{\text{d}}P_{\text{iloadd}} - P_{\text{rsd}})\right\} \tag{3}$$

In the formula, c_a and c_b are the important load power shortage coefficients on the AC side and the DC side, respectively; P_{iloada} and P_{iloadd} are the important load capacities on the AC side and the DC side, respectively; P_{rsa}, P_{rsd} are the standby power supply capacities of the AC side and the DC side, respectively.

3. Capacity configuration method

3.1. Minimum volume method

For some large-scale, high-reliability AC/DC hybrid microgrids, the total system investment is high, the proportion of interconnected converter costs is small. The money to reduce the capacity savings of interconnected converters is far less than the loss of power loss due to load. It is generally not allowed to sacrifice the load power supply reliability in exchange for the cost reduction of the interconnect converter[15-16].

3.1.1. Objective function. The capacity configuration of the interconnected converter in this scenario generally only considers the principle of power exchange between the AC and DC microgrids and the reliability requirements. The minimum capacity method is adopted, and the objective function is

$$f = \min P_{\text{inv}} \tag{4}$$

3.1.2. Constraints. According to the capacity optimization configuration principle, λ=100% and λ_{ad}=100% are not included in the economics of the interconnect converter, and there is no upper limit on the interconnected converter capacity. The constraints in the grid-connected mode and the island mode are equations (5) and (6).

$$\begin{cases} P_{\text{inv}} \geq P_{\text{e}}(\lambda = 100\%) \\ P_{\text{inv}} \geq c_{\text{u}}P_{\text{iloadu}} - P_{\text{rsu}} \end{cases} \tag{5}$$

$$\begin{cases} P_{\text{inv}} \geq P_{\text{ade}}(\lambda_{\text{ad}} = 100\%) \\ P_{\text{inv}} \geq \max\left\{(c_{\text{a}}P_{\text{iloada}} - P_{\text{rsa}}),(c_{\text{d}}P_{\text{iloadd}} - P_{\text{rsd}})\right\} \end{cases} \tag{6}$$

3.2. Minimum capacity method based on economic optimization

For some AC/DC hybrid microgrids with smaller scale and lower reliability requirements, the cost of interconnected converters is relatively large, and interconnected converters configured with minimum capacity method work in light load conditions, resulting in resources, Waste; at this time, the cost-optimized minimum capacity method can be used to reduce the interconnected converter capacity by sacrificing the reliability of the partial load (for example, limiting the time-phase load, etc.) [17-18].

3.2.1. Objective function. Under the premise of meeting the capacity allocation principle, consider the comprehensive cost of economy and reliability, and establish an optimization objective function:

$$\min C = \min\{C_{\text{inv}} + C_{\text{ls}} + C_{\text{es}}\} \tag{7}$$

Where C_{inv}, C_{ls}, C_{es} represent interconnected converter cost, loss of power loss, and excess energy loss, respectively.

The cost of interconnected converter includes investment cost, operation and maintenance cost, replacement cost and residual value; the cost of power loss includes the loss of power loss and the cost of power failure compensation caused by insufficient capacity of the interconnected converter [15]; the excess energy cost is represented by the interconnection Loss of power generation due to insufficient converter capacity.

$$C_{\text{inv}} = C_{\text{ini}} + C_{\text{opr}} + C_{\text{m}} + C_{\text{r}} - C_{\text{f}} \tag{8}$$

$$C_{\text{ls}}=n(C_{\text{e}}+C_{\text{mp}})\sum_{t=1}^{8760}P_{\text{ls}}(t)-C_{\text{ls0}} \tag{9}$$

$$C_{\text{es}}=nC_{\text{e}}\sum_{t=1}^{8760}P_{\text{es}}(t)-C_{\text{es0}} \tag{10}$$

Where C_{ini}, C_{opr}, C_{m}, C_{r}, C_{f} are the interconnected converter investment cost and the operating cost, maintenance cost, and replacement cost of the whole life cycle n years respectively. And the residual value after the end of life. C_{e}, C_{mp} are the electricity price and unit load loss compensation cost. P_{ls} (t), P_{es} (t) are the power loss and excess energy of power at time t. C_{ls0}, C_{es0} are the inherent power loss and inherent energy loss of the system.

$$C_{\text{ini}}=k_{\text{inv}}P_{\text{inv}} \tag{11}$$

$$C_{\text{opr}}=\sum_{i=1}^{n}\left[8760\cdot C_{\text{e}}\left(\frac{1+R_{\text{opr}}}{1+r_0}\right)^{i}\eta_{\text{inv}}P_{\text{inv}}\right] \tag{12}$$

$$C_{\text{m}}=\sum_{i=1}^{n}\left[k_{\text{m}}\left(\frac{1+R_{\text{m}}}{1+r_0}\right)^{i}P_{\text{inv}}\right] \tag{13}$$

$$C_{\text{r}}=\sum_{i=1}^{N}\left[k_{\text{r}}\left(\frac{1+R_{\text{r}}}{1+r_0}\right)^{i\times m}P_{\text{inv}}\right] \tag{14}$$

$$C_{\text{f}}=Nk_{\text{fu}}P_{\text{inv}} \tag{15}$$

Where k_{inv}, k_{m}, k_{r}, and k_{fu} are unit investment cost, unit annual maintenance cost, unit replacement cost, and unit residual value; η_{inv} is the loss rate; R_{opr}, R_{m}, R_{r} are the annual change rates of operating expenses, maintenance costs and replacement costs respectively; r_0 is the discount rate; m and N are the operating years and replacement quantities of interconnected converters respectively. P_{LSA}(t), P_{esA}(t) are the power loss and excess energy of the AC microgrid respectively; P_{lsD}(t), P_{esD}(t) are respectively for the DC microgrid Loss of power and excess energy.

3.2.2. Constraints. At time t, the power loss and excess power of the AC-DC hybrid microgrid can be obtained according to equations (16) to (19).

$$P_{\text{lsA}}(t)=\begin{cases}\Delta P_{\text{AA}}(t),\ \Delta P_{\text{AA}}(t)<\Delta P_{\text{A-}}\\ 0,\ \text{others}\end{cases} \tag{16}$$

$$P_{\text{esA}}(t)=\begin{cases}\Delta P_{\text{AA}}(t),\ P_{\text{AA}}(t)>\Delta P_{\text{A+}}\\ 0,\ \text{others}\end{cases} \tag{17}$$

$$P_{\text{lsD}}(t)=\begin{cases}\Delta P_{\text{DD}}(t),\ \Delta P_{\text{DD}}(t)<P_{\text{D-}}\\ 0,\ \text{others}\end{cases} \tag{18}$$

$$P_{\text{esD}}(t)=\begin{cases}\Delta P_{\text{DD}}(t),\ \Delta P_{\text{DD}}(t)>P_{\text{D+}}\\ 0,\ \text{others}\end{cases} \tag{19}$$

Where $\Delta P_{\text{A-}}$ and $\Delta P_{\text{A+}}$, $\Delta P_{\text{D-}}$ and $\Delta P_{\text{D+}}$ are the negative and positive safety limits of ΔP_{A}(t) and ΔP_{D}(t), respectively; ΔP_{AA} (t), ΔP_{DD} (t) are the residual supply and demand power difference of the AC-DC hybrid microgrid.

Since the system allows load power loss and micro power supply excess, the interconnect converter only needs to meet the power exchange requirements for most of the year: $\lambda<100\%$, $\lambda_{\text{to}}<100\%$, then the grid-connected mode and island The constraints under the mode are Equation (20) and Equation (21), respectively.

$$\begin{cases} P_{\text{inv}} \geq P_{\text{e}}(\lambda < 100\%) \\ P_{\text{inv}} \geq c_{\text{u}} P_{\text{iloadu}} - P_{\text{rsu}} \\ P_{\text{inv}} < \Delta P_{\text{e}}(\lambda = 100\%) \end{cases} \tag{20}$$

$$\begin{cases} P_{\text{inv}} \geq P_{\text{ade}}(\lambda_{\text{ad}} < 100\%) \\ P_{\text{inv}} \geq \max\{(c_{\text{a}} P_{\text{iloada}} - P_{\text{rsa}}), (c_{\text{d}} P_{\text{iloadd}} - P_{\text{rsd}})\} \\ P_{\text{inv}} \leq P_{\text{ade}}(\lambda_{\text{ad}} = 100\%) \end{cases} \tag{21}$$

3.3. Solution method

3.3.1. The minimum capacity method solving step. The minimum capacity can be found immediately based on the objective function and constraints.

3.3.2. The solution step based on the cost-optimized minimum capacity method. ① Sampling to obtain the annual supply and demand power difference data series of AC/DC hybrid microgrid, and obtain the theoretically required interconnected converter power transmission data sequence; ② Calculate the interconnected converter according to the converter unit price, electricity price and other parameters Cost and loss of power loss and excess energy loss; Calculate the optimal capacity according to the principle of minimum total cost.

4. Case analysis

4.1. Simulation study

This example takes the AC-DC hybrid microgrid project running on an island as an example to simulate the optimal configuration capacity of the interconnected converter. According to the annual supply and demand power deviation data of the AC and DC microgrids, the theoretical interconnected converter power transmission data sequence is obtained, as shown in Figure 3.

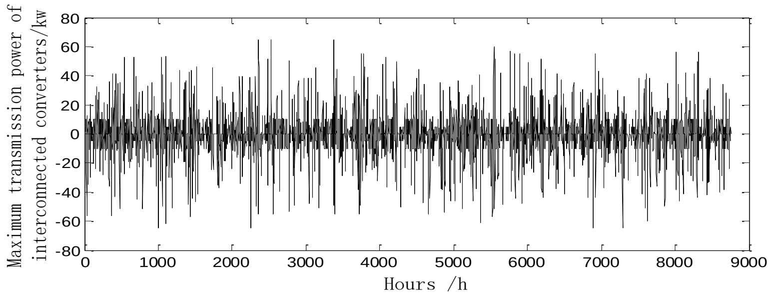

Figure 3. Power transfer data of interconnected converter.

Table 1. Base parameters of AC/DC hybrid microgrid.

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
P_{Nac}	300kW	P_{rsa}	32kW	k_{inv}	5000yuan/kW	c_{a}	0.4
P_{Ndc}	200kW	P_{rsd}	36kW	k_{m}	50yuan/kW	c_{d}	0.5
P_{iloada}	80kW	n	20years	k_{r}	5500yuan/kW	R_{opr}	0.115
P_{iloadd}	60kW	m	10years	k_{fu}	500yuan/kW	R_{m}	0.12
R_{r}	0.15	η_{inv}	0.07				

The basic parameter settings of the AC/DC hybrid microgrid are shown in Table 1. The reliable transmission probability of power is set to 0.95, the discount rate is 10%, the electricity price is 0.7 yuan/kWh, and the unit load compensation cost is 1.2775 yuan/kWh [18].

4.2. Optimization results analysis

Using the data given in this example, the interconnected converter capacity is configured based on the economical optimal minimum capacity method. The optimization result is: when the capacity value ranges from [28.1, 64.8] kW, the optimal capacity of the interconnected converter is 28.1kW, the total cost is a minimum of 846,000 yuan.

4.2.1. Influence of reliable transmission probability on optimization results. The optimal configuration of the power reliable transmission probability λ_{ad}={0.90, 0.92, 0.94, 0.96, 0.98, 1.0} is optimized, and the optimization results are shown in *Figure* 4 and *Figure* 5.

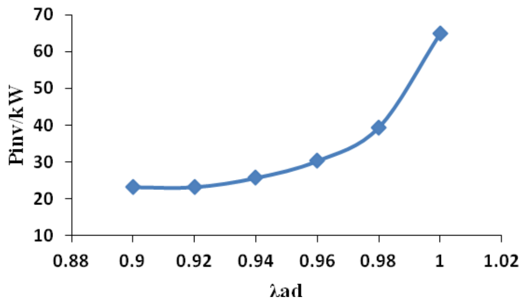

Figure 4. Capacity optimization for different λad.

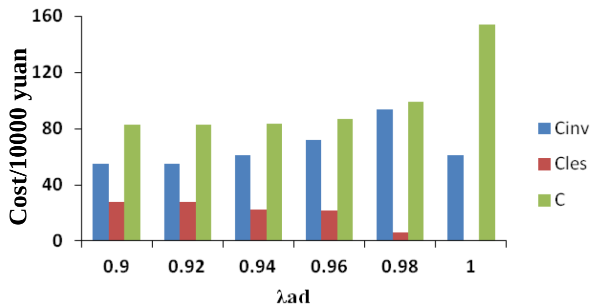

Figure 5. System cost contrast for different λad.

It can be seen from Figure 4 and Figure 5 that when λ_{ad} is less than 0.92, the cost per unit capacity is not much different from the loss reduced by power loss and excess energy, and the optimal capacity is always 23.2 kW, and the total cost remains unchanged; When λ_{ad} is greater than 0.92, the cost per unit capacity is significantly greater than the loss due to power loss and excess energy, and the larger λ_{ad}, the larger the optimal capacity increase and the total cost. Therefore, it is possible to appropriately reduce the probability of reliable transmission of power within the allowable range of the system, which can greatly reduce the optimal capacity and reduce investment. Capacity optimization for different λad

4.2.2. The effect of unit cost of interconnected converter on optimization results. As technology advances, the price of converters may decline in the future. Let λ_{ad}=0.94, and configure the cost per unit capacity interconnect converter to be 0.4 times, 0.6 times, 0.7 times, 0.8 times, and 0.9 times. The optimization results are shown in *Figure* 6 and *Figure* 7.

It can be seen from Figure 6 and Figure 7 that as the unit cost of the interconnected converter decreases, the larger the drop in the optimal capacity, the lower the total cost; And when the unit cost of the interconnected converter decreases in a certain range, the optimal capacity remains basically unchanged. It can be seen that reducing the unit cost will reduce the capacity of the optimized configuration and save investment; on the contrary, increasing the unit cost is equivalent to increasing the capacity of the interconnected converter, indirectly reducing the load loss and improving the reliability of the load.

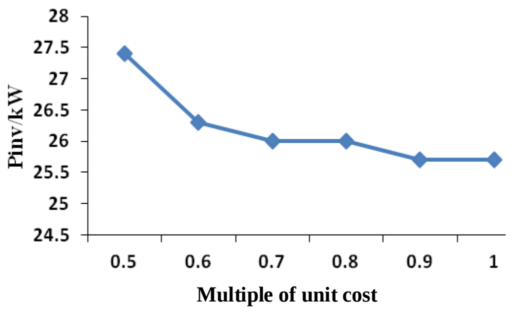

Figure 6. Capacity optimization for different unit cost.

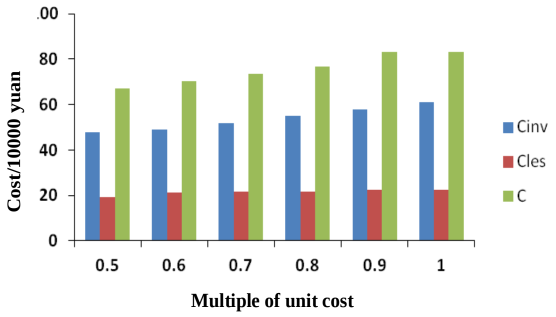

Figure 7. System cost contrast for different unit cost.

4.2.3. Impact of load power supply reliability requirements on optimization results. According to the requirements of power supply reliability, the other loads after the removal of the power-off load are classified into Class III load and Class IV load. Since the load reliability requirement is positively correlated with the loss of power loss, the unit load loss loss can be set according to the ratio of Class III and IV loads in the AC/DC hybrid microgrid. Let λ_{ad}=0.94 be configured for (Class III load capacity: Class IV load capacity)={(1:9), (2:8), (3:7), (4:5)} The optimization results are shown in Table 2.

Table 2. Capacity optimization results for different unit compensation.

Load type		Unit load loss of power loss /yuan	C_{inv} / 10,000 yuan	C_{les} / 10,000 yuan	C / 10,000 yuan	P_{inv}/kW
Class III	Class IV					
10%	90%	0.3286	61.0	14.8	75.8	25.7
20%	80%	1.2775	61.0	22.3	83.3	25.7
30%	70%	2.0137	62.4	26.6	89.0	26.3
40%	50%	2.8736	68.1	26.7	94.8	28.7

Analysis Table 2 shows that as the proportion of Class III load increases and the loss per unit load increases, the optimal capacity increases, but the increment is not obvious, and the total cost also increases. Therefore, the load power supply reliability requirements have less impact on the optimal configuration results.

5. Conclusions

Interconnected converters are important equipment for connecting AC microgrids and DC microgrids. According to the requirements of the system, this paper gives the principle of optimal capacity allocation to meet the power transmission requirements between AC and DC hybrid microgrids and meet the requirements of reliable power supply for important loads. Two capacity optimization configuration methods are proposed: 1) the minimum capacity method to meet the annual power transmission requirements, 2) the minimum capacity method that combines economic and reliability costs. Finally, the effectiveness of the proposed principles and methods is verified by an example. It is concluded that the power transmission reliability probability can be appropriately reduced within the allowable range of the system, which can greatly reduce the optimal capacity of the interconnected converter and reduce the investment. The cost will reduce the optimal capacity and save money; the reliability of the load power supply will have less impact on the optimal configuration results.

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