Research on capacity configuration optimization for island microgrid with PV-wind-diesel-battery and seawater desalination load

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Abstract. According to the situation of abundant renewable energy but insufficient fresh water on the island, using seawater desalination equipment as a time-shifting load can better absorb the output of renewable energy and eliminate the surplus electric energy. In this paper, the optimal configuration of wind solar diesel storage island microgrid capacity considering the time-shifting load of seawater desalination equipment is studied. The optimal allocation model of island microgrid capacity with wind solar diesel storage and seawater desalination load is established. The optimal objective function of capacity allocation is the system equivalent annual investment cost. The results show that considering the time-varying load of seawater desalination equipment, the optimal configuration strategy of wind solar diesel storage island microgrid capacity can improve the consumption of renewable energy, reduce the waste of capacity, solve the problem of island freshwater shortage to a certain extent, and improve the economic and environmental benefits of the island.

1. Introduction
With the continuous maturity of available energy power generation technology, combined with the abundant natural resources surrounding the island and the lack of fresh water resources, the use of renewable energy technology to establish an island power supply system to maximize the utilization of island resources, to better improve the public service level of the island hydropower supply and other infrastructures, and to further meet the global advocacy of green, environmental and safe island development concepts are hot issues studied by many scholars.

It is of great practical significance to study the optimal configuration model of the island microgrid with seawater desalination load to improve the system efficiency. Reference [1] added a seawater desalination device to the island microgrid modelling and used the chaotic search algorithm to obtain the optimal power capacity configuration plan. It verified that the addition of time-shiftable loads for seawater desalination can reduce the optimal configuration of the island microgrid. Reference [2] studied the operation strategy of the island wind and firewood storage microgrid, and designed the operation control strategy when the load of seawater desalination was considered. In actual operation, it can be seen that the addition of seawater desalination can reduce energy waste. Reference [3] proposed the combination of renewable energy power generation and seawater desalination units, and established an optimization model with the goal of minimizing the cost of water production. Reference
[4] proposed a method for optimal configuration of the capacity of wind-solar hybrid desalination system and the genetic algorithm is used to solve the problem, which can minimize the cost while ensuring the water demand of residents.

This article takes the island microgrid as the research object, and takes Shenzhen Neilingding Island as an example to establish a wind power, photovoltaic, diesel generator, and battery power source for wind and solar diesel storage island microgrid models. In order to further cope with the fluctuation of renewable energy and increase renewable energy utilization rate, make up for fresh water resources, the time-varying load of seawater desalination is increased while the energy storage equipment is used, and the minimum annual equivalent investment cost of the system is taken as the optimization objective function. The simulation results of the network verify the rationality and economy of the strategy.

2. Island microgrid system model

2.1. Island microgrid system structure
In order to improve the economy and stability of the system and maximize the consumption of renewable energy, this paper configures a battery as an energy storage device on the basis of the wind power system. In addition, seawater desalination devices are added. The addition of seawater desalination devices can not only solve the problem of lack of fresh water in the island area, but also can be used as a transferable load to further reduce the volatility of wind and solar power generation, making the system more economical and stable.

The system is mainly composed of diesel generators, photovoltaic power generation, wind power generation, storage batteries, seawater desalination devices, and general load on the island. The storage batteries are used as backup energy storage equipment. Diesel generators, photovoltaic power generation, wind power generation, and storage batteries converge energy to the DC bus through a converter, and then convert the DC voltage into an AC voltage matching the grid through a grid-connected inverter, and then feed it into the power distribution through a step-up transformer. The voltage level of the grid and bus is determined by the power supply area of the island, the positional relationship between multiple power sources, and the system capacity.

2.2. Wind power model
The output power of the wind turbine can be expressed as

\[
\begin{align*}
P_w &= 0 & V < V_{ci} \\
P_w &= aV_r^3 - bP_r & V_{ci} < V < V_r \\
P_w &= P_r & V_r < V < V_{co} \\
P_w &= 0 & V > V_{co}
\end{align*}
\]

where \( P_r \) is the rated power; \( V_{ci} \) is the cut-in wind speed; \( V_r \) is the rated wind speed; \( V_{co} \) is the cut-out wind speed; \( a = P_r / (V_r^3 - V_{ci}^3) \); \( b = V_{ci}^3 / (V_r^3 - V_{ci}^3) \).

2.3. Photovoltaic power generation model
The power output of the photovoltaic cell depends on the size of the photovoltaic panel, the light intensity, the temperature of the panel, etc. The model can be expressed as

\[
P_{pv} = I_T \eta A_{pv}
\]

where \( P_{pv} \) is the output power per hour of photovoltaic; \( I_T \) is the solar irradiance; \( A_{pv} \) is the area of photovoltaic panels; \( \eta \) is the system efficiency, which is related to the temperature of the panels.
2.4. Diesel generator model
The output power of diesel generators is mainly related to energy consumption and can run between 0 and rated power. The fuel power output characteristic is

\[ F(t) = aP_{RP}(t) + bP_{GEN}(t) \]  

where \( F(t) \) is the fuel consumption of the diesel generator; \( P_{RP}(t) \) and \( P_{GEN}(t) \) are the rated output power and the actual output power respectively; \( a \) and \( b \) are the fuel slopes respectively.

2.5. Battery model
The remaining power of the battery at time \( t \) is related to the remaining power of the battery at \( t-1 \) and the amount of charge and discharge of the battery during the period \([t-1, t]\).

When the battery is discharged, the remaining capacity at time \( t \) is

\[ S(t) = S(t-1)(1-\sigma) - P_{SBd}(t)/\eta_d \]  

(4)

When the battery is charging, the remaining capacity at time \( t \) is

\[ S(t) = S(t-1)(1-\sigma) - P_{SBc}(t)/\eta_c \]  

(5)

where \( S(t) \) is the remaining capacity of the battery at time \( t \); \( P_{SBd}(t) \) is the battery discharge power at time \( t \); \( P_{SBc}(t) \) is the battery charging power at time \( t \); \( \eta_d \) is the battery discharge efficiency; \( \eta_c \) is the battery discharge efficiency; \( \sigma \) is the self-discharge ratio of the battery per hour.

3. Time-shiftable load modelling of seawater desalination equipment

3.1. Time-shiftable load characteristics
The characteristic of time-shiftable load is that it can transform the uncontrollable load in traditional dispatching into a partly controllable load, and track the power generation output of the uncontrollable power source to reduce or offset the impact of the uncontrollable power source on system stability. Introducing the time-shiftable load of the seawater desalination device into the wind and solar storage system can not only absorb the excess renewable energy to produce fresh water when the renewable energy output is surplus, but also cannot work when the renewable energy output is insufficient. As a controllable load, it can accept real-time scheduling and realize real-time power balance [5].

3.2. Modelling of desalination plant
The energy balance relationship of the desalination unit is

\[ \overline{P} = \frac{P_s Q_1 + (P_s - P_m) Q_2}{3.6 \times 10^6 Q_1 \eta_c \eta_p} \]  

(6)

where \( P \) is the motor power; \( P_s \) is the seawater pressure after boosting; \( Q_1 \) is the high-pressure pump inlet water flow; \( Q_2 \) is the boosted seawater flow; \( \eta_c \) and \( \eta_p \) is the efficiency of the pump and the motor subsystem respectively.

Under normal circumstances, in addition to the consumption of motors and high-pressure pumps, the seawater desalination device also needs to consume energy to maintain the operation of the various subsystems of the device. The input power of the desalination device is

\[ P = \overline{P} + \eta P_s \]  

(7)

where \( \eta \) is the coefficient of rated power consumed by the subsystem; \( P_s \) is the rated power.
4. Optimal configuration model of power supply for island microgrid
This article considers the optimal configuration of the wind and solar storage island microgrid system of the seawater desalination device to study the optimal capacity combination of various units. Comprehensive cost, the objective function is

\[ \min C_{ACS} = \min \left( C_{Acap} + C_{Aom} + C_{Arep} \right) \]  

where \( C_{ACS} \) is the annualized cost of system; \( C_{Acap} \) is the annual average cost of installation costs of each unit; \( C_{Aom} \) is the average annual operation and maintenance cost; \( C_{Arep} \) is the average annual replacement cost.

The capacity optimization configuration in this paper considers the following constraints.
(1) System power supply reliability constraint

\[ \rho_{LPSP} \leq \rho_{LPSP}^{\text{max}} \]  

where \( \rho_{LPSP} \) is the probability of power shortage, which is the main measure of system reliability.

Power balance constraint

\[ P_w(t) + P_{pv}(t) + P_{bs}(t) = P_L(t) \]  

where \( P_w(t) \) is wind power generation per hour; \( P_{pv}(t) \) is photovoltaic power generation per hour; \( P_{bs}(t) \) is battery output per hour; \( P_L(t) \) is load demand per hour.

Battery charging restriction

\[ S_{SOC \min} \leq S_{SOC}(t) \leq S_{SOC \max} \]  
\[ \begin{cases} 0 \leq P_{bsd}(t) \leq P_{bsd \max} \\ 0 \leq P_{bsc}(t) \leq P_{bsc \max} \end{cases} \]  

where \( S_{SOC \min} \) is the minimum energy storage capacity of the battery; \( S_{SOC \max} \) is the maximum energy storage capacity of the battery; \( P_{bsd \max} \) is the maximum discharge rate of the battery; \( P_{bsc \max} \) is the maximum charge rate of the battery.

Since the objective function and constraint condition format in this article are more typical, the parameters can be correspondingly substituted into the Yalmip platform in MATLAB to call the CPLEX solver to solve.

5. Simulation analysis
This article takes Neilingding Island as the actual research object. Neilingding Island is rich in wind and light resources. The average monthly temperature of the island is 28.2 ℃, and there is a large amount of solar radiation on the island. The average daily peak irradiation time of the horizontal plane is 3.59 hours, and the daily average peak radiation time under the optimal inclination angle is 3.7 hours. The maximum load power on the island is 700 kW, and the daily load data and corresponding renewable energy output forecast data for 24 periods of a typical day are selected.

5.1. Basic data of the research plan
According to the above method combined with the island microgrid planning problem, the time-shiftable load of seawater desalination is added to optimize the power supply configuration. Combining the actual situation on the island and related equipment parameters, the parameters of wind
power generation system, photovoltaic power generation system, storage battery and desalination equipment are shown from Table 1 to Table 4, respectively.

| Table 1. Parameters of wind power generation system |
|--------------------------------------------------|
| Rated power of single unit (kW) | Unit price (million yuan/set) | Cut in wind speed (m/s) | Rated wind speed (m/s) | Cut out wind speed (m/s) |
|---------------------------------|-------------------------------|------------------------|------------------------|------------------------|
| 100                             | 1                             | 3                      | 10                     | 22                     |

| Table 2. Parameters of PV power generation system |
|--------------------------------------------------|
| Rated power of single unit (kW) | PV module price (thousand yuan/kW) |
|---------------------------------|-----------------------------------|
| 100                             | 8.5                               |

| Table 3. Parameters of storage battery system |
|-----------------------------------------------|
| Rated battery capacity (kW·h) | Charging efficiency | Discharge efficiency |
|---------------------------------|---------------------|----------------------|
| 500                             | 0.9                 | 0.9                  |

| Table 4. Parameters of desalination equipment |
|-----------------------------------------------|
| Consumption per ton of water ((kW·h)/t) | Rated power of single unit (kW) | Feed water concentration (kg/m³) | Feed pump efficiency (%) | Water production flow (m³/h) | Desalination rate (%) | Fresh water tank capacity (m³/set) |
|--------------------------------------------|-------------------------------|---------------------------------|--------------------------|---------------------------|----------------------|-----------------------------------|
| 6                                          | 25                            | 35                              | 0.741                    | 0.946                     | 99.6                 | 1000                              |

According to the annual forecast data of Neilingding Island, the forecast data of wind speed and light intensity are shown in Figure 1 and Figure 2, respectively.

Figure 1. Wind speed distribution throughout the year          Figure 2. Annual sunshine intensity

5.2. The project configuration and technical and economic evaluation
According to the area and load demand of Neilingding Island, the construction and operation cost and capacity allocation plan of different scenarios are analyzed under the condition of meeting the power demand of the island. The analysis results are shown in Table 5.

Scenario 1: In this scenario, 4 diesel generators with a rated power of 200 kW are selected, the unit fuel consumption is 200 g/(kW·h). The service life is about 30 years, and the maintenance cost is 300,000 yuan per year, which is equivalent to the annual operating cost of 4.454 million yuan. Although the cost of this energy supply mode is relatively small, it will cause environmental pollution.

| Table 5. Power supply mode of energy island in different scenarios |
|-------------------------------------------------------------------|
| Diesel engine set | Wind power generation | PV power generation | Desalination plant | Battery |

5
Scenario 1

Scenario 2

Scenario 3

Scenario 2: The optimized configuration results show that 5 wind turbines are required, with a photovoltaic power generation capacity of 200 kW, a storage battery capacity of 500 kW, a rated power 200 kW diesel unit. The life of fan is about 20 years, the life of photovoltaic modules is about 25 years, and the life of battery is about 8.5 years. The maintenance cost of wind turbines and photovoltaic modules is 250,000 yuan/year and 200,000 yuan/year, which is equivalent to 5.832 million yuan in annual operating costs.

Scenario 3: The optimized configuration results show that 6 wind turbines, 200 kW photovoltaic power generation capacity, and 2 diesel units with a rated power of 200 kW are required. Based on the maintenance costs and service life of the diesel generator sets, photovoltaic modules, and wind turbines mentioned above, with the same indicators, the equivalent annual operating cost is 4.177 million yuan.

On the premise of meeting the load demand of Neilingding Island, according to the optimized configuration results and by comparing the economic operation costs of different scenarios, it can be seen that the cost of scenario 1 is lower than that of scenario 2, but scenario 1 has the problem of environmental pollution, which is not recommended for long-term consideration. In scenario 3, fresh water can be provided through the configuration of seawater desalination device, which greatly reduces the cost of fresh water transportation. It not only makes full use of renewable energy, but also improves the environmental efficiency and economy.

6. Conclusion

In this paper, an independent micro-grid system for wind and diesel storage seawater desalination is established, three capacity allocation schemes are proposed, and economic comparison studies are carried out. The results of the study show that the wind-solar-storage island micro-grid that takes into account the time-shifting load of seawater desalination can be realized under the premise of stable operation of the system. The consumption of renewable energy is increased, the waste of capacity is reduced, the problem of lack of fresh water on the island is solved to a certain extent, and the economic and environmental benefits of the island are improved.

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