Optimal Configuration of Micro-Energy-Network of Cogeneration Type in Near Land Island

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Abstract. In order to effectively solve the problem that the offshore island energy supply system can not be applied to the near land island, the micro energy network optimization configuration model under the typical scenes of the near land island is constructed, and the specific load data is used to configure the capacity of the main equipment in the scheme. The model satisfies the problems of electricity load, heat load and desalination. The objective function of the model is the minimum operating cost and the maximum customer satisfaction. Considering the constraints of various types of power generation and energy storage, thermal power balance and desalination, particle swarm optimization algorithm is used to solve the problem. Taking a micro energy network of an island as an example, this paper simulates the micro energy network of cogeneration type, and makes a comparative analysis with the common micro energy network of the island. The results show that the optimized configuration model of the micro energy network of the near land island studied in this paper can effectively provide the power load and heat load for the users, improve the satisfaction of the users, and thus improve the economy of the micro energy network.

Keywords: Near land island · Micro-energy-network · Energy supply system · Optimal allocation

1 Introduction

China has a large number of islands and a long coastline. How to ensure the safety and stability of energy supply is the top priority for island residents. The island is rich in renewable energy such as wind energy and wave energy. The island micro energy network provides energy for residents by combining multiple renewable energy sources, which is an effective way to solve the island energy supply problem [1–4]. In reference [5], According to the water demand of the island and the characteristics of the desalination system, and considering the economic and environmental benefits of the system operation, the paper puts forward the power distribution strategy of coordinating the

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desalination load, battery and diesel generator operation. In reference [6], a scheme of island micro grid power supply is proposed, in which the sea water pumped storage power station is used as energy storage equipment, and the wind farm and diesel generator are operated. Based on the modeling of wind farm, sea water pumping and storage power station and diesel generator respectively, considering their operation constraints and island load requirements, the scheme of optimal scheduling of island micro-grid is proposed. All of the above documents have optimized the energy storage system of the micro energy network on the basis of satisfying the power load of the residents, and they are all off grid islands. When the islands are close to the mainland, this mode cannot be applied. Therefore, this paper proposes a micro energy network system of land island combined heat and power supply, which takes the grid connected micro energy network system as the object, and operates the micro energy network in the scheduling cycle according to the time-sharing electricity price strategy based on the principle of minimum cost and maximum customer satisfaction, a micro energy network optimization model including each output unit, energy storage unit and cogeneration system is established and solved by particle swarm optimization. Taking an island micro energy network as an example, this paper compares the micro energy network system of cogeneration with that of common Island micro energy network, and verifies the validity and feasibility of the optimal configuration model and solution method of the near land island micro energy network studied in this paper.

2 Island Micro-Energy-Network Structure and Equipment Model

The micro energy network system studied in this paper is mainly composed of electricity, heat and residential water. Next, the mathematical model of micro energy network system equipment is analyzed (Fig. 1).

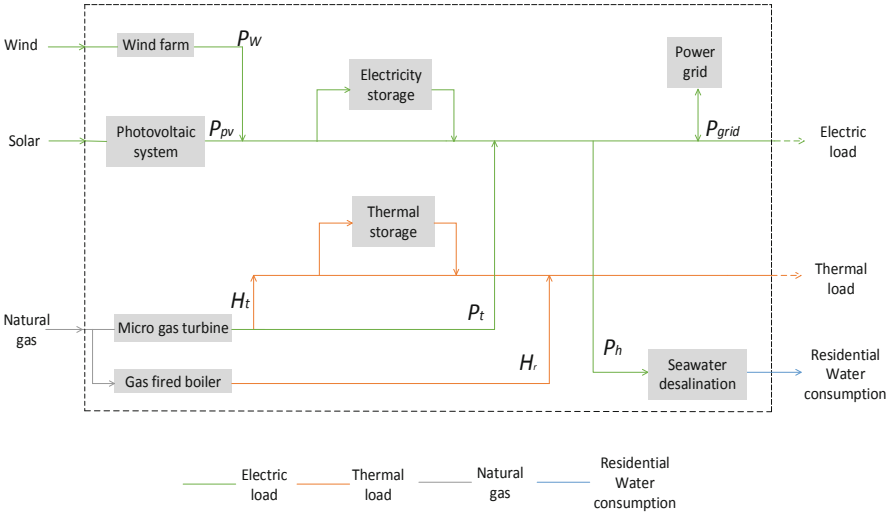

Fig. 1. Basic framework of micro-energy-network

2.1 Renewable Energy Power Generation Equipment

The mathematical models of wind power and photovoltaic power generation are as follows [7, 8]:

$$P_w = \begin{cases} P_r & V_r \le v \le V_{co} \\ P_r(A + Bv + Cv^2) & V_{ci} \le v < V_r \\ 0 & v < V_{ci} \ or \ v > V_{co} \end{cases} \tag{1}$$

$$\begin{cases} A = \frac{1}{(V_{ci}-V_r)^2}[V_{ci}(V_{ci}+V_r) - 4V_{ci}Vr(\frac{V_{ci}+V_r}{2V_r})^3] \\ B = \frac{1}{(V_{ci}-V_r)^2}[4(V_{ci}+V_r)(\frac{V_{ci}+V_r}{2V_r})^3 - (3V_{ci}+V_r)] \\ C = \frac{1}{(V_{ci}-V_r)^2}[2 - 4(\frac{V_{ci}+Vr}{2V_r})^3] \end{cases} \tag{2}$$

$$P_{PV} = f_{loss} P_{STC} \frac{G_{AC}}{G_{STC}}(1 + k(T_c - T_r)) \tag{3}$$

Where, cut in wind speed $V_{ci} = 3$ m/s, rated wind speed $V_r = 12$ m/s, cut out wind speed $V_{co} = 22$ m/s; P_{STC} is the maximum output power of solar panel; G_{AC} is the average solar radiation intensity; G_{STC} is the solar radiation intensity under the standard test conditions, with a value of 1000 W/m^2; k is the power temperature coefficient, with a value of -0.0047/°C; T_r is the ambient temperature under the standard test conditions, It is 25 °C.

2.2 Seawater Desalination System

In order to meet the water demand of island residents, the desalination system is composed of a reservoir and several desalination units. The system model is as follows:

$$\begin{cases} P_h = NP_N \\ N = \begin{cases} \left\lceil \frac{R_n(t)-R_x(t)+R_d(t)}{P_N} \right\rceil & R_n(t) > R_x(t) - R_d \\ 0 & R_n(t) \le R_x(t) - R_d \end{cases} \end{cases} \tag{4}$$

Where, N is the number of desalination units to be opened; P_N is the rated power of a single desalination equipment; $R_n(t)$, $R_x(t)$ and R_d are the water load required by the user at time t, the storage capacity and the minimum storage capacity of the reservoir at time t; the initial water volume of the reservoir is 50 t; the minimum water demand is 10 t.

2.3 CHP System

The mathematical models of micro gas turbine and gas boiler are as follows:

$$\begin{cases} \eta_t(t) = 0.4166(\frac{P_t(t)}{200})^3 - 1.0134(\frac{P_t(t)}{200})^2 \\ \qquad +0.8365(\frac{P_t(t)}{200}) + 0.0926 \\ H_t(t) = \frac{P_t(t)(1-\eta_t(t)-\eta_l)}{\eta_t(t)} \\ F_{MT} = \frac{J_{NG}\sum P_t(t)\Delta t}{\eta_t(t)L_{NG}} \end{cases} \tag{5}$$

$$\begin{cases} H_r = R_{GB}\eta_{GB} \\ F_{GB} = \frac{J_{NG}\sum H_r(t)\Delta t}{\eta_{GB}L_{NG}} \end{cases} \tag{6}$$

Where, $\eta_t(t)$ is the generation efficiency of micro gas turbine at time t; $P_t(t)$ is the power of micro gas turbine at time t; $H_t(t)$ is the heat recovery of micro gas turbine at time t; η_l is the heat loss coefficient, taking 0.03; F_{MT} is the cost of purchasing natural gas for micro gas turbine; J_{NG}, L_{NG} is the price of natural gas and the calorific value of natural gas, taking 2 CNY/m^3 and 9.78 kwh/m^3 respectively. η_{GB} is the energy conversion efficiency of gas boiler, taking 0.91.

2.4 Energy Storage System

The energy storage system adopts battery power storage and heat storage tank. The mathematical model is as follows [9]:

$$\begin{cases} E_H(t+1) = E_H(t)(1-\sigma_E) + P_{H,c}(t)\eta_{H,c}\Delta t - \frac{P_{H,d}(t)\Delta t}{\eta_{H,d}} \\ E_G(t+1) = E_G(t)(1-\sigma_G) + P_{G,c}(t)\eta_{G,c}\Delta t - \frac{P_{G,d}(t)\Delta t}{\eta_{G,d}} \end{cases} \tag{7}$$

In the formula, $P_{H,c}(t)$, $P_{H,d}(t)$, $P_{G,c}(t)$, $P_{G,d}(t)$ are the power of charging and discharging at time t, and the power of heat storage and heat release respectively; σ_E, σ_G are the self discharging and heat release rate of the battery and the heat storage tank respectively; $\eta_{H,c}$, $\eta_{H,d}$, $\eta_{G,c}$, $\eta_{G,d}$ are the charging and discharge efficiency of the battery and the heat storage and heat release efficiency of the heat storage tank respectively; the initial electric quantity and heat quantity of the battery and the heat storage tank are 50 KW; the minimum electric quantity is 40 kW.

3 Objective Function and Constraints

3.1 Objective Function

In this paper, the operation of micro energy network is to consider the operation cost and user satisfaction of micro energy network in a one-day time scale. This paper studies the optimization of micro energy network, including the minimum operation cost and the maximum user satisfaction.

1) Micro energy network economy

$$\min price = \min(F_{grid} + F_{MT} + F_{GB}) \tag{8}$$

$$\begin{cases} F_{grid} = \sum_{i=1}^{24} P_{grid}(t)F_{grid}(t) \\ F_{MT} = \sum_{i=1}^{24} F_{MT}(t) \\ F_{GB} = \sum_{i=1}^{24} F_{GB}(t) \end{cases} \tag{9}$$

Where, $F_{grid}(t)$ is hourly price; $P_{grid}(t)$, $F_{GB}(t)$, $F_{MT}(t)$ are the exchange value of power between the system and the grid at time t, the purchase cost of natural gas for gas turbine at time t and the purchase cost of natural gas at time t respectively.

2) User satisfaction

Customer satisfaction consists of power supply satisfaction and heating satisfaction. The satisfaction of power supply requires that the less the amount of purchased electric energy is, the higher the satisfaction of power supply is. The satisfaction of heat supply is the proportion of other heat energy in the heat load except the complete heat supply equipment. Customer satisfaction:

$$S(\mathrm{t}) = \frac{1}{2}\mathrm{S_d(t)} + \frac{1}{2}\mathrm{S_r(t)} \tag{10}$$

$$\begin{cases} S_{\mathrm{d}}(\mathrm{t}) = \frac{P(t)-F_d(t)}{P(t)} \\ S_{\mathrm{r}}(\mathrm{t}) = \begin{cases} 0.6 & Q_r(t) = 0 \\ \frac{Q_r(t)}{Q(t)} & Q_r(t) > 0 \end{cases} \end{cases} \tag{11}$$

Where, $S_d(t)$ is the satisfaction degree of power supply; $S_r(t)$ is the satisfaction degree of heat supply; $P(t)$, $F_d(t)$, $Q(t)$ are respectively the power load required by the user, the total cost of power purchase and gas purchase, and the heat load required by the user at time t.

3.2 Constraint Condition

1) Heat balance constraint:

$$H_r(t) + H_t(t) + H_x(t) \geq Q_{load}(t) \tag{12}$$

Where, $Q_{load}(t)$ is the required heat load at time t; $H_x(t)$ is the difference between the heat stored in the heat storage tank at time t and the minimum heat stored.

2) Electrical balance constraints:

$$P_w(t) + P_{pv}(t) + P_x(t) + P_t(t) + P_{grid}(t) \geq P_{load}(t) + P_b(t) + P_h(t) \tag{13}$$

Where, $P_{load}(t)$ it is the required electric load at time t; $P_{grid}(t)$ is the power exchange value between the system and the external power grid at time t; $P_x(t)$ is the difference between the stored energy of the battery and the minimum stored energy at time t, and the required electric energy of the heat pump.

3) Micro gas turbine operation constraints:

$$P_t^{\min} \leq Pt(t) \leq P_t^{\max} \tag{14}$$

Where, $P_t^{\min}$ and $P_t^{\max}$ are the minimum and maximum output power of micro gas turbine.

4) Desalination constraints:

$$0 \leq N \leq N\max \tag{15}$$

Where, $N\max$ is the maximum number of desalination units opened.

4 Simulation Example

In order to verify the validity and correctness of the micro energy network optimization model of cogeneration in this paper, the comparison between the model and the island common micro energy network energy supply system is made and the conclusion is drawn. Diesel generator is the main power supply equipment and heat pump is the heat supply equipment. Select an island as the verification point of the micro energy network, and simulate the micro energy network. The main equipment parameters of the micro energy network are shown in Table 1, the purchase/sale price is shown in Table 2, the predicted output curve of wind power, photovoltaic power generation and electric heating load is shown in Fig. 2, and the residential water load is shown in Fig. 3.

Table 1. Device parameters

Parameter	Numerical value
Wind farm/kW	500
Photovoltaic system/kW	250
Micro gas turbine/kW	200
Gas fired boiler/kW	200
Diesel generator/kW	200
Heating coefficient of heat pump	3
Power of single desalination plant/kW	25
Water yield of single desalination plant/t/h	5

Table 2. Online purchase/sale price

	Time	Power purchase/(kW·h/CNY)	Selling electricity/(kW·h/CNY)
Peak time	21:00–4:00	0.82	0.6
Peacetime	5:00–6:00 20:00 10:00–12:00 14:00–17:00	0.65	0.6
Valley time	7:00–9:00 13:00–14:00 18:00–19:00	0.25	0.6

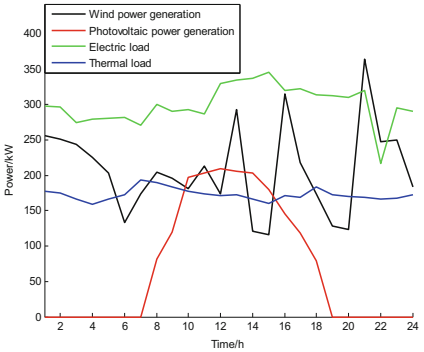

Fig. 2. Predicted output curve of renewable energy and electric heating load

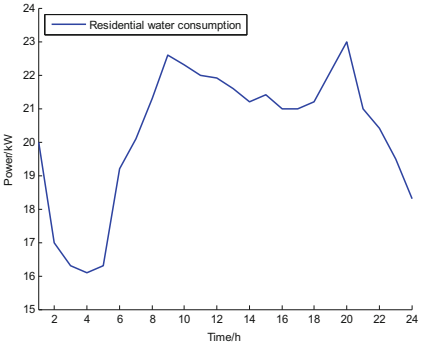

Fig. 3. Residential water load

The electric and thermal power dispatching results of the common energy supply system and the optimized configuration system of the island micro energy network are shown in Fig. 4, 5, 6 and 7 respectively.

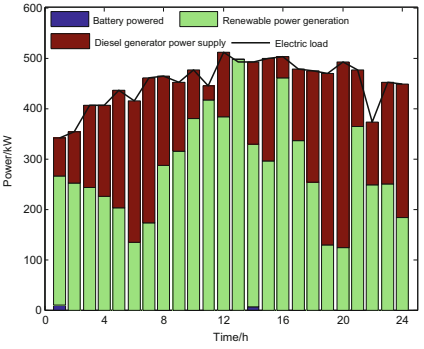

Fig. 4. Electric load dispatching results of common systems

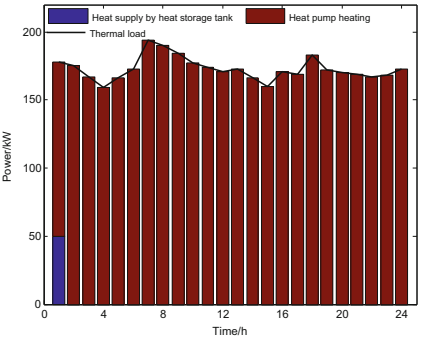

Fig. 5. Thermal load scheduling results of common systems

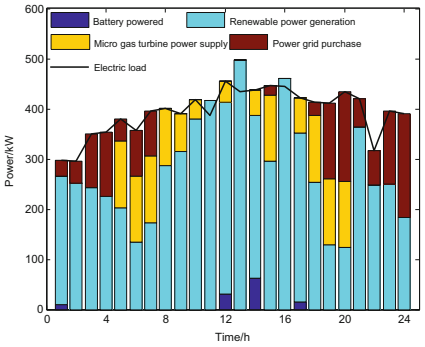

Fig. 6. The result of electric power dispatch in this paper

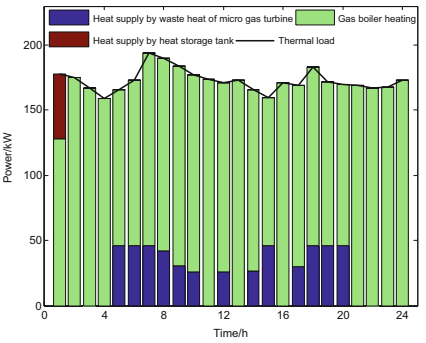

Fig. 7. The results of thermal power scheduling in this paper

It can be seen from the comparison between Fig. 6 and Fig. 7, Fig. 4 and Fig. 5 that the power supply system of common Island micro energy network will increase in the power load required by users every hour due to the heat pump heating. The power supply system of common Island micro energy network has only 13 h of slight power storage, and most of the time, the renewable energy can not meet the demand of users' power load, so diesel generator is needed for power generation Electricity causes the loss of cost and the aggravation of pollution, and heat supply is all completed by heat pump. The system studied in this paper can better meet the needs of users. It can store electricity at 11, 13 and 16 h, and provide power load for users in the following time. When the power supply of renewable energy is insufficient, it can choose the side with better economy to draw power from the grid and micro gas turbine, which can not only meet the demand of power load, but also reduce the expense. The heating system is composed of heat storage The waste heat of tank, gas boiler and micro gas turbine is no longer supplied by a single heat pump, which realizes the diversity of heating system.

Figure 8 and Fig. 9 show the operating costs and user satisfaction of the common island micro energy network energy supply system and the optimized configuration system in this paper.

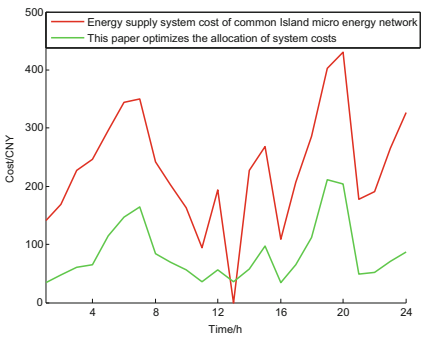

Fig. 8. Operating expenses

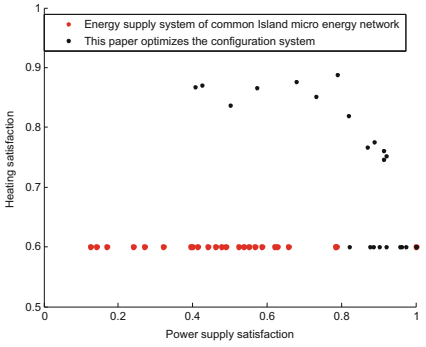

Fig. 9. User satisfaction

It can be seen from Fig. 8 that in one day, the hourly operation cost of the micro energy network system in this paper is about 100, which is far lower than that of the common micro energy network energy supply system. Only at 13:00, the cost is 0, which is lower than that of the system in this paper. This is because the thermal energy provided by the common micro energy network energy supply system is generated by electric energy conversion. When the renewable energy generation capacity is greater than the electric load, the battery is charged without using Diesel generator generates electricity, so the cost is 0. In this paper, the heating system of micro energy network is not completely affected by electric energy, so it needs to buy natural gas for heating, so the cost is slightly higher at 13:00.

It can be seen from Fig. 9 that the power supply satisfaction of the micro energy network studied in this paper is about 0.8 on average, the heating satisfaction is about 0.75 on average and the maximum is 0.9, and the two energy supply systems of the common micro energy network are about 0.4 and 0.6 respectively. Therefore, in this paper, the efficiency and customer satisfaction of converting cost into electricity are improved.

5 Conclusion

According to the characteristics of near land island, this paper proposes a micro energy network architecture of near land island cogeneration, which configures the capacity of the main equipment in the system, models a variety of energy supply and storage equipment in the micro energy network, and constructs two indicators that can reflect the operating cost and user satisfaction. According to the daily load demand, particle swarm optimization algorithm is used to solve the micro energy network, which is compared with the common Island micro energy network energy supply system. The example analysis shows that the micro energy network energy supply system studied in this paper can effectively reduce operating costs and improve user satisfaction.

References

1. Lei, J., Bai, H., Ma, X., et al.: Summary and prospect of multi-energy complementary island microgrid developed by china southern power grid. Southern Power Syst. Technol. **12**(3), 27–34 + 73 (2018)
2. Wang, J.: Modeling and simulation of island microgrid base on tidal current generation system. Zhejiang University (2018)
3. Yu, P., Liu, X., Sun, S., et al.: Study on operation control of island microgrid with high renewable energy penetration. Power Syst. Technol. **42**(3), 779–788 (2018)
4. Yao, Y., Ye, L., Qu, X., et al.: Exergy analysis model of wind-solar-hydro multi-energy generation power system. Electric Power Automation Equipment **39**(10), 55–60 (2019)
5. Zhang, J., Yu, L., Liu, N., et al.: Capacity configuration optimization for island microgrid with wind/photovoltaic/diesel/storage and seawater desalination load. Trans. Actions China Electrotech. Soc. **29**(2), 102–112 (2014)
6. Fan, L., Wang, K., Li, G., et al.: A optimization dispatch study of micro grid with seawater pumped storage plant in isolated islands. Power Syst. Technol. **40**(2), 382–386 (2016)

7. Sun, C., Wang, Z., Jiang, X., et al.: Coordinated optimization strategy for grid-connected microgrid considering demand response. Proc. CSU-EPSA **30**(01), 30–37 (2018)
8. Fang, B.: Multi-energy complementarity and integrated optimal allocation for hybrid renewable energy system. Hunan University (2017)
9. Li, Y.: Research on operation of the combined cooling, heating and power micro energy grid. Beijing Jiaotong University (2018)