Research on the Dispatching Strategy of Desalination Load Participation in Distributed Renewable Energy Consumption

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Abstract. In this paper, the dispatching problem of desalination load participation in distributed renewable energy consumption is taken as the research object, and the various characteristics of desalination system operation are analysed. According to the operating characteristics of the system, the operation constraints and optimal dispatching objectives of the multi-energy system with desalination load are proposed. An optimal dispatching model for distributed renewable energy consumption with desalination load participation was established and the linear simplex algorithm was used to solve the dispatching model according to the characteristics of the optimization model. The example shows that by optimizing the operation of the multi-energy system with seawater desalination load, it will help the local high-density distributed power supply to be consumed locally and improve certain economic benefits.

1. Introduction

In recent years, seawater desalination technology has developed rapidly. China has built many seawater desalination industrial parks in coastal areas to carry out seawater desalination [1]. Desalination production through the rational use of distributed energy sources such as wind energy can not only reduce environmental pollution and save energy, but also reduce the power recirculation of distributed energy sources such as wind power, which can help local consumption of distributed energy sources [2-4].

At present, relevant scholars have carried out related research on the models of desalination systems. Reference [5] established dynamic operation models of different types of desalination equipment, which can describe the dynamic response capability of seawater desalination equipment and the response potential to the power distribution system to a certain extent. Reference [6] studied five different configuration models of photovoltaic-driven desalination systems, and made comparisons between different configurations to determine the best technical and economic system configuration in different scenarios. Reference [7] analyzed the load characteristics of desalination and established a model of desalination load. According to the characteristics of desalination load, a multi-energy system operation mode and control scheme including wind power, energy storage and desalination load were proposed.

In terms of seawater desalination load treatment modes in multi-energy systems, scholars have conducted process modeling and research on distillation and reverse osmosis methods, namely the thermal method and membrane method [8-10]. Reference [11] pointed out that seawater desalination is
divided into membrane method and thermal method and these two methods have different desalination processes and therefore have different electrical power needs. Generally, the membrane method uses more electricity than the thermal method and the method also needs some heat sources to complete desalination [12-14]. These two mainstream desalination methods have been widely used in some demonstration projects. Reference [15] designed a monitoring system through model predictive control (MPC) to optimize the management and operation of integrated wind power generation and reverse osmosis (RO) desalination systems, and supervised MPC can coordinate wind and solar subsystems and battery packs, which provides sufficient energy for the RO subsystem, so that it can produce enough desalinated water to meet water demand and freshwater storage needs.

In this paper, research is conducted on the operating characteristics of multi-energy systems with desalination loads, system modelling, operation constraints of multi-energy systems with desalination loads, optimal dispatching goals and optimization algorithms. An optimal dispatching model for distributed renewable energy consumption with desalination load participation was established and the linear simplex algorithm was used to solve the dispatching model according to the characteristics of the optimization model. The example gives the optimal dispatching strategy of the system under the maximum consumption target of distributed energy resources and the economic optimal situation is also solved as a comparison. Finally, a typical desalination system in a workshop of Tianjin Xinquan desalination plant is taken as an example to verify the effectiveness of the dispatching strategy proposed.

2. Operation Constraints of Multi-Energy Systems with Desalination Loads

Reasonable control of the operating status of the multi-energy system with seawater desalination load can enhance the distributed energy resources consumption rate while ensuring the desalination output, and enhance the adaptability of the multi-energy system with seawater desalination load. When optimizing the dispatching process, the operating status of various production equipment of the multi-energy system containing seawater desalination load must be considered, and the equipment cannot be operated at the safe and stable operating boundary. Therefore, it is necessary to formulate the operating constraints of the multi-energy system containing seawater desalination load for optimal dispatch.

2.1. Constraints on Total Water Output from Desalination Equipment

The total water output constraint mainly takes into account the production goals of desalination enterprises. With the cooperation of the desalination membrane method and the thermal method, the total water output of daily desalination should meet the following conditions:

\[ S = \sum_{r=1}^{24} f_m(P_M^r) + \sum_{r=1}^{24} f_r(P_R^r) \]  

(1)

Where \( P_M^r \) is the operating power of the seawater desalination membrane equipment at time \( t \); \( P_R^r \) is the operating power of the seawater desalination distillation equipment at time \( t \); \( f_m(P_M^r) \) is a function of the operating power of the seawater desalination membrane equipment at time \( t \) with the amount of seawater desalinated; \( f_r(P_R^r) \) is a function of the operating power of the seawater desalination distillation equipment at time \( t \) with the amount of seawater desalinated; \( S \) represents the total amount of freshwater produced by the desalination system in one day.

2.2. Load Balance Constraints of Multi-Energy Systems with Desalination Load

The formula for the constraint conditions of electric power balance in a multi-energy system is as follows:

\[ P_{\text{Grid}}^r + P_{\text{Disnet}}^r + P_{\text{Discon}}^r = P_{M_i}^r + P_{\text{Load}}^r + P_{R_i}^r \]  

(2)
Where $P_{\text{Grid}}^t$ is the purchased power at time $t$ of the multi-energy system; $P_{\text{Disnet}}^t$ and $P_{\text{Discon}}^t$ are the on-grid power and locally consumption power of the $i$-th distributed energy sources at time $t$ of the desalination enterprise which include wind power and distributed photovoltaic; $P_{\text{Load}}^t$ is the other pure electric load value at time $t$ in the multi-energy system $P_{Mi}^t$ is the operating power of the $i$-th membrane process equipment of the desalination enterprise at time $t$; $P_{Ri}^t$ is the operating power of the $i$-th distillation process equipment of the desalination enterprise at time $t$.

The formula for thermal power balance constraints in a multi-energy system is as follows:

$$P_{aba}(t) \geq H_{\text{Space}}^t + H_{\text{Water}}^t P_{Ri}^t$$

(3)

Where $P_{aba}(t)$ is the thermal power provided by the municipal heating pipe network at time $t$; $H_{\text{Space}}^t$ is the other heat load value in the multi-energy system at time $t$; $H_{\text{Water}}^t P_{Ri}^t$ is the heat water load function required by the $i$-th distillation process equipment of the desalination enterprise at time $t$. Since the heat load does not need to be balanced in real time, the municipal heating power can be greater than the heat loads in the system.

2.3. Power Operation and Climbing Constraints of Desalination Equipment

The constraints of the desalination system mainly take into account the power limit of the desalination load device to ensure that the desalination device does not operate at overload state. When the desalination equipment is running at maximum power, the desalination system is in the maximum operating mode, and all the high-pressure pump and the booster pump are in a high-frequency operating state. When the power supply exceeds the maximum power, various types of motors will not work properly due to the speed limit and the system will be in a shutdown state, so the desalination equipment constraints are as follows:

$$0 \leq P_{R}^i(t) \leq P_{R}^i \text{max}$$

(4)

$$0 \leq P_{M}^i(t) \leq P_{M}^i \text{max}$$

(5)

Where $P_{R}^i(t)$ and $P_{M}^i(t)$ are the output power at time $t$ of the $i$-th distillation process equipment and membrane process equipment respectively, $P_{R}^i \text{max}$ and $P_{M}^i \text{max}$ are the power output limit of the $i$-th distillation process equipment and membrane process equipment respectively.

Within the allowable power operation range, the operating state of the high-pressure pump and the booster pump in the membrane process and the distillation process of the desalination system can be changed with the change of the power supply. However, due to the speed limitation of the motor, the seawater desalination membrane equipment and the distillation equipment have hourly maximum power climbing constraints:

$$\left|P_{R}^i(t+1) - P_{R}^i(t)\right| \leq P_{R}^i \text{max}(t)$$

(6)

$$\left|P_{M}^i(t+1) - P_{M}^i(t)\right| \leq P_{M}^i \text{max}(t)$$

(7)
Where $P_{R}^{i}(t+1)$ and $P_{M}^{i}(t+1)$ are the output power at time $t+1$ of the $i$-th distillation process equipment and membrane process equipment respectively. $P_{R}^{i,\text{max}}(t)$ and $P_{M}^{i,\text{max}}(t)$ are the power climbing limits at time $t$ of the $i$-th distillation process equipment and membrane process equipment respectively.

3. Dispatching Objective of Desalination Load Participation in Distributed Renewable Energy Consumption

Desalination enterprises can effectively cut peaks and fill valleys, reduce the impact of power loads on the power grid and reduce the peak and valley difference of the power grid. At the same time, for the distribution network with a high proportion of distributed energy access, seawater desalination load as a flexible and adjustable load resource can participate in the flexible consumption of distributed energy, greatly reducing the light and wind abandonment of the distribution network, and reducing energy waste. Based on consumption of distributed renewable energy in the multi-energy system containing seawater desalination loads as much as possible and meeting seawater desalination production, the system interact with the public grid to purchase and sell electricity and conduct heating transactions with municipal networks.

According to the operating characteristics of the desalination system, the objective function of the multi-energy system with desalination load was established to optimize the daily operation. The objective function is the highest distributed energy consumption rate of the entire system:

$$\min R = \min \left( \frac{\sum_{i=1}^{l} \sum_{t=1}^{24} P_{\text{Disnet}i}^{i}}{\sum_{i=1}^{l} \sum_{t=1}^{24} P_{\text{Disex}i}^{i}} \right) \quad (8)$$

Where $R$ is the distributed energy consumption rate of the system, $P_{\text{Disnet}i}^{i}$ is the on-grid power of the $i$-th distributed energy source at time $t$ with the unit of kW, $P_{\text{Disex}i}^{i}$ is the predicted generated power of the $i$-th distributed energy source at time $t$ with the unit of kW, $l$ is the total number of distributed power generation equipment in the system.

4. Case Study

Figure 1 is a typical daily electrical and thermal load forecast curve of Tianjin Xinquan desalination plant and surrounding loads. Figure 2 is the forecast generation curve of a typical daily distributed photovoltaic and wind turbine in Tianjin Xinquan desalination plant [16].

The desalination plant and the surrounding loads adopt the time-of-use electricity pricing mode and the specific time period and electricity price are shown in Table 1.
Fig 1. Typical daily electrical and thermal load forecast curve of Tianjin Xinquan desalination plant and surrounding loads

![Typical daily electrical and thermal load forecast curve of Tianjin Xinquan desalination plant and surrounding loads](image1)

Fig 2. Generation curve of a typical daily distributed photovoltaic and wind turbine in Tianjin Xinquan desalination plant

![Generation curve of a typical daily distributed photovoltaic and wind turbine in Tianjin Xinquan desalination plant](image2)

Table 1. Time of use price and period

| Period | Time                  | Price(Y/kWh) |
|--------|-----------------------|--------------|
| Peak   | 08:00-11:00,18:00-23:00 | 0.813        |
| Valley | 23:00-07:00           | 0.345        |
| Flat   | 07:00—8:00,11:00-18:00 | 0.572        |

The heat load of the desalination plant is directly supplied by the municipality, considering the operation and maintenance costs of the heat pipe network, the heating cost is converted to 0.462 CNY / kWh.

In the example, the main desalination equipment in the desalination plant includes four sets of membrane desalination devices and one set of distillation desalination devices. The maximum power of membrane desalination devices is 75kW, the maximum operating power of distillation desalination devices is 100kW. The system contains one set of photovoltaic power generation equipment with the maximum generating power of 212kW and one distributed wind turbine with the maximum generating power of 250kW.
power of 440kW. This system is connected to the public transformer of the distribution network by a centralized power bus. The relevant parameters of the system are shown in Table 2 and Table 3.

Table 2. Types and parameters of energy production equipment in the multi-energy systems

| Equipment          | Parameters                  | Values |
|--------------------|-----------------------------|--------|
| Wind turbine       | Maximum power generated $P_{\text{tur, max}}$ | 440kW  |
| Public network     | Maximum power exchange $P_{\text{Bus, max}}$ | 400kW  |
| Photovoltaic       | Maximum power generated $P_{\text{sol, max}}$ | 212kW  |

Table 3. Types and parameters of equipment within the desalination system

| Parameters                                      | Membrane desalination devices | Distillation desalination devices |
|------------------------------------------------|------------------------------|----------------------------------|
| Sets                                           | 4                            | 1                                |
| Power consumption / 0.3 tons of fresh water production | 1.7 kW·h                  | 0.95 kW·h                       |
| Thermal energy consumption / 0.3 tons of fresh water production | /                        | 0.63 kW·h                       |
| Maximum operating power                        | 75kW                         | 100kW                            |
| Maximum climbing power                         | 25kW/h                       | 100kW/h                          |

The total daily fresh water production is set to a minimum of 1500 tons. By solving the dispatching model of the multi-energy system containing desalination load for the distributed renewable energy consumption, the system’s distributed power curve to be consumed and electric load balance dispatching curve under the objective of maximum consumption of distributed energy are shown in the figure below.

![Power curve of distributed energy system to be consumed](image-url)

Fig 3. Power curve of distributed energy system to be consumed
In Figure 4, when the system adopts the maximum distributed energy consumption mode, the system matches the electricity generated by wind and photovoltaic power generation with seawater desalination load and the distributed power source is consumed by increasing the seawater desalination load. Since the distributed power generation increased the output of two types of desalination equipment, the total amount of desalination was increased. The dispatching strategy can calculate the amount of increasing desalination load and find the time when the desalination cost is expensive then reduces the power of the equipment at the expensive time of freshwater production, thus reduces the operating cost of the entire system while meeting the constraints of the total daily desalination of the entire system.

Fig 4. Electric load balance dispatching curve under the objective of maximum consumption of distributed energy

Fig 5. Electric load balance dispatching curve under economic optimal target
For comparison, Figure 5 shows the system electrical balance curve under the economic optimal operating mode. Under the economic optimal operating mode, the system does not consider the power amount of distributed energy sources connect with the public grid and uses the valley electricity to maximize desalination production and load balancing. Therefore, it can be seen from the figure that there is a large amount of distributed renewable energy power sent to the grid at 9-20 hours, and the local energy consumption rate of distributed energy is lower than the dispatching strategy proposed in this paper.

The comparison of the local power consumption rates of the distributed energy in three operating modes is shown in Figure 6. Under the maximum distributed energy consumption objective mode, although the system uses DG resources as much as possible, when the power generation of the distributed energy source exceeds the combined maximum power of pure electric load and the two desalination equipment, wind power and photovoltaic power abandonment are unavoidable. Therefore, there exists a small amount of energy wasted. Among the three operating modes, the operation and maintenance of the desalination equipment in the uniform operation mode are simple, but the system operating cost is higher and the consumption rate is lower. The cost under the economic optimal operation mode is slightly cheaper than that under the distributed energy consumption optimal operation mode, but the energy consumption rate is much lower than that under the distributed energy consumption optimal operation mode. The operating cost under the distributed energy consumption optimal operation mode is also low and the overall benefit is the best. From the above, it can be seen that by optimizing the operation of the multi-energy system with seawater desalination load, the energy cost of the seawater desalination system can be effectively reduced and the consumption rate of renewable energy sources can be improved greatly, which verify the effectiveness of the dispatching strategy proposed.

5. Conclusion
In this paper, research is conducted on the operating characteristics of multi-energy systems with desalination loads, system modelling, operation constraints of multi-energy systems with desalination loads, optimal dispatching goals and optimization algorithms. An optimal dispatching model for
distributed renewable energy consumption with desalination load participation was established and the linear simplex algorithm was used to solve the dispatching model according to the characteristics of the optimization model. The example gives the optimal dispatching strategy of the system under the maximum consumption target of distributed energy resources and the economic optimal situation is also solved as a comparison.

(1) By optimizing the operation of the multi-energy system with seawater desalination load, it will help local consumption of high-density distributed energy sources along the coast while improving certain economic benefits.

(2) When the system adopts the distributed energy consumption optimal operation mode, if the amount of renewable energy generation in the system is too large, it will cause a certain amount of wind and photovoltaic power discard, which can be reduced by increasing the scale of desalination system in the multi-energy system.

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