Energy Hub Dispatch Considering Heating Network Flexibility

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Abstract. Under high-penetration wind power, multi-energy complementary cooperation has provided new ideas to cope with its uncertainties. The widely distributed heating network affords high heat flexibility, which reflects in the mismatch between energy production value (EPV) and energy consumption value (ECV). The concept of generalized energy storage system (GESS) is introduced in this paper. To describe the relationship and build thermoelectric energy hub (EB) model considering heating network flexibility, temperature is employed as characteristic quantity. The result shows that the proposed method can decouple the Combined Heat and Power (CHP) unit's coupling constraints to some extent and cooperate in dealing with wind power uncertainty during the process of ensuring active power coordination.

1. Introduction

Under high-penetration wind power, it has become a huge dispatch challenge to cope with the uncertainty of wind power and ensure the safe and economic operation of power system. The multi-energy cooperation, represented by thermo-electric interconnected system namely energy hub, has provided new ideas to deal with wind power uncertainties. As a common energy form in social life, extensive research has been conducted at home and abroad on thermos-electric cooperation. The peak shaving capacity of Combined Heat and Power (CHP) units with heat storage or auxiliary electric boilers heating configuration is analyzed in [1][5] respectively. These references pointed out that the CHP units equipped with heat storage or auxiliary heating can decouple thermoelectric coupling constraints and obtain a wider operating range simultaneously. The research mentioned above relied on secondary investment in thermal power plants, but did not explore the heating network flexibility itself. So the studies in [6][9] describe a detailed model of the pipeline network and thermal load, in which the heat transfer properties of heating network and the flexibility of thermal load are explored. Thus the variable dimension is expanded and the model is made complicated accordingly.

In this paper, the generalized energy storage system (GESS) featured by temperature is introduced to describe the mismatch relationship between heat source and load. Changes in the status of GESS are reflected by the temperature change interval. Therefore a thermoelectric joint optimization model considering heating network flexibility is constructed to study the energy hub performance responding to the wind power uncertainties. Moreover, case is studied and analyzed to verify the performance of the proposed idea.
2. The Flexibility of Heating Network

Centralized heating methods are generally adopted in modern cities construction, thus a comprehensive regional heating network is established herein. Heat hysteresis may occur due to the heat capacity characteristics of the heating pipeline network during the heat transfer process, which is reflected by the mismatch between energy production value $E_G$ and the energy consumption value $E_L$, as shown in Figure 1, the difference value of them is the energy stored in heating network.

![Energy mismatch between EPV and ECV](image)

Figure 1. Energy mismatch between EPV and ECV

In this paper, the GESS is introduced to describe the mismatch relationship. The energy generated by the heat source enters the heating network to be stored in the GESS and then released to supply the heat load (to ensure that the thermal load’s characteristic quantity is constant). Taking the temperature as characteristic quantity of the GESS, the power difference between the heat source and load is transferred to the change of the feature quantity through the heat capacity, as depicted in Equation (1).

$$\frac{dE}{dt} = P$$

where the subscript $ch$ and the subscript $dis$ denote the charge status and discharge statue respectively, the subscript $s$ denotes the GESS, $C_s$ is the amount of energy used to increase or decrease the temperature by 1°C (MJ°C), reflecting the heat capacity of the heating network, $T_s^t$ is the temperature of the GESS at period $t$ (°C), $Q_{ch}^t$ and $Q_{dis}^t$ are the charge power and discharge power (MW) respectively. When the charge power is greater than the discharge power, the heat energy is stored in the network and the temperature rises. On the contrary, when the charge power is less than the discharge power, the heat energy stored in the network is consumed and the temperature drops.

3. Energy Hub Economic Dispatch Model

The general structure of energy hub is shown in Figure 2. The energy hub has one bus, containing wind generator, CHP plant and electrical load.
### 3.1. Objective function

The system operator aims at minimizing the energy hub cost, so the objective function can be expressed as Equation (2).

\[
\min C_{\text{total}} = \sum_{i=1}^{T} (C_{\text{chp}}^i + C_{\text{pun}}^i) = \sum_{i=1}^{T} [a(P_{\text{chp}}^i)^2 + bP_{\text{chp}}^i + c \cdot P_{\text{chp}}^i \cdot H_{\text{chp}}^i + d(H_{\text{chp}}^i)^2 + eH_{\text{chp}}^i + f + \sigma_{\text{pun}}(L_{\text{chp}}^i - L_{\text{e}}^i)]
\]  

where \( C_{\text{total}} \) is the total cost of the energy hub, \( C_{\text{chp}}^i \) is the operation cost of CHP unit, \( C_{\text{pun}}^i \) is the tie line power penalty, \( P_{\text{chp}}^i \) and \( H_{\text{chp}}^i \) are the electric power and the heat power of the CHP (MW), \( a, b, c, d, e \) and \( f \) are the cost coefficients of CHP, \( L_{\text{e}}^i \) is the actual tie line power (MW), \( L_{\text{chp}}^i \) is the schedule power of the tie line (MW), \( \sigma_{\text{pun}} \) is the power penalty coefficients ($/MWh$).

### 3.2. Constraints

#### 3.2.1. Energy hub.

An energy hub aims at satisfying the load demand via multi-carriers [10] and is an important tool to study multi-energy systems. The energy hub in this paper can be modelled as Equation (3).

\[
\begin{cases}
L_{\text{e}}^i = P_{\text{chp}}^i + P_{\text{w}}^i - P_{d}^i \\
L_{\text{chp}}^i = H_{\text{chp}}^i
\end{cases}
\]  

where \( P_{d}^i \) is local electrical load power (MW).

#### 3.2.2. Reserve capacity for wind power uncertainties.

In order to cope with wind power uncertainties, sufficient reserve capacity must be provided in the energy hub.

\[
\begin{align*}
\min [P_{\text{chp}}^i - P_{\text{chp}}^i \cdot r_{\text{up}} \cdot \Delta t] & \geq R_{\text{res}} \cdot P_{\text{af}}^i \\
\min [P_{\text{chp}}^i - P_{\text{chp}}^i \cdot r_{\text{down}} \cdot \Delta t] & \geq R_{\text{res}} \cdot P_{\text{af}}^i
\end{align*}
\]
where $P_{\text{chp}}^\text{max}$ and $P_{\text{chp}}^\text{min}$ are the maximum electrical power and minimum electrical power of the CHP unit (MW), $r_{\text{up}}$ and $r_{\text{dw}}$ are the unit ramp rate (MW/h), $R$ is the stand-by factor for wind power.

3.2.3. The GESS.
The charge power of the GESS is equal to the heating power of the CHP unit.

$$Q_{\text{ch}}^\text{t} = L_{\text{h}}^\text{t} = H_{\text{chp}}^\text{t}$$

(6)

The discharge power of the GESS is the heat transfer power from the heating network to thermal loads, used to maintain a constant thermal load temperature.

$$Q_{\text{dis}}^\text{t} = \frac{T^\text{t} - T^\text{i}}{R}$$

(7)

where $T^\text{i}$ is the temperature of the GESS (°C), $T^\text{t}$ is the temperature of thermal loads to maintain(°C), assuming that $T^\text{i}$ is constant. $R$ is the equivalent thermal resistance between heating network and thermal load, reflecting the heat transfer capacity (°C/MW).

Replace Equation (1) with Equation (6) and Equation (7), we can get Equation (8).

$$T_{s}^{t+1} = (H_{\text{chp}}^t R_s + T_i) + [T_i^{t} - (H_{\text{chp}}^t R_s + T_i)] e^{-\frac{\Delta t}{R_s C_s}}$$

(8)

The capacity constraints of the GESS can be described by temperature variation intervals, as Equation (9) shows.

$$T_{\text{min}} \leq T_{s}^{t} \leq T_{\text{max}}$$

(9)

4. Case Study

In order to verify the performance of the proposed idea, a case study is conducted in this section. The parameters used in the model are listed in Table 1.

| Parameters | Value | Parameters | Value | Parameters | Value |
|------------|-------|------------|-------|------------|-------|
| $a$        | 0.000169 | $f$        | 11.426 | $r_{\text{up}} / r_{\text{dw}}$ | 70    |
| $b$        | 0.2698  | $R$        | 0.0556 | $R_{\text{res}}$       | 0.05  |
| $c$        | 0.0000507 | $C$        | 18    | $\sigma_{\text{pun}}$ | 76    |
| $d$        | 0.000038 | $C_{\text{v}}$ | 0.15 | $P_{\text{chp}}^\text{max}$ | 300   |
| $e$        | 0.04047  | $C_{\text{m}}$ | 0.75 | $P_{\text{chp}}^\text{max}$ | 200   |

A case without counting the heating network flexibility is introduced for comparison as well. The model is solved by GAMS and the optimization results are shown in Table 2, Figure (3) and Figure (4).

As shown in Figure (3), when the heating network flexibility is not taken into consideration, the electric power of the cogeneration unit is limited by a constant heat load and can only be changed within a very small interval, resulting in a large amount of wind power curtailment during the active power coordination process. Figure (4) shows that the CHP can get a larger operating domain by decoupling the constraints when considering the flexibility and the wind power curtailment is also greatly reduced.
5. Conclusion
An energy hub economic dispatch model is presented in this paper, in which the flexibility of heating network is considered. The concept of GESS featured by temperature is proposed to describe the flexibility characteristic. The simulation results show that the flexibility of heating network can decouple the CHP unit's coupling constraints to some extent and serve as reserve for wind power uncertainties effectively, ensuring active power coordination with electrical network.

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