Big Data Configuration Optimization Strategy Analysis of Thermal-Electric Hybrid Energy System Based on Energy Cascade Utilization

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Abstract. In this paper, a typical heat-electric hybrid energy system is taken as an object to construct an economic model of demand-side management optimization and regulation, which aims to minimize the main body cost of terminal source system operation. On this basis, the key influencing factors are detailed modeled. Finally, an example is given to verify the validity of the model and observe the impact of changes in key influencing factors on the results of optimization and control. The research results are conducive to further tap China’s electricity demand side resources, improve its scale and reliability of applications, are conducive to the overall coordination of system reliability, cost, energy efficiency and so on.

Keywords: Thermo-Electric Hybrid Energy, System Configuration, Optimization, Big Data

1. Foreword
According to the strategic planning of energy conservation and emission reduction during the “13th Five Year Plan”, the focus should be on reducing total energy consumption and improving terminal energy efficiency in the energy field under the new situation. On one hand, it is ongoing major and profound change for the world energy development pattern to realize the sustainable development of energy. On the other hand, the use of large-scale renewable energy source poses grave challenge for safe and stable operation of electric power system. The singular focus on the operating mode of electric power system on the supply side is no longer able to meet requirements. In order to solve above problems and build reasonable energy pattern and effective supply-demand market, it is necessary to give full play to the resources on the demand side. Therefore, it is necessary to combine with the development trend of our electric power market, fully develop the demand-side response resource potential available for optimization in future and integrate the above resource resources by reasonable method and technology and apply them to the planning and operating process of the whole electric power system so as to promote the efficiency improvement and supply-demand coordination of electric power system and the smooth realization of supply-side reform objective of the energy and power industry.

The traditional demand-side management and demand-side response resource control are often to carry out research toward an aspect of system operation. Reference [1] proposes the introduction of
demand-side response mechanism into wind power integration. Reference [2] proposes a practical demand response benefit analysis method and selects the typical cases to analyze and evaluate the overall benefit when the demand response is applied to distribution network. Reference [3] proposes a competitive strategy of the demand response participating in the electric power market when the wind power uncertainty is considered. Reference [4] elaborates the specific ideas and countermeasures of developing the demand-side management under the background of big data. Reference [5] minimizes the power supply and demand gap based on the enterprise daily load curve and cost-benefit analysis. Reference [6] proposes the building intelligent energy management system based on power demand-side management and analyzes the intelligent utilization mode of power demand-side management in the regional energy system [7]. The demand-side management and control are often studied by Monte Carlo method, load prediction, game theory and other methods.

However, the future thermal-electric hybrid energy system and demand-side management cover various energies and multiple subjects and are influenced by many factors. The above study has large one-sidedness, which is harmful to coordinate the system reliability, operating risk, cost, price, energy efficiency and environmental impact. This document takes the typical thermal-electric hybrid energy system as an object to build the demand-side management optimization control economic model which aims at minimizing the operational body (energy service principal of grid company, power consumer and other third party) cost of terminal energy system.

On this basis, the key influence factors are modeled in details. Finally, we use examples to verify the model effectiveness and observe the influence on optimization control results from key influence factors. The results are helpful to further tap the power demand-side resources in our country and improve their application field and reliability. In addition, they are also helpful to bring the multi-sided benefits and build the all-win situation.

2. Basic Model of Thermal-Electric Hybrid Energy System

The existing study defines the demand-side control preliminarily: The operational body of terminal energy system is based on technology or economic objective to make a series of optimizing production/consumption arrangements for user-end energy resources. The thermal-electric hybrid energy system is a carrier integrating electric power, natural gas and various energies to utilize thermal and electric resources in a more efficient and economical way.

The thermal-electric hybrid energy optimization control is modeled to minimize the energy consumption cost of operational body of terminal energy system. It should be noted that if the multi-objective optimization is considered, such as minimum transmission loss, minimum carbon emission, then it can be used as an integral part of objective function and can be realized by giving weight to different objectives. The Formula (1) shows the basic form of thermal-electric hybrid energy system optical control model, which is used to minimize the total energy consumption cost of thermal-electric hybrid energy system in many time periods. The cost is function of the energy output P and influenced by the cost coefficient c. The cost coefficient c often shows the market price of an energy and a price signal of the system operator to stimulate the terminal optimal energy consumption.

\[
f(P) = \sum_{t=1}^{n_t} \sum_{a \in e} f_{t,a}(P_{t,a}) = \sum_{t=1}^{n_t} \sum_{a \in e} C_{t,a} P_{t,a}
\]  

(1)

The multi-period optimization of thermal-electric hybrid energy system needs an important resource, namely, the energy storage device. Therefore, it is necessary to consider the state of each energy storage device in each time period during optimization, namely, the energy stored in energy storage device at each time period. So the multi-period optimization of thermal-electric hybrid energy system needs to meet following constraints:

(1) Energy balance constraint

\[
L_t - C_t P_t + S_t E_t = 0
\]

(2)

(2) Upper and lower limit of each input energy
3. Capacity constraint of each energy carrier

\[
p_{\min, t}^c \leq P_t^c \leq P_{\max, t}^c \quad \forall c \in [1, \ldots, C_o]
\]

(4) The technical constraint of each energy storage device includes energy-stored capacity constraint and energy-stored power constraint.

\[
E_{\min, w} \leq E_{s, w} \leq E_{\max, w}, \quad P_{\min, w} \leq P_{s, w} \leq P_{\max, w}
\]

(5) The charging power constraint considers the energy storage state and energy storage efficiency of previous time period to prevent the charging energy exceeding the energy storage capacity.

\[
P_{w, t} = (E_{w, t} - E_{w, t-1} + E_{w, t, loss}) / e_{w, a}
\]

(6) Observe the energy balance constraint of each energy storage device within the time period T.

\[
E_{w, n_r} = E_{w, 0}
\]

Where, EWO needs to meet the capacity constraint of energy storage device.

\[
E_{\min, w} \leq E_{0, w} \leq E_{\max, w}
\]

It should be noted that if the thermal-electric hybrid energy system includes no energy storage device, then the third item in the Formula (1) shows zero and the optimization problem is the optimization for a time period. The more the optimization periods and installed energy storage devices are, the more complicated the optimization problem is.

3. Basic Model of Thermal-Electric Hybrid Energy System

This document selects a typical thermal-electric hybrid energy system in the northern area for example analysis. In the example, the management mode of electricity price and natural gas price in the base case is as follows:

1. The feed-in tariff exceeding the self-generated and self-consumed electricity is directly proportional to the energy quantity and is distinguished as per day and night formation.
2. The natural gas use expense is composed of three parts, fixed expense (Yuan/year), expense based on peak hours (Yuan/year/ (m^3/day)), and expense based on natural gas consumption (Yuan/m^3).
3. The electricity use expense is composed of three parts, fixed expense (Yuan/year), expense based on peak hours (Yuan/KWP/month), and expense based on electric energy consumption (Yuan/MWH (three electricity prices within 24h, namely, peak price, valley price and transition price). In addition to the base case, the cases A, B and C are established to observe the influence of electricity price policy on terminal energy consumption. In the price cases A, B and C, the electricity price difference between day and night is increasing, which can be adjusted by the price difference system K.

\[
C_{F1,s} = k C_{F1} \quad \forall s \in \{A, B, C\}
\]

\[
C_{F2,s} = k C_{F2} \quad \forall s \in \{A, B, C\}
\]

\[
C_{F3,s} = k C_{F3} \quad \forall s \in \{A, B, C\}
\]

In all cases, in order to strengthen the day/night control of natural gas, the natural gas price will be increased by 0.04 Yuan/m^3 of peak rate, of which the peak factor shows the ratio between the natural gas peak flow rate and the average flow rate.

\[
M = 0.04 \times \left( \frac{\text{max(m)} \text{c}}{\text{average(m) c}} - 1 \right)
\]
Under four different cases, the power consumption price of the system is as shown in Table 1 and other parameters are as shown in Table 2.

**Table 1. Parameters of different price cases**

| Situation | K | F1 7:00-8:00, 19:00-23:00 | F2 8:00-19:00 | F3 0:00-7:00, 24:00 |
|-----------|---|------------------------|--------------|------------------|
| Basic     | 1 | 152                    | 126          | 90               |
| A         | 1.33 | 202                  | 126          | 16.89            |
| B         | 1.66 | 252                  | 20.25        | 0                |
| C         | 2   | 304                  | 0            | 0                |

**Table 2. Parameters of other models**

| Parameter | Residential users | Data |
|-----------|-------------------|------|
| transfer efficiency/% | 98 |      |
| electrical efficiency of combined heat and power generation/% | 35 |      |
| heat efficiency of combined heat and power generation/% | 45 |      |
| furnace efficiency/% | 90 |      |
| charge efficiency of thermal storage/% | 70 |      |
| discharge efficiency of thermal storage/% | 90 |      |
| electrical storage loss/p.u. | 0 |      |
| heat storage loss/p.u. | 0.3 |      |
| power input limit/p.u. | ±4 |      |
| gas input limit/p.u. | 0/4 |      |
| power input of combined heat and power generation | 3.5 |      |
| gas input of combined heat and power generation | 4 |      |

The electricity price sold from thermal-electric hybrid energy system to power grid is assumed as follows: 9,000 Yuan/MWh from 8 am to 8 pm; in other time periods, the electricity price is 450 Yuan/MWh in “base case”. The natural gas consumption cost is assumed as 18,500 Yuan/day and 3.58 Yuan/m3; the electric energy consumption cost is 121,800 Yuan/day and the electricity price is as shown in Table 1. For each electricity price case, four situations shall be considered:

1. Include no energy storage device;
2. Include energy storage device;
3. Include thermal storage device;
4. Include energy and thermal storage devices at the same time.

The cost is calculated as per “Yuan/day”, the total cost shows the sum of energy storage investment and operating cost, and the service life is 10 years. The daily maximum energy storage capacity and output electricity are expressed in per-unit value (p. u.). The pay-back period (PBP) of energy storage device is dependent upon the investment cost and reduced expenditure of co-generation units.

It should be noted that there is no obvious benefit value at the base electricity price if there is energy storage only but a best thermal-electric hybrid energy system solution can be obtained when there are energy and thermal storage devices at the same time.

The benefit generated from the day-night price difference can be verified by observing the energy consumption of thermal-electric hybrid energy system. By comparing the optimal energy input, storage and power generation of thermal-electric hybrid energy system within 24 under the price case B and base price case, it is found that under the former case the co-generation (and natural gas input therefore) is very similar with the power load curve; under the incentive price (case B), the thermal-
electric hybrid energy system can utilize the energy and thermal storage device in a better way. In peak hours, its energy can appropriately adjust the natural gas input and co-generation into a more unified system. In addition, the energy exchange realized by the thermal-electric hybrid energy system reduces the operating cost of energy consumer and plays the load shifting role in the external power grid so as to realize the all-win of multiple subjects.

4. Conclusion
This document takes the typical thermal-electric hybrid energy system as an object to build the demand-side management optimization control economic model which aims at minimizing the operational body cost of terminal energy system. On this basis, the key influence factors are modeled in details. Finally, we use examples to verify the model effectiveness and observe the influence on optimization control results from key influence factors. The results are helpful to further tap the power demand-side resources in our country, improve their application field and reliability, and coordinate the system reliability, cost, energy efficiency and so on. However, this document takes insufficient account of the economical efficiency, energy conservation and emission reduction of thermal-electric hybrid energy system. In future, we will further study the optimization control of more complicated thermal-electric hybrid energy system.

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