Optimization of integrated energy system for combined cooling, heating and power supply of new energy based on energy storage

Tieyan Zhang1*, Junbao Yang1, Yaru Wang2,3, Min Li4, Dawei Zhang5 and Yuri Wang6

1Shenyang Ligong University
2Shenyang Institute of Engineering
3Key Laboratory of Regional Multi-energy System Integration and Control of Liaoning Province
4GD Hefeng Wind Power Development Co., Ltd.
5Liaoning Shengfang Electric Power Technology Co., Ltd.
6Benxi High-tech Industrial Development Zone Power Supply Branch, State Grid Liaoning Electric Power Co., Ltd.

*Corresponding author’s e-mail: zhangty@sylu.edu.cn

Abstract. With the development of science and technology, people also pay more and more attention to the development of new energy. Although there are also many studies on integrated energy systems now, integrated energy systems containing energy storage should also be further studied. This paper proposes an optimization of integrated energy system for combined cooling, heating and power supply of new energy based on energy storage, which analyzes the gas turbine, absorption refrigerating machine, electric refrigerator, photovoltaic power generation units, wind turbine and the work characteristics of the energy storage device. In this paper, an integrated energy system optimization model of new energy cogeneration with energy storage equipment is established. An example shows that the integrated energy system with energy storage can effectively solve the independent decoupling operation relationship among cool, heat and electricity. At the same time, the proposed model can also solve the energy interaction among cool, heat and electricity. In this way, the optimal operation of the integrated energy system can be realized.

1. Introduction

Nowadays, the social demand for energy is increasing, but the existing traditional energy is increasingly exhausted, so the development and utilization of new energy are also urgent. In the development and utilization, we should also pay attention to environmental problems[1]. At present, the research on integrated energy system mainly includes three aspects: system modeling, planning and operation optimization[2]. In paper[3], Integrated energy systems are connected with the heat network and then optimized, but the randomness of renewable energy is not taken into account. Therefore, the description of energy storage components in this paper is not detailed, which is far from the actual operation results. In paper[4], this article optimizes multiple regional integrated energy
systems through the thermal network. This article does not fully consider the energy storage equipment, which has a certain distance from the actual operation results.

This paper proposes an optimization of integrated energy system for combined cooling, heating and power supply of new energy based on energy storage, which analyzes the gas turbine, absorption refrigerating machine, electric refrigerator, photovoltaic power generation units, wind turbine and the work characteristics of the energy storage device[5]. In this paper, an integrated energy system optimization model of new energy cogeneration with energy storage equipment is established. An example shows that the integrated energy system with energy storage can effectively solve the independent decoupling operation relationship among cool, heat and electricity. At the same time, the proposed model can also solve the energy interaction among cool, heat and electricity. In this way, the optimal operation of the integrated energy system can be realized[6].

2. Structure of Integrated energy system

Integrated energy system refers to the energy system that is highly coordinated in the development, transformation, reserve, transportation and use of different forms of energy, and jointly meet the terminal energy needs[7]. In this paper, an optimization of integrated energy system for combined cooling, heating and power supply of new energy based on energy storage is proposed, and its structure is shown in figure 1.

![Figure 1. Integrated energy system structure diagram for combined cooling, heating and power supply of new energy based on energy storage.](image)

3. Objective function and units model of integrated energy system

3.1. Objective Function

Under the conditions of load balance of cool, heat and power and related constraints, and on the premise of absorbing new energy, the energy scheduling and transformation among cool, heat and power should be coordinated, and the operating cost of the integrated energy system of cool, heat and power should be the lowest as the objective function[8]. The objective function of the optimization model can be expressed as:

\[
\min M = \sum_{i=1}^{T} [M_i(t) + M_G(t) + M_m(t)]
\]

\[
M_{GT}(t) = M_{GT,G}(t) V_{GT}(t)
\]

\[
M_m(t) = L_{GT,m} P_{GT}(t) + L_{AC,m} P_{AC}(t) + L_{EC,m} P_{EC}(t) + L_{WHB,m} P_{WHB}(t) + L_{ES,m} P_{ES}(t) + L_{CS,m} P_{CS}(t) + L_{HS,m} P_{HS}(t)
\]

\[
M_G(t) = M_{P}(t) P_G(t)
\]
where $M_m(t)$ is the maintenance cost in time period; $M_r(t)$ is the system raw material cost in time period; $M_G(t)$ is the cost of purchasing electricity from the grid in time period; $L_{GT,m}$, $L_{AC,m}$, $L_{EC,m}$, $L_{WHB,m}$, $L_{ES,m}$, $L_{CS,m}$ and $L_{HS,m}$ represent the maintenance cost coefficient of gas turbine, absorption chiller, electric refrigerator, waste heat boiler, electric storage equipment, cool storage equipment and heat storage equipment respectively; $P_{GT}(t)$, $P_{AC}(t)$, $P_{EC}(t)$, $P_{ES}(t)$, $P_{ES}(t)$, $P_{CS}(t)$ and $P_{HS}(t)$ represent its output power at time period; $G_{GT}(t)$ is the unit price of natural gas; $M_G(t)$ represents the consumption of natural gas in time period; $M_p(t)$ is the electricity purchase price in time period.

3.2. Wind turbine model
The relationship between fan output power and wind speed can be expressed by equation (5):

$$\begin{align*}
P_{\text{out}} &= \begin{cases} 
0 & s < s_1 \text{ or } s > s_2 \\
\frac{P_r}{s_1 - s_2} (s - s_1) & s_1 \leq s \leq s_2 \\
P_r & s \leq s_2
\end{cases} 
\end{align*}$$

where $P_{\text{out}}$ represents the power output of the wind power; $P_r$ represents the rated power that the fan can reach; $s$ represents the actual speed of the fan, its unit is $m/s$; $s_1$ is the speed of entering the fan; $s_2$ is cut out wind speed; $s_r$ is rated wind speed.

3.3. Photovoltaic generator set model
The output power of the photovoltaic system is affected by solar radiation intensity, environmental temperature, wind speed and other factors, and can be generally adjusted within the range of output power under standard test conditions[9]. The output power can be expressed by equation (6) and equation (7):

$$P_{PV} = \partial_{PV} P_S \frac{R}{R_S} [1 + m(T_b - T_z)]$$

$$T_0 = T_z + 0.0138(1 + 0.0138 T_z) (1 - 0.042 W_{\text{w}}) R$$

where $P_{PV}$ represents the power output of the photoelectric unit; $P_S$ represents the maximum power that the photoelectric unit can output under standard test conditions; $\partial_{PV}$ represents the generation factor of photounits. Generally, we take this factor to 0.9; $R$ indicates the actual irradiation intensity of the sun, and its unit is $W/m^2$; $R_S$, $T_b$ and $T_z$ indicate the irradiation intensity of the sun, the temperature of the environment, and the actual temperature around the surrounding environment under the standard test conditions; $T_b$ represents the temperature of the photoelectric unit surface; $m$ represents the temperature factor on the surface of the photoelectric, its unit is $^oC$; $W_{\text{w}}$ indicates the wind speed on the surface of the photoelectric, and its unit is $m/s$.

3.4. Gas turbine model
The heat and electricity production of a gas turbine is related to its equipment efficiency and gas intake, and their relationship is shown in equation (8) and equation (9):

$$P_{GT,h}(t) = \beta F_{GT}(t) \cdot G_C$$

$$P_{GT,p}(t) = \beta F_{GT}(t) \cdot G_C$$
where $P_{GT,A}(t)$ and $P_{GT,e}(t)$ are the thermal power and electrical power of the gas turbine; $\beta_1$ and $\beta_2$ are the thermal conversion coefficient and electric conversion coefficient of gas turbine; $G_C$ indicates the combustion heat value of natural gas; $F_{GT}(t)$ represents the volume of gas consumed by the gas turbine.

3.5. Electric storage element model

Assuming that the discharge efficiency of the storage device is equal to the charging efficiency, then:

$$S_e(t + 1) = S_e(t)(1 - \phi_{ES}) - \frac{\phi_{ES} P_{ES} \cdot 1}{V_{ES}}$$

(10)

$$S_{e,\min} \leq S(t + 1) \leq S_{e,\max}$$

(11)

where $S_e(t + 1)$ and $S_e(t)$ are respectively the state of charge of the storage device at time points $t + 1$ and $t$; $S_{e,\min}$ and $S_{e,\max}$ represent the minimum and maximum of the storage capacity; $\phi_{ES}$ is self-discharge rate and $\phi_{ES}$ charge-discharge efficiency.

3.6. Solution method

In this paper, the integrated energy system model for combined cooling, heating and power supply of new energy based on energy storage is a mixed integer nonlinear programming problem, which is transformed into a mixed integer linear programming model by genetic algorithm[10].

4. Case Analysis

This article takes a certain building as an example. Below figure are the output of the integrated energy system without the energy storage elements and the integrated energy system containing the energy storage elements.

According to figure 2 and figure 3, when the cool and heat demand are large, the heat discharge of the heat storage equipment greatly reduces the peak heat of the waste heat boiler. Due to the existence of power storage equipment, the trough power can be fully utilized, increasing the trough power purchased from the power grid. Discharging at peak power consumption increases the selling power to the power grid at peak, and effectively moves the peak to fill the valley of the power grid.
Figure 4. Comparison of operating costs of integrated energy without and with storage.

From figure 4, we can clearly see that the comprehensive energy system containing energy storage elements has good economic benefits and can effectively reduce the systematic operating cost.

5. Conclusion
This paper analyzes the working characteristics of gas turbine, absorption chiller, electric refrigeration, photovoltaic generator set, wind turbine generator unit and energy storage equipment. The optimization model for integrated energy systems proposed here includes energy storage elements and outputs of cold, thermal and electrical. Furthermore, this paper proposes to use genetic algorithms to transform mixed nonlinear mathematical models into mixed linear models, then illustrated by an analytical example. In this paper, an integrated energy system optimization model of new energy cogeneration with energy storage equipment is established. An example shows that the integrated energy system with energy storage can effectively solve the independent decoupling operation relationship among cool, heat and electricity. At the same time, the proposed model can also solve the energy interaction among cool, heat and electricity. In this way, the optimal operation of the integrated energy system can be realized.

Acknowledgments
This work was supported by Key R&D Program of Liaoning Province (2020JH2/10300101, 2018220017), Technology Innovation Talent Fund of Shenyang (RC200252, RC190360) and Key R&D Program of Shenyang (GG200252).

References
[1] Kang C Q, Yao L Z. (2017) Key scientific issues and theoretical research framework for power systems with high pro-portion of renewable energy. J. Automation of Electric Power Systems, 9: 2–11.
[2] Li Z, Wang C F, Liang J, et al. (2018) Expansion Planning Method of Integrated Energy System Considering Uncertainty of Wind Power. J. Power System Technology, 211: 3477–3487.
[3] Liu D C, Ma H R, Wang B, et al. (2018) Operation optimization of regional integrated energy system including cool-heat-electricity co-generation and energy storage. J. Automation of Electric Power Systems, 4: 113–120, 141.
[4] Feng W, Lu H Y, CHRIS M, et al. (2019) Development of distributed energy microgrid system in US. J. Electric Power, 6: 45–51.
[5] Xu H H, Wang X D, Zhu X Y, et al. (2020) Research on the optimal configuration of energy storage in user side integrated energy system. J. Power Demand Side Management, 2: 13–20.

[6] Xue S H, Li N, Zhou X M, et al. (2020) Optimal operation of integrated energy system considering integrated demand response. J. Power Demand Side Management, 5: 7–12.

[7] Xiong W, Liu Y Q, Su W H, et al. (2019) Optimal configuration of multi-energy storage in regional integrated energy system considering multi-energy complementation. J. Electric Power Automation Equipment, 1: 124–132.

[8] Jiang C F, Ai X. (2019) Integrated energy system operation optimization model considering uncertainty of multi energy coupling units. J. Power System Technology, 8: 2843–2852.

[9] Zeng M, Liu Y X, Zhou P C, et al. (2018) Overview and prospect of integrated energy system modeling and benefit evaluation system. J. Power System Technology, 6: 1697–1708.

[10] Huo X X, Wu M, Xu K, et al. (2018) Capacity allocation of micro-grid energy storage system considering uncertainty. J. Renewable Energy, 4: 544–549.