ANALYSIS ON OVERALL ENERGY EFFICIENCY AND FLEXIBILITY OF THERMAL INTEGRATED ENERGY SYSTEM

by

Hui WANG*, Xiu JI, Xu LIAO, Hong ZHANG, and Yinping AN

National Local Joint Engineering Research Center for Smart Distribution Grid Measurement and Control with Safety Operation Technology, Changchun Institute of Technology, Jilin, China

Original scientific paper
https://doi.org/10.2298/TSCI2302975W

In order to solve the problem of energy consumption, improve the efficiency of energy utilization and develop new energy, the total energy consumption and fluctuation of thermal integrated energy were analyzed. Four suggestions are put forward for the integrated power system of flexible thermal power plant, namely, electric heat storage system, electric heat pump heat storage system, g, heating system and high pressure heating system via steam turbine, which can improve the air energy consumption capacity of the system and reduce the total coal consumption of the system. Among them, in the case of small air conditioning units or small air conditioning units do not use electric heating furnace and electric heat pump furnace. Heat storage technology of thermal power unit is not suitable for daily exhaust. In contrast, the high pressure/IP bypass heating process of steam turbine is more flexible and less restrictive, which is the best method for comparison. Compared with other schemes discussed by the author, this scheme has the highest flexibility and the least restrictions, and is the best one among the four.

Key words*: thermal synthesis, energy system, energy efficiency, flexibility*

Introduction

With the progress of society, a series of environmental pollution and ecological deterioration problems caused by unreasonable energy utilization have become increasingly prominent, restricting the development of the national economy [1, 2]. Therefore, reducing the dependence of human society on fossil energy, vigorously developing new energy, breaking through the traditional energy system, and improving the efficiency of new energy utilization have become the key measures to alleviate the contradiction between the total growth of energy demand and the shortage of energy resources, energy utilization and environmental protection [3]. However, in modern social life and production, in view of various forms of energy consumption with different characteristics and qualities, such as cold, hot and electricity, generally, the energy supply mode of separate production, separate transmission and separate use is adopted to meet various energy demands of users. In the mode of independent design and separate operation of multi-power system, there are lack of co-ordination among the system, low power conversion rate and high utilization rate. At the same time, with the continuous development of wind power installation capacity in the system, wind access power capacity has become a bottleneck restricting the development of new technologies, and new types are urgently needed, *g*. A thermal power plant combined with an electric power supply system as the basis provides

* Corresponding author, e-mail: wanghui841013@163.com

integrated planning and operation for the use of clean energy in traditional and diverse energy systems. First, the planning, construction and optimal operation of a community energy system will be achieved through the use of electricity, water, heat, energy storage and other fully organic materials. Secondly, enhance the flexibility, safety, economic and self-healing ability of different energy sources to achieve the overall optimization of energy and co-ordination of related systems, and finally, establishing a unified thermal power flow system with power supply as the core, realizing the coordination and execution of the various power and thermal power systems, and realizing the integration of power flow and data flow [4].

However, in the traditional combined dispatching of heat and power, the power and heat loads are balanced at all times, which limits the peak shaving capacity of the system, leading to a high incidence of wind abandonment, for the thermal system itself, both the network side and the demand side have great storage potential, the detailed modelling of thermal inertia on the network side and load side of the thermal system makes the electric and thermal energy systems more flexible and co-ordinated, this is essential to improve energy efficiency, promote the use of renewable energy sources and reduce the pressure of energy conflicts and environmental issues [5].

The power generated by these three plants is sent to power users through the grid to meet their electrical load. In a heating system, there are two types of heat sources: hot furnaces and combined power plants, which provide heat to users in different areas. In fig. 1, P_{wp}, P_{tpp}, and P_{chp} are, respectively wind farm, thermal power plant and thermal power plant, while Q_{chp} and Q_{ccb} are thermal power plant and thermal power plant [6].

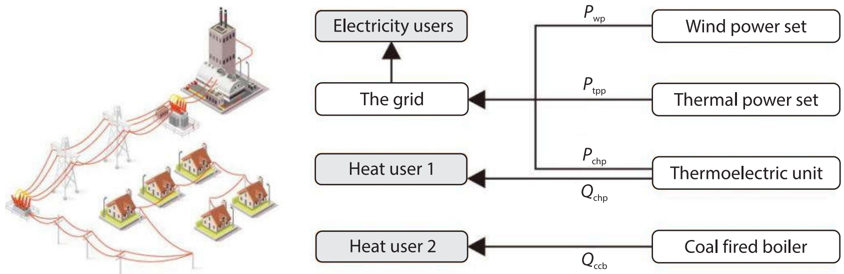


Figure 1. Schematic diagram of the infrastructure of the electric thermal integrated energy system

In the context of the coming era of ubiquitous power IoT, theoretical research on cogeneration system will lay an important foundation for further integration of clean energy in the future. Electric energy and thermal energy are two important energy demands in daily life. With the deepening of the coupling degree between electric and thermal energy networks and the maturity of the inter conversion technology of electric and thermal integrated energy systems, the interactive impact between electric and thermal integrated energy systems is increasingly prominent, at the same time, complementary technologies between electric and thermal integrated energy systems directly provide opportunities for improving energy utilization efficiency, renewable energy penetration, system regulation flexibility and rational energy use [7].

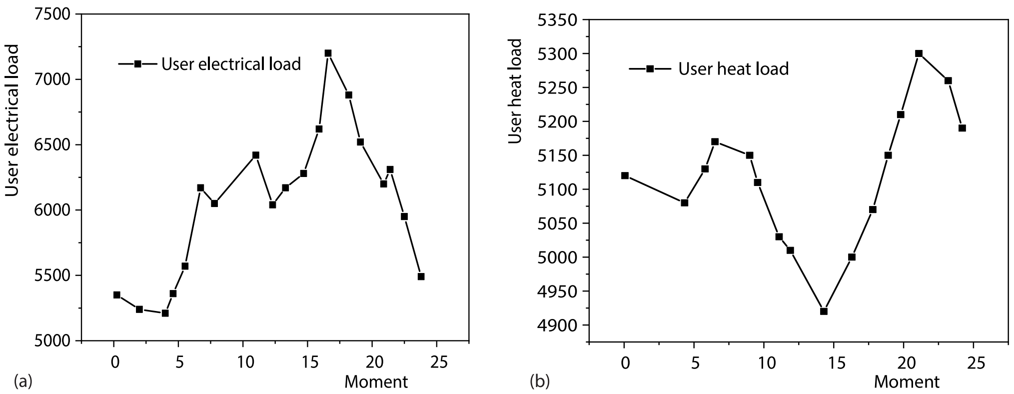
Analysis of electric thermal integrated energy system and flexibility transformation

Flexibility transformation scheme model of electric thermal integrated energy system

In view of the difficulty in consuming renewable energy in the cogeneration system, the author proposes a variety of flexibility transformation schemes. The author will discuss four typical schemes: electric heating and heat storage scheme, electric heating pump heating scheme, thermal power unit heat storage scheme, and steam extraction and heat supply scheme for high/medium pressure bypass of steam turbine [8].

Coal consumption of raw power thermal integrated energy system

Figures 2(a)-2(c) show the change curves of user power load, heat load and maximum wind power generation capacity on typical days in the calculation example adopted by the author.



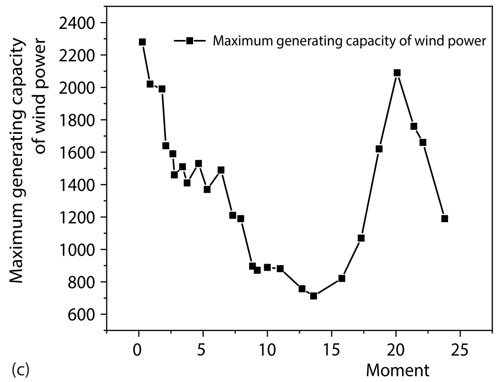


Figure 2. Daily variation curve of; (a) user electric load, (b) user heat load, and (c) maximum generation capacity of wind power (basic data) user's power/heat load and maximum wind power generation capacity

The maximum total capacity of thermal power plant is 3000 MW, the minimum total capacity is 1500 MW, and the upper limit of the height is 5 MW per minute. The total maximum output power of the power plant is 6000 MW, the minimum output power is 3000 MW, and the upper limit of the surge is 10 MW pe minute, and the upper limit of the surge is 10 MW per minute. The upper limit of the altitude is 10 MW pe minute. The heat release rate of the heat load accounts for 60% of the heat load, and the heat load accounts for 40% of the rest of the heat load.

The basic calculation results are shown in fig. 3. Figure 3 shows the total daily energy consumption of the system by changing the ratio of the heating energy to the heat load without changing the heating and heating power. The abscissa *wind power generation range* is the maximum wind power generation set in the calculation. It can be seen from the diagram that with the increase of wind power supply, the total energy consumption of the system decreased, but the cost decreased. In the case of less energy, increasing the equilibrium heat output of the blast furnace gas will help reduce the total coal consumption of the system. At the same time, the application of cogeneration technology has improved the local power consumption of the unit, thus improving the overall performance of the system. However, when there are many wind power plants, increasing the equivalent thermal power of thermal load of thermal power plants will increase the total coal consumption of the system [9]. At the same time, cogeneration system restricts the wind power consumption of the system and impedes the development of the whole energy consumption of the system. Therefore, although the cogeneration technology improves the energy-saving efficiency of the unit, in the context of larger power system reform, although the technology can improve the overall performance of the system depending on the power and demand of the system.

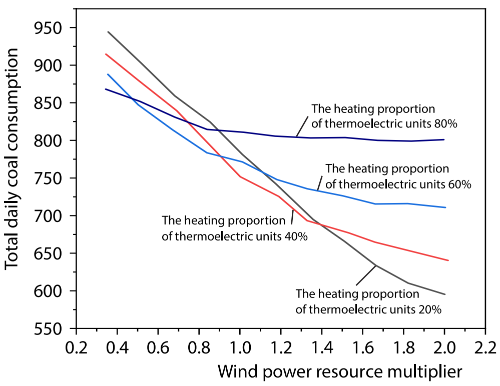


Figure 3. Calculation results before flexibility modification

Analysis on coal consumption of electric thermal integrated energy system after transformation

Electric heating and heat storage

Electric heating, heat storage and heating make up 5% of household heating, thermal energy sources account for 55% of heat, and furnace temperature accounts for 40%. Calculation results of electric heat storage process are shown in fig. 4. Under different maximum power generation capacities of wind power, the total daily coal consumption and air rejection rate of the system with and without electric heating and heat storage scheme are compared.

It can be seen from fig. 4 that in this example, when the wind power consumption capacity exceeds 0.9, the heat pump system is used to reduce the total coal consumption of the system. When the wind power consumption ratio is less than 0.9%, the total energy consumption of the system will be increased by using the thermal power storage technique. This is because when the air supply is low, the air is provided for a short period of time and the air volume is very low per day, the heater only uses waste air to generate electricity to heat and store heat, which is not enough to meet the heat requirements of the users. Meanwhile, thermal power or thermoelectric power must be

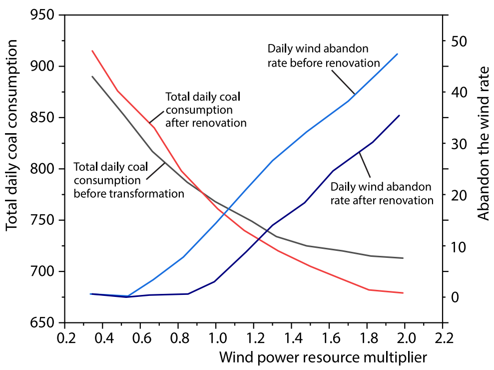


Figure 4. Calculation results of electric heating and thermal storage scheme

used for heating, which will lead to the increase of the total coal consumption of the system. Therefore, the flexibility of unit is limited when electric heating and heat storage technique is adopted, and it is difficult to play a role when the wind power installation scale is small or the waste air volume is small.

Heating by electric pump

The thermoelectric unit heating accounts for 55%, and the coal-fired boiler heating accounts for 40%. The calculation results are shown in fig. 5. Under different wind power resource ratios, the total daily coal consumption and air rejection rate of the system with and without electric heat pump heating scheme are compared.

It can be seen from fig. 5 that in this example, when the wind power consumption capacity is more than 0.7, the electric heat pump heat pump is adopted to reduce the total coal consumption of the system. However, when the wind power consumption ratio is less than 0.7, the total energy consumption of the system will be increased by using electric heat pump heating system. This is because the heating capacity of the thermal power plant needs to meet the user's thermal load at all times, and the increased thermal power is the most feasible. When the waste air volume is large, the heat exchanger can increase the energy consumption of the air. In this calculation example, as the cost of the thermoelectric unit supplying 1 W heat is 0.19 W less electricity, but the cost of the electric heat pump supplying 1 W heat is 0.33 W electricity consumption, the application of electric heat pump heating scheme is not as economical as using thermoelectric units to supply heat.

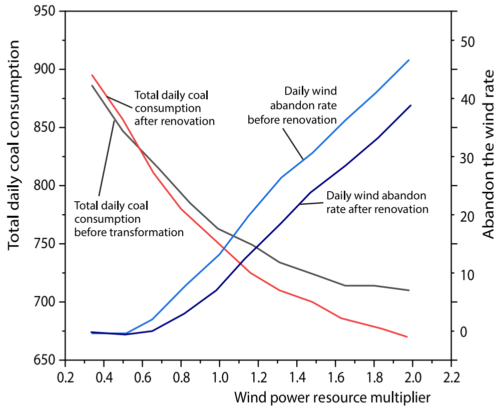


Figure 5. Calculation results of electric heat pump heating scheme

Thermal power unit heat storage

The heat supply of thermal power units accounts for 60% of the household heat load, and coal-fired boilers account for 40%. The calculation results of thermal storage scheme of thermal power unit are shown in fig. 6. Under the conditions of different maximum power generation capacities of wind power, the total daily coal consumption and air rejection rate of the system with and without thermal power unit thermal storage scheme are compared.

It can be seen from fig. 6 that in this example, when the heating energy consumption ratio is less than 1.8. However, when the heating energy ratio is more than 1.8, the effect of thermal power unit heat storage process will be gradually decreased. This is because the use of electric heating steam heaters to maximize the energy consumption of air is based on the observed amount of air discharged at some point, while no air is discharged at any given time. If

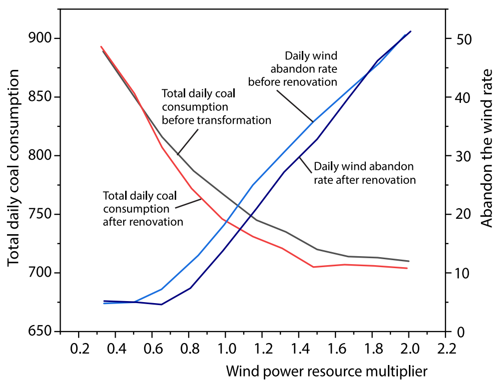


Figure 6. Calculation results of thermal storage scheme of thermal power unit

there are too many wind power sources or heats left over by day, and the grid is in the state of most runaway air, the heat exchanger storage system is difficult to play a role [10].

The high pressure/IP bypass steam extraction heating of turbine

The high/medium pressure bypass steam extraction of steam turbine is used for heat supply, and the maximum regulating capacity is set as 200 MW, the heat supply of thermal power units takes up 60% of the household heat load, and that of coal-fired boilers takes up 40%. As shown in fig. 7. Under different maximum power generation capacities of wind power, the total daily coal consumption and air rejection rate of the system when the high pressure/IP bypass steam extraction heating scheme of steam turbine is applied and not applied are compared.

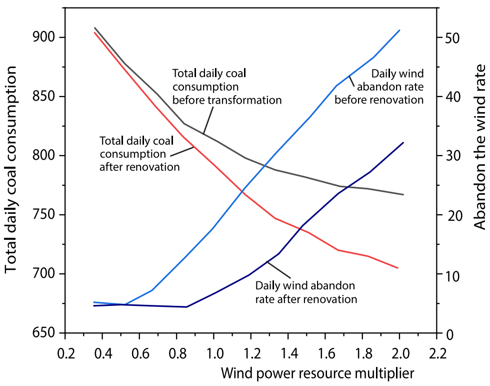


Figure 7. Calculation results of steam extraction and heating scheme for high pressure/IP bypass of turbine

Whether the energy consumption ratio is high or low, the adoption of steam extraction heating technique for high and middle pressure cross-section of turbine can increase energy consumption and reduce the total daily energy consumption of the system. When the system does not discard air, the unit can operate in the original mode. In general, compared with other schemes discussed by the author, this scheme has the highest flexibility and the least restrictions, and is the best scheme among the four [11, 12].

Conclusion

The combined power and thermal power of wind turbine, thermal power plant and thermal power plant are studied in this paper. The influence of combined heat and power generation technology on the overall performance of the system is analyzed based on the total energy consumption of some electric and thermal units. The characteristics of four transient modes of heat storage system, electric heat pump system and cogeneration system are discussed. The principle and applicability of thermal power unit heat storage and steam turbine high pressure/IP bypass heat extraction are analyzed to provide reference for further research. At present, the high proportion of cogeneration units limits the overall performance of the system under the *heat-determined power* mode. The high pressure/IP bypass heat extraction process of steam turbine has few application restrictions and can improve the control ability of thermal power equipment. It is an ideal transformer.

Acknowledgment

Jilin Province Science and Technology Development Plan Project (20210203101SF).

References

[1] Zhou, W., *et al.*, Developing a Generic System Dynamics Model for Building Stock Transformation Wards Energy Efficiency and Low-Carbon Development, *Cambridge Working Papers in Economics*, *13* (2020), 1, pp. 36-43

[2] Huang, C., *et al.*, Economic Model Predictive Control for Multi-Energy System Considering Hydrogen-Thermal-Electric Dynamics and Waste Heat Recovery of MW-Level Alkaline Electrolyzer, *Energy Conversion and Management*, *256* (2022), 1, pp. 63-69

[3] Dubey, S. K., *et al.*, Charging and Discharging Analysis of Thermal Energy Using Magnesium Nickel Hydride Based Thermochemical Energy Storage System, *Sustainable Energy Technologies and Assessments*, *515* (2022), 1, 52

[4] Ameli, H., *et al.*, Investing in Flexibility in an Integrated Planning of Natural Gas and Power Systems, *Energy Systems Integration*, *132* (2020), 1, 64

[5] Zhou, K., *et al.*, Integrated Energy Services Based on Integrated Demand Response, *Springer Books*, *421* (2022), 1, pp. 78-84

[6] Mm, A., *et al.*, Identifying Efficiency and Flexibility Measures for Energy-Oriented Factory Management, *Procedia CIRP*, *105* (2022), 1, pp. 302-307

[7] Fini, M. A. *et al.*, Efficiency Improvement of Hybrid PV-Teg System Based on an Energy, Exergy, Energy-Economic and Environmental Analysis, Experimental, Mathematical and Numerical Approaches, *Energy Conversion and Management*, *265* (2022), 1, pp. 61-66

[8] Huang, C., Energy Efficiency Analysis and Financial Assessment of Building Integrated Alternative Energy Source, *Advances in Computational Sciences and Technology*, *133* (2020), 2, pp. 100-104

[9] Wang, C., *et al.*, Analysis of Economy, Energy Efficiency, Environment: A Case Study of the CHP System with Both Civil and Industrial Heat Users, *Case Studies in Thermal Engineering*, *30* (2022), 1, 636

[10] Haifeng, W. U., *et al.*, Integration of a Thermochemical Energy System Driven by Solar Energy and Biomass for Natural Gas and Power Production, *Science China Technological Sciences*, *65* (2022), 6, pp. 1383-1395

[11] Weber, R. E., *et al.*, Solar Exoskeletons – An Integrated Building System Combining Solar Gain Control with Structural Efficiency, *Solar Energy*, *240* (2022), 1, pp. 201-206

[12] Aghaei, A., *et al.*, Comparison of the Effect of Using Helical Strips and Fines on the Efficiency and Thermal-Hydraulic Performance of Parabolic Solar Collectors, *Sustainable Energy Technologies and Assessments*, *115* (2022), 1, 422

Paper submitted: June 7, 2022
Paper revised: August 8, 2022
Paper accepted: August 19, 2022