Urban integrated energy demand forecasting method considering multi-station fusion

Haoyu Wu1, *, Jiaxin Ma1, Chunyan Zhang2, Hua Zhou2, Shimin Bian2 and Ming Zeng1

1 School of North China Electric Power University, Beijing, China
2 State Grid Shanghai Municipal Electric Power Company, Shanghai, China

*Corresponding author e-mail: 120192206005@ncepu.edu.cn

Abstract. Under the background of energy reform, China's energy-related industries actively innovate from the top to the bottom, vigorously promote the "Internet + Energy" strategy, and promote multi-station integration to deeply integrate energy, information communication and other pillar industries of the national economy to help China's industrial upgrading and economic development. This paper proposes a method for forecasting urban comprehensive energy supply and demand that considers multi-station integration. Through the prediction and analysis of energy supply and demand under various scenarios of multi-station fusion, the comprehensive energy design scheme under different types of multi-station fusion scenarios is clarified to assist the early development of market developers and provide decision support for the promotion and application of comprehensive energy technology facing multi-station fusion.

1. Introduction

With the expansion of power grid scale, the development of clean energy access and parallel ac-DC operation, China's power system is characterized by diversified operation modes, rapid change of power flow and complex operation control. As the core node of energy transmission and operation control, substation is the key link of power system energy conversion and distribution, information acquisition and transmission processing, and the supporting node of power grid operation monitoring and management. At this stage, domestic substations have gradually developed from conventional substations to digitization and intelligence.

This paper proposes an urban comprehensive energy supply and demand forecasting method considering the multi-stations integration. Based on the multi-energy synergy and coupling characteristics of the urban energy Internet, the typical heterogeneous energy synergy methods such as electric heating and electricity are considered to predict the urban multi-energy load. The correction has realized the forecast of the development trend of multi-energy load under the background of multi-station integration. Finally, a certain city in Fujian Province was selected as the object, and the applicability of the algorithm proposed in the analysis and verification report was analyzed.
2. Comprehensive energy supply and demand prediction model for typical scenarios considering multi-station integration

2.1. Benefit boundary in typical scenarios of integrated energy
Considering that the primary goal of users investing in building and operating energy interconnection coupling equipment is to optimize energy use methods and reduce energy costs, the report sets user energy economy as the benefit boundary in energy interconnection scenarios. Energy economy mainly includes annual investment costs and annual operating costs.

\[
\min C_{\text{total}} = C_{\text{inv}} + C_{\text{op}} + C_{\text{ele}} + C_{\text{heat}} + C_{\text{gas}}
\]  

In the formula, \( C_{\text{total}} \) is the total annual cost, yuan; \( C_{\text{inv}} \) is the annual investment cost, yuan; \( C_{\text{op}} \) is the annual operation and maintenance cost, yuan; \( C_{\text{ele}}, C_{\text{heat}} \) and \( C_{\text{gas}} \) are the annual power purchase, heat purchase and gas purchase cost respectively, yuan.

In formula (1), the investment cost \( C_{\text{inv}} \) is shown as follows:

\[
C_{\text{inv}} = \sum_{i=1}^{n} c_i \cdot p_i \cdot k_i
\]

where \( c_i \) is the operating capacity of type i equipment, \( p_i \) is the unit capacity cost of type i device, \( k_i \) is the iso annual factor of type i device, \( \alpha \) is the discounting factor of the device, \( m \) is the life of the device, \( n \) is the total number of equipment in operation.

In formula (2), the annual operation and maintenance cost \( C_{\text{op}} \) is shown as follows:

\[
C_{\text{op}} = \sum_{i=1}^{n} d_i \cdot \lambda_i \cdot p_i^0
\]

where \( d_i \) is the annual equivalent running time of type i device, \( \lambda_i \) is the operating cost per unit of type i device, \( p_i^0 \) designs capacity for type i devices.

2.2. Comprehensive energy typical scenario model construction

2.2.1. Equipment characteristic model. (1) EB operating characteristics. Under the energy Internet scenario, users can rely on EB equipment to meet their own thermal consumption demands by using electric energy:

\[
0 \leq P_{\text{EB}} \leq P_{\text{EB}}^R
\]

\[
P_{\text{EB}} = \eta_{\text{EB}} P_{\text{ele,EB}}
\]

\[
Q_{H,EB} = P_{\text{EB}} \cdot t
\]

In formula (4), \( P_{\text{EB}} \) is the heating power of electric boiler, \( P_{\text{EB}}^R \) is rated design power for electric boiler, \( \eta_{\text{EB}} \) is the thermal efficiency of electric boiler, \( P_{\text{ele,EB}} \) is the electric boiler heat consumption electric power, \( Q_{H,EB} \) is an electric boiler which can meet the heat load, \( t \) is for working hours.

(2) HP operating characteristics. Under the energy Internet scenario, users can rely on HB equipment to meet their own thermal consumption demands by using electric energy:

\[
0 \leq P_{\text{HP}} \leq P_{\text{HP}}^R
\]

\[
P_{\text{HP}} = \eta_{\text{HP}} P_{\text{ele,HP}}
\]

\[
Q_{H,HP} = P_{\text{HP}} \cdot t
\]

In formula (5), \( P_{\text{HP}} \) is the heating power of electric heat pump, \( P_{\text{HP}}^R \) is rated design power for electric heat pump, \( \eta_{\text{HP}} \) is the thermal efficiency of electric heat pump, \( P_{\text{ele,HP}} \) is the electric heat pump heat consumption electric power, \( Q_{H,HP} \) is an electric heat pump which can meet the heat load, \( t \) is for working hours.
In formula (5), $P_{HP}$ is the heat pump heating power, $P_{HP}^0$ is a heat pump rated design power, $\text{cop}$ is the energy efficiency coefficient of heat pump, $P_{de, HP}$ is a heat pump that produces heat and consumes heat power, $Q_{H, HP}$ is a heat pump that can meet the thermal load.

(3) P2G operating characteristics. In the energy Internet scenario, users can rely on P2G equipment to meet their gas consumption demands by using electric energy:

\[
\begin{align*}
0 & \leq P_{P2G} \leq P_{P2G}^0 \\
P_{P2G} &= P_{de,P2G} \\
Q_L &= \frac{P_{P2G}}{\rho} \\
\end{align*}
\]  

In formula (6), $P_{P2G}$ is P2G heating power, $P_{P2G}^0$ is designed for P2G rating, $P_{de,P2G}$ is P2G heating consuming electrical power, $\phi$ is P2G energy conversion coefficient. $\rho$ is the low calorific value of gas, $Q_L$ is the gas load that can be satisfied.

(4) GT operating characteristics.

\[
\begin{align*}
P_{GT, min} & \leq P_{GT} \leq P_{GT}^0 \\
P_{GT} &= \eta_{GT} \cdot V_{gas} \cdot \rho \\
Q_{GT} &= P_{GT} \cdot t \\
Q_{H, GT} &= \rho_{GT} \cdot t \\
\end{align*}
\]  

In formula (7), $P_{GT, min}$ is the minimum heating power for GT, $P_{GT}$ is the heating power for GT, $P_{GT}^0$ is designed for GT rating, $\eta_{GT}$ is the thermal efficiency for GT, $V_{gas}$ is the volume of gas consumed by GT, $Q_{E, GT}$ is the electrical load that GT can satisfy, $Q_{H, GT}$ is the heat load that GT can satisfy, $\rho_{GT}$ is the thermal load of GT.

(5) GB operating characteristics.

\[
\begin{align*}
P_{GB, min} & \leq P_{GB} \leq P_{GB}^0 \\
P_{GB} &= \eta_{GB} \cdot V_{gas} \cdot \rho \\
Q_{H, GB} &= P_{GB} \cdot t \\
\end{align*}
\]  

In formula (8), $P_{GB, min}$ is the minimum heating power in GB, $P_{GB}$ is GB of heating power, $P_{GB}^0$ is designed for a GB rating, $\eta_{GB}$ is the thermal efficiency for GT, $Q_{H, GB}$ is the heat load that GT can satisfy.

2.2.2. Energy balance constrains. Under the energy Internet, users' construction and operation of energy interconnection and coupling equipment change the form of energy access, but it will not change the overall multi-energy load demand, so there should be the following energy balance constraint:

\[
\begin{align*}
Q_E &= Q_{E,GT} + Q_{E, bus} \\
Q_H &= Q_{H,GT} + Q_{H, GB} + Q_{H, bus} \\
Q_G &= \alpha Q_{P2G} + Q_{G, bus} \\
\end{align*}
\]  

In formula (9), $Q_E$, $Q_H$, $Q_G$ are pluripotent load predictions that take into account city maturity. That is to predict the city's medium - and long-term demand for electricity, heat and gas. To sum up, the medium and long-term multi-energy load of cities under the urban energy internet is as follows:

\[
\begin{align*}
Q_{E, bus} &= Q_{E, bus} + P_E \cdot t_E + P_{PB} \cdot t_{PB} + P_{P2G} \cdot P_{P2G} \\
Q_{H, bus} &= Q_{H, bus} \\
Q_{G, bus} &= Q_{G, bus} \\
\end{align*}
\]  

In formula (10), $Q_{E, bus}$, $Q_{H, bus}$, $Q_{G, bus}$ are pluripotent load predictions that take into account city maturity. That is to predict the city's medium - and long-term demand for electricity, heat and gas. To sum up, the medium and long-term multi-energy load of cities under the urban energy internet is as follows:
In formula (10), \( Q_{E,Bus} \), \( Q_{H,Bus} \), \( Q_{G,Bus} \) are multi-energy load prediction results considering typical energy interconnection scenarios, namely, urban medium and long term electricity, heat and gas loads.

3. Case empirical analysis

The report selected City X in Fujian Province as the analysis object and carried out prediction research on the multi-energy loads during the 14th five-year Plan period.

3.1. Calculate the basic parameters and scenario setting

(1) Parameter setting of energy interconnection equipment

The relevant parameters and information of the current energy interconnection equipment are collected in the report, as shown in Table 1

| Device Type | The cost of investment yuan/kW | Operational costs yuan/kWh | Fixed number of the life/year | Value of characteristic parameter |
|-------------|-------------------------------|----------------------------|-------------------------------|----------------------------------|
| EB          | 400                           | 0.010                      | 20                            | 0.95                             |
| HP          | 3000                          | 0.010                      | 20                            | 3.00                             |
| P2G         | 8000                          | 0.010                      | 20                            | 0.70                             |
| GT          | 5500                          | 0.068                      | 30                            | 0.40                             |
| GB          | 80                            | 0.002                      | 20                            | 0.80                             |

3.2. Consider the supply and demand prediction of typical integrated energy scene in City X with multi-station fusion

The influences of different operation and operation capacity levels of the heat pump on the multi-energy of City X and the thermal economy of users are shown in Figure 1 and Figure 2 below:

![Figure 1. The impact of HP's operating capacity on City X load in 2020.](image)

As can be seen from Figure 1, relatively more central heating heat pump has good economic benefits. In the early stage, with the increase of the heat pump operating capacity, the users' heat will be transferred from central heating to heat pump production, which will lead to the gradual increase of the electric load on the urban electric bus and the gradual decrease of the thermal load on the thermal bus tube. In the later stage, as the alternative heat load reaches the upper limit of \( 1.26 \times 10^5 \)kJ, the increase of the installed capacity of the heat pump will not cause changes in the electrical load and thermal load.
Figure 2. The influence of HP's operating capacity on the thermal economy of City X in 2020.

As can be seen from Figure 2, with the increase of the installed capacity of the heat pump, the unit heat cost of the user will gradually decrease to 69.9 yuan /GJ of central heating. When the installed capacity is 27MW, the unit heat cost will decrease to 67.15 yuan /GJ. When the alternative heat load reaches the upper limit, the fixed cost will rise with the increase of the installed capacity of the heat pump, thus the unit heat cost will rise. When the installed capacity is 36MW, the unit heat cost will rise to 67.48 yuan /GJ.

Based on the prediction results of electricity and heat load during the 14th five-year Plan period of X, the influence of different heat pump installation capacities on medium and long-term electric heat load is analyzed, as shown in Figure 3:

Figure 3. The influence of HP operating capacity on the electric heating load in City X during the 14th five-year Plan period

4. Conclusion

Compared with the form of separate supply of electricity, heat, and gas, at this stage, we can focus on the development and construction of heat pump energy stations to develop electricity and heat interconnection and electric energy substitution. From the perspective of energy interconnection, taking into account the actual situation in Fujian Province, the interconnection of electric and heating energy should be developed around industrial users, mainly through the construction of heat pumps to produce hot water or steam to replace concentrated heat loads. It can be seen that the development of electric and heating interconnection for distributed coal-fired boilers can generate greater power substitution benefits. Finally, power grid companies can guide the government to introduce clean heating policies or
implement policies such as electricity price subsidies for electric heating users, and guide distributed coal-fired boiler heating users to gradually remove coal-fired boilers, so as to achieve social environmental protection benefits, the scope of electric power substitution, and the improvement of the company's economic efficiency.

Acknowledgments
The Project Supported by the Science and Technology Project of STATE GRID Corporation of China (SGSH0000HLJS2000197 Research and Demonstration Application of Key Technologies of Energy Management in Integrated Energy System for Multi-station Fusion).

References
[1] Zheng Mingzheng, SHENG Wenyue. Application and Practice of "Multi-station fusion" in the Ubiquitous Power Internet of Things [J]. Automation Applications, 2020 (09): 73-75.
[2] Bai Zhonghua, Li Qiang, Chen Jing, Yuan Fusheng. Energy storage power station in the station integration scenarios more running strategy optimization [J]. China power: 1-11.
[3] Cui Hengzhi, Yang Bin, Tang Yiming, Li Yefei, Chen Guolin. Architecture and scheme design of a comprehensive energy hub in the context of multi-station fusion [J]. Power supply, 2020, 37(08): 16-20.
[4] Meng Chao, LIU Wenliang, Yang Qi, ZHAO Yingru, GUO Yiyan. Research on operation Optimization of edge Data Center under the background of "Multi-station Fusion" [J]. Engineering science and technology, 2020, 52(04): 49-55.
[5] Yang Peng, GU Ying, Zhou Xu. Research on application Scenario and Construction Operation Mode of Multi-station fusion Business [J]. Data Communication, 2020(03): 1-3+6.
[6] Wang Baichao, Chen Yankui, Liu Yuzhen, Wang Hao, Xu Likai, Li Guozhu, Zhan Jinguo. Research on DC Power Supply System based on multi-station Fusion [J]. Digital Communication World, 2020 (02): 75-76.
[7] Lu Chengyu, Key technologies and applications of multi-station collaborative operation based on multi-source information fusion. Power Science Research Institute of State Grid Zhejiang Electric Power Co., LTD., 2019-12-06, Zhejiang Province, China.
[8] Xu Wenbo, Cheng Huafu, Bai Zhonghua, Miao Changhai, Sun Fengchang. Optimal design and operation of energy storage power station in multi-station fusion mode [J]. Power supply, 2019, 36(11): 84-91.
[9] Sun Xiaoyan, Li Jiazhao. A small sample day-ahead power load prediction for integrated energy System based on feature Transfer Learning [J]. Control theory and application: 1-9.
[10] Zhang Tieyan, Sun Tianhe. Meter and seasonal factors and trend of integrated energy system load forecasting [J]. Journal of shenyang university of technology: 1-7.
[11] Zhu Chenguang, Tian Yuan, Guan Shaofeng, Sun Yanling. Technology of Supply and demand prediction and Optimal Operation of regional Integrated Energy System [J]. China High And New Technology, 2020(13): 109-110.
[12] Jiang Xin. Research on supply and Demand Prediction of Regional Integrated Energy System [D]. Xi 'an University of Science and Technology,2020.
[13] Li Ran, Sun Fan, Ding Xing, Han Yi, Liu Yingpei, Yan Jinguo. A user-level integrated energy system ultra-short term load prediction method considering multienergy space-time coupling [J]. Grid technology: 1-14 [2020-10-31].
[14] Chen Juncai, Zhu Lin, ZHONG Fanyuan, Wen Wei, Zhou Fengqi. Architecture of multi-energy complementary distributed energy system and design of integrated energy system [J]. Electronic design engineering, 2020, 28(09): 176-178+183.
[15] Zhang Jiaohua, Huang Yunfeng, Xu Peifeng. Research on operation Optimization of regional Integrated Energy System including Wind Power [J]. Henan Science and Technology, 2019(35): 148-150.