Research on Intelligent Energy System and Power Metering Optimization Based on Multi-objective Optimization Decision Algorithm

Kang Liyan*, Shang Ying and Zhang Muxin

State Grid Liaoning Electric Power Co., Ltd. Marketing Service Center, Shenyang, 110000, Liaoning, China
E-mail: forecon2@163.com
Corresponding Author

Received 26 May 2024; Accepted 13 July 2024

Abstract

In this paper, the intricate problem of optimizing power metering within an intelligent energy system, utilizing a multi-objective optimization decision-making algorithm, is thoroughly explored. Given the current energy landscape, achieving efficient energy utilization and environmental sustainability has become a focal point of research. As a pivotal aspect of future energy management, the precision and optimization of power metering in intelligent energy systems directly influence the effectiveness and cost of energy consumption. To begin, this paper delves into the fundamental principles and application backdrop of intelligent energy systems, highlighting the significance of power metering in such systems. Subsequently, addressing the multi-objective optimization challenges in power metering, a novel optimization method based on a multi-objective optimization decision algorithm is introduced. This algorithm achieves comprehensive optimization of power metering, encompassing multiple objectives such as power cost reduction,

Distributed Generation & Alternative Energy Journal, Vol. 39_4, 807–830.
doi: 10.13052/dgaej2156-3306.3946

enhanced energy efficiency, and environmental protection. The experimental results underscore the remarkable performance of this algorithm, which not only elevates the precision of power metering but also achieves substantial savings in energy costs and significantly boosts energy efficiency. Furthermore, the algorithm exhibits robust adaptability, making it capable of addressing power metering optimization challenges across diverse scenarios. Finally, this paper discusses the practical application prospects of the optimization algorithm in intelligent energy systems, and points out the direction of future research. The research in this paper provides new ideas and methods for the optimization of power metering in intelligent energy systems, and has important theoretical and practical significance for promoting the intelligence and refinement of energy management.

Keywords: Smart energy systems, multi-objective optimization decision algorithm, power metering optimization, energy efficiency.

1 Introduction

Since the beginning of the 21st century, the rapid development of the industrial economy has promoted the same rapid development of the energy industry, and electricity, as the most important form of energy, is receiving more and more attention and research [1, 2]. At present, the power industry around the world is facing countless challenges, such as the diversity of power generation methods, optimal scheduling of expensive resources, demand-side response, energy storage, and reduction of overall industrial carbon emissions. Under the current framework of conventional power grids, the key problems mentioned above obviously cannot be solved. The existing grid is essentially a one-way network, which can only convert one-third of fuel energy into electricity and cannot reuse waste heat. About 8% of the output power is lost on the transmission line and only 20% of the generation capacity can cope with peak load requirements. In addition, due to the hierarchical topology of resources, the existing power grid is prone to domino effect faults. Smart grid integration technology and methods to realize the intelligent integration of energy structure. It supports stakeholder interaction and optimizes energy trading and consumption [3, 4]. Smart grids possess the capability to predict and mitigate faults, optimize operations, and streamline maintenance. Serving as a complementary enhancement to existing power grids, they elevate performance, enable organic growth, maintain compatibility with legacy systems, and facilitate the adoption of cutting-edge technologies. At the core of their functionality lies the integration of components under intelligent distributed command, while growth and innovation hinge critically on the development of smart microgrids. As the research into smart grids deepens and specific demonstration projects are implemented, the innovative concept of the smart energy grid has gradually garnered widespread attention [5, 6]. The original intention of smart grid research is to better deal with global energy shortage and environmental problems, promote the development of renewable energy and optimize the energy structure of the current society, so smart grid has a great correlation and interaction with heat, gas and hydraulic energy. Although electric energy is the main energy used in the current social development, it cannot exist independently. It must be converted from other energy sources or converted into other energy sources in order to be better used by people [7, 8]. Therefore, the in-depth research and development of smart grids must have From the overall point of view, this requires the establishment of a higher level of intelligent energy grid for unified management. At the same time, the establishment of a complete intelligent energy network will also pave the way for the large-scale access of renewable energy and new energy in China in the future, so that renewable energy and new energy can be used to a greater extent to optimize energy allocation and achieve the goal of "by 2020, the proportion of non-fossil energy in primary energy consumption in China will reach about 15%". All over the world, many countries have carried out research on intelligent energy network. On September 25, 2009, the National Institute of Standards and Technology (NIST) announced the "General Framework and Development Roadmap of Intelligent Network Industry Standards" version 1.0 (draft), which is the outline of the construction of intelligent energy networks in the United States [9]. Soon after, on November 27, 2009, the "China Smart Energy Network Development Model and Implementation Plan Project" was formally initiated. The project successfully underwent internal review on July 15, 2010, and its findings were publicly disclosed both domestically and internationally on August 5, 2010. These groundbreaking research results garnered significant recognition and praise from esteemed organizations like the International Smart Grid Alliance and the Smart Grid Working Committee of the International Electrotechnical Commission, marking China's leadership in setting global standards for smart energy grids. Although countries have established industry standards and development models related to smart energy grids, compared with the research on smart grids, the research on smart energy grids is in the initial stage, and there is currently a lack of specific strategies for dispatching various energy sources. How to fully learn from smart grids the key to promote the research of the entire smart energy grid is to study the rich and detailed research materials in order to study other energy grids such as heat and gas.

2 An Overview of Intelligent Energy Network

2.1 Concept of Intelligent Energy Grid

At present, there is no unified definition of smart energy grid in the world. Wu Jiandong, an energy expert in China, first put forward the concept of intelligent energy network. He and his research group pointed out in the "China Intelligent Energy Network Development Model and Implementation Plan Project" that intelligent energy network is essentially an energy interactive network that includes various types of energy and has functions such as production, supply and sales. Intelligent energy network needs to make comprehensive use of advanced communication, sensing, energy storage, massive data optimization management and intelligent control technologies, and develop from a single intelligent power network framework of smart grid to an intelligent network framework covering power, heat, water power, gas and other energy sources. The goal of the smart energy network is to transform the existing energy circulation system, establish a network architecture for multiple energy production, transmission, and exchange, so as to improve energy utilization efficiency, and promote the evolution of the existing one-way energy system to include multiple types of energy and two-way the operating energy system enables energy consumers in the energy grid to consume energy and sell energy.

In China, "China Intelligent Energy Network Development Model and Implementation Scheme Project" puts forward a more specific and detailed development model and implementation scheme for the development of China's intelligent energy network, mainly including four major systems, eight major fields, ten-element process models and ten aspects of intelligent energy network reform and application [10, 11], among which the priority development of eight major fields and ten-element process models have been strongly affirmed by the International Electrotechnical Commission.

Figure 1 shows flow chart of multi-objective optimization of intelligent energy system. The topic pointed out that in the future, my country will establish a smart energy grid that fully covers the water, electricity and thermal industry, and has a higher level and larger scale than the smart grid. Specific measures will be put on the agenda during the "Twelfth Five-Year Plan" period [12, 13]. Different from the United States, my country's

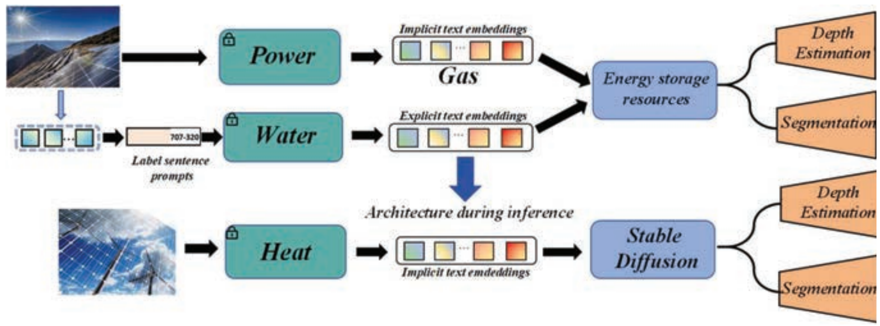

Figure 1 Flow chart of multi-objective optimization of intelligent energy system.

model of establishing a smart energy grid can be attributed to a "commanding heights" model of large-scale system integration. This model needs to bundle electricity, water affairs, heat, gas, and energy storage resources into overall resources, and consider the construction of energy networks from the perspective of overall energy. It is no longer treated differently and integrated according to different types of energy such as electricity, gas, and heat. The energy network design is carried out as a whole from the very beginning, so that redundant construction can be avoided and the compatibility of the energy network is better, which is conducive to development and growth [14].

Currently, the smart energy network demonstration city project in Zhangjiang Park, Pudong, Shanghai, is in full swing. The primary objective of this demonstration project is to establish a comprehensive smart energy network industry chain and supporting industrial bases [15]. By the conclusion of the 12th Five-Year Plan, the park aims to generate an output value of 30 billion yuan. Statistics from relevant departments indicate that upon the completion of China's smart energy network, the entire industrial chain is anticipated to reach a staggering trillion-yuan scale.

To sum up, at present, most of the research on smart energy networks in the world is at the level of macro theoretical research and industry standard establishment. The actual engineering projects are mainly demonstration projects. It can be said that smart energy networks are in the initial stage of development, and many fields still need to be explored.

2.2 Basic Structure of Intelligent Energy Network

Due to the diversity of distributed energy types and the fact that electric energy is not the only interactive energy, smart energy networks cannot be divided into AC micro-grids, DC micro-grids and AC and DC micro-grids according to the different ways in which distributed power sources are connected to micro-grids like micro-grids. Hybrid micro-grids and other types generally need to be analysed in detail for the distributed energy actually connected.

The intelligent energy network in the low-level area of Shanghai central area involves three coupled energy quantum networks: electric network, cold network and thermal network. The heat network includes oil-gas dual-purpose boilers, ground source heat pump system heating part in winter and triple-supply system heating part. The power network includes the mains power connected to the periphery, the power supply part of the triple power supply system and small wind turbines. The energy that the entire intelligent energy network needs to be connected from the periphery is mains electricity, diesel or natural gas consumed by boilers, and natural gas consumed by the triple supply system. These energy sources are converted into cooling and heating power through electric refrigerators, boilers and triple supply systems. Transmitted within the network and supplied to users in the building for use. It is a typical example of the intelligent energy network. Therefore, the research on its optimal scheduling strategy can provide certain reference and suggestions for the research on energy management of the intelligent building subnet of the intelligent energy network in the future.

2.3 Centrifugal Electric Refrigeration Unit

A refrigerator is essentially a device that transfers heat from a cooled object to its surrounding medium, thereby achieving a colder temperature. Depending on their operating principles, refrigerators can be categorized into four main types: compression, absorption, steam jet, and semiconductor. Within the category of compression refrigerators, we have further subdivisions based on structural characteristics, such as piston-type, centrifugal-type, screw-type, and rotary-type. Notably, the intelligent energy grid in the lower level of Shanghai Centre exclusively utilizes centrifugal electric refrigerators [16].

This section delves into the operational mechanism of the centrifugal electric refrigerator and establishes a correlation between its pivotal performance indicator, namely the energy efficiency ratio, and two critical factors: the cooling water inlet temperature (T_c) and power consumption (P_{in}). This foundational understanding provides theoretical grounding for the development of an economic model in subsequent chapters.

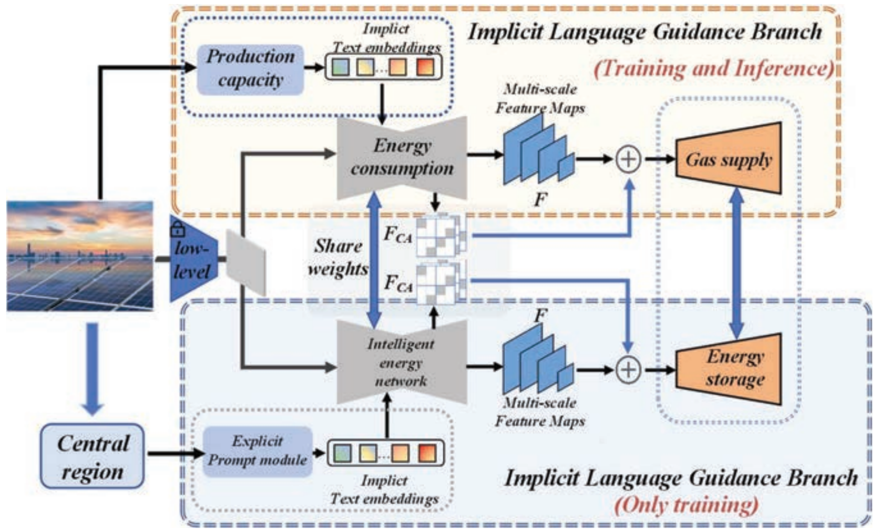

Figure 2 Basic structure of centrifugal electric refrigerator.

2.4 Structure of Centrifugal Electric Refrigerator

Centrifugal electric refrigerators mainly consist of compressor, expansion valve, evaporator, and condenser. Powered by electricity, they evaporate refrigerant (usually water) in the evaporator to absorb heat for cooling. The vaporized refrigerant absorbs energy in the compressor, transforming into high-temp, high-pressure gas. This gas condenses back to liquid in the condenser, then returns to the evaporator via the expansion valve, completing the cycle [17, 18]. The whole system finally produces low-temperature chilled water by consuming electric energy to supply users' needs. Figure 2 below depicts the basic structure of a centrifugal electric refrigerator.

The meanings of the parameters in Figure 2 are shown in Table 1, and all parameters default to positive values.

3 Ice Storage System

As the social economy continues to grow and urban landscapes expand, urban electricity consumption is also increasing at a remarkable rate. This is particularly evident during peak hours, when thousands of households turn on their air conditioners, causing the total load to surpass the grid's capacity, leading to frequent power outages that disrupt the daily lives of

Table 1 The meaning of the parameter

Parameter Name	Meaning
P_{in}	Input electrical energy
Q_c	Condenser exchange energy
Q_e	Energy exchanged by evaporator
T_c	Condenser refrigerant temperature
T_{in}	Condenser cooling water inlet temperature
T_{out}	Condenser cooling water outlet temperature
T_e	Evaporator refrigerant temperature
T_{ein}	Inlet temperature of evaporator chilled water
T_{eout}	Chilled water outlet temperature of evaporator

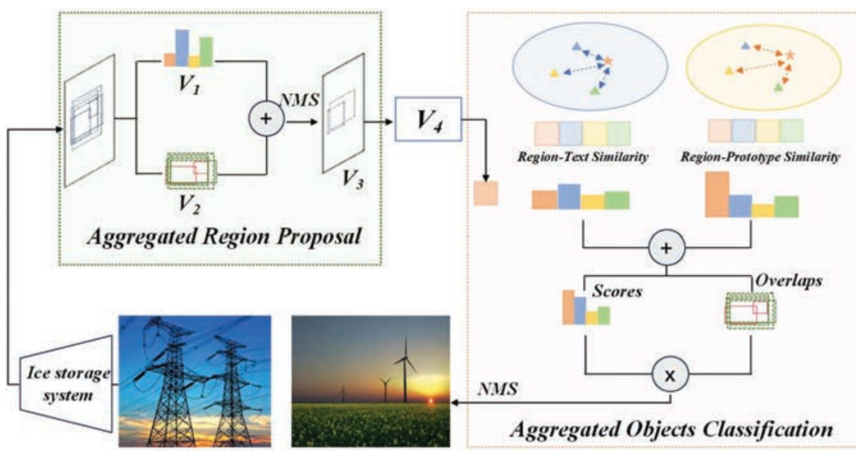

Figure 3 Ice storage system structure.

urban residents. Conversely, during periods of low electricity consumption, the urban load diminishes, resulting in a significant waste of power supply capacity. Such significant fluctuations in power load can lead to grid frequency instability, compromising the grid's stable operation. Given the absence of energy storage devices on the grid side, it becomes necessary to devise an energy management system on the user side to balance power loads and achieve peak shaving and valley filling. This necessity gave birth to the ice cooling system [19]. Figure 3 below shows the basic structure of the ice storage system.

The four valves V_1, V_2, V_3 and V_4 in the figure above can form four different operating conditions of the entire ice storage system through different switch combinations. The chiller creates ice, and it works in tandem with the dual-mode unit and the ice storage tank for cooling purposes. Alternatively, the ice storage tank can function independently to melt ice for cooling, or the dual-mode centrifugal chiller can provide cooling autonomously. It is crucial to note that these operational modes are mutually exclusive; at any given moment, the entire system can operate under a single condition only. For instance, it is not feasible for the dual-mode chiller to produce ice simultaneously while the ice storage tank melts ice. These operations cannot occur concurrently.

3.1 Centrifugal Electric Refrigerator Model

According to the first law of thermodynamics, the formula (1) can be obtained:

$$Q_c = P_{in} + Q_e \tag{1}$$

The above formula reflects the basic energy relationship of the centrifugal refrigerator, that is, a certain high-grade energy is given to the compressor, and the compressor improves the energy grade through an equal moisture process, so that the energy is transferred from the low-temperature body (evaporator) to the high-temperature body (condenser), that is to say, the refrigerator does not directly convert the input electric energy into cooling output, but uses high-grade electric energy to transfer low-grade heat energy from low-temperature objects to high-temperature objects, so the cooling capacity obtained by the refrigeration mechanism can be greatly more than consumed electric energy. Considering the process of constant moisture, there is a formula (2).

$$\frac{Q_c + q_c}{T_c} = \frac{Q_e + q_e}{T_e} \tag{2}$$

In Formula (2), q_c and q_e are the heat loss of condenser and evaporator respectively, which are mainly caused by internal losses such as liquid friction between compressor and expansion valve, throttling loss of expansion valve, deheating of condenser and heat leakage. The most important performance parameter COP of a centrifugal electric refrigerator is defined as (3):

$$COP = \frac{Q_e}{P_{in}} \tag{3}$$

COP measures refrigeration efficiency, typically 2–8 for fridges. Higher COP equals better efficiency and energy savings, with less power for more cooling. The formula (4) can be obtained by synthesizing the above formulas (1), (2) and (3).

$$\frac{1}{COP} = -1 + \frac{T_c}{T_e} + \frac{1}{Q_e}\left(\frac{q_e T_c}{T_e} - q_c\right) \tag{4}$$

For a refrigerator, the operating characteristics of the refrigerator are usually described by the inlet temperature T_c of the condenser cooling water and the outlet temperature Tout of the evaporator chilled water. Therefore, it is necessary to convert the refrigerant temperature Tc of the condenser and the refrigerant temperature Te of the evaporator in the formula (4) to obtain the formula (5).

$$\begin{cases} T_c = T_c^{in} + \dfrac{Q_c}{M_c} \\ T_e = T_e^{out} - \dfrac{Q_e}{M_e} \end{cases} \tag{5}$$

In formula (5), Mc and Me are the heat exchange coefficients of the condenser and evaporator, respectively, and they are substituted to obtain (6).

$$\frac{1}{COP} = -1 + \frac{T_c^{in} + \frac{Q_c}{M_c}}{T_e^{out} - \frac{Q_e}{M_e}} + \frac{1}{Q_e}\left(\frac{q_e\left(T_c^{in} + \frac{Q_c}{M_c}\right)}{T_e^{out} - \frac{Q_e}{M_e}} - q_c\right) \tag{6}$$

As you can see, the formula mentioned earlier is quite intricate. Then according to the experimental data points, the COP can be fitted into the function of the cooling water inlet temperature T_{in} and power consumption P_{in}, as shown in (7).

$$COP = f(T_c^{in}, P_{in}) \tag{7}$$

After obtaining the COP characteristic fitting function of the cooler used, according to the current electricity price policy, the economic model of the electricity cost required by the cooler in the corresponding period of time can be established, and the economic optimal scheduling of the entire network in steady state can be further carried out.

3.2 Ice Storage System Structure

During periods of low power consumption, the ice storage system efficiently utilizes excess power capacity to create and store ice in its designated storage

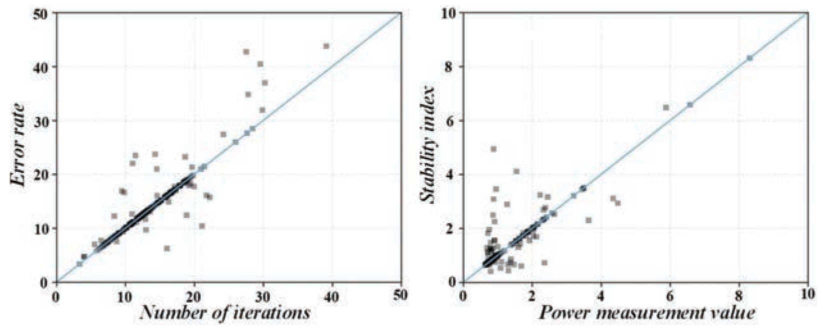

Figure 4 Power metering error distribution map.

device [20]. Then, during peak power consumption hours, the system releases the stored cold capacity by melting the ice, thereby reducing the peak power load on the grid. This innovative approach not only helps balance power demand but also signifies the advancement direction of the current air-conditioning industry, truly embodying the concept of peak shaving and valley filling.

Figure 4 shows power metering error distribution map. Ice storage system includes dual-mode fridge, ice tank, and heat exchanger. Fridge serves as cold source. As its name suggests, it differs from the traditional centrifugal electric refrigerators mentioned earlier. The standard air-conditioning refrigeration mode and the supplementary ice-making refrigeration mode. When operating in the ice-making mode, the chiller efficiently produces chilled water at a reduced temperature, effectively supporting the freezing process for cold storage [21]. Concurrently, the ice storage tank serves as an energy storage device within the ice storage system. The specialized medium within the tank has the ability to solidify, thereby storing cold capacity, or liquefy, releasing cold capacity. This allows for the flexible transition between energy storage and energy release states of the entire system. The plate heat exchanger serves as the conduit for the ice storage system to exchange cold energy with the external chilled water network [22]. It is made of many metal sheets, and the channels for liquid flow are formed between the metal sheets. The chilled water supplied by the ice storage system and the cold water from the external network exchange heat through the metal sheets, and the heat recovery rate can reach more than 90%. Table 2 below shows the correspondence between the operating conditions of the ice storage system and the switching conditions of the four valves.

Table 2 Operating condition of ice storage system

Operating Condition	Open Valve	Regulating Valve	Close Valve
Ice Making of Centrifugal Chiller with Dual Working Conditions	V_2, V_4	/	V_1, V_3
Combined Cooling of Dual Working Condition Unit and Ice Storage Tank	1	V_1, V_2, V_3, V_4	/
Ice storage tank melting ice for separate cooling	/	V_1, V_2, V_3	V_4
Separate cooling of centrifugal chillers with dual working conditions	V_1	V_3, V_4	V_2

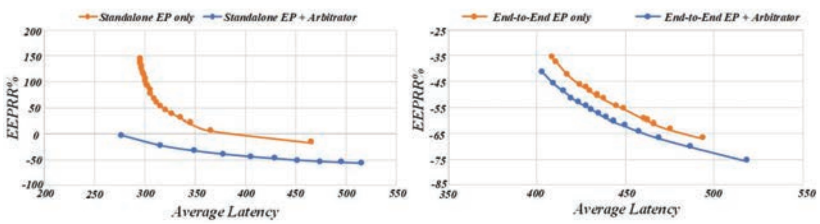

Figure 5 Cost-effectiveness analysis under different optimization strategies.

4 Dynamic Scheduling Strategy of Intelligent Energy Network Based on Distributed Predictive Control

4.1 Overview of Distributed Predictive Control

Different from the traditional control theory, these algorithms take the step response or impulse response of the control object as the model, use the rolling optimization method to calculate the optimal value of each sampling point of the control quantity in a certain time domain and implement the control effect on the system. This control method shows good control effect in the complex industrial process that is difficult to accurately model [23]. Subsequently, in 1978, Richard analyzed the cause, principle and actual control effect of this kind of algorithm in detail, so Model Predictive Control (MPC) was born as a new control theory.

Figure 5 shows cost-effectiveness analysis under different optimization strategies. Compared with the traditional control theory, model predictive control has the following important characteristics: (1) It does not completely rely on the precise mathematical model of the controlled plant, and can adopt traditional transfer functions, state equations, and non-parametric models such as step response or impulse response; (2) Industrial systems under model predictive control have better performance under uncertain disturbances, that

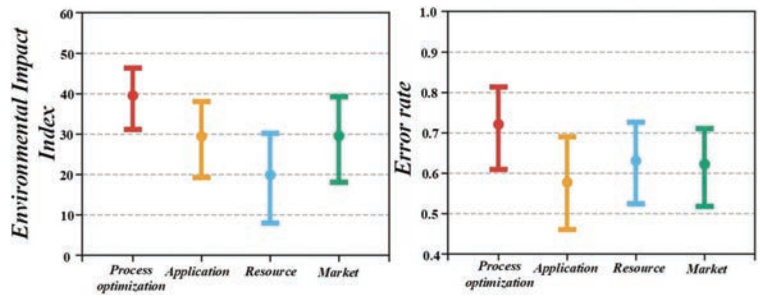

Figure 6 Comparison of the convergence performance of the multi-objective optimization algorithm.

is, excellent robustness; (3) The mathematical form of the model predictive control algorithm is simpler, and it is easier to implement the algorithm for industrial computers.

Figure 6 shows comparison of the convergence performance of the multi-objective optimization algorithm. Although there are many kinds of model predictive control algorithms, the specific ideas can be summed up in three parts: predictive model, rolling optimization and feedback correction [24]. Predictive models form the foundation of predictive control. Model predictive control focuses on the control sequence within a specific control time domain, utilizing these models to calculate the output at each sampling point across a predetermined predictive time domain in the future. At the heart of this process lies rolling optimization, which serves as the crucial component of model predictive control. It takes a certain index of the system as the control requirement [25]. Usually, the minimum sum of the variance of the index of the control object and the expected trajectory deviation in the prediction time domain is used as the goal of the entire optimization problem [26]. In summary, model predictive control is a model-based, rolling implementation combined with feedback correction optimal control algorithm [27].

Figure 7 shows convergence analysis of multi-objective optimization decision algorithms. In practical industrial applications, model predictive control can predict future changes of the plant through the impulse or step response sequence of the controlled plant and can naturally introduce process time delays. For multivariable systems, it can obtain better control effects than conventional control methods [28]. In large-scale systems, traditional model predictive control derives from the form of distributed predictive control (DMPC) [29]. The large system is decomposed into multiple subsystems, and the data between the subsystems communicate with each other.

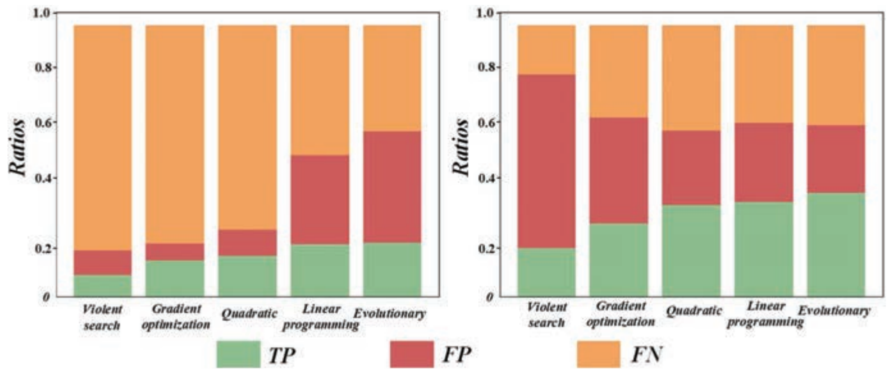

Figure 7 Convergence analysis of multi-objective optimization decision algorithms.

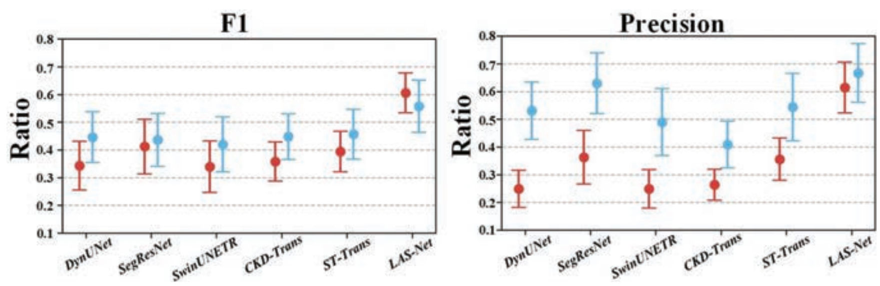

Figure 8 Cost-effectiveness analysis under different optimization algorithms.

Each subsystem uses the data of itself and other subsystems to complete its own MPC problem solving, which significantly reduces the amount of calculation and can Reach the optimal state of the entire system. According to the characteristics of distributed network structure in industrial field, the researchers formulate a distributed predictive control algorithm based on Nash optimization, and discuss the information interaction problem of this network structure.

Figure 8 shows cost-effectiveness analysis under different optimization algorithms. Drawing upon the aforementioned coordination method for coupled systems, this chapter delves into the dynamic optimization of distributed systems that feature coupled objectives yet possess uncoupled subsystems. The objective is to ensure that the entire system operates in an efficient and economical manner, while upholding the prerequisite of satisfying the total predicted cooling load. Figure 9 illustrates the stability assessment of intelligent energy systems.

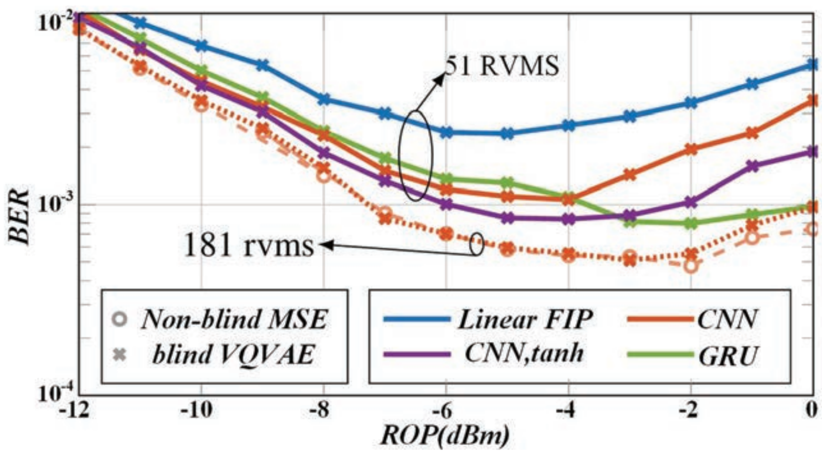

Figure 9 Stability assessment of intelligent energy systems.

4.2 Design of Distributed Predictive Control for Multi-Refrigerator Cooling System

Conventional electric refrigerator and ice storage system combined control strategy is divided into upper and lower layers. The upper layer economic optimization strategy is mainly introduced in chapter three. According to the predicted load data, the power of each electric refrigerator under air-conditioning and ice-making conditions and the cooling power of the ice storage tank are calculated in steady state operation. In order to make the entire system electricity cost the lowest. In the lower-level dynamic performance optimization strategy employing distributed predictive control, we consider the inherent dynamic process involved in the actual start-up of electric refrigerators. As such, each electric refrigerator utilizes model predictive control (MPC) to determine the real-time cooling power setpoint. The expected value for this cooling power is derived from the upper-level strategy, representing the steady-state cooling power setpoint of each refrigerator under specified air-conditioning conditions. In order to overcome the shortcomings of centralized control, such as huge calculation, high time and high cost, this chapter uses DMPC to coordinate the control quantities of each sub-controller, and all MPC data interact in real time, so that each electric refrigerator can track the expected value of cooling and the total cooling power can track the total expected value [30]. The electric refrigerator that is not used or the electric refrigerator in the ice-making working condition directly skips the dynamic control. The dashed line network is the data

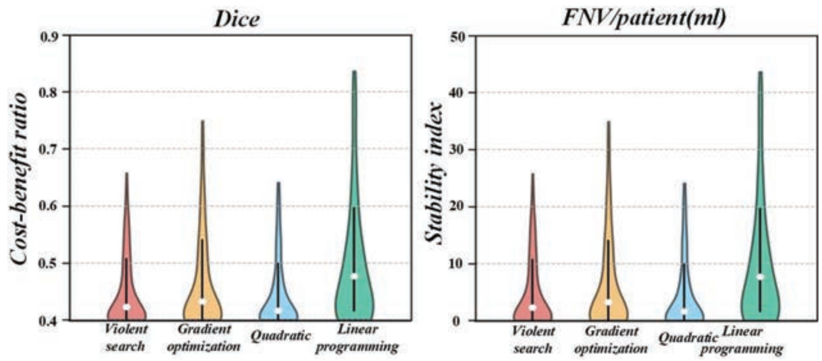

Figure 10 Energy system stability assessment.

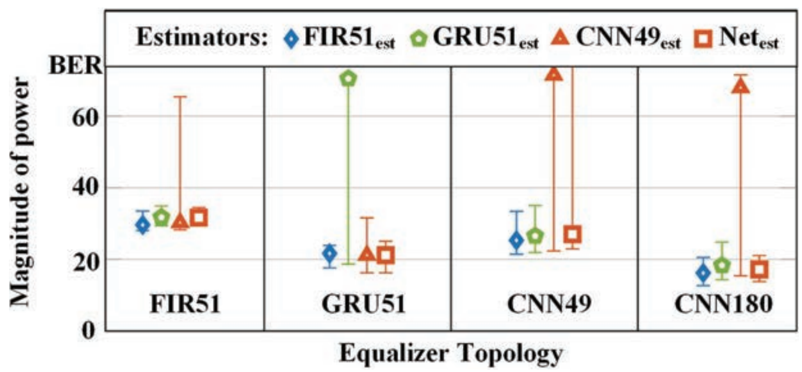

Figure 11 Power measurement optimization before and after the comparison.

transmission channel between the subsystems MPC. Figure 10 shows energy system stability assessment.

4.3 Dynamic Model of Electric Refrigerator

The lower control system is divided into N subsystems according to the number of electric refrigerators under air conditioning conditions. Each subsystem is composed of MPC and corresponding controlled electric refrigerators. The data of different subsystems MPC are exchanged in real time by a communicator to complete the calculation task, so that the cooling power of each electric refrigerator under air conditioning conditions can track the expected value and the total cooling power can track the total expected value.

Figure 11 shows power measurement optimization before and after the comparison. The fridge's refrigeration power approximates a first-order system response. Its step response time is four times its time constant, estimated using startup time. Considering the delay in the actual control system, the transfer function of the process when the refrigeration power of the electric refrigerator reaches the set value is shown as (8).

$$H(s) = \frac{1}{1+\tau s}e^{-\tau_d s} \tag{8}$$

d is the first-order inertia link time constant and *e* is the delay time, then the discrete state space model form of the *s*-th subsystem is shown as (9).

$$\begin{cases} x_s(k+1) = A_s x_s(k) + B_s u_s(k) \\ p_s(k) = C_s x_s(k) \end{cases} \tag{9}$$
$$s = 1, 2, \ldots, N$$

Where $u(k)$ is the set value of the output power of the electric refrigerator at time k, that is, the optimization variable of the following optimization problem, $p(k)$ is the actual output power of the electric refrigerator at time $k+1$, and x is the multiple of the delay time of the electric refrigerator relative to the sampling time of the discrete system. $x(k) = [p,(k)p,(k+1)\ldots p(k+n)]$ is a state variable. A is determined by the sampling time and the time constant of the electric refrigerator. If the sampling time is A, there are (10) and (11) formulas.

$$A_s = \begin{bmatrix} 0 & 1 & \cdots & 0 \\ 0 & 0 & \ddots & \vdots \\ \vdots & \ddots & \ddots & 1 \\ 0 & \cdots & 0 & e^{-\Delta t/\tau} \end{bmatrix} \tag{10}$$

$$\begin{cases} B_s = \begin{bmatrix} 0 & \cdots & 0 & 1-e^{-\Delta t/\tau} \end{bmatrix}^T \\ C_s = \begin{bmatrix} 1 & 0 & \cdots & 0 \end{bmatrix} \end{cases} \tag{11}$$

5 Research Conclusion

This paper first introduces the defects of the current conventional power grid and the advantages of the next generation smart grid, and leads to a higher level of smart energy grid concept including electricity, heat, hydraulic, gas and energy storage by the in-depth research and development and implementation of smart grid. Subsequently, the development model and implementation plan of China's intelligent energy network are elaborated in detail according to the content of the "National 12th Five-Year Plan for China's Intelligent Energy Network Development Model and Implementation Plan Project". Given the intricate and varied energy components of the intelligent energy network, effectively managing and dispatching these various energy sources to ensure the network's overall efficiency represents a pivotal technology. Upon reviewing domestic and international research in the realm of smart energy grids, it becomes evident that, in comparison to the research on smart grids, the study of optimal dispatching in intelligent energy networks is still in its infancy. Furthermore, there is a paucity of research focusing on the optimal dispatching of other energy sources, such as heat and gas. This paper takes the intelligent energy network in the low-rise area of Shanghai Center as a case study, and conducts a detailed study on the optimal dispatching method of the intelligent energy network in the actual high-rise building.

The research in this paper starts from the operating characteristics and control methods of the distributed energy sources at the bottom of the intelligent energy network, and then analyzes the optimal scheduling strategy of the intelligent energy network from the perspectives of steady state and dynamic state. The main work and innovations can be divided into the following three aspects:

(1) The basic working principles and control methods of distributed energy sources in the intelligent energy grid in the lower level of Shanghai central area are analyzed and studied. Conventional electric refrigerators, ice storage systems, fans and combined cooling, heating and power systems are emphatically introduced. The model of power consumption of conventional electric refrigerators with respect to refrigeration power and cooling water inlet temperature is established. The control strategy of grid-side and machine-side converters of wind turbines is expounded. The energy flow and management model of combined cooling, heating and power systems is explained by graphs and formulas.

(2) The steady-state economic dispatch strategy of intelligent energy network is put forward. According to the supply source of electric load, cooling load and heat load of intelligent energy network in the low-level area of Shanghai center and the actual distribution energy allocation situation, the steady-state dispatch is simplified, and the dispatch problem of conventional electric refrigerator and ice storage combined cooling system is mainly studied. Continuous variables are utilized to quantify

the output power of the electric refrigerator, while discrete variables represent the start-stop states of the refrigerator and the ice storage tank. To this end, the concept of the average cooling price of the ice storage tank is introduced, enabling the establishment of an economic model for the joint cooling system. This, in turn, forms a mixed integer mathematical programming problem. The economic value of the strategy is verified by using the branch and bound algorithm in Matlab environment.

References

[1] Kumar, G., Kumar, L., and Kumar, S. (2023). Multi-objective control-based home energy management system with smart energy meter. Electrical Engineering, 105(4), 2095–2105.

[2] Wang, X., Mao, X., and Khodaei, H. (2021). A multi-objective home energy management system based on internet of things and optimization algorithms. Journal of Building Engineering, 33, 101603.

[3] Zhang, D., Zhu, H., Zhang, H., Goh, H. H., Liu, H., and Wu, T. (2021). Multi-objective optimization for smart integrated energy system considering demand responses and dynamic prices. IEEE Transactions on Smart Grid, 13(2), 1100–1112.

[4] Wang, Q., Chen, G., Khishe, M., Ibrahim, B. F., and Rashidi, S. (2023). Multi-objective optimization of IoT-based green building energy system using binary metaheuristic algorithms. Journal of Building Engineering, 68, 106031.

[5] Ullah, K., Hafeez, G., Khan, I., Jan, S., and Javaid, N. (2021). A multi-objective energy optimization in smart grid with high penetration of renewable energy sources. Applied Energy, 299, 117104.

[6] Haseeb, M., Kazmi, S. A. A., Malik, M. M., Ali, S., Bukhari, S. B. A., and Shin, D. R. (2020). Multi objective based framework for energy management of smart micro-grid. IEEE Access, 8, 220302–220319.

[7] Wu, X., Cao, W., Wang, D., and Ding, M. (2019). A Multi-Objective optimization dispatch method for microgrid energy management considering the power loss of converters. Energies, 12(11), 2160.

[8] Ali, S., Ullah, K., Hafeez, G., Khan, I., Albogamy, F. R., and Haider, S. I. (2022). Solving day-ahead scheduling problem with multi-objective energy optimization for demand side management in smart grid. Engineering Science and Technology, an International Journal, 36, 101135.

[9] Ramezani, M., Bahmanyar, D., and Razmjooy, N. (2020). A new optimal energy management strategy based on improved multi-objective

antlion optimization algorithm: applications in smart home. SN Applied Sciences, 2, 1–17.

[10] Prebeg, P., Gasparovic, G., Krajacic, G., and Duic, N. (2016). Long-term energy planning of Croatian power system using multi-objective optimization with focus on renewable energy and integration of electric vehicles. Applied energy, 184, 1493–1507.

[11] Dimitrios P. Panagoulias, Elissaios Sarmas, Vangelis Marinakis, Maria Virvou, George A. Tsihrintzis & Haris Doukas. (2023). Intelligent Decision Support for Energy Management: A Methodology for Tailored Explainability of Artificial Intelligence Analytics. Electronics (21).

[12] Chaouachi, A., Kamel, R. M., Andoulsi, R., and Nagasaka, K. (2012). Multiobjective intelligent energy management for a microgrid. IEEE transactions on Industrial Electronics, 60(4), 1688–1699.

[13] Bahmanyar, D., Razmjooy, N., and Mirjalili, S. (2022). Multi-objective scheduling of IoT-enabled smart homes for energy management based on Arithmetic Optimization Algorithm: A Node-RED and NodeMCU module-based technique. Knowledge-Based Systems, 247, 108762.

[14] Wang Yongzhen, Zhang Lanlan, Song Yi, Han Kai, Zhang Yan, Zhu Yilin and Kang Ligai. (2024). State-of-the-art review on evaluation indicators of integrated intelligent energy from different perspectives. Renewable and Sustainable Energy Reviews (PA).

[15] Wang, J., Yang, W., Du, P., and Li, Y. (2018). Research and application of a hybrid forecasting framework based on multi-objective optimization for electrical power system. Energy, 148, 59–78.

[16] Liu, B., and Rodriguez, D. (2021). Renewable energy systems optimization by a new multi-objective optimization technique: A residential building. Journal of Building Engineering, 35, 102094.

[17] Zaoyi, Z., Dongling, W., Yuming, Z., Manokaran, K. B., and Antony, A. B. (2021). IoT driven framework based efficient green energy management in smart cities using multi-objective distributed dispatching algorithm. Environmental Impact Assessment Review, 88, 106567.

[18] Liu, Y., Ćetenović, D., Li, H., Gryazina, E., and Terzija, V. (2022). An optimized multi-objective reactive power dispatch strategy based on improved genetic algorithm for wind power integrated systems. International Journal of Electrical Power & Energy Systems, 136, 107764.

[19] Zhang, B., Hu, W., Cao, D., Li, T., Zhang, Z., Chen, Z., and Blaabjerg, F. (2021). Soft actor-critic–based multi-objective optimized energy conversion and management strategy for integrated energy systems with renewable energy. Energy Conversion and Management, 243, 114381.

[20] Wang, J., Zhang, L., and Li, Z. (2022). Interval forecasting system for electricity load based on data pre-processing strategy and multi-objective optimization algorithm. Applied Energy, 305, 117911.
[21] Wang, R., Li, G., Ming, M., Wu, G., and Wang, L. (2017). An efficient multi-objective model and algorithm for sizing a stand-alone hybrid renewable energy system. Energy, 141, 2288–2299.
[22] Dilliwar Vikas, Sahu Mridu and Rakesh Nitin. (2024). Cluster computing-based EEG sub-band signal extraction with channel-wise and time-slice-wise data partitioning technique. International Journal of Information Technology (5), 2763–2773.
[23] Mayer, M. J., Szilágyi, A., and Gróf, G. (2020). Environmental and economic multi-objective optimization of a household level hybrid renewable energy system by genetic algorithm. Applied Energy, 269, 115058.
[24] Salinas, S., Li, M., and Li, P. (2012). Multi-objective optimal energy consumption scheduling in smart grids. IEEE Transactions on Smart Grid, 4(1), 341–348.
[25] Alzahrani, A., Hafeez, G., Ali, S., Murawwat, S., Khan, M. I., Rehman, K., and Abed, A. M. (2023). Multi-objective energy optimization with load and distributed energy source scheduling in the smart power grid. Sustainability, 15(13), 9970.
[26] Sepehrzad, R., Moridi, A. R., Hassanzadeh, M. E., and Seifi, A. R. (2021). Intelligent energy management and multi-objective power distribution control in hybrid micro-grids based on the advanced fuzzy-PSO method. ISA transactions, 112, 199–213.
[27] Zhang, J., Cho, H., Mago, P. J., Zhang, H., and Yang, F. (2019). Multi-objective particle swarm optimization (MOPSO) for a distributed energy system integrated with energy storage. Journal of Thermal Science, 28, 1221–1235.
[28] Alzahrani, A., Rahman, M. U., Hafeez, G., Rukh, G., Ali, S., Murawwat, S., … and Abed, A. M. (2023). A strategy for multi-objective energy optimization in smart grid considering renewable energy and batteries energy storage system. IEEE Access, 11, 33872–33886.
[29] Yang, R., and Wang, L. (2012). Multi-objective optimization for decision-making of energy and comfort management in building automation and control. Sustainable Cities and Society, 2(1), 1–7.
[30] Golpîra, H., and Khan, S. A. R. (2019). A multi-objective risk-based robust optimization approach to energy management in smart residential buildings under combined demand and supply uncertainty. Energy, 170, 1113–1129.

Biographies

Kang Liyan was born in Shenyang, Liaoning, China in 1975. She obtained a Master's degree in Engineering from Northeast Electric Power University. She works at the Marketing Service Center of State Grid Liaoning Electric Power Co., Ltd. Her research interests include electricity metering, construction of electricity consumption information collection systems, information security, and big data analysis.

Shang Ying was born in 1988 in Liaoyang, Liaoning, China. She obtained a Master's degree in Engineering from North China Electric Power University. She works at the Marketing Service Center of State Grid Liaoning Electric Power Co., Ltd. Her research interests include electricity metering, electricity inspection and anti theft, and big data application analysis. Encryption and information security.

Zhang Muxin was born in Huludao, Liaoning, China in 1992. He obtained a Bachelor's degree in Computer Science from Northeastern University. He works at the Marketing Service Center of State Grid Liaoning Electric Power Co., Ltd. His research interests include electricity metering, electricity information collecting, and line loss analyzing.