Optimal allocation of distributed energy storage capacity based on smart node terminal technology

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ABSTRACT

In the context of the poor time performance of some distributed energy storage capacity optimisation methods, a distributed energy storage capacity optimisation method based on smart node terminal technology is designed. Quantify the distributed energy demand response characteristics, extract the economic index of the energy system, calculate the natural gas consumption of the internal combustion engine and the recovered waste heat respectively, obtain the storage capacity equipment operation coefficient, set the application scenario selection mode based on the intelligent node terminal technology, improve the load factor of the gas internal combustion engine, and design the storage capacity optimization allocation method. Test result: The average time required for the distributed energy storage capacity optimisation allocation method in the paper is: 72.36s, indicating that the designed distributed energy storage capacity optimisation allocation method is more suitable for application to practical tasks after the introduction of smart node terminal technology.

Keywords: Smart node terminal technology; distributed energy; storage capacity; optimal configuration; user side; demand response.

1. INTRODUCTION

Distributed energy systems are distributed on the customer side, making full use of and consuming local energy in close proximity to the customer, which improves the efficiency of energy use and the safety of the energy supply system. By supplying and using energy close to the customer, transport losses can be avoided, which in turn improves economic efficiency. New energy non-fossil grid connected generation is done through energy routers. The different energy networks, energy storage devices, loads, power supplies, etc. are independent of each other in the grid and their information can be shared within the network, operating either integrated into the grid or offline and self-organised. Depending on the size of the energy supply range, the distribution can be divided into building-type and regional-type. Building-type energy systems are mostly used in buildings with the same type of load demand, while regional-type energy systems are mostly used in large-scale areas such as industrial parks and industrial zones. The energy router is the core of this mode of operation and is usually built from an intelligent energy management system, solid state transformers, etc. The network distributes data such as electricity load conditions, storage capacity levels and distributed power generation to the intelligent energy management system, which then analyses and makes decisions on the data and obtains optimised control instructions to guide energy distribution operations. The storage capacity approach is divided into single storage capacity and multi-functional storage capacity.

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With the technological iteration of energy conversion devices, it is of practical importance to study the economics of multiple storage capacity combinations, considering that the cost of different storage capacity devices will bring greater economic benefits. The key technology for distributed storage capacity is to improve power quality, guarantee load levels, maintain the emergency power supply system in working order and ensure the reliability of the supply. With the continuous development of energy internet technology, how to implement intelligent power management systems, reduce environmental pressure, develop clean energy and achieve energy savings under limited conditions is an urgent issue in the current grid system. For this reason, the optimal configuration of distributed energy storage capacity based on intelligent node terminal technology is proposed. First, the response characteristics of distributed energy demand are quantified. Then, the economic indicators of the energy system are extracted according to the characteristics. Then, the natural gas consumption of the internal combustion engine and the waste heat recovered are calculated respectively. According to the calculation results, the operation coefficient of the energy storage equipment is obtained, and the application scenario selection mode based on intelligent node terminal technology is set, The load coefficient of gas engine is improved, and the distributed energy storage capacity is optimized. The research shows that the average time required by the design method is relatively short, and after the introduction of intelligent node terminal technology, it has a good configuration effect.

2. QUANTIFYING DISTRIBUTED ENERGY DEMAND RESPONSE CHARACTERISTICS

Energy supply optimisation requires achieving a balance between supply and demand, on the one hand providing new energy sources from the supply perspective, improving supply efficiency and reducing energy emissions. On the other hand, it can also adjust the demand side, especially during peak periods of electricity consumption, when meeting energy demand to achieve a balance between supply and demand may put enormous pressure on the larger grid. In essence, wind energy is the energy that comes from the flow of air. At this point, if the demand for energy can be adjusted to shift peak energy use, it will promote system stability and safety. Price-based demand response includes self-elasticity and cross-elasticity. The self-elasticity is the effect of the price of electricity on the electrical load in the current period and the cross-elasticity is the effect of the price of electricity in other periods on the load in the current period:

$$L = \delta + \sum_{\varepsilon=1}^{24} \frac{(\delta \times \eta)^2}{D} \tag{1}$$

$$|R - h| \le \frac{1}{W^2} \times g \tag{2}$$

In equations (1) and (2), δ represents the demand for electricity before the demand response in time period ε, η represents the demand for electricity after the demand response in time period ε, D represents the elasticity of demand coefficient, R represents the amount of change in the price of electricity before and after the demand response in time period g, h represents the price of electricity before the demand response in time period g, and W represents the cross-elasticity. Wind turbines are the core equipment in wind power generation and the largest proportion of investment in wind power, typically accounting for 60 percentage points of the overall investment. Similarly, in an energy trading system, the amount of energy demanded by customers is affected by price fluctuations. Demand response means that by changing prices and creating relevant incentives by grid companies and energy companies, end-users will adjust their own demand for energy. In fact, the cost of wind power is the fastest declining of all power generation technologies, with the cost of wind power shrinking by more than 80% compared to the initial cost. It is easy to see that as science and technology continue to advance, the cost of wind power is bound to continue to fall. If the cost of wind power generation can reach the lowest value, then it will inevitably provide a reference basis for promoting investment in risky projects. The current electricity price demand response mechanism includes time-of-day price, real-time price, peak price, etc. Based on the dispatch optimisation of actual projects, economy is the first consideration. At the same time, with the massive use of renewable energy, energy efficiency and environmental protection are also key indicators to be considered. In terms of spatial structure, internally, each distributed energy system includes a renewable energy conversion unit, a distributed energy supply unit and a storage capacity unit to meet the electricity, heat and cooling load requirements of the users within the system. Due to various constraints, wind power is often abandoned and limited, which results in a waste of wind power energy and contradicts the original intention of developing wind power [1-2]. At the same time, abandonment of wind power brings additional costs in addition to reduced wind power revenues. The economics of an energy system are crucial and are a key indicator of how the energy system will be used in practice. It generally includes investment costs, operating costs, maintenance costs, etc. The economic indicators are as follows:

$$C = e + l - \sum (\gamma \times \phi)^2 \tag{3}$$

In equation (3), e represents the cost of purchased energy, l represents the cost of maintaining the system, γ represents the benefit the system receives from supplying electricity and ϕ represents the benefit the system receives from heating. On the energy demand side, the load side includes the user demand and the storage capacity system. The user demand includes electrical, thermal and cooling loads, and the storage capacity system includes electrical storage units, thermal storage units and cooling storage units, each of which has two operating states. One is the storage capacity state, when the storage capacity unit is considered to be the load demand, consuming energy from the system, and the other is the discharge state, when the storage capacity unit is considered to be the supply energy, supplying energy to the system.

3. GETTING THE STORAGE CAPACITY DEVICE OPERATING FACTOR

The original equipment installation of the energy station contains the CCHP system, soil source heat pump system, gas boiler refueling system, electric refrigeration unit refueling system, water reservoir and its manifold, water collector and all kinds of valves and fittings, circulation pumps and other ancillary facilities, and its sub-system equipment coupled with the original operation mode and load bearing equipment vary according to the heating and cooling seasons. Gas-fired internal combustion engines have advantages over gas turbines in terms of fast start-up, good part-load performance, mature technology, high power generation efficiency and low fuel requirements. In order to be able to achieve a stepwise use of energy, the natural gas consumption of the internal combustion engine and the recovered waste heat are calculated separately, as follows:

$$P = \frac{\sigma}{\varpi_z} \tag{4}$$

$$Q = \frac{\sigma}{\lambda_z} \tag{5}$$

In equations (4) and (5), σ represents the power generated by a Type z gas-fired internal combustion engine, ϖ represents the power generation efficiency of a Type z gas-fired internal combustion engine and λ represents the thermoelectric ratio of a Type z gas-fired internal combustion engine. The upper tier is the integrated energy system operator, which is responsible for the operation and management of the entire electricity-gas coupled integrated energy system and issues time-of-use tariffs, gas prices and electricity self-sufficiency regulation orders to the lower tier energy network operators. The flue gas temperature after the primary heat exchange is 80~90 ℃, which is passed into the heat exchanger for secondary heat exchange with water to provide users with domestic hot water. The lower layer is the optimization operation layer of each micro energy network. Each micro energy network determines its own optimal operation strategy according to the electricity price and natural gas price, taking into account the regulation instruction of the self-sufficiency rate of electric energy issued by the operator of the integrated energy system. The insufficient hot and cold electrical loads are provided by electric chillers, gas-fired hot water boilers and purchased electricity respectively. Power supply strategy, gas-fired internal combustion engine power generation priority to meet the equipment electricity and customer electrical load, insufficient power, from the grid to purchase electricity to supplement [3-4]. On the basis of equations (4) and (5), the load factor for the actual operation of a model internal combustion engine can be expressed as:

$$F = \frac{\sigma}{V_{\max}} \tag{6}$$

Formula (6), $V_{\max}$ indicates the rated power of the gas internal combustion engine. The formula for calculating the thermal power output of a gas-fired boiler is:

$$U = \xi \times d \tag{7}$$

In equation (8), ξ represents the natural gas consumption of the gas boiler and d represents the heat production efficiency of the gas boiler. In addition, the energy grid participates in integrated demand response by regulating the electricity self-sufficiency rate and responding to time-of-use tariffs, by contracting with the integrated energy system operator to respond to its instructions for the adjustment of the electricity self-sufficiency rate for certain periods of time, from which it receives certain compensation incentives. The integrated energy system operator publishes time-of-day tariffs and natural gas prices. Its heating strategy is to provide the heat generated by the engine waste heat driven lithium bromide absorption chiller and the residual heat to the customer heat load, with the shortfall being provided by the gas boiler. The micro-energy network solves the optimal operation strategy based on its optimal operation model and feeds back to the integrated energy system operations the plan for purchasing electric power and natural gas at each moment. The cooling strategy, with the waste heat from the engine driving the lithium bromide absorption chiller, provides the cooling capacity to the customer's cold load, with the shortfall being provided by the electric chiller. A ground source heat pump has been added to the CCHP, using electrical energy and shallow underground geothermal resources for cooling and heating.

4. SETTING UP APPLICATION SCENARIO SELECTION MODELS BASED ON SMART NODE TERMINAL TECHNOLOGY

Intelligent node terminal technology mainly includes two parts, sensor nodes and controller nodes, mainly using sensor nodes to collect environmental parameters, such as humidity, temperature, PM2.5 concentration, etc., and upload the data information to the cloud control server in real time through the Internet of Things. At the same time, it can receive control commands from the cloud control server, and the controller node performs relevant operations such as turning on fans, lights, etc. This intelligent terminal allows the free addition of sensors and electrical equipment, etc., depending on the application, while effectively controlling costs in order to facilitate large-scale diffusion and use. The distributed energy system takes the energy hub as the basic unit, which is an energy conversion unit capable of meeting the needs of multiple types of energy, and can clearly portray the coupling relationship between electricity, heat and cold in a distributed energy system. It is thus clear that the development of wind power is not simply a matter of supplying resources, but also of considering the level of regional development and the construction of the electricity grid. Photovoltaic power depends mainly on photovoltaic cells, and then the process is usually divided into three stages, namely through the solar effect in the final time frame through the conversion between light and electrical energy to achieve the first, photovoltaic cells absorb photons in order to produce photogenerated carriers, i.e. electron holes. Electricity storage devices are generally storage batteries, heat storage devices are generally heat storage tanks, and cold storage devices are generally cold storage tanks [5-7]. The battery device mainly carries out peak-shaving and valley-filling functions, storing electricity when the price of electricity is high and releasing it when the price of electricity is low; the heat storage device mainly stores capacity when the heat load is small and the electrical load is high, and releases energy when the heat load demand is high. The storage and cooling device can effectively reduce the cost of supplying energy and operating power consumption of the electric chiller and improve the comprehensive benefits of the distributed energy system. Secondly, the carriers are forced to separate under the action of the electrostatic field of the PN junction. Thirdly, photogenerated carriers will be attracted to the PV cell electrodes to generate circuit current and form electrical energy. The lower the primary energy use, the greater the energy efficiency, which is generally described by equation (4):

$$S = \frac{\mu' - \mu}{\mu'} \times 100\% \tag{8}$$

In equation (8), μ' represents the energy consumption of the reference system and μ represents the amount of primary energy used in the DES. Photovoltaic power generation systems generally consist of the following main components, one is the alternator, the second is the filter, the third is the photovoltaic cell array, the fourth is the controller and so on. In the entire PV array, it is mainly used as a carrier to produce the photovoltaic effect, and the current exchange is carried out through the converter. In the serial port and network protocol settings, set the baud rate for data transmission to 9600 and the data bits to 8 bits. The module needs to establish communication with the cloud control server, by specifying the server address and port number for data transfer. After completing the above settings and restarting, the module will automatically connect to the local network and establish a connection with the cloud control server for data communication functions. The integrated energy system operator simulates system currents, determines whether there is a node voltage drop over the limit or a node air pressure drop over the limit, etc., and issues instructions to the micro-energy network operator to adjust the electrical energy self-sufficiency rate as required. Each micro-energy network adjusts its electrical energy self-sufficiency rate according to the instructions of the superior electrical energy self-sufficiency rate adjustment. The aggregated load curve of the end load is used to represent the electrical load, mainly considering the transfer of the electrical load, i.e. the electrical demand response of the leveling load, in order to reduce the impact on the user's experience of electricity consumption and to ensure that the total electricity consumption of the user remains unchanged throughout the day, as follows:

$$E = \sqrt{\frac{\kappa}{q}} \times (1-\kappa)^2 \tag{9}$$

In equation (9), κ represents the post-response electrical load demand and q represents the electrical load regulation factor. At the same time, the low-grade energy of shallow geothermal heat can be converted into higher temperature heat through ground source heat pumps, or the load factor of gas-fired internal combustion engines can be increased to use their power generation to achieve the effect of cooling and heating, thus reducing the purchase of electricity. The use of ground source heat pumps can enhance the environmental friendliness, energy efficiency and safety of the combined supply system. In integrated demand response, the end-user's electrical load requirements can be met either by generating electricity from gas turbines or by purchasing electricity from the grid. Electricity loads can be divided into critical loads, such as personal computers, televisions etc., whose use cannot be interrupted or shifted. Responsive loads such as washing machines, irons, dishwashers etc. can be shifted from peak to low hours etc. The electrical energy self-sufficiency rate is constantly adjusted and the operating strategy is updated until the upper integrated demand response requirements are met and the voltage and air pressure no longer exceed the limits. Gas boilers are used as supplementary combustion equipment to convert the chemical energy of gas combustion into the internal energy of high temperature hot water for heating or providing domestic hot water. Electric chillers (chillers) are used as supplementary cooling equipment, mainly centrifugal and screw chillers with better efficiency, consuming electricity purchased from the grid or generated by gas-fired internal combustion engines to provide the cooling load demand on the customer side.

5. DESIGN OF STORAGE CAPACITY OPTIMISATION ALLOCATION METHODS

Applications of storage capacity in transmission and distribution include reactive power support, deferring investment in transmission and distribution equipment and relieving transmission congestion. In terms of reactive power support, the economic advantage of storage capacity is not obvious due to its high cost compared to the original equipment. Compared to the simple expansion and upgrade of traditional power grids, the access to storage capacity systems gives the grid a more flexible option in solving problems such as transmission and distribution blockages. The operation of the electricity network is inseparable from the plan, and the forecast of the electricity load is the basis of the plan. The normal operation of the power grid and the development of the energy internet for energy management requires the analysis and collation of historical electricity consumption data, the use of scientific methods for data mining and the identification of patterns of change in electricity consumption loads. Storage capacity also has the advantage of reducing investment risk and increasing the utilisation of system power assets compared to traditional methods. As the stability of the transmission and distribution network determines the reliability and security of the entire grid, the reliability of storage capacity is required to be demonstrated and needs to be tested in the necessary demonstration projects. When performing power load forecasting, the regularity of the power load can be used over a certain period of time, combined with factors such as holidays, weather, temperature and electricity prices to obtain power load forecasting results. The accuracy of the power load forecasting results directly determines the economic efficiency of the entire power generation system and grid. In the short term, the capacity of the transmission lines is a fixed value, but the load on the system varies over time, with trough and peak loads. With social and economic development, the load will gradually increase and the corresponding peak load will be higher than the capacity of the transmission line, at which point the grid will need to be expanded and modified for the corresponding line, increasing the marginal cost of system operation and increasing the investment of the grid company. In addition, energy storage equipment is required to meet both charging and discharging power constraints, as follows:

$$K = \frac{\left(\left|E^2 - U^2\right|\right)}{2} \times m \times n \tag{10}$$

In equation (10), m indicates the energy storage capacity of the energy storage element and n indicates the discharge power of the energy storage element. The electricity grid in commercial operation for electricity consumption load forecasting is actually energy internet demand-side forecasting, which will directly affect the optimal allocation of energy storage equipment. Electricity load forecasting is the analysis of historical data to obtain electricity load patterns and the use of mathematical models to express them, thus improving the accuracy of the forecasting results and ultimately providing the energy router with a basis for the development of optimal management strategies. When the expansion demand is not large, storage capacity can defer the corresponding line expansion and renovation investment costs [8-10]. For example, the storage capacity system can be connected to the downstream location of the transmission and distribution equipment that needs to be upgraded, replacing the need for significant investment in grid line expansion by matching the smaller investment in storage capacity system equipment. Energy converters are still modelled using a black box model, which considers only the energy efficiency characteristics of the components from an energy efficiency perspective, and whose output and input relationships can be expressed as:

$$G = \frac{1}{\varphi \times y} \tag{11}$$

In equation (11), φ denotes energy conversion efficiency and y denotes transformer efficiency. At this point, the application of storage capacity can improve the efficiency of the use of grid assets, reduce the investment risk associated with investing large amounts of capital and make the use of grid company funds more efficient. Applications for storage capacity on the customer side include time-of-use tariff management, power quality improvement and demand response management. Energy storage devices allow for the temporal transfer of energy, storing surplus energy and releasing it when there is a shortage to balance the load. Alternatively, energy can be stored when energy prices are high and released when energy prices are low, for use in the system to save energy costs. The output power constraint of an energy conversion device can be expressed as a source branch power constraint:

$$M_{\min} \le x \times p \le M_{\max} \tag{12}$$

In equation (12), x represents the source branch output power matrix and p represents the source branch input power matrix. Commonly used energy storage devices include storage batteries, thermal storage devices (e.g. thermal storage tanks, phase change thermal storage devices, etc.) and cooling storage devices (e.g. ice storage, water storage devices, etc.). The specific process of distributed energy storage capacity optimization configuration is shown in Figure 1.

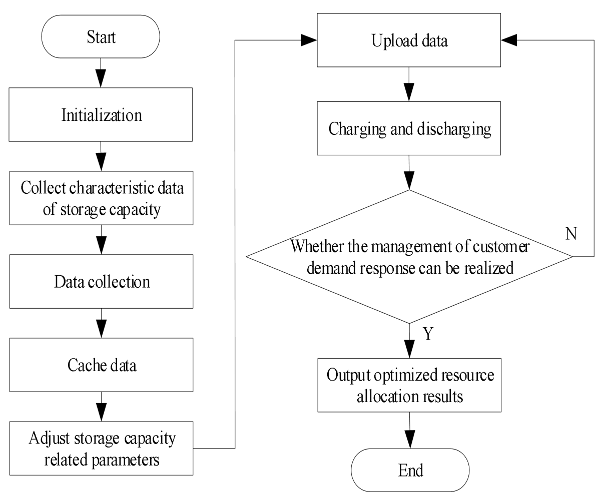

Figure 1. Flow Chart of Distributed Energy Storage Capacity Optimization Configuration

According to Figure 1, the application of time-of-use tariff management on the customer side depends mainly on the time-of-use tariff system implemented in the electricity market. The storage capacity can be used to reduce voltage fluctuations and flicker by regulating storage capacity-related parameters in a timely and effective manner according to the characteristics of different types of storage capacity and in response to changes in the system, thus avoiding voltage transients and transient rises in the system and improving the quality of the power supply. Distributed storage capacity, when operated on the customer side for charging and discharging, enables demand response management for customers with as little change as possible to their electricity consumption behaviour. Depending on the time constraints of the electricity load forecast, it can be divided into four categories, long term, medium term, short term and very short term. The ultra-short-term power load forecasting is to estimate the power consumption in a short period of time (usually less than a few hours) and to adjust the grid plan in time for the future application of DC power facilities and the construction of DC distribution networks according to the changes in the power load within this time frame. Effectively smoothing out the random fluctuations in the power output of distributed power sources and mitigating the negative impact of their uncertainty on the quality of electricity consumed by customers. Improving the regulation potential of the distribution network in terms of energy and power, increasing equipment utilisation and thus optimising the allocation of resources.

6. SIMULATION TESTS

6.1 Environmental deployment

Using simulation software, the electricity load data of a building building on weekdays and holidays is obtained, and by overlaying these data with actual data, the actual load of distributed energy consumption is derived. Combined with smart node terminal technology, data exchange with the node service processing module is carried out via the WebSocket protocol, and the smart terminal node state is received and processed and controlled. Using an efficient asynchronous publish-subscribe method, a communication connection is established between the external request and the server by opening the mqtt request interface 1883 and the WebSocket request port 8089. Firstly, for the distributed energy output simulation results, we use them as a negative stochastic conformity and then superimpose them algebraically with the historical data and thus obtain the actual load on this basis, and then with the help of HOMER software, we simulate these actual load values to obtain the simulation data for 365 days of the year. At the same time, the Python service handler is the control centre of the server. the MATT communication processing module and the node service processing module are programmed using the Python language, using shared variables and shared addresses to achieve communication and mutual invocation between modules, decoupling the client and the intelligent terminal, reducing coupling and improving the system's ability to handle exceptions and expand migration capabilities.

6.2 Test results

In order to verify the practical use of this proposed method for optimal allocation of distributed energy storage capacity, this test was chosen to be carried out as a comparative analysis. The particle swarm algorithm based distributed energy storage capacity optimisation allocation method and the convolutional neural network based distributed energy storage capacity optimisation allocation method are selected for comparison with the distributed energy storage capacity optimisation allocation method in the paper. Using the actual demand of the heating season as a background, three methods of optimising the configuration of distributed energy storage capacity under different tank volume conditions were tested separately for the time taken to meet the heating standards, as shown in Figures 2.

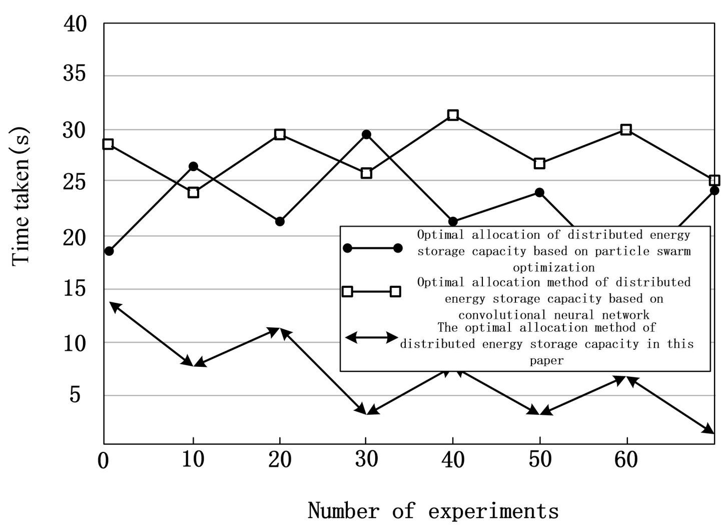

Figure 2. Time required for a water tank volume of 10,000m3(s)

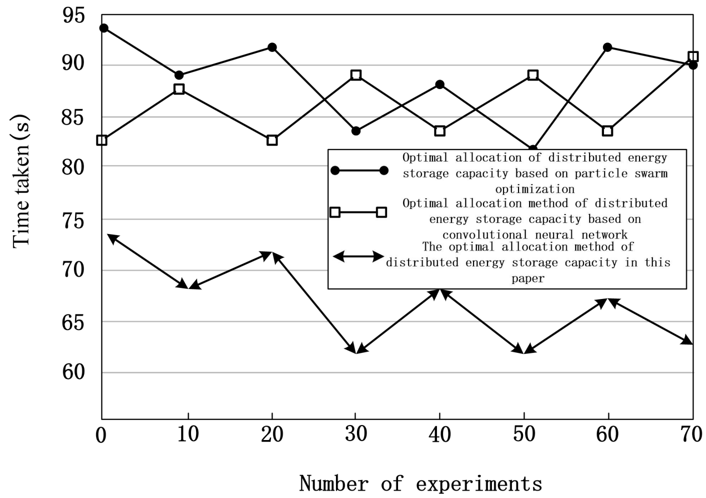

Figure 3. Time required for a water tank volume of 20,000m3(s)

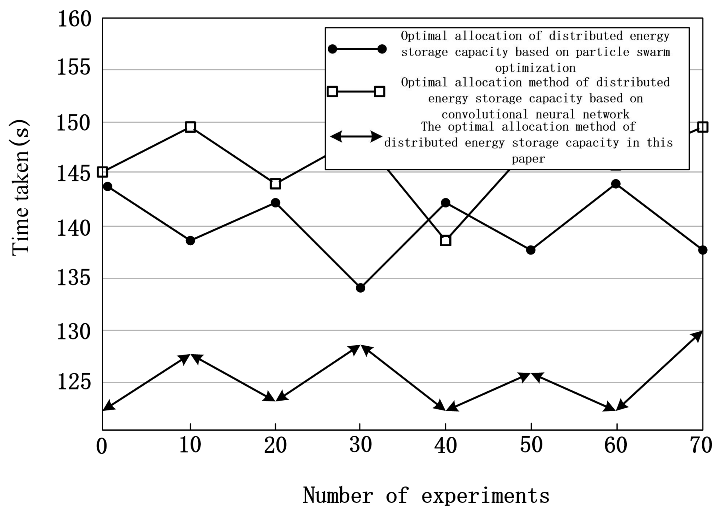

Figure 4. Time required for a tank volume of 30,000m3(s)

From Figure 2 to Figure 4, the average time required for the distributed energy storage capacity optimisation method is 72.36s, the average time required for the particle swarm algorithm based distributed energy storage capacity optimisation method is 86.49s and the average time required for the convolutional neural network based distributed energy storage capacity optimisation method is 87.21s. 87.21s.

7. CONCLUSION

In order to address the problem of the excessive time consumption caused by the deployment of high power supplemental combustion equipment to meet very short peak loads, the rated output of the supplemental combustion system and the actual output of the supplemental combustion during the supply season are analysed, and a comprehensive demand response model and operation mechanism for the micro-energy network considering the energy self-sufficiency adjustment strategy is constructed and proposed from three levels, including the interaction of the energy network with the grid and the natural gas network, the optimal operation of the energy network, and the flexible energy demand of the end load. The use of energy storage, which also plays a peak and valley reduction role, replaces some of the supplementary combustion equipment. The energy self-sufficiency adjustment strategy can be used as an effective means of optimising the operation of micro-energy networks and participating in integrated demand response, which can effectively improve the voltage levels of distribution networks and mitigate load fluctuations in integrated energy systems. In future studies, the efficiency of the equipment is assumed to be constant, ignoring the effect of factors such as partial load characteristics on its efficiency.

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