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Power optimization and control strategy for new energy hybrid power generation system based on deep learning

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Abstract

The continuous shortage of non-renewable energy and the increasingly serious environmental pollution have made clean renewable energy represented by wind and solar energy become the focus of attention. This paper mainly studies the power optimization and control strategy of a new energy hybrid power generation system based on deep learning. This paper introduces the basic principle and structure of a new energy hybrid power generation system and the application of deep learning technology in power optimization and control strategy. In this paper, a power optimization method based on deep learning is proposed, which realizes real-time optimization of power generation system powers by training neural network models. A control strategy based on deep learning is designed to improve the stability and efficiency of the power generation system. The effectiveness of the proposed method in practical application is verified by experiments.

Keywords: New energy hybrid power generation system; Deep learning; Power optimization; Control strategy; Neural network model

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1. Introduction

Renewable energy sources such as wind and solar have significant intermittency and unpredictability. For example, wind speed and solar radiation intensity can vary with weather, season, and geographic location, leading to fluctuations in power generation output. This volatility poses great difficulties for power optimization and control of the system. Due to the intermittency and unpredictability of renewable energy, the output power of new energy hybrid power generation systems often does not match the load demand of the power grid. During peak demand, the system may not be able to provide sufficient power. During periods of low demand, the system may generate excessive electricity, leading to energy waste. Due to the volatility of renewable energy, the stability of new energy hybrid power generation systems has become an important issue. The system needs to be able to quickly respond and adjust output power to maintain stable operation of the power grid. This requires the system to have efficient power optimization and control strategies. In order to cope with the volatility of renewable energy, new energy hybrid power generation systems usually need to be equipped with energy storage devices, such as battery energy storage systems. However, the capacity of energy storage devices is limited, and the charging and discharging process requires fine management to ensure that sufficient power can be provided when needed. In addition, the scheduling strategy of the system also needs to consider the volatility of renewable energy and the demand of the power grid. The report "Grid Flexibility for Energy Transformation" released by the International Renewable Energy Agency pointed out that by 2050, the proportion of renewable energy such as wind power and photovoltaic in the future power system will reach 85% [1]. The rapid development of deep learning technology provides new solutions for power optimization and control strategies of new energy hybrid power generation systems. It uses deep learning algorithms to preprocess and extract features from data and constructs a prediction model for power generation powers. Next, the model is trained to accurately predict future power generation powers. Finally, based on the predicted results, the power generation system is optimized and adjusted, such as adjusting the generator speed and optimizing energy distribution, in order to improve power generation efficiency and stability [2]. In order to realize the smooth implementation of China's energy revolution strategy, which is a sustainable power development model based on renewable energy and clean energy and composed of backbone grid and micro-grid [3]. In the new power system, the micro-grid is not only an important link for large-scale access and consumption of renewable energy, but also, as the main aggregation unit of urban distribution network terminals, it can achieve high-quality support for the dispatching and operation performance of urban distribution network through autonomous operation [4]. There are various energy supply and demand in microgrids, and it is one of the important research contents to realize the consumption of clean energy and the coordination and complementarity of various energy sources through economic and safe energy management [5]. A two-stage multi-time scale scheduling strategy is proposed for industrial microgrids, which realizes the complementary operation of multi-equipment and cost reduction by coordinating energy supply and heat storage devices. The micro energy network in industrial parks refers to a self-sufficient and efficient energy system that integrates multiple energy supply and conversion devices within a specific area. This system can meet the energy needs of different enterprises in the industrial park, achieving diversified energy supply and cascading utilization. A demand-side energy scheduling scheme to reduce energy use costs is proposed for the oil refining industry. A two-layer optimization model is proposed for the air conditioning system in industrial parks, which reduces the operating cost of the user air conditioning system and increases the profit of the user agent. An energy scheduling method considering the reliability of the energy supply is proposed for the integrated energy system of industrial parks, which improves the reliability and economy of the energy supply of the integrated energy system [6]. Although the above studies improve the economy of dispatch operation from different aspects of microgrids, they do not effectively consider the impact of renewable energy and load fluctuation characteristics [7]. And clean renewable energy has become the key to solving these problems. However, renewable energy is seriously affected by the weather, resulting in great fluctuation of its power generation, which affects the stable operation of the power grid [8]. To solve this problem, the addition of energy storage technology can effectively help stabilize the power output of wind power and photovoltaic power generation. At present, the energy storage device that has been studied more frequently and is relatively mature is the battery, which belongs to the energy storage device with high energy density, but short cycle life and relatively poor fast response ability [9]. As the capacity of new energy power generation systems continues to increase, the grid-connected requirements become higher and higher, which cannot be met by a single energy storage device. Therefore, a Hybrid energy storage system (HESS) is formed by configuring complementary power storage devices for energy storage devices. Energy storage devices are playing an increasingly important role in new energy generation systems. Energy storage devices can quickly respond to power fluctuations in new energy generation systems, balance supply and demand, stabilize grid voltage and frequency, and ensure the reliable operation of the power system. In addition, energy storage devices have the potential to extend their service life, and through scientific management and maintenance, their economic and social benefits can be further improved. [10]. However, the utilization of these renewable energy sources is greatly affected by weather, resulting in unstable power generation, which has an impact on the power system [11]. To solve this problem, energy storage technology came into being. The energy storage device can stabilize the output power. However, a single energy storage device cannot meet the growing capacity and grid-connection requirements of new energy power generation systems, so a hybrid energy storage system (HESS) has become a research hotspot [12]. However, problems such as control and optimal configuration of hybrid energy storage systems need to be solved urgently to further improve its utilization efficiency and promote the popularization and application of new energy [13].

2. Literature review

At present, the development and research of new energy is mainly divided into wind energy and solar energy, because the two are inexhaustible, and the research and application are relatively early [14]. However, renewable energy is seriously affected by the weather. When there is no wind or rainy weather, wind energy and photovoltaic power generation systems make it very difficult to generate electricity, and the power generation is very weak. Such intermittency and instability also cause great impact and harm to the power system [15]. Experts and scholars at home and abroad have conducted a large number of studies and experiments on this issue. From the research conclusions, it can be seen that the new energy power generation system can effectively solve the power fluctuation problem when equipped with a certain energy storage device. Wind power generation has gradually become one of the main development goals of new energy power generation [16]. Experts and scholars in various countries have conducted a lot of research and experiments on wind power generation, and more and more wind power stations are being built and put into use. In view of the development of wind power generation, the Party and the government have attached great importance to wind power projects in recent years, and the state vigorously develops the research of wind power stations and wind power scientific research projects. The installed capacity of wind power units keeps rising, and the grid-connected capacity of wind power is also constantly improving. As a renewable and clean energy, wind power occupies an increasingly important position [17]. As a clean renewable energy, photovoltaic power generation has also been widely promoted and strongly supported, with the in-depth research and testing of experts and scholars in various countries, the technology of photovoltaic power plants has gradually matured and been widely used. In many remote areas, transmission lines are difficult to build, but the light intensity is larger, and the light time is longer, which can establish small photovoltaic power stations to supply local residents. The Chinese government strongly supports and advocates the construction and research of photovoltaic power generation, which not only covers a small area and is flexible, but also clean and pollution-free [18]. In new energy generation systems, wind and solar energy have attracted much attention due to their unique advantages. Solar power generation utilizes the photoelectric effect to convert light energy into electricity, which is environmentally friendly, renewable, and long-term stable. Wind power generation generates electricity through the rotation of turbines driven by wind, which has advantages such as wide distribution, low cost, and renewability [19]. These two new energy generation methods not only effectively reduce environmental damage but also have enormous development potential. With the advancement of technology and the reduction of costs, wind and solar power generation will play a more important role in the future energy field. They will be widely used in power and heating systems, replacing traditional fossil fuels, making power systems more intelligent, efficient, and reliable. Meanwhile, wind and solar power generation will also expand into emerging fields such as electric vehicles and the production of renewable energy fuels, driving us towards a greener and more sustainable future [20].

3. Application of deep learning to power optimization and control strategy

3.1 Structure of hybrid power generation system

The hybrid power generation system is mainly composed of new energy power generation systems, energy storage systems and electric energy routers. Wind systems convert wind energy into electricity through wind turbines, and photovoltaic systems convert solar energy into electricity through solar panels. Both of these power generation systems have the characteristics of clean, renewable and pollution-free, but at the same time, there are problems of unstable power generation, such as wind power affected by wind, and photovoltaic power generation affected by light intensity.

The energy storage system mainly includes batteries and supercapacitors. Batteries are mainly used to store electrical energy, and supercapacitors are mainly used to provide instantaneous power. An energy storage system plays a role in stabilizing output power and improving system stability in a hybrid power generation system. The power router is the control centre of the hybrid power generation system, which is responsible for controlling and scheduling the operation of the whole system. The power router realizes the monitoring and control of each source device through the local central controller (PRCC) and realizes the functions of microgrid grid-connected, off-grid, and/or off-grid switching operation, fault protection, data storage and display. At the same time, the power router also needs to realize the system power flow control and algorithm protection to achieve the purpose of maximizing the utilization of clean energy on the spot. The structure of a hybrid power generation system mainly includes three parts: a new energy generation system, an energy storage system and an electric energy router. The new energy power generation system is responsible for generating electricity, the energy storage system is responsible for stabilizing the output power, and the electric energy router is responsible for controlling and scheduling the operation of the entire system. These three parts together form an efficient and stable hybrid power generation system, as shown in Figure 1.

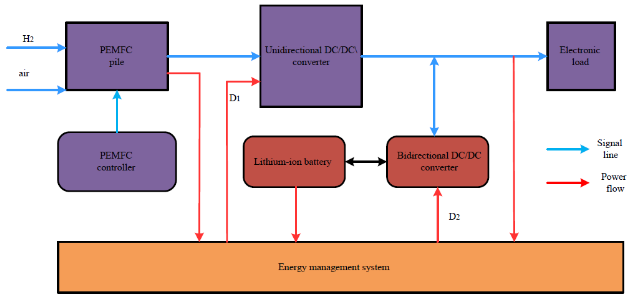

Figure 1. Unidirectional grid-connected structure of hybrid power generation system

The local central controller (also known as the "power routing controller", English abbreviation PRCC) inside the power router is used to monitor and control each source device in the power router and realize the functions of microgrid grid-connected, off-grid, and/or off-grid switching operation, fault protection, data storage and display based on the power router. The system power flows control, and algorithm protection are realized to maximize the utilization of clean energy on site. Power Routers (PRS) are new types of power electronic devices mainly used for power distribution and optimization in power grids. The power router contains multiple source devices (such as photovoltaic, fan, energy storage, etc.), which exchange and distribute power through the power router. PRCC, as the core component of power routers, plays a crucial role in achieving grid connection, disconnection, and switching operations of microgrids. PRCC first monitors key parameters such as voltage, frequency, and phase of microgrids and main grids. Through advanced control algorithms, PRCC ensures that the voltage, frequency, and phase of the microgrid are consistent with the main grid to achieve smooth grid connection. PRCC adopts a grid connected control strategy based on constant voltage and frequency, which maintains the consistency of voltage and frequency between the microgrid and the main grid by adjusting the voltage source converter (VSC) and current source converter (CSC) within the microgrid, as well as the corresponding controller. The core component of the power router is the local central controller (PRCC), which is responsible for monitoring and controlling each source device in the power router, and realizing the functions of the microgrid grid-connected, off-grid, and/or off-grid switching operation, fault protection, data storage and display based on the power router, as shown in Figure 2.

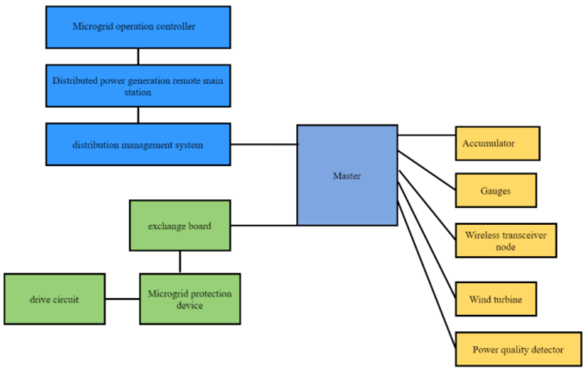

Figure 2. Grid system architecture diagram

The description in Figure 2 focuses on the role of power routers (PRS) and their local central controllers (PRCC) in power grid distribution and optimization, rather than the unique functions of hybrid energy storage systems. The core function of a hybrid energy storage system is to optimize energy utilization, improve system stability and response speed through the complementary characteristics of different energy storage devices. These functions are not highlighted in Figure 2. The left and right sides of the converter need to be superimposed in line with the passing capacitance C_1 and C_2 The reference voltage of the output V_{ref} :

$$V_{01ref} = V_{DC} + V_{0ref} / 2 \quad (1)$$

$$V_{02ref} = V_{DC} + V_{0ref} / 2 \quad (2)$$

$$V_{02ref} = V_{01} - V_{0ref} \quad (3)$$

The controller has two closed-loop adjustments. The outer loop voltage control block diagram of the left part of the boost converter is shown in Figure 3. Voltage control loops are designed to be generated for current control

The current reference power of ring making: (1) the reference voltage of capacitor C1 output is maintained; (2) In new energy generation systems, batteries are usually used as the main energy storage device. When the system starts running, supercapacitors can use their stored energy to provide initial charging current for the battery. The advantage of doing this is that it can avoid causing shock to the battery due to current fluctuations during the initial start-up of the system. Meanwhile, the fast charging and discharging characteristics of supercapacitors also ensure that the battery can quickly reach its operating voltage, thereby accelerating the startup speed of the entire system. The voltage control loop is implemented by a proportional resonant controller (PR) with a transfer function HPR(S), which has a better ability to track sine waves than a proportional-integral controller (PI).

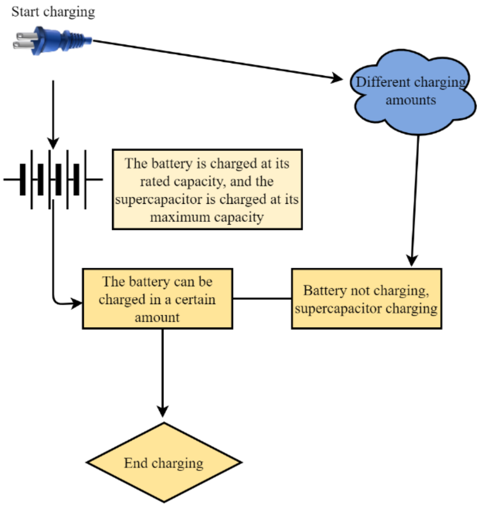

Figure 3. Charging process of hybrid energy storage system

$$H_{PR}(S) = K_{P,PR} + \frac{2_S K_{i,PR}}{S^2 + \varpi^2} \quad (4)$$

Between 50% and 100%. Then the reference voltage of the supercapacitor is:

$$V_{scref} = V_{sc\max} / \sqrt{2} \quad (5)$$

3.2. Battery SOC estimation based on Kalman filter

Kalman filter is a highly efficient recursive filter (autoregressive filter), which can estimate the state of a dynamic system from a series of measurements that do not completely include noise. However, the conventional Kalman filter is only suitable for linear systems, and the nonlinear state space model widely exists in practice, which makes the application of the conventional Kalman filter difficult. extended Kalman filtering (EKF) is the linearization of nonlinear systems, similar to the linear Kalman filtering formula. In practical applications, the calculation formula for SOC of batteries may vary depending on the type of battery and usage scenario. Common methods include using open circuit voltage method, space charge combination method, etc. These methods are based on the electrochemical characteristics and current charge discharge characteristics of the battery to estimate SOC.

$$S = S_O - \frac{\int_0 ibat(\tau)d\tau}{3600C_{bat}} \tag{6}$$

In the formula, S_0 Is the initial SOC value of the battery. The SOC value is very important in the operation of the energy storage system, which can avoid dangerous situations and battery degradation caused by overcharging or over-discharge of the battery. However, integrating the battery current may accumulate measurement errors, so it cannot be directly calculated by calculating the SOC of the battery.

$$y_k = v_{batk} = E_{0K} - V_{2\text{batk}} - i_{batk}R_{0bat} \tag{7}$$

$$x_k = Ax_{k-1} + Bi_{batk-1} \tag{8}$$

This paper mainly studies the control strategy of a bidirectional DC/AC converter connected by hybrid energy storage and AC bus. By using the complementary characteristics of battery and supercapacitor, the supercapacitor can preferentially suppress the high-frequency power fluctuation component and leave reaction time for the battery. At the same time, in order to better extend the service life of the battery, the battery SOC is controlled to prevent the occurrence of overcharge and over-discharge of the battery. Through the analysis of Matlab/Simulink simulation results, the effectiveness of the control strategy is verified (Figure 4).

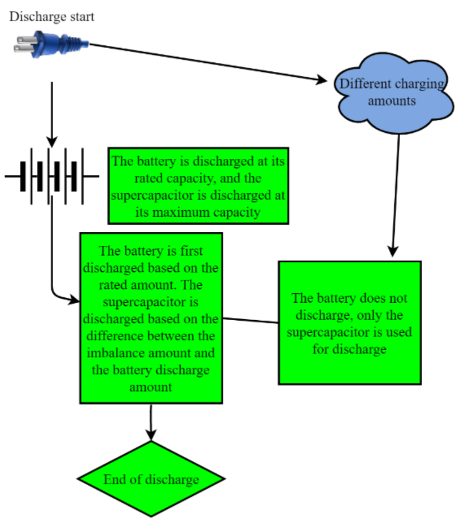

Figure 4. Discharge process of hybrid energy storage system

In the whole LPSP calculation process, the battery is always required to charge and discharge in its amount, which is to protect the battery, prevent it from overcharging or over-discharging, and extend its service life. In contrast, supercapacitors charge and discharge more times, a longer life, in order to protect the battery from making its rapid response to charge and discharge. The State of Charge (SOC) of a battery is one of the key factors that need to be considered in control strategies. To avoid overcharging or overdischarging of the battery, the power component it undertakes can be dynamically adjusted according to the SOC state of the battery. When the SOC of the battery is high, the power component it bears can be reduced to avoid overcharging; When the SOC of the battery is low, the power component it undertakes can be appropriately increased, but attention should be paid to avoiding over discharge.

3.3. Particle swarm optimization

Particle Swarm Optimization (PSO) is a newly developed evolutionary algorithm in recent years. Compared with the traditional genetic algorithm, which has been studied and applied relatively early, PSO has many advantages: model simplification, faster search speed, higher efficiency, and a relatively simple algorithm. At the same time, there are some disadvantages: it is easy to fall into local optimal cases. inertia weight is added to the algorithm formula, then its expression is as follows:

$$V_{id}^{K+1} = \omega V_{id}^{K} + C_1 r_1 (P_{id}^{k} - X_{id}^{k}) + C_2 r_2 (P_{gd}^{K} - X_{id}^{k}) \tag{9}$$

The basic particle swarm optimization (PSO) has great defects. Although the calculation process is fast, it will fall into the local optimal solution. This is caused by a number of factors, mainly because in the second half of the algorithm process, □ slowly decreasing will limit the algorithm to a very small range. Generally speaking, optimization algorithms need to search each individual from a large group to find the optimal solution, but the calculation process is relatively complicated and the calculation amount is very large. Therefore, in order to improve the optimization ability of the algorithm, it is necessary to speed up the search speed in the early stage of the calculation process, but also to ensure that every individual is not missed, and to prevent the algorithm from falling into a small range of optimal solutions. Improve the acceleration factor in the algorithm formula C_1 and C_2 , in the early stages of the calculation process, set C_1 The value as large C_2 The smaller value can not only prevent the calculation process from being limited to a small range but also improve the speed of the calculation process. When the calculation process is carried out step by step, C_1 The value gradually decreases and C_2 The value of the algorithm is gradually increased, thus improving the overall computational performance of the optimization algorithm. The algorithm expression is as follows:

$$C_1 = \frac{C_{1\beta} + (C_{1\alpha} - C_{1,\beta})}{K_{\max}} \quad (10)$$

The calculation flow of the particle swarm optimization algorithm for the capacity optimization configuration of the hybrid energy storage system is shown Figure 5

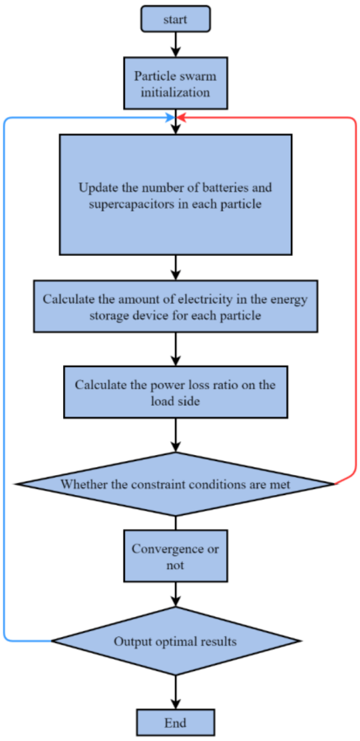

Figure 5. Particle swarm calculation flow of energy storage optimization configuration

For the capacity optimization problem of a hybrid energy storage system in a new energy generation system, based on the whole life cycle cost theory, the capacity optimization objective function of each energy storage unit is established, and the reliability index such as the load power shortage rate of the whole power generation system is taken as the constraint condition of the optimization model, and the calculation process of the system load power shortage rate is elaborated in detail. Finally, apply improvements
A particle swarm optimization algorithm is used to solve the optimization problem. The results show that the optimized capacity configuration can satisfy the reliability of the power supply and reduce the cost of a hybrid energy storage system effectively.

3.4 Energy system optimal scheduling model

The energy system is provided with external energy input by the distribution network and the gas distribution network, and internal energy input by the roof distributed photovoltaic. As shown in the energy system architecture diagram, the energy conversion equipment includes cogeneration units (CHP), gas boilers (GB) and electric boilers (EB), the energy storage equipment includes batteries (BES) and air compression energy storage systems (CAES), and the energy consumption equipment includes industrial electric loads, industrial thermal loads and gas loads (Figure 6).

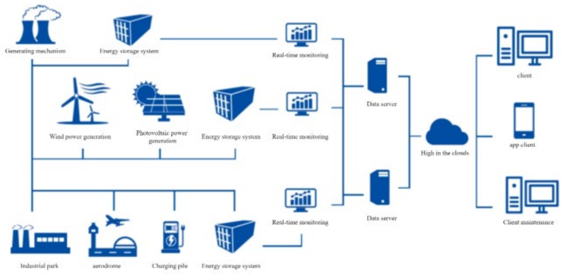

Figure 6. Energy system architecture diagram

Deep learning technology can efficiently couple and model various complex parameters of new energy hybrid power generation systems by training neural network models, thereby formulating precise control strategies. These strategies aim to improve the stability, efficiency, and economy of the system, ensuring efficient and stable operation in various complex environments. Reinforcement learning, as a machine learning technique, develops optimal state action strategies through the interaction between agents and the environment. In reinforcement learning, the state space represents all possible environmental states that an agent can observe. In the energy system, these states can include electricity demand, renewable energy generation (such as wind speed, light intensity), the status of energy storage devices (such as battery capacity), grid voltage and frequency, etc. By mapping this information to the state space, agents can understand the current operating status of the system and make scheduling decisions based on it. Deep learning framework Design reinforcement learning is a method in machine learning to develop optimal state-action strategies through interactive learning between agents and environments. The core of reinforcement learning is the interaction between the agent and the environment. The agent gives the environmental action according to the policy function by observing the state of the environment and calculates the reward of each step based on the state and action. The environment performs the action given by the agent and provides the new state to the agent. The agent looks for a state-action strategy that maximizes the cumulative reward based on the reward at each step. Figure 7 shows the core framework of reinforcement learning.

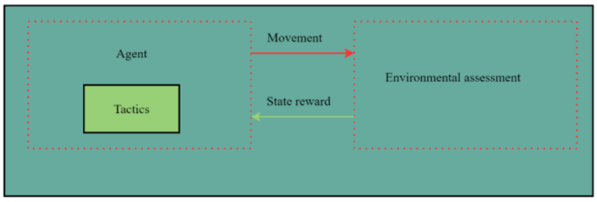

Figure 7. The core framework of reinforcement learning

4. Power optimization and control strategy of new energy hybrid power generation system based on deep learning

In a hybrid power generation system, the establishment of a power optimization model is the key link to realize system control and optimal operation. The model needs to comprehensively consider the characteristics of various new energy power generation equipment, system operating environment and target requirements, so as to maximize the system power generation efficiency and minimize the energy cost. For each power generation device, we need to understand its working principle, power generation characteristics, efficiency curves, etc., in order to correctly reflect its performance in the model. The operating environment of the hybrid power generation system is analyzed in detail, including meteorological conditions, geographical environment, grid conditions and so on. These factors will have an important impact on the operation of new energy power generation equipment, so the impact of these factors needs to be considered in the model. Based on the above analysis, the power optimization model of a hybrid power generation system can be established. The model needs to comprehensively consider the characteristics of various new energy power generation equipment, system operating environment and target requirements, so as to maximize the system power generation efficiency and minimize the energy cost. Specifically, the model can include the following parts: Equipment performance model: describes the working principle of various new energy power generation equipment, power generation characteristics, efficiency curves, etc. Environmental impact model: describes the impact of meteorological conditions, geographical environment, and power grid conditions on power generation equipment. Objective function: describes the optimization objectives of the system, such as maximizing power generation efficiency, minimizing energy costs, etc. Constraints: Describes constraints during system operation, such as device operation restrictions and power grid access restrictions. Optimization algorithm: Suitable optimization algorithms (such as genetic algorithm, particle swarm algorithm, etc.) are used to solve the model to obtain the optimal control strategy.

The combination of deep learning models with existing control algorithms to improve the stability and efficiency of new energy hybrid power generation systems is a cutting-edge and complex research field. Deep learning models can be used to predict the future state of a system, such as the output power of power generation equipment, the remaining capacity of energy storage systems, and so on. These predicted results can serve as inputs for MPC, helping the MPC algorithm develop more accurate control strategies. Through the predictive and learning capabilities of deep learning models, the system can more accurately predict future operating states and take control measures in advance to avoid system instability. After establishing the power optimization model, we need to verify and optimize it to ensure the effectiveness and reliability of the model in practical applications. This usually requires a large amount of experimental data and field testing in order to continuously adjust and improve the model. The establishment of a power optimization model is the key to realising the control and optimal operation of a hybrid power generation system. By establishing an accurate model, we can maximize the system's power generation efficiency and minimize the energy cost, so as to promote the sustainable development of new energy power generation.

5. Conclusion

Research on power optimization and control strategy of new energy hybrid power generation system based on deep learning. Through in-depth analysis and research, a power optimization and control strategy based on deep learning is proposed. Firstly, the optimization model of the new energy hybrid power generation system is established through deep learning training on the operating data of the system. Then, the deep learning algorithm is used to predict the running data of the system, and the optimal control of the system is realized. At the same time, the strategy also has strong adaptability and flexibility and can be adjusted according to the operating state of the system and environmental changes. In addition, this article also found that deep learning models have unique advantages in dealing with the uncertainty of new energy generation systems. Due to various factors such as weather and equipment status, the operation process of new energy generation often has significant uncertainty. However, deep learning models can effectively cope with uncertainty by learning a large amount of historical data, extracting potential patterns and features. This provides the possibility for us to develop more intelligent and adaptive control strategies. Future research needs to explore how to further improve the prediction accuracy and generalization ability of deep learning models. Or research how to combine deep learning with other optimization algorithms to achieve better optimization results.

References

[1] Aziz, Muhammad Shahazad, et al. "Wind-hybrid power generation systems using renewable energy sources-a review." International Journal of Renewable Energy Research 7.1 (2017): 111-127.
[2] Nehrir, M. H., et al. "A review of hybrid renewable/alternative energy systems for electric power generation: Configurations, control, and applications." IEEE transactions on sustainable energy 2.4 (2011): 392-403.
[3] Roy, Pranoy, et al. "Recent advances of wind-solar hybrid renewable energy systems for power generation: A review." IEEE Open Journal of the Industrial Electronics Society 3 (2022): 81-104.
[4] Panapakidis, Ioannis P., Dimitrios N. Sarafianos, and Minas C. Alexiadis. "Comparative analysis of different grid-independent hybrid power generation systems for a residential load." Renewable and Sustainable Energy Reviews 16.1 (2012): 551-563.
[5] Yang J, Yang Z, Duan Y. Optimal capacity and operation strategy of a solar-wind hybrid renewable energy system. Energy Conversion and Management, 2021, 244: 114519.
[6] Javed, Muhammad Shahzad, et al. "Solar and wind power generation systems with pumped hydro storage: Review and future perspectives." Renewable Energy 148 (2020): 176-192.
[7] Pang, Simian, et al. "Hybrid forecasting methodology for wind power-photovoltaic-concentrating solar power generation clustered renewable energy systems." Sustainability 13.12 (2021): 6681.
[8] Nebey, Abraham Hizkiel. "Design of optimal hybrid power system to provide reliable supply to rural areas of Ethiopia using MATLAB and Homer." Renewables: Wind, Water, and Solar 8.1 (2021): 4.
[9] Ammari, Chouaib, et al. "Sizing, optimization, control and energy management of hybrid renewable energy system—A review." Energy and Built Environment 3.4 (2022): 399-411.
[10] Abdali, Layth Mohammed Abdali, B. A. Yakimovich, and V. V. Kuvshinov. "Hybrid power generation by using solar and wind energy." Экологическая, промышленная и энергетическая безопасность-2019. 2019.
[11] Sutikno, Tole, et al. "A review of recent advances on hybrid energy storage system for solar photovoltaics power generation." Ieee Access 10 (2022): 42346-42364.
[12] Khirennas, A., et al. "Overview of fossil fuel-based hybrid power generation systems within mini-grids–The experience of storage-less PV system integration into three of the Great Algerian South mini-grids." Energy conversion and management 221 (2020): 113191.
[13] Ghorbani, Bahram, et al. "Introducing a hybrid renewable energy system for production of power and fresh water using parabolic trough solar collectors and LNG cold energy recovery." Renewable energy 148 (2020): 1227-1243.
[14] Opedare, Ifedayo Mofolorunso, Taiwo Matthew Adekoya, and Adedayo Emmanuel Longe. "Optimal sizing of hybrid renewable energy system for off-grid electrification: A case study of University of Ibadan Abdusalam Abubakar Post Graduate Hall of Residence." Int. J. Smart Grid-ijSmartGrid 4.4 (2020): 176-189.
[15] Clark, Caitlyn E., et al. Wind and solar hybrid power plants for energy resilience. No. NREL/TP-5R00-80415. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2022.
[16] Wang, Li, et al. "Analysis of a novel autonomous marine hybrid power generation/energy storage system with a high-voltage direct current link." Journal of Power Sources 185.2 (2008): 1284-1292.
[17] Zhang, Xia, Qing Sheng Wei, and Byeong Soo Oh. "Cost analysis of off-grid renewable hybrid power generation system on Ui Island, South Korea." International Journal of Hydrogen Energy 47.27 (2022): 13199-13212.
[18] Ghaffari, Abolfazl, and Alireza Askarzadeh. "Design optimization of a hybrid system subject to reliability level and renewable energy penetration." Energy 193 (2020): 116754.
[19] Affam, Azuka, et al. "A review of multiple input DC-DC converter topologies linked with hybrid electric vehicles and renewable energy systems." Renewable and Sustainable Energy Reviews 135 (2021): 110186.
[20] Razmjoo, Armin, et al. "Stand-alone hybrid energy systems for remote area power generation." Energy reports 5 (2019): 231-241.