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Optimal Operation of Power System Based on Artificial Intelligence Algorithm

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Abstract Due to the dual impact of fossil energy crisis and environmental pollution, the power systems (PS for short here) of all countries in the world have turned to clean and clean. This has led to the rapid development of wind power generation technology, and the large-scale access of wind turbines has also brought new challenges to the flexibility of the grid. Photothermal power generation is a new type of renewable energy, which has the inertia and adjustability of traditional energy. Its flexible operation mode has obvious advantages in promoting the consumption of renewable energy, participating in power grid peak shaving and standby. In view of the shortage of flexible resources faced by the current PS in the process of low-carbon transformation, as well as the problem that it was difficult to absorb the new energy (NE) concentration areas in the northwest, this text discussed the optimal operation of the NE power generation system. The experimental results showed that the CO_2 and SO_2 emissions were 41 tons and 62 tons when the proportion of CSP (Concentrated Solar Power) was 20% before DC optimization. After DC optimization, its emissions were 38 tons and 59 tons. With the increase of the proportion of CSP, its operating cost has been significantly reduced, the peak-shaving effect of the unit has been significantly improved, and the pollution emission has been significantly reduced. It can be seen that the application of solar thermal power plant in the system has significant economic benefits, obvious technical advantages, and significant energy conservation and environmental protection benefits.

Index Terms Power System Optimization, Artificial Intelligence Algorithm, Unit Peak Shaving, Running Cost

I. Introduction

Environmental pollution, climate change, and other problems are getting more and more attention. It has been challenging for the conventional fossil fuel-based energy framework to keep up with the world's expanding energy needs. The widespread use of conventional mineral energy has also contributed to the growing environmental pollution issue, which is a major obstacle to the long-term viability of human society. Rebuilding the human living environment and creating a low-carbon economy are widely embraced by the international society. Utilizing continuous energy sources like NE and efficient power plants is essential because the power industry's CO_2 emissions make up 40% of all national emissions.

The new technology for turning solar energy into electrical power is called CSP. The sun energy can be focused on a large mirror, reflected onto the solar power station's collector, and then transformed into thermal energy. In the power generation system, it is transferred to the heat conduction medium and paired with the traditional steam generator to produce electricity. The technology has special benefits since it can swiftly convert and modify energy when it needs to operate and can offer inertial support for peak shaving.

A new technology that produces clean energy from solar radiation is called photothermal power generation. It is crucial in resolving the issue of energy dependence on mineral energy. The scale optimization of a grid-connected hybrid photovoltaic/fuel cell power generating system with hydrogen storage was explained by Okundamiya M. S [1]. For modifying the PS stabilizer's (PS) settings, Devarapalli Ramesh suggested a hybrid enhanced Grey Wolf optimization sine cosine algorithm. By taking into account the multi-objective function, he employed the suggested approach to achieve the best PS parameter modification. Enhancing the integrated multi-machine system's damping and eigenvalue properties was one of the multi-objective functions [2]. Zhang Junbo proposed a data-driven reactive power and voltage sequence control optimization method [3]. Understanding the advantages and limitations of AI machine learning methods was crucial for deciding when and how to deploy PS and improve their optimal performance.

With the major breakthroughs in NE PS in recent years, machine learning in AI has shown great potential in upgrading the PS optimization toolbox. Ruan Guangchun thoroughly considered how this data-driven analysis might enhance rule-based optimization, paying particular attention to the synchronization between machine learning techniques and optimization models [4]. The large-scale, intricate economic load distribution and combined emission economic dispatch challenges in PS were extensively resolved through the application of optimization technology. These issues can be resolved quickly by these technologies. A new AI-based meta-heuristic optimization technique, or improved top-of-class optimization, was proposed by Srivastava Abhishek. In the PS, it was applied to resolve the combined emission economic dispatch and big and complex economic load distribution challenges [5]. Nevertheless, they haven't studied NE and haven't maximized its economic, environmental, and energy-saving advantages.

In order to solve the problems of environmental pollution and energy shortage, this text proposed to optimize the PS and performance by using NE such as photothermal power generation system, and presented a method of distributed energy power optimization based on adaptive genetic algorithm and fuzzy decision. Secondly, in the experimental part, this text analyzed the operation cost, peak shaving effect and green energy effect of the grid planning data of a province in northwest China. The results showed that the application of solar thermal power plant in the system had significant economic benefits, obvious technical advantages, and significant energy conservation and environmental protection benefits. The innovation of this text was the comparative experimental analysis of the installed proportion of CSP. This text then compared three aspects, including operation cost, peak shaving effect and pollution degree, to ensure the availability of this energy-saving system.

II. AI Power System

II. A.Smart Grid

Smart grid is an important trend in China's future development. The five characteristics of smart grid are open, safe, efficient, clean and self-healing. In the process of smart grid development, whether it is digital management, intelligent decision-making or interactive trading, it needs an optimization process to achieve. In smart grid, optimization is the most basic factor. Although many people have used AI algorithms to optimize various aspects of the PS, its main features are as follows. Its single goal and rigid algorithm application make it have great room for improvement in optimization speed and optimization effect. It has certain practical significance in power grid optimization, and its main research contents are as follows [6], [7]:

(1) Multi-objective optimization

Because the operation of power grid requires a lot of resources, it is limited by many factors. Therefore, a single objective optimization method provides a good test platform for AI algorithms, but there is still a big gap in practice. In general, the optimization of power grid should consider four factors comprehensively: economy, environment, resources and operation cost.

(2) Realistic constraints

Because having constraints is a difficult problem to solve the optimal problem, many scholars try to reduce the processing of constraints or avoid them as much as possible. At present, when solving the constraint problem, the commonly used method is the penalty function or the unreachable rejection strategy.

(3) Improved AI algorithm

The biggest feature of AI algorithm is its high adaptability and versatility. The principle, scale and performance of different optimization problems are different. This needs to start from the characteristics of the optimization problem and optimize it accordingly to achieve better optimization results.

(4) Optimization of large-scale systems

At present, China has made great efforts to develop micro-grid, but it is mainly based on large systems. With the increase of system scale and the extension of optimization period, the accuracy of calculation would also be reduced. How to speed up the operation of the large power grid is a key issue for China's power grid.

II. B.MG System

With the acceleration of the scientific and technological revolution, the development mode of the global economy has been continuously upgraded, and electricity has become the main energy consumption mode. It has made major technological breakthroughs in the development of NE, but it still relies heavily on non-renewable mineral energy. As we all know, oil, coal and natural gas are the "three giants" of global energy. However, the reserves of oil, coal and natural gas are very limited. At the same time, the problem of air pollution in the process of their conversion has also received widespread attention. At present, the energy crisis and environmental damage have become important issues affecting the sustainable development of the world and human survival.

Therefore, it is imperative to develop NE. However, at present, China's power grid construction focuses on large-scale distributed power generation and UHV lines. Due to the continuous expansion of the PS, the operation cost of the PS is increasing, the maintenance difficulty is increasing, and the power supply capacity is also increasingly unable to meet customers' requirements for stability, reliability and personalization of energy. According to the needs of energy conservation and emission reduction, green energy and sustainable development, an important feature of smart grid is the introduction of photovoltaic, wind power, geothermal power, tidal power, etc. [8], [9].

Microgrid (MG) system combines power, load and energy storage system (ESS) to form a small and complete power supply system. Figure 1 is a typical MG system.

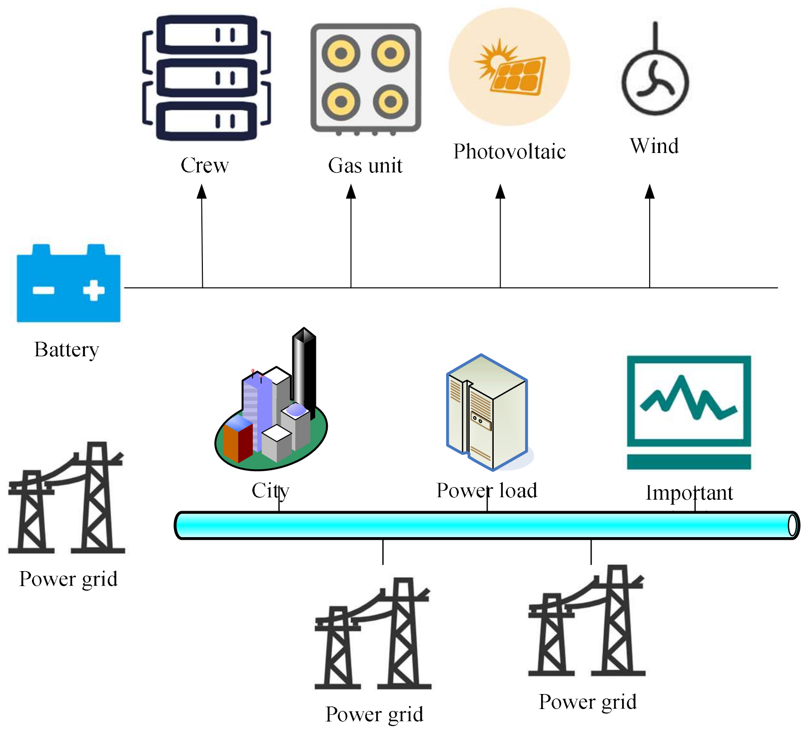

Figure 1: MG system structure diagram

MG can provide users with cold, hot and electric energy, and has the ability of independent operation, energy management and self-healing. MG can operate independently of the isolated island of the main network, and can meet the needs of the load through the unified coordination of the PS. At the same time, it can also be connected to the main network, and the load requirements can also be guaranteed through the main network. From the user's point of view, MG can be regarded as a complete and functional low-PS to meet different power supply requirements. From the perspective of the main network, MG can be seen as a single whole, or a power supply system, or a load.

(1) Energy conservation and emission reduction, improving energy efficiency

MG can realize large-scale use of green energy, reduce energy consumption and reduce air pollution. MG is a modular equipment with complete functions and structure. It can not only meet the single power supply of the main grid, but also meet the needs of different types of heat, cold and electric energy. In this way, it can recover excess heat, reduce energy consumption and improve power generation efficiency. Of course, introducing ESS into MG can not only improve its energy control ability, but also improve its use effect.

(2) One of the ways to integrate DG into the main network on a large scale

At present, in resource-rich regions, large-scale grid connection of distributed renewable energy is an important and difficult problem. Many DG are characterized by unstable power and large floating range due to the influence of environment and other factors. If DG network is directly adopted, it would have a great adverse impact on its operation and control. The biggest feature of MG is to concentrate distributed renewable energy on the power grid, and adopt real-time adjustable control and protection devices to balance the load and maintain the stability of the system.

(3) Improve the reliability of system power supply

MG can monitor the operation of the main network 24 hours through the installed sensors. After receiving the main network fault or abnormal signal, MG can change from grid-connected to isolated island, so as to ensure the stable power supply of MG's main load and reduce the risk caused by power failure. In addition, the use of ESS technology can make the PS uninterrupted, improve the reliability of power supply and maintain voltage stability.

(4) Improve the system's ability to resist disasters

In case of extreme weather such as earthquake, flood and snow disaster, MG, as a standby power plant, has supplemented and maintained the main power grid to a certain extent. In addition, MG also has the ability of "black start", which can quickly recover and continuously supply power to main loads.

Because the control mode and cooperative operation of DG have better operability and flexibility, the development of DC MG has received more and more attention. In addition, due to the reduction of the inverter, the composition cost of the DC MG is reduced, thus reducing the loss. However, the disadvantages of DC MG cannot be ignored. For example, it is easier to realize variable voltage than AC MG, so it is necessary to establish a converter station. Because of its small load capacity, it would produce a large amount of reactive power loss during operation, which would affect the system voltage.

II. C.Distributed Energy Power Optimization of Power Grid Based on Adaptive Genetic Algorithm and Fuzzy Decision

With the development of microgrid and distributed energy, distributed energy is used as the basis of power system. With the development of MG and distributed energy, distributed energy is used as the basis of PS. Through advanced real-time acquisition technology, it can judge its operation status and optimize its various parameters. This can meet the requirements of network loss and power quality [10], [11].

Genetic algorithm is an artificial optimization method that simulates natural genetic evolution. There are three advantages of using genetic algorithm to optimize the solution: first, there is no need to optimize the target, and there are mathematical conditions such as derivability and continuity. The second is the crossover and mutation gene manipulation technology, which makes it have strong global optimization ability and can quickly find the optimal solution. Third, the algorithm has good combination performance with other heuristic algorithms and can achieve better optimization results.

The general form of the optimal solution of the multi-objective problem is shown in formula (1). h and f are the optimal constraints.

$$
\begin{aligned}
&\min g(a)=\min\left[g_1(a),g_2(a),g_3(a),...,g_q(a)\right]\\
&s.t.h(a)\le 0\\
&f(a)=0
\end{aligned}
\tag{1}
$$

However, there is a solution that one or more objective functions cannot be further optimized without worsening other objective functions. This solution is called non-inferior optimal solution, or Pareto optimal solution.

The main objective of this text is to solve the Pareto optimal problem of distributed energy. For the MG containing distributed energy, this text puts forward five objectives, namely: network loss, node voltage deviation, the lowest equipment operating cost, the best environmental protection benefits, and the highest utilization rate of renewable energy. This text does not discuss the reconfiguration of PS. Assuming the loss of line j is, the total loss is formula (2):

$$PLOSS=\sum_j Ploss_j \tag{2}$$

In practical applications, if the node voltage deviation is used as a limit, the size of the initial population must be very large, and good gene fragments can be randomly extracted from the original population. Otherwise, it can only obtain excellent genes through a small number of mutations, thus greatly reducing the computational efficiency and speed. Because the voltage regulation methods of the power grid are relatively rich and flexible. Therefore, this text does not strictly consider the voltage value of a single node, but focuses on global optimization, taking the node voltage offset as the objective function. Assuming that within the range of 90% to 110% of the rated voltage deviation, the unit voltage value of the jth node of the system is V_j, then the voltage deviation of the said node is $|V_j-1|$.

$$Voloff=\sqrt{\frac{\sum_{j=1}^{m}\left[\left(\left[\frac{|V_j-1|}{0.05}\right]\times 10+\frac{|V_j-1|}{0.05}\right)\times 0.05\right]^2}{m}} \tag{3}$$

$\left[\frac{|V_j - 1|}{0.05}\right]$ represents the number in brackets rounded down.

High investment, low operating, maintenance, and fuel costs are characteristics of the majority of renewable energy sources. The straightforward and effective formula (4) can be used to estimate the installation cost of unit power.

$$E = (\frac{k(1+k)^m}{(1+k)^m - 1})(\frac{E_{jmu}}{87.6r}) + E_g \tag{4}$$

k is the fixed annual interest rate, and m is the service life of the equipment. E_{jmu} is the equipment investment capital, r is the capacity coefficient, and E_g is the combustion cost per unit of electricity. Since there are four types of distributed generation in this text, the installation cost is shown in formula (5):

$$E_{cons} = \sum_{j=1}^{4} \varphi_j (\frac{k(1+k)^m}{(1+k)^m - 1})(\frac{E_{jmu,j}}{87.6r}) \tag{5}$$

Among them, φ_j is the proportion of j power generation modes.

As for the operation cost, formula (6) can be used to estimate, MQ is the type of pollutant, and $U_{c,i}$ is the jth pollutant of unit environmental value. P_i is the discharge of pollutants, and U_i is the penalty imposed on the discharge of pollutants. $E_{ZN,j}$ is the operation and maintenance cost per unit of electricity.

$$E_{run} = \sum_{j=1}^{4} \phi_j \left[\sum_{i=1}^{MQ} (U_{c,i} P_i + U_i) + E_{ZN,j} \right] \tag{6}$$

To sum up, balancing node power Q_{jm} constitutes the five objectives of the multi-objective optimization problem in this text, as follows:

$$\begin{aligned} &\min g_1(a) = PLOSS \\ &g_2(a) = Voloff \\ &g_3(a) = Q_{jm} \\ &g_4(a) = E_{cons} \\ &g_5(a) = E_{run} \end{aligned} \tag{7}$$

The calculation results show that the method can quickly and reasonably find the optimal solution, and can be used for real-time control of multi-agent and energy management system in MG.

III. Experimental Analysis on Optimal Operation of Photothermal Power Generation System

The use of UHV DC transmission technology in the consumption of a large percentage of renewable energy would be a significant application sector for the clean transformation of China's power grid, given the distribution characteristics of its resources [12], [13]. A novel form of renewable energy that possesses the inertia and adaptability of conventional energy is photothermal power generation. Its adaptable style of operation clearly benefits the use of renewable energy sources and contributes to the power grid's peak shaving.

On this basis, this text proposes a comprehensive NE consumption scheme based on distributed photovoltaic power generation technology [14], [15].

III. A. Coordinated and Optimized Operation Mode of Solar Thermal Power Plant and DC Tie Line

Because the northwest region is a place where NE is concentrated, the absorption capacity of the local power grid is very small. Therefore, the transmission of UHV DC transmission lines to the load centers in the east is the main means of absorption at present. Combined with the trans-regional absorption and operation scheme of the light-containing thermal power plant dominated by NE in the region, this text comprehensively considers the comprehensive benefits of the system. This text combines the characteristics of flexible operation of optical thermal power plant, flexible adjustment capability of DC tie line, and terminal load characteristics from aspects of improving system economy, improving unit peak shaving conditions, and promoting NE consumption. On this basis, this text constructs a coordinated operation mode of cross-regional consumption of NE.

As shown in Figure 2, in addition to photovoltaic power stations, they also include wind power, photovoltaic power, hydropower, thermal power and other types of power. This is a typical new type of high proportion PS, which is connected with thermal power through UHV DC transmission. The load requirements at the power supply end are realized by DC power supply and local thermal power plants.

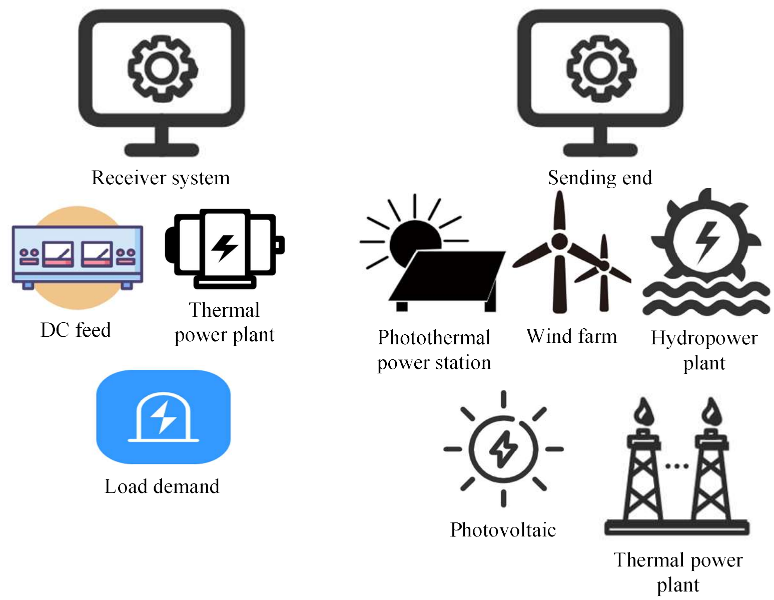

Figure 2: High proportion of NE transmission system including photothermal power generation

III. B. Case Analysis of Power Grid Planning Data of Province in Northwest China

This text applies adaptive genetic algorithm to the PS with distributed PS, and optimizes the distribution of power and energy from five aspects: reducing voltage deviation, line loss, operation cost, equipment cost and maximizing the use of NE. This text gives the implementation scheme of each objective function and adaptive mechanism, analyzes the distribution law of Pareto optimal solution, and selects the appropriate solution through fuzzy judgment.

The power grid development plan of a particular northwest Chinese province serves as the basis for this example. Table 1 displays the installed capacity and installed share for each region based on the planning data.

Table 1: Power supply installation data of the sending end system

Installation	Capacity	Proportion
Hydropower	2437	24.37%
Wind Power	798	7.98%
Photovoltaic	2276	22.76%
Photothermal	1890	18.9%
Thermal Power	2453	24.53%
Geothermal Energy	67	0.67%
Human Resources	79	0.79%
Final Assembly Machine	10000	100%

The power structure of the province is mainly clean energy, and 74.84% of the new solar and thermal energy is an important part of it. In summer, due to the uncertainty of NE, the normal operation of the grid would be affected to a certain extent, so the typical summer day of the province is selected as the basic operation scenario. On this basis, according to the actual historical data, this text determines and forecasts the output of daytime wind power generation and solar power generation.

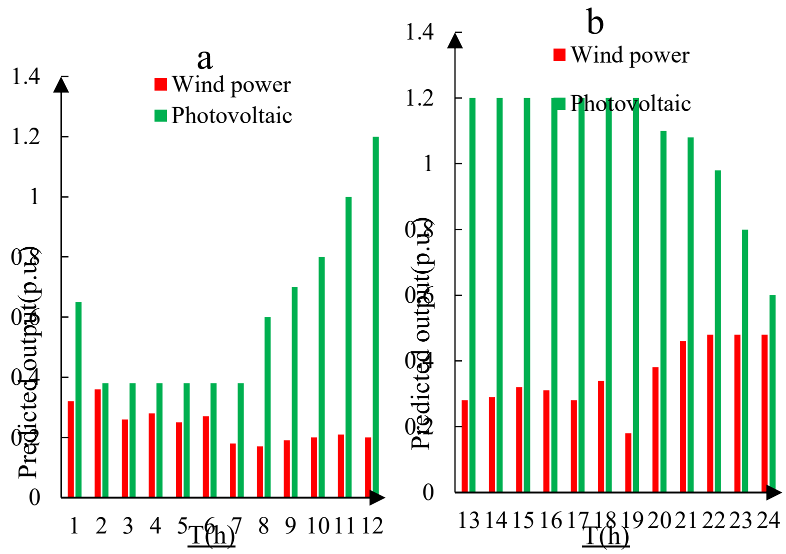

Figure 3: Power statistics of each unit in the dispatching day

As shown in Figure 3, Figure 3 (a) shows the predicted output of wind power and PV at points 1-12, and Figure 3 (b) shows the predicted output of wind power and PV at points 13-24. It can be seen from Figure 3 that the predicted output value of solar power generation began to rise slowly at 8:00. It began to reach its peak at 12 noon, and then maintained this state until 19 o'clock. It can be seen that solar energy supplies power to the whole grid at 8-19 points. The power of wind power generation fluctuates greatly, especially from 18:00 to 20:00 at night.

(1) Economic analysis

Table 2 lists the CSP system operating costs with different proportions. Jc is the system cost before DC optimization, and Je is the system cost after DC optimization. With the gradual increase of the installed capacity of light and heat, the operating costs of the two systems are decreasing. At the same time, using the flexible adjustment function of the tie line can improve the economic benefits of the optical-thermal power plant participating in cross-regional consumption, thus further improving the economy of the power grid.

Table 2: Comparison of system operation costs

Proportion of photothermal installation		15%	20%	25%
Jc(10000 yuan)	Sending terminal	386.37	365.42	337.58
	Receiver	177.32	177.32	177.32
Je(10000 yuan)	Sending terminal	368.54	357.22	328.66
	Receiver	165.43	157.32	148.27

Figure 4 shows the change of the operating cost of the photothermal power plant under different working conditions.

As shown in Figure 4, Figure 4 (a) shows the change of operation cost of each power supply at the sending end before DC optimization, and Figure 4 (b) shows the change of operation cost of each power supply at the sending end after DC optimization. It can be seen from the figure that the operating cost of thermal power is 1.7 million yuan under the condition of 15% of installed capacity before DC optimization. Under the condition of 15% installed capacity after DC optimization, the operating cost of thermal power is 1.6 million yuan. It can show that the operation cost would continue to decrease after DC optimization. Among them, the input of photothermal power plant has a great impact on the operating costs of power generation enterprises. This is mainly because the photothermal power plant has participated in the peak regulation of the system, thus reducing the start-up cost of the unit. At the same time, the flexible operation of optical thermal power stations can improve the utilization rate of wind power, thermal power and other NE sources. It reduces the power generation of coal-fired power plants and saves fuel costs of coal-fired power plants.

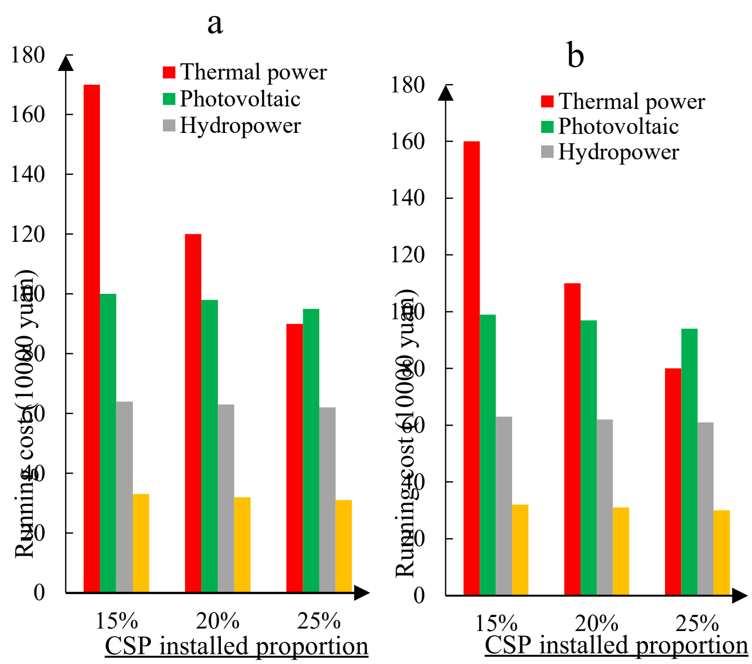

Figure 4: Variation of operation cost of each power supply at the sending end

(2) Analysis of unit peak shaving effect

Table 3 shows the gain effects of the transmitter and receiver under different photothermal access ratios. With the increase of the ratio of light and heat, the peak output and the cumulative climbing capacity of each power transmission equipment are continuously decreasing.

Table 3: Comparison of peak shaving effects of thermal power at the sending and receiving ends

Proportion of photothermal installation		Sending terminal			Receiver		
		15%	20%	25%	15%	20%	25%
Peak shaving parameters before DC optimization	Peak-valley difference	500	248	197	344	258	136
	Cumulative gradeability	798	448	365	1390	879	546
Peak shaving parameters after DC optimization	Peak-valley difference	237	128	86	300	234	178
	Cumulative gradeability	728	289	154	1099	788	567

Figure 5 shows the optimal transmission power curve of DC tie line under different optical and thermal ratios.

As shown in Figure 5, Figure 5 (a) shows the optimization results of DC contact line power at 1-12, and Figure 5 (b) shows the optimization results of DC contact line power at 13-24. It can be seen from Figure 5 that with the increase of the ratio of light and heat, the adaptability of the sending end system is also gradually improved. It has conducted deep peak shaving during the noon photovoltaic peak period, reducing the peak shaving task of thermal power at the sending end. In the night when the NE is insufficient, the efficient use of solar energy can be realized through solar energy storage, which can reduce the peak-valley difference of photovoltaic power generation and achieve the optimal peak shaving effect.

(3) Benefit analysis of green electricity

With the increase of the installed proportion of photo-thermal power generation, various green energy indicators have been improved. The improvement of clean energy and pollution emission is shown in Table 4 and Figure 6. Jkc is the proportion of clean energy power supply before DC optimization, and Jke is the proportion of clean energy power supply after DC optimization.

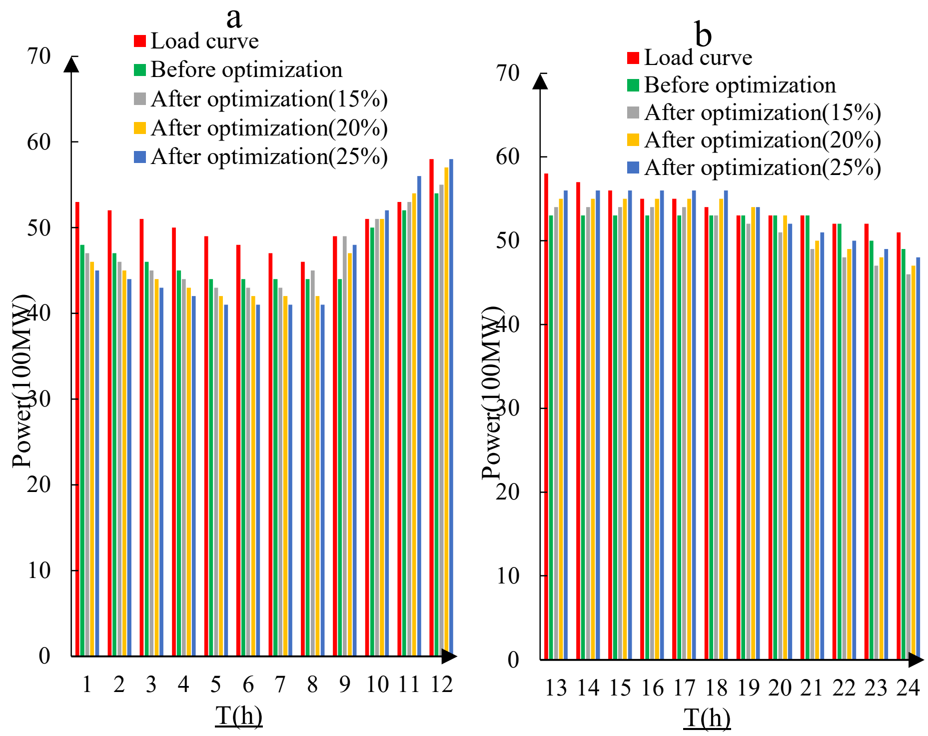

Figure 5: Optimization result of DC contact line power

Table 4: Comparison of clean energy power supply

Proportion of CPS installed capacity		15%	20%	25%
Jkc	Sending terminal	92.46%	93.58%	95.78%
	Receiver	84.26%	86.78%	88.59%
Jke	Sending terminal	93.47%	95.89%	97.33%
	Receiver	85.37%	87.90%	90.45%

As shown in Figure 6, Figure 6 (a) shows the comparison of CO_2 emissions before and after DC optimization, and Figure 6 (b) shows the comparison of SO_2 emissions before and after DC optimization. It can be seen from the figure that when the proportion of CSP is 20% before DC optimization, the emissions of CO_2 and SO_2 are 41 tons and 62 tons respectively. After DC optimization, when the proportion of CSP is 20%, the emissions of CO_2 and SO_2 are 38 tons and 59 tons respectively. With the increase of light and heat, the utilization rate of renewable energy is also increasing. This can also increase the consumption of wind, light and other volatile renewable energy, improve the cleanliness of the system, and reduce the adverse impact of power generation on the environment.

IV. Conclusions

Based on the coordinated control of DC tie lines and the regulation and complementarity of power grids, this text studied the cooperative and optimal operation of photovoltaic power stations and DC transmission lines from the perspective of interconnected systems. This text quantitatively analyzed the flexibility of photovoltaic power generation with three indicators, and illustrated the feasibility of this method with an example. Photovoltaic power generation undertook the peak shaving work of the power grid, improved the peak shaving capacity of traditional units, and reduced the peak shaving cost of the system. In addition, due to the flexible operation of the solar thermal power plant, it can reduce the power consumption of the system, improve the NE consumption and reduce the power generation cost. It can reduce the adverse impact on the environment. In general, the application of solar thermal power plants in the system had significant economic benefits, technical advantages and energy conservation and environmental protection benefits.

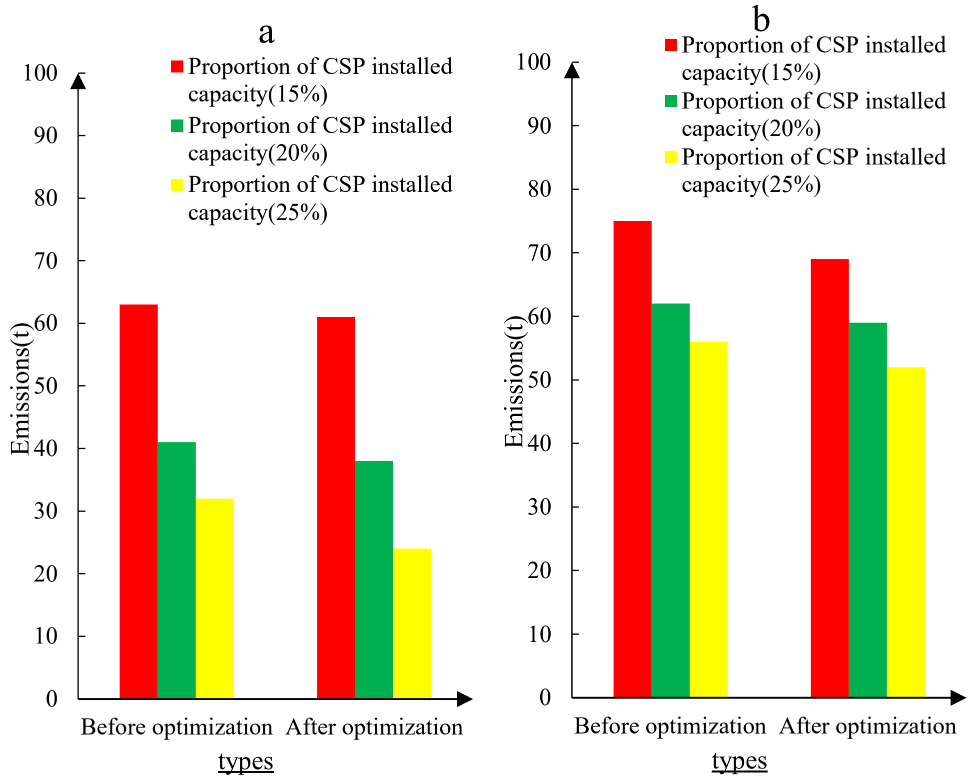

Figure 6: Comparison of system pollutant emissions

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