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Optimal Scheduling Model of Power System Based on Multi-Objective Evolutionary Algorithm

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In today's increasingly prosperous society, almost every industry requires electricity to support its operations, and whether the power system can operate stably and safely has been closely related to the steady development of the economy. Optimal scheduling research plays a decisive role in power system operation and control. In order to ensure reliable power supply and power quality, it is important to optimize the operational efficiency of the power system, so that the system can provide greater economic benefits. Traditional multi-objective optimization methods have major shortcomings, and multi-objective optimization methods based on traditional mathematical planning principles usually have certain vulnerabilities in terms of practical engineering optimization problems, so there is a need for in-depth research on efficient and practical multi-objective optimization algorithms and theories. In this paper, the modeling technology of the power information-physical system is studied and the multi-objective scheduling optimization of power system is explored using a multi-objective evolutionary algorithm. The algorithm analysis results showed that compared with the traditional dispatching model, the proposed multi-objective evolutionary algorithm not only improved the optimization effect of the power system by about 8.95%, but also offered decision makers guidance on dispatching, with good convergence speed and accuracy compared with previous optimization methods and solutions.

Keywords: Power system, multi-objective evolutionary computation, physical communication, scheduling model

1. INTRODUCTION

The optimal operation of a power system has three focuses: excitation, transmission, and substation and power consumption. The power company has to integrate these three aspects in a coordinated and unified way to create an efficient mode of system operation. This mode uses modern high-tech auxiliary management and monitoring to save energy and automate the power system, making the power operation system more efficient, more accurate, safer, and more economical.

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Several scholars have conducted research on the scheduling of power systems. The study by Le concluded that the scheduling for a traditional power plant generation is usually done so as to maximize economic efficiency while taking system safety into account. However, in thermal power generation, fossil fuels emit various pollutants during combustion which cause harm to both human health and the environment [1]. The optimization of a power system is a fundamental issue since the optimal dispatching model of a power system is to optimize the power allocation of each unit so as to minimize the total operating cost of the generating units under the premise that the system load demand is consistent with the operating constraints of the units [2]. Theoretically, the application of linear controllers to nonlinear power systems

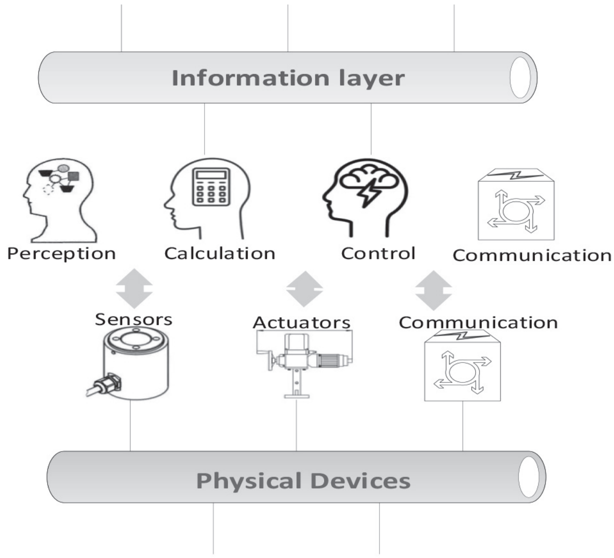

Figure 1 Architecture of an information physical system.

ensures the narrow asymptotic stability of the nonlinear system around this operating point [3]. Bai considers power system dispatch as a multi-objective optimization problem with unit cost of generation and pollution gas emission as the optimization objectives. The multi-objective evolutionary algorithm is one of the iterative search algorithms used to simulate the biological evolution process, and shows great advantages in solving multi-objective optimization problems [4]. Pan argues that optimal dispatching enables correct load forecasting, optimal combination of generators, and accurate decision-making in regard to the operation strategy of all power-generation equipment in the system. Optimal dispatching reduces the amount of fuel required for power generation and reduces network losses in order to achieve the lowest total system operating costs [5]. The management of power system operation aims to ensure maximum cost saving while guaranteeing system safety and power quality. This These goals are achieved by optimal dispatching. A substantial amount of research has been conducted on multi-objective evolutionary algorithms. Mirjalili found that multi-objective optimization is the simultaneous optimization of a multi-objective problem containing two or more objectives, which has attracted increasingly widespread attention in recent years [6]. Wang proposed that the solving of a multi-objective optimization problem often has multiple conflicting objects, so there is no single optimal solution for such problems, but rather a set of solutions representing trade-offs and compromises among the objectives [7]. Jon argued that a multi-objective optimization problem is one in which several objectives are optimized simultaneously, where the objectives to be optimized involve the maximizing or minimization of these two objectives. In practice, to simplify the problem, the maximization or minimization problem can be reversed so that all optimization objectives are minimized or maximized [8]. Moreno found that the solution set obtained by a multi-objective evolutionary algorithm can be measured by a variety of evaluation metrics, and the measure-based multi-objective evolutionary algorithm uses evaluation measures to guide the search direction of the algorithm [9]. Ye found that multi-objective evolutionary algorithms have been applied in many fields of optimization design. However, in multi-objective optimization, often the sub-objectives may conflict with each other, and the improvement of a sub-objective may decrease the performance of other sub-objectives. Hence, these sub-objectives cannot be optimized simultaneously, but only through their mutual coordination and compromise, so as to maximize the effectiveness of each sub objective [10]. The research results show that the improved multi-objective evolutionary algorithm can make the evaluation results more objective and accurate, and can partially overcome the shortcomings of the traditional multi-objective evolutionary ranking selection method and scaling method.

Along with the rapid development of science and technology, and people's improved financial status, demands for electricity are increasing, forcing power supply enterprises to continuously optimize their power system. However, during the optimized operation of the power system, there should be continuous reform and innovation so as to continuously improve the technical quality of the power system for the benefit of all.

2. OVERVIEW OF POWER INFORMATION PHYSICAL SYSTEM

Information physical systems are an important part of modern information science, mapping information and other factors to each other for timely interaction and efficient collaboration [11]. The architecture of information physical systems is shown in Figure 1.

In the architecture, the physical layer is the power network, which includes primary power equipment such as generators, loads, circuit breakers and transmission lines; the information layer is the power information network, which contains various types of monitoring equipment, control equipment, computing equipment and communication network

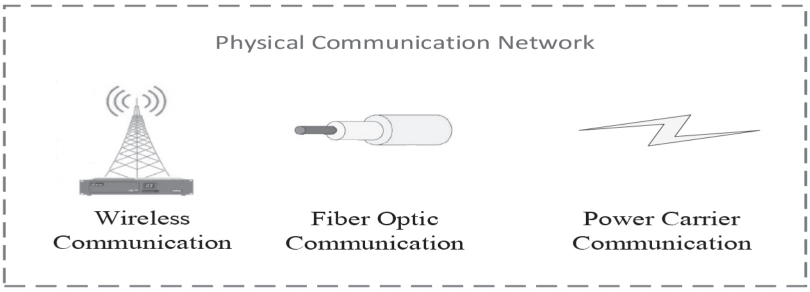

Figure 2 Structure of power information physical system.

equipment as well as other secondary power equipment and information transmission equipment [12]. Figure 2 shows the structure of the physical system of power information, including various primary power devices, communication devices and communication protocols.

3. CURRENT STATUS OF RESEARCH ON OPTIMAL SCHEDULING OF POWER SYSTEMS

The main task of optimal power system scheduling is to plan the power output of each generating unit, fully consider various constraints in power system operation, and ensure safe and reliable operation of the power system while ensuring minimum power-generation cost [13]. While ensuring the safe and stable operation of the power system, the scheduling strategy has to the power output of each unit in the system to make the lowest total cost of system operation and achieve the best profit [14]. Optimal scheduling is crucial to the development of national economy and the economic and reliable operation of power systems, and has always been the focus of attention of academics and power engineers.

The optimal scheduling of power system has several characteristics that make it difficult to find the optimal solution for the model. Scholars have conducted much research on this problem and proposed various approaches to produce an optimal model. To summarize, there are two kinds of optimization algorithms: classical optimization algorithm and artificial intelligence optimization algorithm.

(1) Classical optimization algorithm

Equal micro-increase rate method: The basic principle underlying the equal micro-increase rate method is that each unit consumes fuel at the equal micro-increase rate to equalize the system power, in order to minimize the amount of coal consumed by the units. The approximation function is used to simulate the wind power prediction error, so that the objective function is differentiable and meets the conditions for the application of the equal micro-increment rate criterion to obtain the results of the economic dispatch model solution [15].

Priority sequencing method: This prioritization method involves arranging the dispatchable units in the system in a certain order, and then switching off the units in this order according to the size of the system load. By simulating the charging and discharging behavior of EVs, an optimal dispatching model of the microgrid system with grid-accessible EVs is obtained, and the optimal order method is used to verify the validity of the model for grid-accessible EVs [16].

Although the above methods are relatively mature with widespread engineering applications, the classical algorithms are prone to “dimensional disasters”. As the scale of the grid continues to increase and the number of variables in the model continues to grow, the classical optimization algorithms require continuous and differentiable objective functions. Therefore, in order to solve the above problems, artificial intelligence methods are gradually being applied in the field of economic dispatch research.

(2) Artificial intelligence optimization algorithm

With the continuous advancement of computer technology, artificial intelligence technology is also developing rapidly, and artificial intelligence algorithms are being widely used. Several new and efficient heuristic optimization algorithms are able to handle models containing discrete variables and multiple constraints, and are widely used for the optimal scheduling of power systems [17].

In response to the disturbance caused by wind power grid connection to the safe operation of the power system, a dynamic optimal dispatching model of power system is proposed using planning theory with artificial intelligence chance constraints, which is achieved by using a hybrid algorithm combining sequential operation theory and genetic algorithm to improve the model’s computation speed [18]. The role of wind power limit penetration power in large-scale wind power grid-connected systems, a clean optimal dispatching model for wind power grid-connected generation systems is proposed using a genetic algorithm. The results show the effectiveness of the proposed model and offer a new decision-making basis for solving problems associated with large-scale wind power access systems.

4. MULTI-OBJECTIVE EVOLUTIONARY ALGORITHMS AND RELATED APPLICATIONS

(1) Common algorithms for multi-objective evolution

In recent years, evolutionary algorithms, a new approach to stochastic optimization, have been successful in finding better

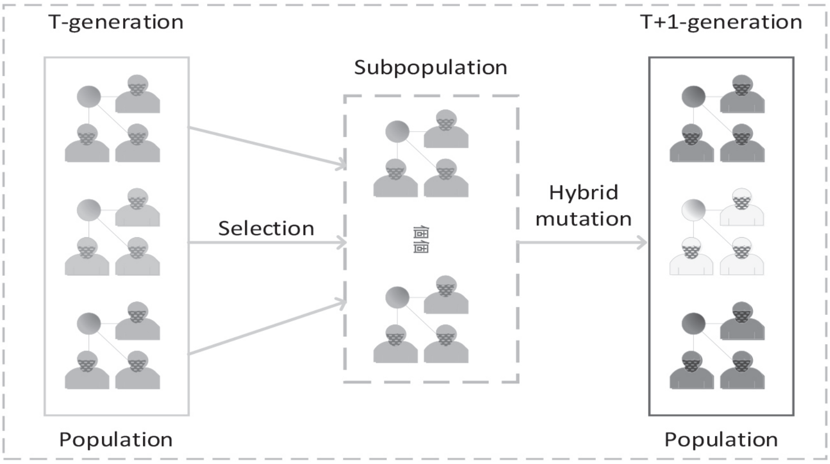

Figure 3 Vector evaluation multi-objective evolutionary algorithm.

solutions to problems in several fields [19]. Evolutionary algorithms are efficient search methods based on genetic principles associated with natural selection. They can dynamically find good solutions to problems over time in large systems containing large amounts of noise that disturb industrial data, and are widely used for optimal control of large systems. The evolutionary algorithm fitness value used to evaluate the performance of the individual offspring must be scalar, and the scalarization process should be a monotonic transformation process of the objective function coordinates to ensure that the individual obtains the best Pareto fitness value [20]. In this non-unique transformation process, when the scalar fitness value is obtained, the evolutionary algorithm will generally select the species according to the usual method. Currently, there are three methods that can be used to solve multi-objective optimization using evolutionary algorithms.

1) Scalarization algorithm

Scalarization algorithms generally optimize multiple objectives by turning them into a single objective, mainly the weighted method, the very large and very small method, and the objective vector method. These methods are almost identical to the general single-objective optimization methods. The main advantages of these three methods are their computational validity and the possibility of generating strong solutions, since they do not require inter-individual comparisons to obtain optimal solutions, and these solutions can often be used as initial solutions for other methods.

2) Group-based non-Pareto algorithm

This method, also known as the vector evaluation method, is distinguished from the traditional simple evolutionary method by its ability to filter the population operator. The vector evaluation method was perhaps one of the first ways proposed to solve multi-objective optimization problems. It constructs n subpopulations, each corresponding to the objective function, and the individuals in each subpopulation are screened according to the ratio of their corresponding objective functions. Then, the individuals in all subpopulations are crossed and mixed with variants, as shown in Figure 3.

It should be noted that the method maximizes the objective function rather than minimizing it. Through the rational selection of weighting functions, the vector evaluation method seeks to make adaptive and balanced improvements to the respective objective functions. If there is a large improvement in some of the objective functions, the subsequent species selection should be favorable for the remaining other objective functions, and the vector evaluation method can maintain the diversity of the multi-objective evolutionary algorithm populations compared with the pure weighting method. Related researchers have devised multi-objective evolutionary strategies whereby next-generation populations are usually generated by proportional selection and are randomly selected with predetermined probability using a certain objective function. This method can be combined with the concept of Pareto dominance ranking to form an extended multi-objective evolutionary algorithm for vector evaluation, as shown in Figure 4.

The vector evaluation method is one of the pioneering approaches in multi-objective evolutionary optimization methods. The biggest advantage of these approaches is that they are very simple to implement.

3) Pareto-based sorting algorithm

The Pareto-based ranking algorithm has also become a Pareto tournament selection method, which is not limited to a comparison between two individuals, but uses a portion of the population to determine the prevailing situation. Since the method does not use Pareto-type selection for the whole population, but only a portion of the population in each generation, its main advantage is that it is very fast and produces better dominance scenarios in the Pareto sense. However, its main disadvantage is that the application of shared factors is demanding and this method also has to select the appropriate size of the tournament individual to ensure the effectiveness of the method, thus limiting its extension in solving practical engineering problems.

(2) Advances in multi-objective evolutionary algorithms

Recently, as the multi-objective optimization problem has gradually become the focus of attention, many new meth-

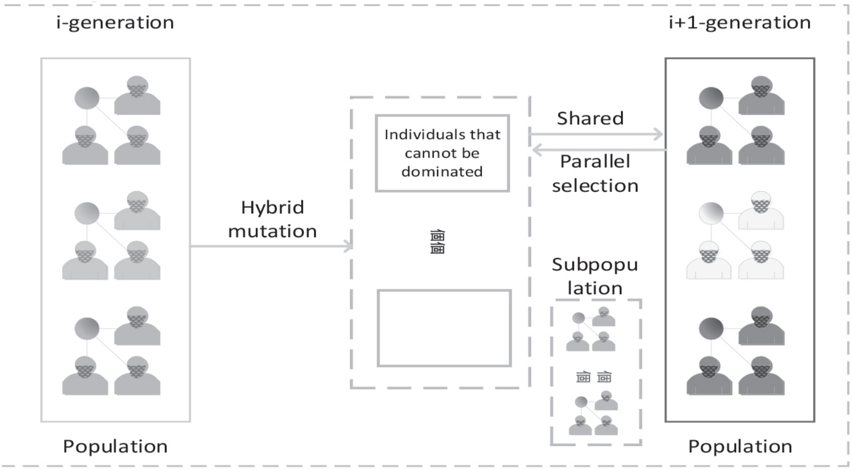

Figure 4 Extended vector evaluation multi-objective evolutionary algorithm.

ods have been used to apply multi-objective evolutionary algorithms to improve their performance. These methods are proposed so as to provide new ideas for subsequent research on multi-objective evolutionary algorithms, among which the more representative ones are: dynamic multi-objective evolutionary algorithm, multi-objective evolutionary algorithm based on immunity principle and fuzzy preference-based multi-objective optimization algorithm.

1) Dynamic multi-objective evolutionary algorithms

With dynamic multi-objective evolutionary algorithms, the target space is divided and individuals are ranked more efficiently based on health indices, and density indices are proposed for the determination of population crowding and the selection of Pareto individuals. A series strategy is used to determine the increase or decrease of population size. The method selects the appropriate number of spatial compartments in order to greatly reduce the computational power of the algorithm, and allows the solution set to converge quickly to the desired Pareto optimal point through dynamic adaptive changes in population size. The testing of the algorithm on several optimization problems has shown that this novel algorithm is superior.

2) Multi-objective evolutionary algorithm based on immunity principle

A multi-objective evolutionary algorithm that maintains population diversity is proposed based on immune adaptive regulation. It uses the concept of the biological immune mechanism in nature during multi-objective evolution, calibrating the degree of adaptation by calculating the antibody concentration, and reducing the selection of similar individuals to effectively maintain population diversity, thus determining the search performance of multiple multi-objective evolutionary algorithms with large theoretical value. The method has been applied to the multi-objective scheduling of flow shop operations, and good design results have been obtained.

3) Fuzzy preference-based multi-objective optimization algorithm

The solution obtained by the multi-objective evolutionary algorithm is an ensemble, and for most engineering problems a final decision filtering of the solution set is required. The fuzzy preference-based approach determines the weights when using the linear weighting method precisely according to the various preferences of the object, so that the resulting solution set is assigned to the interval expected by the decision maker. The method keeps the weights in a certain interval through preference relations, which not only provides more choices for the decision maker, but also makes it easier to choose when there are too many Pareto optimization solutions.

(3) Application of multi-objective evolutionary algorithms in power systems

Multi-objective evolutionary algorithms can be applied to different design problems in many fields, and it is one of the most widely-used algorithms in controller design problems. For controller parameter tuning, the Pareto ranking method combined with the small habitat technique is usually applied to define the objective vector fitness function in the time or frequency domains. The specific applications of the multi-objective evolutionary algorithm for power systems are as follows:

1) Optimized installation of synchronous phase measurement unit

The NSGA (Non-dominated Sorting Genetic Algorithm) method is used to transform the problem of selecting the installation location of measurement units into a bi-objective optimization problem. Firstly, the number of installed measurement units is detected based on the premise that the system topology space is observable, so that the number of measurement units is minimized; at the same time, the maximum redundancy of measurement units is detected, so that the number of measurement units is maximized after any line fault exits from the system. The multi-objective evolutionary method is used to select the specific installation locations of measurement units, and the Pareto-optimal solution set is obtained with respect to the above two objectives.

2) Multi-objective optimal scheduling of power system

A multi-objective evolutionary algorithm is applied to the optimal scheduling of power systems for the purpose of comparative analysis. Unlike the traditional economic dispatch design method, the multi-objective evolutionary algorithm investigates not only fuel consumption but also gas emissions as a factor, and transforms the optimal dispatch into a dual-objective optimization problem with constraints to be addressed.

3) Using it for grid planning

A variable-weight multi-objective evolutionary algorithm is proposed to solve the problem of the multi-objective nature of grid planning. By using the concept of multiple groups, it can better accomplish multi-objective normalization in the optimization process and accelerate the optimization speed. The variable weight factor of the algorithm allows the planner to easily add the decision focus tendency to the optimization process to obtain a solution that better meets the actual needs. The grid planning model is a finite bi-objective optimization model that optimizes both the annual investment cost and the annual network loss cost. The nodal system is calculated and planning solutions with different decision priorities are obtained.

5. This needs to be specific.

5. PROBLEMS RELATED TO THE OPTIMAL OPERATION OF THE POWER SYSTEM

(1) Energy issues

At present, thermal power generation is the main source of electricity, followed by hydroelectric power generation. The raw material used for thermal power generation is coal, but coal combustion will cause greater environmental pollution, and the relationship between the energy supplied and energy consumed is not proportional so, in effect, the demand for generated power is slightly lower than the supply. Although hydroelectric power generation does not pollute the environment, the demand for hydroelectric power generation is not high due to its unique characteristics. Hence, it is necessary to seek new energy sources that generate electricity, reduce environmental pollution, and use energy efficiently.

(2) Management issues

At present, there is inadequate management of the electric power system, the professional person is shortage, the information and emergency services are slow to respond, and accidents occur frequently. Traditional power system management adopts a hierarchical management mode, and there are generally problems such as professional mismatch of management personnel and ineffective articulation of the management system. These conditions not only lead to frequent mistakes in power dispatching, but also make the power supply uncertain and unstable, and the probability of workplace accidents and economic losses increases significantly.

(3) Scheduling coordination issues

After the establishment of the unified power grid, the power grid was effectively divided, requiring a high degree of dispatch cooperation and coordination between regions to ensure energy harmony. However, due to the low level of coordination among regions in the actual power system management process, the above problems cannot be resolved, resulting in the power system posing significant security risks.

6. POWER SYSTEM OPTIMAL SCHEDULING MODEL

Given that the optimal operation of power systems is a fundamental issue, the optimal dispatching model of power systems is intended to optimize the power allocation of each unit at the lowest total operating cost of the generating units under the premise that the power demand of the system load is consistent with the operating constraints of the units. Therefore, optimal dispatching of the power grid is fundamental for the power system to achieve maximum production, efficient management, and operational safety.

(1) Mathematical modeling of multi-objective economic scheduling problems

Due to the limitations of research methods and computational tools, previous studies have reduced economic dispatching to a single-objective optimization under multiple constraints. However, the essence of the economic dispatch problem is a multi-objective optimization problem consisting of equation constraints and inequality constraints, and the main objectives of related research are to: minimize fuel cost, minimize pollution emissions and minimize network loss. Although fuel cost is the main issue in general, a comprehensive review of the trade-offs between multiple objectives will be more helpful for the formulation of dispatching strategies and the determination of different economic operation methods from different perspectives.

The classical optimal scheduling of power systems is as follows.

Objective function:

$$F = F(x, u) \tag{1}$$

where x is the control variable and u is the state variable with a multi-objective basis condition.

$$h(x, u) = 0 \tag{2}$$

After multi-objective optimization, there is:

$$g(x, u) \leq 0 \tag{3}$$

The objective function of the optimal power system dispatch is usually the minimum energy consumption or the

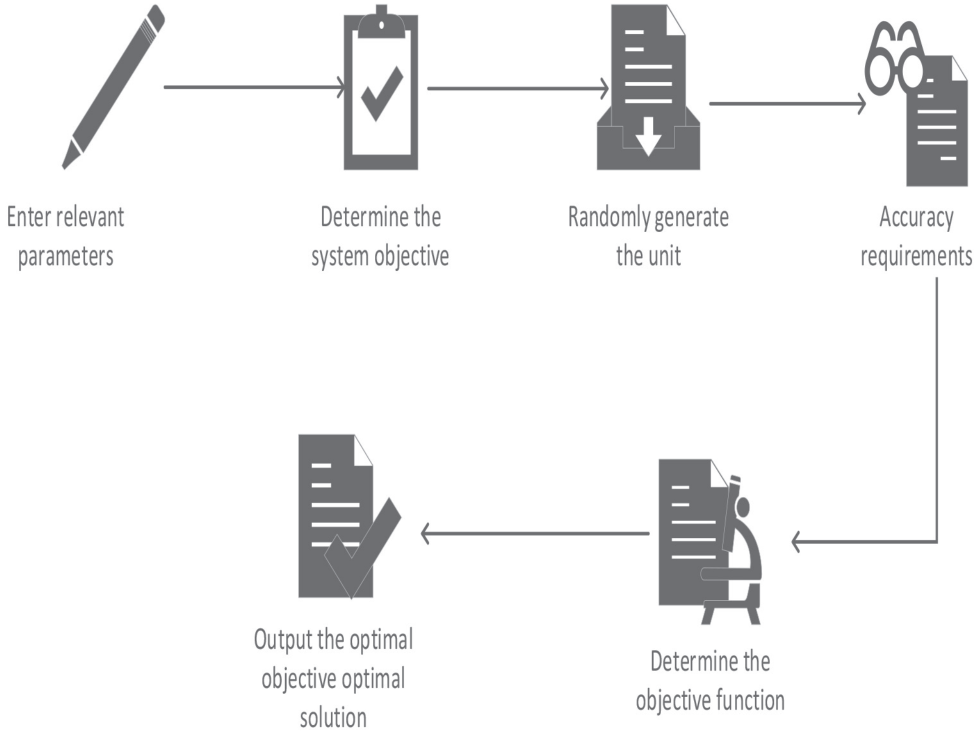

Figure 5 Solution flow of optimization algorithm.

lowest cost of power generation, and the relationship between generator energy consumption and output power is as follows.

$$\widehat{F}_i = f(P_{Gi}) \tag{4}$$

The objective function of optimal power system dispatch is:

$$\min F = \sum_{i=1}^{g} \widehat{F}_i = \sum_{i=1}^{g} f_1(P_{Gi}) \tag{5}$$

(2) Constraints

The main power system constraints are: power balance constraints, operating constraints, and generator power balance constraints.

$$\sum_{i=1}^{N} P_{it} + \sum_{j=1}^{N_w} P_{jt}^{w} - D_t = 0 \tag{6}$$

where D_t is the load at time t, N_w is the number of WTGs in the grid, and P_{jt}^{w} is the output of the jth WTG at time t. To simplify the model, the system network loss is reduced to a linear equation, which is expressed as:

$$P_{loss} = \sum_{i=1}^{N}\sum_{j=1}^{N} P_{Gi} B_{ij} P_{Gj} + \sum_{i=1}^{N} B_{Oi} P_i + B_{OO} \tag{7}$$

B_{ij}, B_{Oi}, B_{OO} is the constant matrix.

Climbing limit: In actual operation, by the physical constraint of the unit, the change of the unit's active output is constrained by its own climbing limit. Therefore, within a certain time interval, the increase or decrease of the unit's active output must be limited to a certain range.

$$P_i^k - P_i^{k-1} \le UR_i \tag{8}$$

$$P_i^{k-1} - P_i^k \le DR_i \tag{9}$$

where P_i^k, P_i^{k-1} is the active output for the kth and k-1st iteration of unit i. UR_i. DR_i are the uphill limit and downhill limit of unit i, respectively.

$$\max\left(P_i^{\min}, P_i^k - DR_i\right) \le P_i \le \min\left(P_i^{\max}, P_i^{k-1} - UR_i\right) \tag{10}$$

where $P_i^{\min}$, $P_i^{\max}$ are the lower and upper limits of the active output of unit i, respectively. P_i is the active output of unit i.

(3) Optimal scheduling model

The optimal solution is actually a multi-constrained mixed-integer nonlinear programming approach as can be seen from the proposed optimal scheduling model. The algorithm uses the global search method, which has the same convergence and high solution accuracy, and has obvious advantages as the algorithm can solve multi-objective optimal scheduling problems of power systems. The multi-objective optimization function of the proposed algorithm solution is depicted in Figure 5.

(4) Analysis of algorithm results

The multi-objective optimal dispatching model proposed in this paper is constructed based on mathematical software, and the optimization model is programmed and applied by combining an actual regional power grid with an example analysis. In order to determine the superiority of the

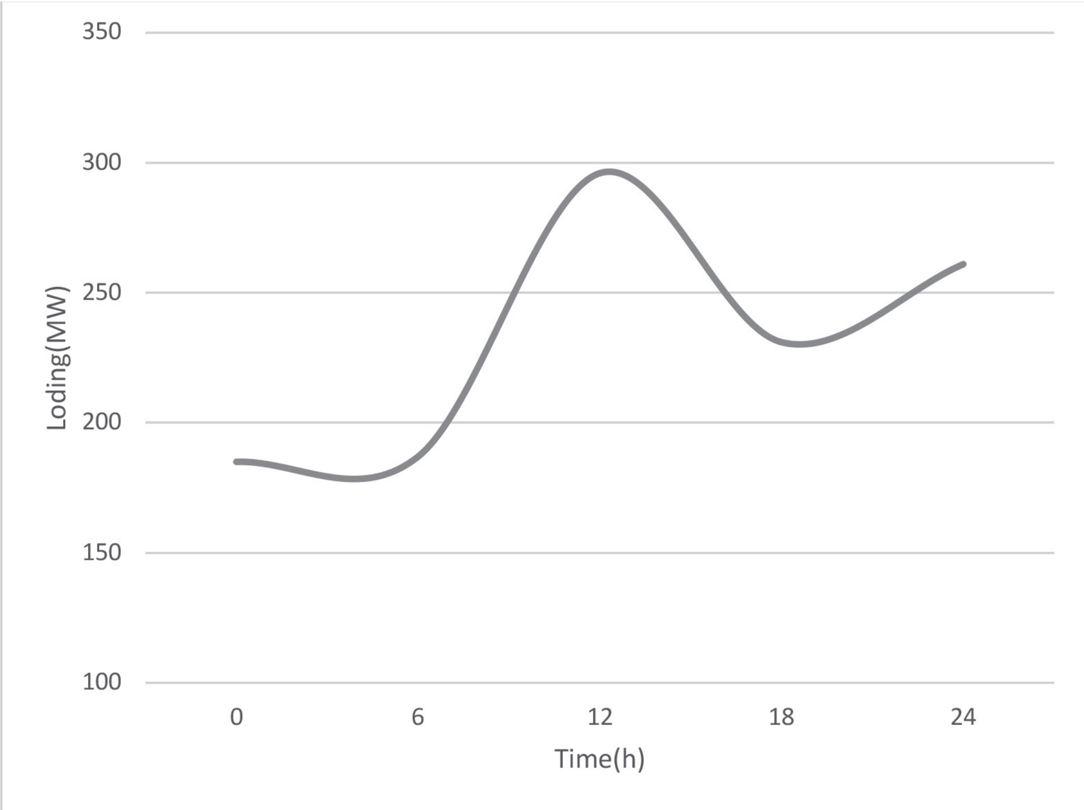

Figure 6 Load output prediction curve.

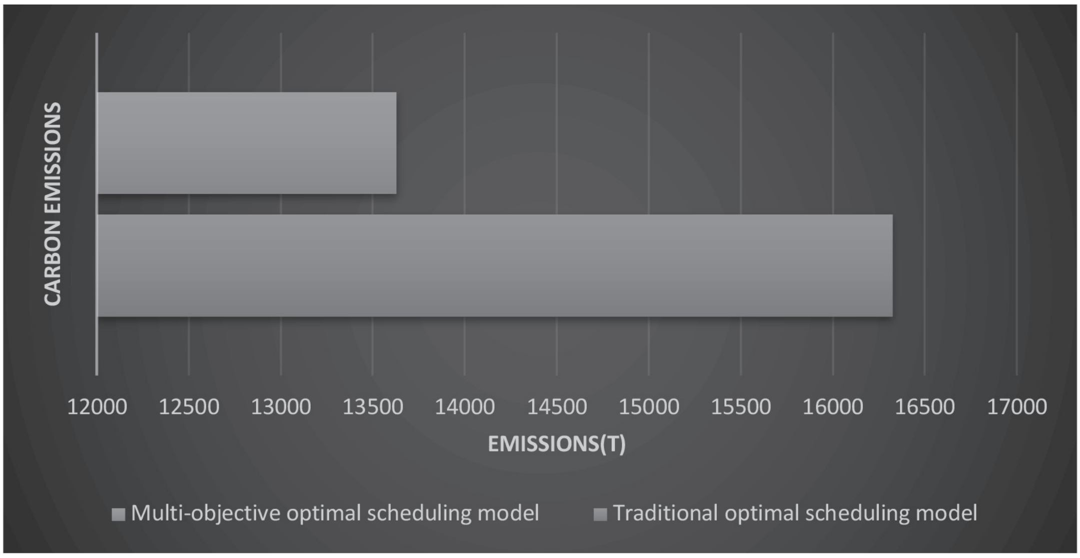

Figure 7 Carbon emission results for the multi-objective model and the traditional model.

proposed environmental protection and economic efficiency dispatching model by comparing it with the traditional optimal dispatching model, a calculation example is used for analysis. The test data comprise 6 thermal and 6 hydroelectric units with a 24-hour time value and a carbon emission trading price of \$20/t CO1. The curve of the system load output is shown in Figure 6.

For comparison, Figure 7 shows the carbon emissions of the multi-objective optimal dispatch model and those of the conventional optimal dispatch model. The simulation results indicate that if only the traditional optimal scheduling model is used, without environmental protection and the economy taken into account, the generation cost of both conventional hydropower units and thermal power units is low, but the carbon emissions will exceed, by a large margin, the target value set by the system. The main reason is that the optimal scheduling model does not take into account the economics of carbon emissions, which makes it difficult to use conventional units with low carbon emissions and high generation costs efficiently.

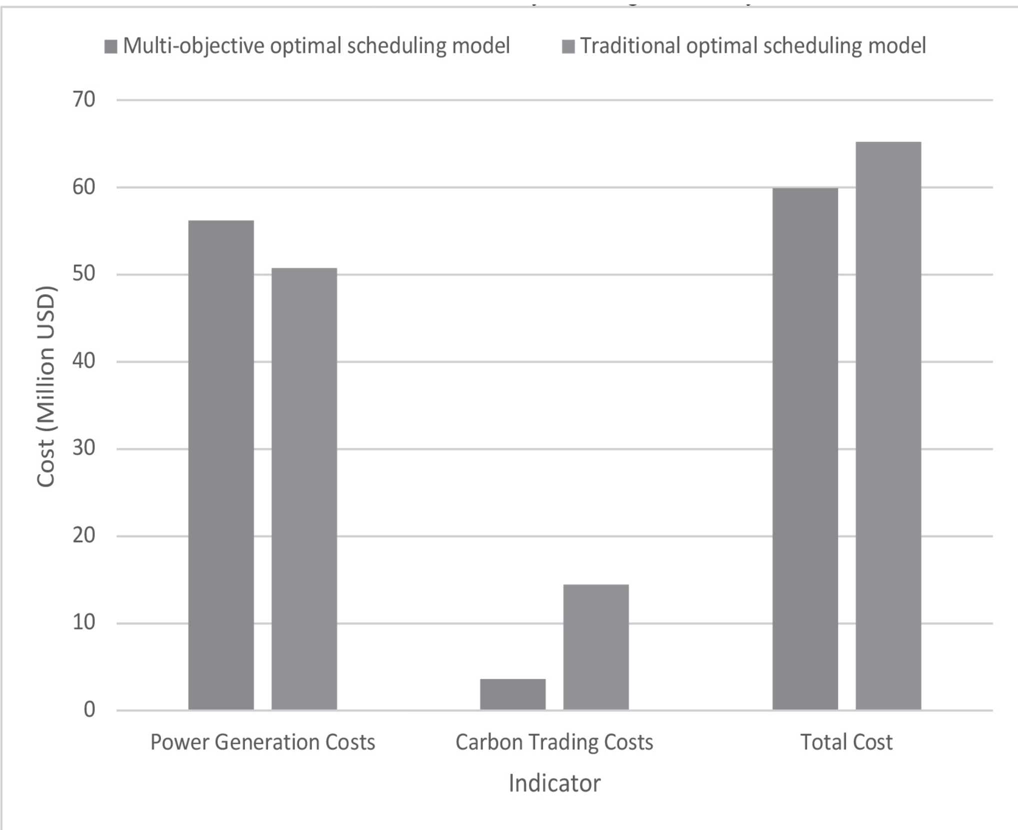

Figure 8 Results of power generation cost, carbon transaction cost and total cost for the multi-objective model and the traditional model.

For comparison, Figure 8 shows the generation cost, energy saving and emission reduction carbon trading cost and total system cost indexes of the multi-objective optimal dispatching model and those of the traditional optimal dispatching model. Using the established optimal dispatching model with environmental protection and economic benefits, the carbon emissions and the corresponding trading cost are significantly reduced despite the increase of unit output in the case of carbon emission cost, thus effectively reducing the total system cost.

Hence, compared with the traditional dispatching model, the multi-objective evolutionary algorithm dispatching model not only improves the optimization degree of power system by about 8.95%, but also promotes the optimization of power operation system, helps to manage any defects in the power operation process, and gradually achieves the stable upgrading of the power system.

7. CONCLUSIONS

The optimal scheduling of a power system plays a key role in ensuring the safe and efficient operation of the system. In this paper, after discussing the algorithms commonly used for power system optimal scheduling, a multi-objective evolutionary algorithm is proposed and used to produce optimal scheduling of a power system. This makes a significant contribution to the theory and implementation of economic scheduling in power systems. Furthermore, this paper explores the optimal scheduling problem in more depth, concluding that the multi-objective evolutionary algorithm has a broad application in terms of the safe and economic operation of power systems.

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