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Application of Firefly Algorithm in Scheduling Optimization of Combined Cooling, Heating and Power with Multiple Objectives

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This paper aims to investigate the application of firefly algorithm in scheduling optimization of combined cooling, heating and power with multiple objectives. Based on the latest multi-system optimization model of combined cooling, heating and power, a comprehensive analysis of various limiting factors such as cost, energy utilization, and environmental protection was conducted. Firefly algorithm was used to perform single-target search. The results show that through the firefly algorithm, the speed of search can be improved, and an optimal scheduling scheme of cooling, heating, power system with multiple targets can be found in a very short time. In this system, the application of firefly algorithm is beneficial to solve the system optimization problem. Therefore, it has certain promotion and application value.

1. Introduction

With the continuous improvement of people's quality of life and economic level, the demand for electricity is becoming higher and higher, and the traditional electrical equipment functions can no longer fully meet current people's requirements. Therefore, a device that combines heating and cooling has emerged. Under the rapid development of modern technology, the scope of application of the combined cooling, heating, and power (hereinafter referred to as CCHP) supply system has continued to expand, and its safety has also been highly concerned by various industries. The CCHP is mainly composed of heating and refrigeration equipment, generators, heat recovery system and auxiliary boiler of these four parts, and multi-functional system is a kind of comprehensive utilization of energy, also can be regarded as a whole to realize the energy cascade utilization. According to relevant data, the energy utilization rate of CCHP systems can reach up to 80%, and its energy utilization rate is obviously higher than that of traditional independent energy supply systems. The large-scale CCHP system can quickly track the user load during the operation process, and it is also helpful to improve the stability of the system. It is one of the keys to ensure the power quality. At the same time, the medium and small CCHP systems can also be configured with a variety of structures to meet the energy requirements of multiple users. Because CCHP system has the characteristics of environmental friendliness, low cost, and high energy utilization rate, it occupies a dominant position in the energy supply system and is an indispensable part of people's production and life.
Based on the excess power generated by the CCHP system during operation, it is received by the power system. In order to ensure the safety and stability of the power system, the potential hazards of the power system must be comprehensively analyzed and studied in the process of CCHP system optimization and dispatch. For the power system and the CCHP supply system operation, it has a very important significance.

2. Literature review

The CCHP (Combined Cooling Heating and Power) system is also called the CHP system. As a new energy utilization scheme, the combined cooling heating and power system can realize the comprehensive cascade utilization of energy. At present, the developed countries in the world have studied and put into production a large number of combined cooling heating and power (CCHP) system using their own years of technology

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accumulation. And after the end of the cold war, in order to make full use of existing resources, the United States has transformed a large number of eliminated aircraft engines into gas turbines as the main capacity device of the CCHP system. After this, a large range of power outage time caused by the "9.11" time has occurred, and many developed countries have studied the energy supply mode. In order to prevent a large scale power outage, the distributed generation system deployed in the region is strongly advocated to avoid a large scale of electrical network collapse.

The combined cooling heating and power (CCHP) system integrates the generators, auxiliary boilers, heat recovery systems, refrigeration and heat production equipment, which can be used as a whole to achieve the comprehensive and cascade utilization of energy. The data show that the energy utilization of the CCHP system can reach 60% to 80%, which is obviously higher than that of the traditional independent energy supply system (Jiang et al., 2016). The large-scale CCHP system can quickly track the user load, improve the stability and power quality of the system, and the medium and small CCHP system can also configure the variable structure to meet the different user's energy needs. Therefore, because of the high utilization rate of energy, low cost and friendly environment, the combined cooling heating and power system is an indispensable part of life as the energy supply system. However, the first letter of the word "C" in the English abbreviation word "CCHP" can mean combined, which means the inherent complexity of energy utilization. Because cooling, heating and power are produced by different equipment, all the equipment must be operated under coordination at any time. During the whole transformation, it is not only influenced by internal factors, but also the load is subject to the weather, the seasonal change of the four seasons, the industrial production and the society at any time. In order to deal with such complex problems, the CCHP system must work in safety mode and economic mode. Therefore, the research on energy utilization, environmental protection and safety of CCHP system cannot be ignored. The traditional optimization method and application of CCHP system are tracking power load mode and tracking thermal load mode, and selecting the best operation mode of the current CCHP system according to the comprehensive performance index. Xue proposed a method based on thermal demand management and power demand management. The main consideration is profit oriented optimization management technology (Xue et al., 2014). Jayasekara, in terms of load uncertainty and multi constraint scheduling risk management technology, used a model predictive control method to reduce the risk of assessment (Jayasekara et al., 2014). For the problem of CCHP system economic scheduling, some researchers also carried out some research. For instance, Marave and others put forward hybrid electrothermal technology, and the purpose was to select the best daily fuel value, so that emissions and costs could be reduced (Marave et al., 2013). However, the current main optimization methods involved the optimization of the CCHP system and lacked the consideration of the impact on the power system. The power supply of the medium and large CCHP system will indirectly affect the power system, making some potential problems. For example, when the superfluous electricity generated by the CHP system will be delivered to the power system, it may cause the energy loss, low voltage and phase jump of the power system lines. From this point of view, the potential danger of the power system must be considered in the process of optimal scheduling of the CCHP system, which will be of great significance to both the cooling and power supply system and the operation of the power system.

The firefly swarm algorithm is a heuristic swarm intelligence algorithm proposed by the scholar Wang for the first time in the research and improvement of the continuous optimization problem of ACO solution. Wang and others successfully applied it to group robot cooperation (Wang et al., 2013). The idea of the algorithm comes from the higher biological activity of higher fluorescein in the mating behaviour of firefly. After that, Wang improved the dynamic decision domain of firefly algorithm (Wang et al., 2014). In the following year, Wu and so on made a preliminary exploration of the convergence theory of the algorithm (Wu et al., 2014). Subsequently, Wang and others applied the algorithm to multi extremum function optimization (Wang, et al., 2014). In 2016, Ceng Guotai of Taiwan applied the algorithm to cluster analysis successfully. In the same year, Li Yingshan of Taiwan applied it to the layout of wireless sensor networks. In 2017, some scholars proposed some improved algorithms for the algorithm of firefly swarm. In addition, there has not been a paper published on the algorithm of firefly swarm so far. In a word, there are relatively few researches on firefly swarm algorithm at home and abroad. At present, the research on firefly swarm algorithm is mainly focused on the following two aspects: firstly, it focuses on improving the basic framework of the firefly swarm algorithm and establishing the relevant theoretical basis. Secondly, it pays attention to how to expand the firefly swarm algorithm to other application domains, and designs more effective algorithms for specific problems.

To sum up, the research on firefly algorithm has been gradually improved, but its research on multi-objective optimal scheduling of CCHP is rare. As a result, based on the above research status, this paper mainly takes into account the optimization of two overall systems of the power system and the combined cooling heating and power system. The purpose is to improve the economic efficiency, security and environmental benefits of the two whole systems. Based on the established dual objective optimization model, an improved firefly algorithm based on normal constraints is proposed, and the multi group search optimization algorithm, multi-objective evolutionary algorithm and improved non-inferior sorting genetic algorithm are simulated and compared. Finally, in order to verify the single target optimization ability of IFA, the multi-objective problem is transformed into a single objective problem through linear weighting, and then the simulation and contrast particle swarm algorithm, the traditional firefly algorithm and the differential evolution algorithm are simulated and compared.

3. Research method

The research of this dissertation mainly considers the optimization of the two integrated systems of the power system and the CCHP system. The purpose is to improve the operational economic benefits, safety and environmental benefits of the two integrated systems. Based on the established bi-objective optimization model, NNCIFA, MGSOA, MOEA, NS-GAII are proposed. Simulations show that: The simulation results show that NNCIFA is superior to other algorithms in the optimization of the cold and heat power supply system and the power system. Finally, in order to verify the single-objective optimization ability of IFA, the linear multi-objective problem is transformed into a single-objective problem. Then the particle swarm optimization (PSOA) and the traditional firefly algorithm (firefly algorithm, FA) are simulated. Differential evolution algorithm (DEA), simulation shows that: IFA converges fast and can obtain optimal solution.

This paper proposes an improved firefly algorithm based on the classic firefly algorithm, using multi-group search, step-size factor a update, merge and delete internal populations, and finally the dominance test method. This purpose is to solve the traditional intelligent method is slow and difficult to find optimal solution. At the same time, NNCIFA is proposed. First, NNC first converts the dual-objective problem into two types of single-objective problems, and then optimizes it through IFA single-target search. This can increase the range, uniformity and convergence characteristics of the Pareto frontier (PF) search. Firefly L to k Attraction factor βkl Cartesian distance: β = β0er2kl (20) rkl = ‖xk- xl‖ (21) Fireflies k are attracted by the brighter firefly L, moving updates: xk= xk+βxl-x (X1-X2) k+ αe (22) Where: a is a constant, it can generally take the [0,1] number, and e is a random number vector obtained by uniform distribution.

4. Research results and discussion

4. 1 Firefly algorithm

The Firefly algorithm is a heuristic algorithm inspired by the firefly's flickering behavior. Firefly's flash is mainly used as a signal system to attract other fireflies. (1) The classic firefly algorithm assumes that the firefly L is brighter than the firefly k, and the firefly k is attracted by the firefly L to move toward lL. (2) Improved firefly algorithm Step 1: Group initialization: Because the optimization effect of the firefly search algorithm does not depend on its initial position, the groups in each group can be obtained through evenly distributed randomized initial positions. This paper adopts multi-group optimization. The purpose is to speed up the convergence: Pi = LB + Ri. (UB - LB) (23) In the formula: Pi, LB, Ri are the result of the initialization of group 1, group 2, and group 3 respectively, and LB and UB are the upper and lower limits of the firefly population. Ri is the uniform random matrix between [0,1] and the operator "." The product of the two matrices. Step 2: Population update (movement) (1) Group internal initialization: x = x + δ (xmax-xmin) (24) (2) Change a value α = 1()-M α (25)M = 1 - e1 -iter100(26) where: it is the number of iterations. As the number of iterations increases, the attraction rate will slow down as it gets closer to the attractor. (3) Merge sort: Initially initialized internal populations and updated populations are merged and then ranked according to their brightness from the largest to the smallest; (4) Deletion within the population: Because the population moves faster in order to prevent rapid separation from the attracting side (brighter squares), the screening combination is combined and the firefly that combines the first half of the brightness is selected. This population is the current new population. Step 3: After the dominance test for each group iteration, because the three populations have their own minimum optimization values to obtain the minimum optimization value; the dominance test method is used to obtain their minimum values. Step 4: The maximum number of termination condition iterations will terminate the search for the optimal value.

4.2 NNC method

The NNC method is one of the commonly used methods for solving multi-objective problems. By uniformly cutting the multi-object solution space, a series of single-objective optimization problems are constructed to obtain a uniform PF. Figure 1 shows the PF diagram after normalization. The concave curve at the bottom left is PF. F1 and F2 are the two endpoints of PF. The connection at both ends is the Utopia line. This paper proposes to construct two kinds of single-objective problems. The classification is bounded by point A. If part A of point A solves the space, then this kind of single-objective problem transforms along f1 single target search. On the contrary, the other type is a single target search along f2. Because the two objective functions have different dimensions and orders of magnitude, however, by transforming the single-objective problem by constraints, the spatial normalization of the objective function must be converted: I = (f1, f2) = (u1(x) - umin, x1umax, x1-umin, x2, u2 (x)- umin, x2umax, x2- umin,x1) (27) where: (u1, u2) corresponds to the (f1,f2) function before the specification.

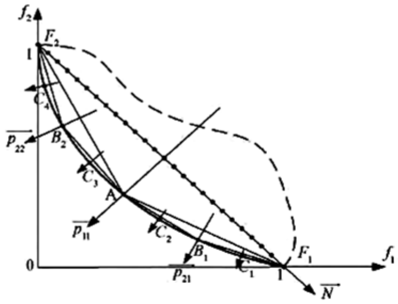

Figure 1 : Pareto frontier bi-objective of NNC method

4. 3 The improved firefly algorithm based on normal constraints

This paper proposes a bi-objective optimization problem based on NNCIFA for solving CCHP system. Firstly, the NNC method is used to construct two kinds of single-objective problems and then a single-target search is performed by the improved firefly algorithm to find their optimal single-target solution. All single-target solutions correspond to the reactive frontier. NNCIFA solves the multi-objective optimization model, and the convergence criterion adopted is one of the following conditions: first, the maximum number of iterations (60 times set in this paper); Second, the pareto point is maximum (33 points and 17 points are set for this article).

4.4 Simulation examples and analysis

4. 4.1 Parameter setting

The standard IEEE39 node system is taken as the research object and the system simulation part. The user load data of the thermoelectric power supply system is used in a Shenzhen building, and the 19th node of the standard IEEE39 node system is used to connect the cold-heat power supply system. CCHP system and IFA parameter values listed in table 1, respectively, in addition, in order to simplify the analysis and calculation of PGU electricity conversion efficiency, heat recovery system conversion efficiency and the conversion efficiency of auxiliary boiler set to a fixed value.

Table 1: CCHP system and IFA parameters

	parameter	value
CCHP system	ηGT、ηrec	0.9、0.8
	COPch、ηhc	0.7 0.8
	Cf (Yuan/KW·h)	3.23
	Cs (Yuan/KW·h)	0
	HVg (kJ/m3)	389.31
	ηboiler	0.8
IFA	A (Initial value)	0.5
	β0、γ	0.2、1

4.4.2 Simulation and analysis

In order to evaluate the comprehensive performance index of the proposed dual target algorithm, three basic indexes are considered for evaluation. These three basic indicators include: (1) Convergence: the distance between pareto front and real front is the smallest; (2) Span index: the greater the span value between the endpoints obtained by pareto front; (3) Spacing: the spacing uniformity of pareto points remains obvious. In order to make a fair comparison, the proposed two-objective algorithm and the comparison algorithm were optimized 20 times, and there were 33 points along pareto. The network loss of the power system and the operating cost of the combined cooling and heating power supply system are the main two objective optimization objectives. The simulation statistics are shown in Table 2. The statistical results of convergence indicators of various algorithms are shown in Table 3.

Table 2: Statistical span metrics of different algorithms (p. u)

algorithm	NNCIFA	MOEA	MGSOA	NSGAII
minimal value	1.4541	0.568	1.2342	1.184.4
maximum	1.6532	0.986.5	1.6565	1.2542
mean	1.5536	0.7774	1.4454	1.2193
variance	0.4631	0.2681	0.3485	0.1042

Table 3: Statistical convergence metrics of different algorithms (p. u.)

algorithm	NNCIFA	MOEA	MGSOA	NSGAII
minimal value	0.0048	0.0108	0.0096	0.0085
maximum	0.0112	0.0421	0.0265	0.0456
mean	0.0080	0.0265	0.0181	0.0271
variance	9.561	467.3	56.20	452.6
algorithm	NNCIFA	MOEA	MGSOA	NSGAII
minimal value	0.346	0.0432	0.0359	0.469
maximum	0.358	0.1348	0.0410	0.2156
mean	0.352	0.0890	0.0385	0.1313
variance	3.6821	13.621	7.3452	38.659

Under the same optimization objective function, the proposed algorithm is clear. It should be pointed out that: The variance of the proposed interval between the table 2 and the convergence index in Table 3 is the smallest, which is obviously superior to other algorithms, which means that the Pareto front is the most uniform and the closest to the real Pareto boundary.

Taking Figure 2 as an example, the Pareto front endpoints are (1.614 = 7, 0.822 4), (1.634 2, 0. 778 0). Obviously, these two values are Euclidean distances. The other algorithms are the largest, thus confirming the correctness of Table II. The proposed algorithm Pareto front maintains a wide distribution range. At the same time, we can see from Fig. 3 that the proposed algorithm is obviously more evenly distributed and seldom fluctuates, thus further verifying that the proposed algorithm is feasible and highly efficient in solving the dual-target problem.

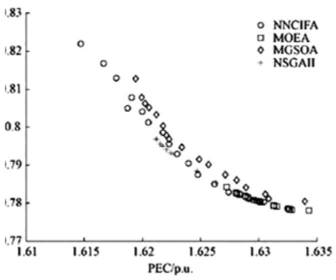

Figure 2: Pareto frontier of power DeV and PEC

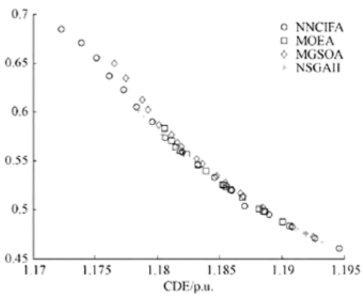

Figure 3: Pareto frontier of power Loss and CDE

In order to analyze the optimization effect of the improved firefly algorithm in the CCHP system, comprehensive performance indicators were analyzed by analyzing the convergence speed, running time, and optimal solution performance index. In addition, for the sake of fairness, the algorithms were run thirty times and iterated 200 times. The average time of each iteration is shown in Table 4.

Table 4: Running time per generation of different algorithms

	IFA	PSOA	FA	DEA
Average running time/s	395	383	389	452

5. Conclusion

In order to further promote the development of the CCHP system, we must respond to the concept of sustainable development advocated in the current social and economic development process, increase its safety, and increase its research on environmental protection technologies and performance, and constantly introduce new ones. The technology will make the functions of the CCHP system more perfect, meet the production needs of different people and companies, and then realize the sustainable development of the CCHP system. Therefore, the optimization of power system and CCHP power supply system is very important. According to the optimization of rice noodles for the power system and the combined cooling, heating and power system, an improved firefly algorithm and an improved firefly algorithm based on the specification normal constraints are proposed. These two algorithms are compared with FA, DEA, and PSOA, respectively, and are used. Linear weighted conversion single target to verify IFA validity. At the same time, the proposed two-target algorithm NNCIFA is compared with the three intelligent algorithms MGSOA, MOEA, and NSGALL, and then verified by the PE indicator. The verification data show that the proposed algorithm has certain advantages.

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