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Multi-object optimization algorithm applied in integrated energy system : a review

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Abstract
In the face of the current severe energy problems, we should increase the proportion of renewable energy development, especially focus on the development of wind power and solar energy, and realize the diversification of energy utilization. Integrated energy system (IES), combined with multiple renewable energies, can improve energy efficiency, and reduce carbon emissions by optimizing energy complementary strategies. In order to solve the problems caused by insufficient energy supply and other reasons, researchers introduced multi-objective optimization algorithm into the application of integrated energy system. The multi-object optimization algorithm can deal with the optimization model with multiple objectives, multi-level and multi-criteria, and obtain a group of non-dominated solutions (Pareto optimal solution). The algorithm can deal with the problems with multiple conflicting objectives appropriately.

Keywords:*Integrated energy system,Multi-object optimization algorithm.*

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I. INTRODUCTION

With the development of national industrialization, carbon emissions have increased rapidly, leading to global warming and threatening the earth's ecology and human health. Energy is an important pillar of social and economic development and progress. While the demand for energy is increasing, the problems of environmental pollution and theimbalancebetween energy supply and demand is becoming increasinglysevere. Therefore, the rational utilization of renewable energy and the improving of the efficiency of fossil energy have become the focus of research. Under the goals of "carbon peak" and "carbon neutral", the new energy industry will usher in high-quality leapfrog development. Achieving the core objectives of the Paris Agreement requires large-scale reform of the energy system. In order to achieve the goal of decarbonization and ensure the safe, stable and efficient operation of thepower grid, it is necessary to accelerate the integration of "source-network-load-storage" and the development of multi-energy complementation, and build a comprehensive energy system with multi-energy complementation. At the same time, it is increasingly urgent to explore a broader clean energy consumption model, a more efficient energy comprehensive utilization method, and a more optimized means of energy system regulation. Therefore, the centralized and distributed renewable energy power station network from different sources - "Integrated Energy System (IES)" - will become the backbone of the future power industry.

Integrated energy system is an important way to promote the green development of energy, support the efficient energy utilization, conservation, and emissions reduction. Comprehensive energy is a new technology that comprehensively considers different energy forms such as electricity, heat, cold and gas on the user side. When considering IES, it can be said that there are many alternatives, Define IES as: "IES adopts advanced information technology and management mode to integrate coal, oil, natural gas, electric energy, thermal energy and other energy sources in the region to achieve coordinated planning, optimal operation, collaborative management, interactive response, and mutual assistance among heterogeneous energy subsystems. This is a new energy system that can improve energy efficiency and promote the development of renewable energy. In the coordination and complementarity of various energy sources, the integrated energy system can match dynamic load in the most economical way to maximize the use of energy, so as to provide appropriate energy forms and improve the overall efficiency. Integrated energy system combined with multiple renewable energy sources can improve energy efficiency and reduce carbon emissions by optimizing energy complementary strategies.

However, the traditional IES capacity optimization focuses on integer programming, but cannot optimize the capacity of components. Some researchers have applied multi-objective optimization algorithms to the potential applications of integrated energy in some special scenario from the perspectives of economy and carbon emissions, and proposed a two-level multi-objective genetic algorithm to optimize the capacity and strategy of IES. NSGA-II regulates the capacity of equipment according to external constraints, and then solves the objective function of all individuals by internal constraints, i.e. energy supply and demand balance constraints. Rank ranking is performed according to the pareto level, and the pareto optimal solution method is output; MOPSO calculates the local optimal pbest from the Archive set (storing the current non-inferior solution) according to the pareto governing principle, calculates the Archive set, selects the global optimal gbest, updates the speed and position of particles, and calculates the fitness value to update the Archive set (pay attention to prevent overflow).These multi-objective algorithms can be applied to the integrated energy system to reduce carbon emissions and improve the economy and energy efficiency of the entire energy system.

II. METHODOLOGY

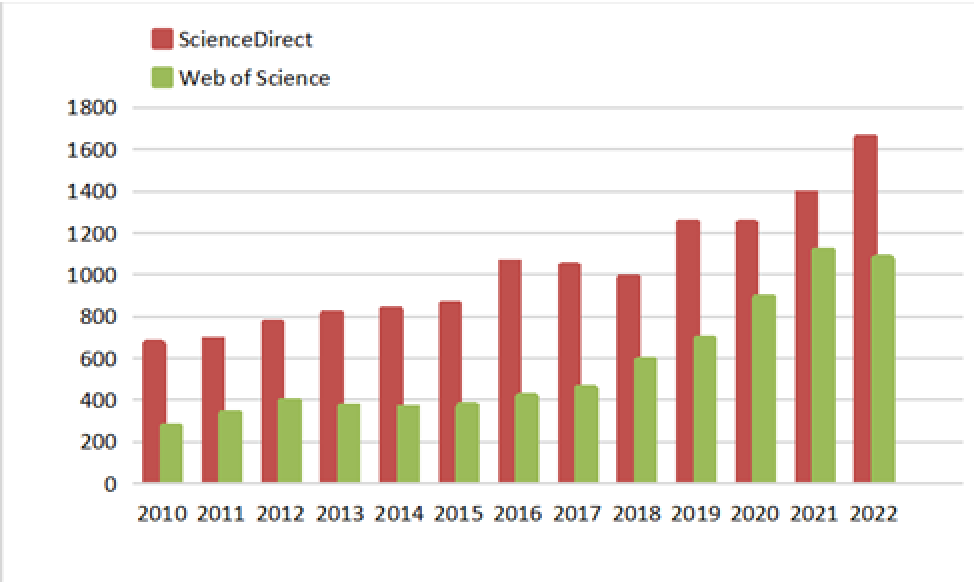

Figure1: Publication of IES related paper from 2010 to 2022

In order to achieve the goal of decarbonization, ensure the safe and efficient operation of the power grid, and build a comprehensive energy system with multiple energy complements, it is necessary to introduce an important way to promote the development of clean energy, support the efficient use of energy and energy conservation and emission reduction - comprehensive energy system. In addition, the multi-objective energy algorithm is used to optimize energy complementary strategies from the perspective of economy and carbon emissions to improve energy efficiency. The two-layer optimization algorithm bases on the matching between the regional user load and supply. the outer layer adopts multi-objective optimization algorithm to carry out systematic multi-objective optimization planning for the capacity of each energy equipment in the system; The inner layer analyzes the constraint conditions of the energy system equipment operation status, carries out linear modeling, and solves the optimal operation strategy respectively. This article reviews 8 literatures about the application of multi-object optimization algorithm in IES from the ScienceDirect and Web of Science databases from 1995-2022, analyzes their application algorithms and conclusions, and finally compares the advantages and disadvantages of various algorithms in application.

III. LITERATURN REVIEW

In order to meet the energy needs of buildings by increasing geothermal energy and solar thermal energy, multiple energy sources are used simultaneously as inputs, and the complementarity between them is used to avoid oversize and reduce the cost of the overall system. SOULEY etal. [4] proposed an optimization model that enables the design of multi-load renewable energy systems with three renewable energy sources: solar (electric heat), wind and geothermal.Multi-energy complementary systems (MRES) consisting of multiple renewable energy sources (e.g. wind, solar and geothermal drives) are designed by MATLAB programming software, which integrates the modeling, operational processes, and combination of GA and LPSP methods for optimization of system equipment. This method enables the optimal capacity of energy equipment to be found by using a combination of GA and LPSP methods to minimize costs and ensure load reliability.

In the context of integrated energy system grid-connection,[5] Cui proposed a modeling method combining energy hub method and transient simulation and a multi-objective optimization method based on hourly dynamic balance of supply and demand in the annual energy supply cycle. A general model of integrated energy system was constructed, the overall structure of the integrated energy system was established through the structure of the energy hub, the input, conversion and output relationship of the system energy was described by using the matrix equation, and the transient simulation models of different energy supply units were constructed on the TRNSYS platform with the weighting of the annual cost savings rate, the primary energy saving rate and the shadow cost savings rate of environmental pollutants as the optimization objective function, and the integrated energy system transient simulation and optimization software was developed. The objective function of Jeeves algorithm is solved to realize the optimization of the integrated energy system, and the rationality of the theoretical method and the practicability of the developed software are verified by case studies.

The existing research mainly focuses on the technical aspects of integrated energy systems and the game exchange of electric energy between subjects, while there are few studies on multi-energy coupling and benefit distribution of cooperation between multiple subjects in the system. Wang et al. [6] proposed an integrated energy system operation optimization method based on cooperative game. Firstly, the typical structure of the integrated energy system is analyzed, and the energy flow under the two modes of independent operation and cooperative operation of different subjects is analyzed. Secondly, with the goal of minimizing system operating costs and carbon emissions, a collaborative game model of integrated energy system is constructed considering constraints such as energy supply and demand balance, safe operation of equipment, and energy storage capacity. The improved NSGA-II algorithm is used again to solve the cooperative game, and the best compromise solution of the Pareto optimal solution set is sought by the Topsis method; Finally, a benefit allocation model combining improved Shapley value and nucleoli method is established to allocate cost savings.

In order to provide buildings with the required heating, cooling and electrical loads with higher thermal efficiency and lower energy consumption, SepehrSanaye et al. [7] propose a new integrated system. The system includes the Cascade Organic Rankine Cycle (CORC), an innovative ORC heat recovery and power generation system with a high and low temperature circuit that uses gas engine (GE) exhaust gases as a heat source to generate electricity. It also includes an electric chiller with ice storage (VCR + ice hot energy storage system ITES) with vapor compression refrigeration cycle. The genetic algorithm (GA) method is used to perform multi-objective optimization of the designed and proposed system. GA is a search method for finding exact or approximate solutions to optimization problems. This algorithm is one of the special categories of evolutionary algorithms inspired by evolutionary biology concepts such as genetics, mutation, selection, and crossover of VCR-ITES integrated systems obtained by dual-objective genetic algorithms in FOM optimization results.

Aiming at the problem of load optimization and scheduling of multi-source complementary heating system under the background of energy Internet, an economic benefit model of heating system including multiple energy complementarities was established. Chen et al. [8] introduced environmental cost factors such as pollutant emissions, and proposed a multi-objective optimization model with the largest system economic benefits and the lowest environmental costs. On the basis of establishing the operating economic benefits of the cogeneration system, the multi-objective optimization scheduling model of the heating system combining various forms of heat sources is introduced into the comprehensive consideration of the distribution capacity between the heat source and the heat user, and the Pareto solution set of the multi-objective optimization model of the improved particle swarm algorithm is used to solve the multi-objective optimization model for the above-mentioned multi-day standard optimization problem, and the central heating system of an industrial park containing coal cogeneration unit and gas-steam combined cycle cogeneration unit is taken as an example to optimize the distribution of the heat load of the park.

Integrated Energy Systems (IES) can improve energy efficiency and reduce carbon emissions through multi-energy production, storage, transportation and supply. However, the flow of energy in traditional IES is usually unidirectional: from electricity to hot/cold, or from hot to cold. Hu et al. [9] can also use waste-to-energy coupling (WTP) to convert waste heat into electricity, further improving flexibility and reducing pollutant emissions. The research focuses on exploring the value and application scenarios of IES-WTP from the perspective of economics and carbon emissions. A two-layer optimization method is proposed to realize multi-objective optimization of operation strategy and system design. The outer layer first determines the component capacity. The inner layer then determines the optimal operating mode based on capacity and calculates annual operating costs. Then the cost and CO_2 emission are fed back to the outer layer, resulting in a two-layer optimization. Internal optimization was transferred to the MILB problem, solved by full-fledged commercial software (Grubi with Yalmip). In external optimization, because PV, wind turbines, and other components are already set up in the model. Only the number of units needs to be determined. Therefore, the use of the nondominated ranking genetic algorithm II (NSGA-II) on the MATLAB platform solves the optimization problem of the outer layer. This IES-WTP system is then compared to a conventional IES that considers three different load profiles. The results show that coupling WTP can significantly improve the overall performance of IES.

Most continuous processing industries generate electricity through cogeneration by using the thermal energy required by the process. Electricity is also purchased from external sources, such as the grid, and generated from internal sources, such as diesel generator sets. This leads to the question of determining the economically optimal energy mix in the short and long term. ARivalaganet al. [10] proposes a mixed integer (0 – 1) linear programming model to solve the above decision problem, and solves the optimal combination decision problem of electricity and heat energy production through the MIRP model. and the use of different forms in the energy system of the process industry to achieve optimal short- and long-term energy economic benefits.

In order to fill the research gap on the performance comparison of these two typical nuclear hydrogen production systems and enrich the existing research methods and contents. Wang et al. [11] proposed and studied two improved nuclear hydrogen production systems based on VHTR and I – S cycles. The two systems were thermodynamically modeled using energy and energy analysis methods, and a complete I-S model was developed using Aspen Plus in order to be as close as possible to the actual hydrogen production process. In addition, the parameters of the two improved systems are optimized based on the particle swarm optimization (PSO) algorithm, and the system performance is compared according to the optimization results.

IV. COMPARISON OF APPLICATION OF ALGORITHMS

Traditional optimization algorithms, such as GA and PSO, can only solve single objectives, or convert multiple objectives into single objectives by weighting, which has certain limitations, while multi-objective optimization algorithms, such as NSGA-II and MOPSO, can comprehensively measure various indicators. Theapplication of algorithms in the above literature is as follows:

1. Constrained genetic algorithm (GA) combined with power loss probability (LPSP) optimal design technology: It helps to use a variety of renewable energy sources such as wind, solar and geothermal energy, and designs multi-carrier renewable energy systems that can be used in many places, but this technology shows its limitations under the conditions of low availability of some renewable resources.

2. The transient simulation model of different energy supply units is constructed on the TRNSYS platform, and the objective function of Hooke-Jeeves algorithm is used to solve it: considering the economy, environment and primary energy consumption, the weighted sum of the annual cost saving rate, the shadow cost saving rate of environmental pollutants and the primary energy consumption saving rate is the optimization objective function, but the method has the problem of strong subjectivity in the selection of weighting coefficient, which affects the accuracy of the optimization results.

3. Integrated energy system operation optimization method based on cooperative game: different entities can effectively reduce the total energy cost and carbon emissions of the system by building an integrated energy system through cooperative game; The benefit distribution scheme that combines the improved Shapley value with the nucleoli method is reasonable and effective, and the scheme is considered to be a problem nucleolar from the perspectives of the whole, individual and alliance. On the one hand, this method makes up for the insufficient consideration of unstable factors in the Shapley value, and on the other hand, it makes up for the equality and fairness brought by the nucleolus method, which can more effectively motivate subjects to participate in collaborative operations. The proposed improved NSGA-II algorithm can significantly improve the efficiency of model solving. The example shows that the solution time of the improved NSGA-II algorithm is only 9.56% of that of the traditional NSGA-II algorithm, and the global optimal solution can be sought faster. However, the layout of the pipe network between different entities and the energy loss of energy transmission are not considered, which will constitute one of the constraints on whether the subjects participate in the overall optimization of the alliance.

4. multi-object optimization of the designed and proposed system by genetic algorithm (GA) method: Compared with POM, FOM has lower power consumption and lower power cost, but its investment cost (1.65 ×106$) is 8.5% (1.51×106$) larger than POM, due to the larger size (equipment capacity) in FOM. Therefore, the FOM strategy was chosen for the VCR-ITES cooling system, which also has greater capacity and is safer, due to the effective reduction of energy costs and the sufficiently short payback period. The cost of the chiller.

5. The Pareto solution set of the multi-objective optimization model is solved by improving the particle algorithm, which makes up for the shortcomings of directly converting the multi-objective problem into a single target for solving in the past, so that the decision maker can select the optimal solution that meets the demand preference from the Pareto optimal solution set according to the actual situation.

6. Mixed integer nonlinear programming model is a common optimization method, which considers nonlinear characteristics and solves nonlinear problems. The mixed integer linear programming (MILP) algorithm is applied to have higher solver efficiency.

The advantages and disadvantages of various algorithms are as follows：

1、GA has its unique advantages: it directly operates on structural objects, has no qualification on the objective function, has no requirements for derivability and continuity, and has inherent implicit parallelism and better global optimization ability; The search based on random probability does not require strict rules and constraints, and can automatically search the space within the solution space and adjust the search direction adaptively.Its disadvantages and limitations: there is no theoretical proof of the solution time required to obtain the optimal solution.

2、 NSGA-II algorithm is good for low-dimensional multi-objective optimization problems, but for high-dimensional multi-objective optimization problems, the first thing it faces is the problem that the selection pressure is too small due to its Pareto dominance relationship, and secondly, the crowding distance is not applicable in high-dimensional space, and the computational complexity is relatively high.

3、PSO algorithm: Compared with the genetic algorithm, the advantage of PSO is that it is simple and easy to implement, and there are not many parameters that need to be integrated.

The downside is that performance isn't particularly good on some issues. The encoding of network weights and the selection of genetic operators are sometimes troublesome.

4、The solution algorithms of mixed integer linear programming models mainly include two types: exact algorithms and heuristic algorithms.Among them, the exact algorithm can find the accurate optimal solution of the model, but its disadvantage is that under the existing computer technology, it cannot deal with the problem of many decision variables in a limited calculation time. Although the heuristic algorithm can deal with the problem of many decision-making variables, the optimal solution obtained is the approximate optimal solution, and it is easier to fall into the local optimal solution, and the gap between the approximate optimal solution and the actual optimal solution cannot be measured and estimated.

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