A Review on Optimal Operation of Power System Including Wind Farms

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Abstract. In order to comprehensively generalize the research status quo, achievements as well as deficiencies on the optimal operation of power system including wind farms, this paper introduced the optimal operation models for power system including wind farms, according to the difference of optimization objective, the models are divided into the single objective model and the multi-objective model. A variety of traditional optimization algorithms and artificial intelligence optimization algorithms common used were summarized, including dynamic programming, Lagrangian relaxation method, genetic algorithm, particle swarm optimization, ect, the principle, advantages and disadvantages of each algorithm were analyzed in this paper. Finally, some suggestions are given for further studies on the optimal operation of wind power.

1. Introduction

Wind power is a power generation technology that converts wind energy into electricity, which is a more mature type of distributed power generation technology. The use of wind energy to generate electricity, not only can reduce environmental pollution, but also can reduce the fuel costs of power systems, greatly improving the economic efficiency. With the rapid development of social economy and the continuous progress of science and technology, the scale of wind power in China has reached a high level in the world, and has made great contributions to energy conservation, emission reduction, and the growth of the national economy, it also mitigate the power supply pressure in many areas of our country.

But the wind energy is unstable, it is random and intermittent. With the change of wind speed, the active output of the wind turbine will change, So when the large wind turbine parallels in the grid, it will bring bad influences to the power systems, such as voltage flicker and harmonic pollution [1-2]. With the increasing concern about renewable energy, there are many large-scale new wind farms in the power system, which puts forward new challenges to the optimal operation of power system. Therefore, it is helpful to promote the steady and stable development of the wind power industry by studying the optimal operation of the wind power system.

The optimal operation of power system is a problem of arranging the operation of the unit and distributing the load among the operating units based on the change of the load in each period of the dispatching cycle. In general, the optimal operation of power system with wind farm includes the establishment of optimization model and the determination of optimization algorithms. Different algorithms exhibit different optimization performance, according to the characteristics of the actual problem, we can choose the appropriate optimization algorithm, and this helps to get better optimal operation results.

2. Optimal Operation Model of Wind Power

At present, domestic and foreign scholars have carried out a lot of research on optimal operation model of wind power grid, by improving the original model or put forward a new modeling method to make the system scheduling more reasonable. In the process of modeling, according to the different optimization goals, the model can be divided into a single-objective model or a multi-objective model.

2.1 Single-Objective Model

According to different objective functions, it can be divided into the following models: a model that targets the generation cost or fuel cost of conventional generators, a model that targets the cost of wind power generation, a model that targets a risk indicator, a model that targets environmental costs or a model that targets the purchase cost for the power market. According to different constraints, it can be divided into the following models: a model that takes the reserve constraints into account, a model that takes the constraints of the environmental limits into account or a model that takes system risk constraints into account and so on.

In the literature [3-13], an optimal operation model of wind power with the goal of generation cost or fuel cost of conventional generator is constructed.In order to reflect the randomness of wind power, the literature [3] uses the trapezoidal membership function to apply the fuzzy theory to the problem of optimal operation model of wind power, which solves the problem that the prediction accuracy of wind power is low. Then, it is equivalent to seeking the problem of maximizing satisfaction index; the idea of descending search is introduced into particle swarm optimization to improve the convergence of the algorithm, the example show that, considering the economic scheduling problem of wind power uncertainty, the fuzzy theory can be used to express the wishes of decision makers. The example shows that, using the fuzzy theory to solve the economic optimal operation problems that considering the uncertainty of wind power can express the wishes of the decision makers. In [4], the valve point effects of the units are considered, for the multi-peak and non-different characteristics of the optimized model, it can be smooth processed by the aggregate function. The literature [5] proposed information sharing strategies and elite learning strategies, which can enhance the global optimization ability and avoid the local optimal. In the optimal operation model of [6-7], considering the relationship between grid-connected wind capacity and system operating cost and system reserve capacity, a certain proportion of wind power is taken as the reference value of standby demand, this ensures the reliability of the system to a certain degree. In the literature [8-9], the Weibull distribution is used to describe the random characteristics of the wind speed, and the probability expression of wind power is obtained by wind speed-power conversion relation, and the wind power prediction error is quantified by introducing the penalty cost in the objective function of the model. In [10], the risk index is used as the objective function, which can fully reflect the system dispatcher’s subjective consciousness about the risk and cost considerations. In [11], the optimal operation model aiming at the purchase cost for the power market is constructed, which makes the optimal operation of the wind power system in the power market environment more reasonable and economical, and has high credibility. In [12-13], the environmental cost is regard as a goal, and a membership function is defined to describe the relationship between the system safety level and wind power penetration or between the system safety level and operating costs.

The single-objective model emphasizes the optimal benefit of some aspects in the optimal operation, and ignores the optimal benefit in the overall optimal operation. Therefore, the following will introduce a multi-objective model with multiple targets as a whole.

2.2 Multi-Objective Model

Multi-objective model takes the combination of multiple indicators in the single-objective model as a goal, in the process of power system optimal operation, it considers the factors such as resource consumption, economic benefit and environmental benefits, which can better achieve economic, resource and environmental sustainable development.

The literature [14] considered various factors, such as the profit that the generation enterprises get by selling electricity to the grid, the profit that the generation enterprises get by selling electricity to large customers, own operating costs, start and stop costs and so on. Under the premise of satisfying all kinds of constraints of the system, the expected benefit function is maximized. In [15], consumption dispatch mode is introduced, such as consumption stimulation a interruptible load management, which can improve the economics of the wind power grid optimal operation model. In [16], a dual-objective economic dispatch model is proposed, and the multi-objective particle swarm optimization is used to calculate the Pareto optimal solution under the two objectives of risk and power generation cost. Operators can balance the two optimization objectives according to the actual operation of the system to get the final optimization results. In the literature [17], the proposed unit combination problem is based on the minimum cost of wind power and the minimum expected loss load. The membership function is obtained by mixing integer programming with minimum cost and minimum expected loss load, and then transformed into fuzzy problem. In [18], the general distributed model is used to fit the actual wind power distribution under different wind power forecast levels, and a stochastic optimization model of dynamic economic dispatching with underestimation or overestimation cost is established. [19] proposed a multi-objective optimal operation model considering generation costs, environmental benefits and system operational safety, this dispatching scheme focuses on the ecological environment, it has great practical significance under the strategic policy of vigorous development of wind power and reduce environmental pollution. In [20], on the basis of describing the randomness of the wind farm in the form of probability, the loss of load and the punishment of giving up the wind power are included in the economic consideration, and the broader meaning of the system optimization is discussed.

In addition, in recent years, multi-objective models with chance-constrained programming have been widely used in power system optimal operation problems. In the chance-constrained programming, the constraint condition with random variable is expressed as the probability form, and the probability of its establishment should be not less than the set confidence level, so that the random characteristic of wind power can be described very well and the dispatching result will not be too conservative. In the literature [21], the reliability index of wind power is introduced, and the chance-constrained programming is established for the wind power random variable, and the unit combination model is established based on the sampling average approximation theory. In this paper, the probability chance constraint is transformed into deterministic constraint by introducing multiple 0/1 auxiliary variables. Finally, the mixed integer programming method is used to solve the linear model. In [22], the Markov chain principle is used to describe the law of wind speed change, and it is combined with scene tree technology to simulate the actual wind speed with a certain number of typical scenes. On this basis, a double-level stochastic model considering unit combination and load distribution is established by using chance-constrained programming.

3. Optimal Operation of Wind Power Problem Solving Method

From the mathematical point of view, optimal operation of power system is a multi-constraint, nonlinear, non convexity, high-dimensional mixed integer optimization problem. It is very difficult to solve the exact optimal solution in theory. In this regard, domestic and foreign scholars have done a lot of research, put forward a lot of algorithms. To sum up, it is mainly divided into traditional optimization algorithm and artificial intelligence algorithm.

3.1 Traditional Optimization Algorithm

Common traditional optimization algorithms include dynamic programming method, Lagrangian relaxation method, mixed integer programming method and so on, the following describes their optimization performance.

Because dynamic programming method can not take into account the shortcomings of the unit start and stop characteristics and the climbing constraints, in [23], an interpolation dynamic programming method is proposed to find the optimal path to satisfy other constraints in the path satisfying the time constraint. In [24], a controlled Petri network model is introduced on the basis of dynamic programming method, which not only deals with the unit start and stop time constraints, but also reduces the number of calculation states, this method greatly improves the efficiency of the algorithm. In [25], the traditional Lagrangian relaxation method is used to solve the problem of economic scheduling problem. The dynamic programming method is used to determine the start and stop of a single unit. The Lagrangian multiplier is updated by the subgradient method. The solution of the dual problem is a feasible solution to the original problem. In [26], the variable metric method is used to optimize the Lagrangian multiplier instead of the subgradient method, which improves the convergence of the dual problem. Both [27-28] use a mixed integer programming method to solve the model. In [27], the scene method is applied to wind power generation, and the wind power grid and grid security constraint model is established. [28] also requires the unit output program under the forecast scenario and the transition between scenarios under error scenarios meet the slope rate constraints, this is ensure the operability of the method. In [29], the speed and accuracy of the calculation are improved, and a feasible way to solve the problem of unit combination in multi-wind field is explored by using the mixed integer programming method.

3.2 Artificial Intelligence Optimization Algorithm

With the development of science and technology and the development of computer technology, a series of artificial intelligence algorithms are widely used, including genetic algorithm, simulated annealing algorithm, particle swarm algorithm and so on. They have been successfully applied to the power system economic scheduling problem. This kind of algorithm has better global search ability than the traditional algorithm, and the random search strategy can be used in the whole space to make it more practical value.

3.2.1 Genetic Algorithm

The genetic algorithm was proposed by Professor J.Holland of Miehigan University in the United States in 1975. The algorithm is based on natural selection and genetics of random search optimization. After the initial population, through the selection, crossover, mutation and other operations, according to the principle of survival of the fittest, gradually evolved to get the optimal solution. This is the most widely used artificial intelligent optimization algorithm.

In [30], on the basis of the optimal operation of power system, the influence of various parameters of the migration strategy on the performance of the algorithm is analyzed qualitatively, and some general conclusions are drawn. In [31], genetic algorithm and Lagrangian relaxation method are combined. First, it use genetic algorithm and Lagrangian relaxation method to find a feasible solution, and then use genetic algorithm to update the Lagrangian multiplier, this method can reduce the dual gap and get a better solution.

3.2.2 Simulated Annealing Algorithm

The simulated annealing algorithm is based on the similarity between the annealing process of solid matter in physics and the general optimization problem. Its physical background is the physical phenomena of solid annealing and statistical mechanics model. Simulated annealing algorithm is based on the expansion of the local search algorithm, in theory, it is a good global optimal algorithm.

Based on the traditional genetic algorithm,[32] use the orthogonal test to determine the parameters and introduces the simulated annealing algorithm to control the transboundary penalty, which improves the optimization performance and convergence speed of the algorithm. In [33],in the process of solving the wind-heat joint scheduling problem, it use the improved simulated annealing algorithm which greatly improves the algorithm optimization speed.

3.2.3 Particle Swarm Optimization Algorithm

The particle swarm optimization algorithm was first proposed by J. Kennedy and R.C. Eberhart in 1995. The idea came from the predation of birds, each individual according to their own and companion flight experience, constantly revised flight direction and speed, and finally to achieve the purpose of searching the optimal solution from the full space. The algorithm has the characteristics of parallel processing, and it has a faster calculation speed and better global convergence ability in solving high dimensional mathematical optimization problems.

In [34], the risk index is used to describe the uncertainty of wind power and photovoltaic power generation. The multi-objective particle swarm optimization algorithm is used to solve the multi-objective model with the system economy and environmental protection. Finally, the final scheduling scheme is determined by the entropy method. In [35], a hybrid particle swarm algorithm is proposed. The binary particle swarm optimization algorithm is used to solve the unit start and stop situation. The real particle swarm optimization algorithm is used to solve the economic load distribution, and the two algorithms are optimized at the same time. The particle swarm algorithm is easy to prematurely into the local optimum, so [36] introduce feedback mechanism and closed-loop control strategy, which ensures the diversity of the population and improves the global optimization ability of the algorithm. At the same time, a new strategy is adopted to reduce the dimension of the problem and to ensure the feasibility of the particles in the process of optimization. [37] using the improved quantum discrete particle swarm optimization algorithm to solve the problem of unit combination, and introduce heuristic adjustment and greedy mutation strategy in the algorithm, so that the particles have better global optimization performance.

4. Conclusion

Due to the randomness and intermittence of wind power, the large-capacity wind power grid has brought a lot of uncertainty factors to the optimal operation of power system. In the study of the optimal operation of power system including wind farms, it needs to be discussed in terms of its optimization model and solving method. In this paper, according to the difference of optimization objective, the models are divided into the single objective model and the multi-objective model. In the method of solving, the traditional algorithm and the artificial intelligence algorithm are described in detail.

In recent years, with regard to the optimization of power systems with wind farms, domestic and foreign scholars have been studying in depth and have made great achievements. This paper summarizes the current research, then thinks that the future research needs to be carried out from the following aspects:

(1) To improve the accuracy of wind power prediction. The prediction of wind power output is very important to the optimization of power system with large amount of wind power, the existing wind power forecasting technology error is still very large, so improving the accuracy of wind power prediction will make the scheduling results more reasonable.

(2) The statistical characteristics should be used to describe the random characteristics of wind power and system operation mode in future time period. Accurately express the static and dynamic characteristics of the component. Coordinate various control parameters with optimization algorithm. This can realize to achieve the entire process optimization in the future period just through a numerical calculation.

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