Hindawi
Journal of Sensors
Volume 2022, Article ID 7037451, 8 pages
https://doi.org/10.1155/2022/7037451

Research Article

Investment Strategy of Reactive Power Compensation Scheme in Wind Turbine Distribution Network Based on Optimal Allocation

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Received 14 February 2022; Revised 2 March 2022; Accepted 10 March 2022; Published 27 April 2022

Academic Editor: Wen Zeng

The development and application of new energy have been paid more and more attention by governments of various countries since the 21st century. It is of practical engineering significance to study reactive power compensation of wind turbine distribution network. In view of the problems of poor grid quality and increased active power loss caused by a large amount of reactive power transmission during the operation of wind farms, based on the improved genetic algorithm, aiming at the minimum compensation capacity and the minimum voltage deviation of load nodes, a multiobjective optimization scheme of reactive power in wind farms is proposed, and an example is analyzed in Matlab. The results verify the effectiveness of the improved genetic algorithm in reactive power optimization of wind motor.

1. Introduction

Energy consumption, as the focus of all countries in the world in the new era and new stage, not only promotes the rapid development of global economy and continuous innovation in the field of science and technology but also triggers a series of energy security challenges [1–5]. A series of energy security challenges, such as resource competition among countries, global energy shortages, and environmental pollution caused by excessive use of fossil energy, have caused problems for countries all over the world and seriously threatened humanity's survival and development. Since the twenty-first century, China's overall national strength has grown, as has its energy consumption for social development and scientific and technological innovation [6]. In recent years, research shows that China has surpassed the United States and become the world's largest energy consumer. Although China is rich in total resource storage, there are great drawbacks in energy consumption structure, mainly reflected in low per capita resource reserves, unbalanced regional distribution of energy, high utilization rate of nonrenewable resources such as coal and oil in the energy system, etc. Figure 1 shows the appearance of wind motor.

To avoid the potential consequences of energy consumption, the United Nations places a high value on energy consumption and other issues [7–11] and makes an extremely harsh appeal: before the twenty-second century, all countries must reduce greenhouse gas emissions to zero. As one of the five permanent members of the United Nations Security Council, China has fulfilled its responsibilities and responded to the call of the United Nations with practical actions. At the APEC meeting held in Beijing, China promised that relevant departments should do a good job of supervision and strictly control the emissions of greenhouse gases from various factories; at the same time, the proportion of nonfossil energy in total energy consumption increased to about 20%, and the carbon dioxide emission per unit GDP decreased by 60%-65% compared with that in 2005. Later, at the G20 meeting in Hangzhou, China declared that in the second half of this century, it is necessary to fulfill the requirements of the United Nations and reduce greenhouse gas emissions to zero. In order to realize China's commitment on energy consumption, various types of factories must be reformed, and the energy consumption will gradually transform from fossil energy to renewable clean energy such as wind power, hydropower, and photovoltaic.

At present, all countries in the world have realized the importance of renewable energy. Wind energy resources have been widely used because of its large energy storage, wide distribution, and green and clean energy in the world. According to the prediction of the Global Wind Energy Council (GWEC), by 2030, the annual new market of wind power will reach 145 GW, and the cumulative market will reach 2110 GW. By 2050, the annual new market will reach 208 GW, and the accumulated market capacity will reach 5806 GW [2].

Reactive power optimization (RPO) of a power system refers to a special optimal power flow problem that seeks the ideal reactive power flow distribution that satisfies definite physical and safety restrictions under the condition that the active output power of the generator set is decided, so that the power grid operation cost (minimum loss) or voltage quality is the highest.

In order to better save energy and reduce emissions, expand the installed capacity of wind power, and solve the problems of voltage exceeding limit, reactive power surplus, and waste of electric energy caused by wind turbines; it has become an important research topic.

Figure 1: Appearance of wind motor.

2. Related Work

Reactive power optimization (RPO) of a power system refers to a special optimal power flow problem that seeks the optimal reactive power flow distribution that satisfies certain physical and safety constraints under the condition that the active output power of the generator set is determined, so that the power grid operation cost (minimum loss) or voltage quality is the highest [12, 13]. RPO is the most commonly used measure for the system to adjust the node voltage balance and maintain all kinds of equipment in a stable working state [14]. By changing the number of reactance/capacitor switching groups, OLTC tap position, adjusting generator output, etc., the goal of not exceeding the limit of node voltage and minimizing the cost of equipment operation and inspection is achieved [15].

2.1. Fan in Reactive Power Optimization. The introduction of distributed generation will alter the security and stability of the distribution network. Experiment results in recent years show that energy nodes and capacity factor of distributed generation are closely related to the power system's safety performance index [16–18]. The location of distributed generation needs to consider various factors, such as energy richness of installation location, distance from urban area, and economic cost. The selection of suitable installation location and the determination of installed capacity can solve a series of problems caused by the access of distributed generation to distribution network and promote the popularization of distributed generation. Therefore, it is of great significance to rationally plan the installation position and determine the installed capacity of distributed generation for reactive power and voltage regulation of power system [19]. Figure 2 shows a general configuration of an OWF network.

Scholars in the United States and abroad have conducted extensive research on the location and capacity determination of DG. The selection of DG nodes in this manner not only consumes a significant amount of planner time but also introduces some human factors into the problem of distributed generation location and capacity determination. In general, planners are more willing to select the planning model of the unknown distributed generation access points to be selected, i.e., to find a group of DG access points to be selected from the DG location model using a mathematical method. The notion of equivalent net loss incremental rate calculates the iterative rate using a sensitivity analysis method and sorts it to determine the best DG installation position.

2.2. Reactive Power Optimization Model and Optimization Algorithm. Carpentier, a French electrical engineer, developed an early mathematical model of reactive power optimization through rigorous mathematical deduction and introduced a series of equality and inequality constraints such as upper and lower voltage limits, line power limits, and reactive power compensation limits, as well as traditional intelligent methods to solve the optimal power flow problem [20]. Literature [21] proposes to control wind farms with DFIG units by hierarchical voltage control mode. The upper layer is reactive power optimization of distribution network considering global economic cost, and the lower layer carries out DFIG automatic voltage control according to the control results of the upper layer. The literature [16] established a computational formula of reactive power optimization that begins with a comprehensive cost analysis of the distribution network, in which the influence of equipment operation times was considered, and the wide range of tool times was reduced to adjustment cost, as well as the loss cost and adjustment cost. A two-population particle swarm optimization algorithm is proposed, which effectively solves the control variable optimization problem via special coding.

In reference [18], a reactive power optimization model based on equipment action cost is established according to the control requirements of the actual regional power network. In this model, not only the switching changes of OLTC in adjacent periods are considered, but also the constraints of capacitor switching times are considered in combination with the actual operation principle of variable capacitors. The improved hybrid intelligent algorithm is used to effectively solve the reactive power optimization model.

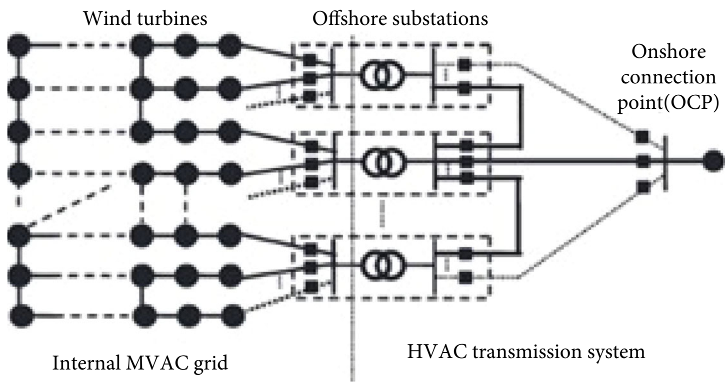

Figure 2: General configuration of an OWF network.

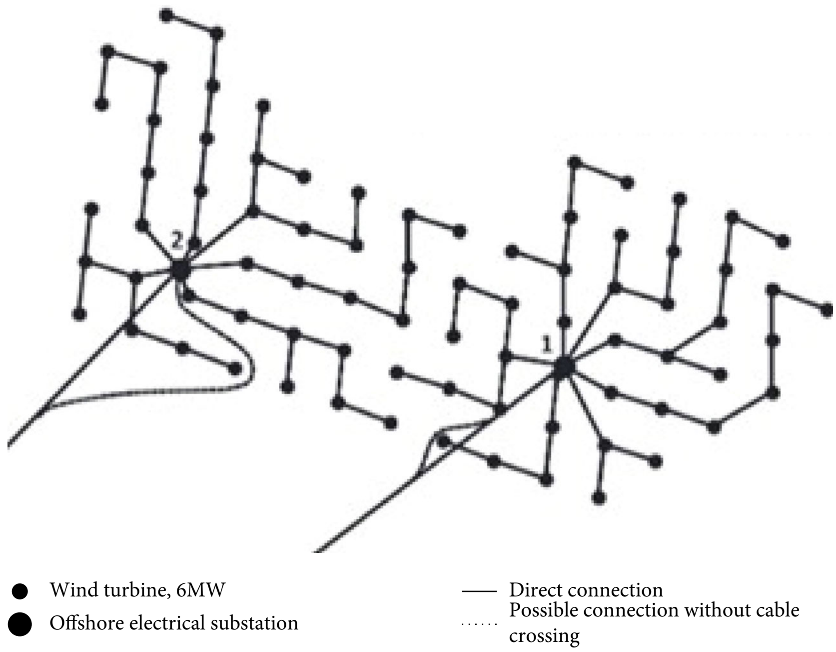

Figure 3: Optimal connection topology of the wind farm network.

2.3. Intelligent Optimization Algorithm. Conventional optimization algorithms have high requirements on the accuracy of mathematical models and cannot solve the problem of multiextremum. And the processing of discrete variables is poor, and most reactive power compensation equipment are discrete variables, so it is difficult for them to meet the requirements of real-time state control of complex power systems. In recent years, the intelligent optimization algorithm has been continuously developed, gradually replacing the conventional optimization algorithm, and applied to solving reactive power optimization problems [15]. Simulated annealing algorithm belongs to a probabilistic algorithm, which effectively solves the difficulty that the calculation process easily falls into local optimum by giving the search process a time-varying probability jump which eventually tends to zero. In the iterative process of the algorithm, the regression of the optimization results may occur, and the convergence speed is slow [12].

3. Improved Genetic Algorithm

The first step in the search for genetic algorithm optimization is to accomplish the mapping of individuals from phenotype to genotype using reasonable coding operations and then form the first generation population [8, 9]. The superiority of the first people is closely related to the algorithm's optimization efficiency and solution convergence. Although a population of random individuals can better reflect all of the information in the sample space, it will lose the initial population's superiority [10]. Figure 3 shows the proposed optimal connection topology of the wind farm network.

3.1. Adaptive Crossover Operator. Crossover operation is an important way to produce excellent individuals, which promotes the evolution from feasible solution to optimal solution. If the initial crossover rate of iteration is still adopted

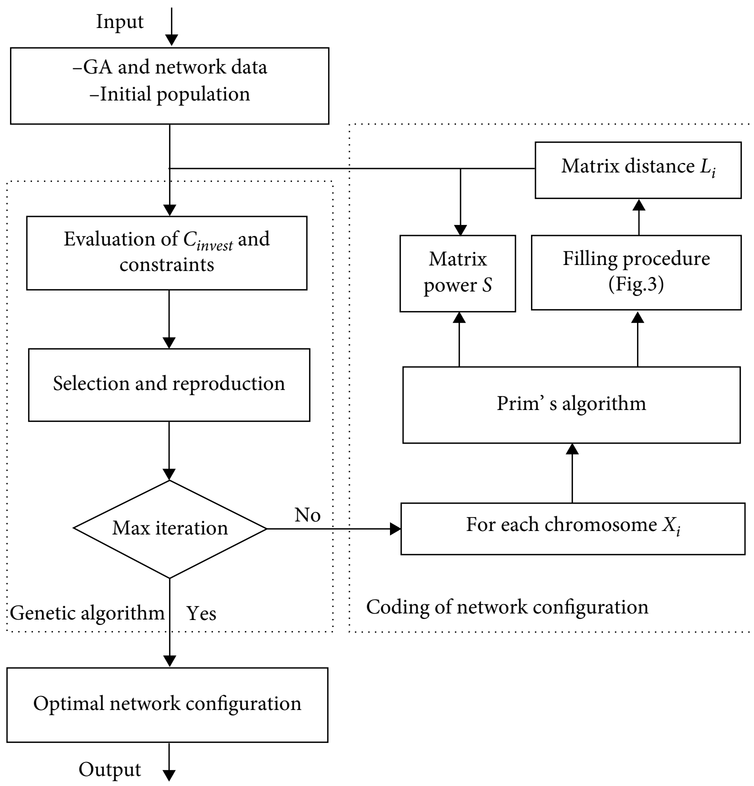

FIGURE 4: Reactive power optimization algorithm flow.

at this time, the proportion of excellent individuals in contemporary population will be reduced, which will increase the convergence difficulty of the algorithm and affect the quality of the solution.

Therefore, this paper adopts the adaptive crossover operator which changes with the evolution of population, namely,

$$P_c = P_{c1} - \frac{(P_{c1} - P_{cmin})d}{D}, \quad (1)$$

in which P_{c1} is the initial crossover rate, d represents the current population evolution times, d represents the maximum population evolution times, and P_{cmin} is the minimum population crossover rate.

In this paper, when using genetic algorithm to solve the problem, triple convergence criterion is adopted:

(1) Reaching the maximum number of evolutions

(2) The difference of the optimal solution of successive generations of genetic algorithm is smaller than the preset small positive number

(3) The fitness value of the objective function is less than the preset small positive number

In this paper, the triple convergence criterion is applied to enhance the efficiency of the algorithm and the quality of the solution.

3.2. Reactive Power Optimization Algorithm Flow. The genetic algorithm operates with only an arbitrary initialization population and gradually evolves the population into an increasingly optimal region in the search space through selection, heredity, crossover, mutation, and other operations, in order to find the best solution to the problem. The genetic algorithm is continued to improve in this paper as follows:

(1) The initial population selection adopts the method of uniform distribution sampling, which avoids the generation of infeasible solutions by random methods. The solution space is evenly divided into n subspaces, the same number of M chromosomes are selected in each subspace, and the $m * n$ chromosomes are used as the initial population

(2) The coding improvement adopts the combination of binary coding and floating-point coding to reduce the search space of the system. The switching state of reactive power compensation device is selected as the control variable in wind farm reactive power optimization, which is expressed by integer. The switching amount of reactive power of reactive power compensation device, the position of on load transformer tap, and the terminal voltage of wind turbine generator are selected as control variables, which are expressed by floating-point numbers

Figure 4 shows the proposed reactive power optimization algorithm flow.

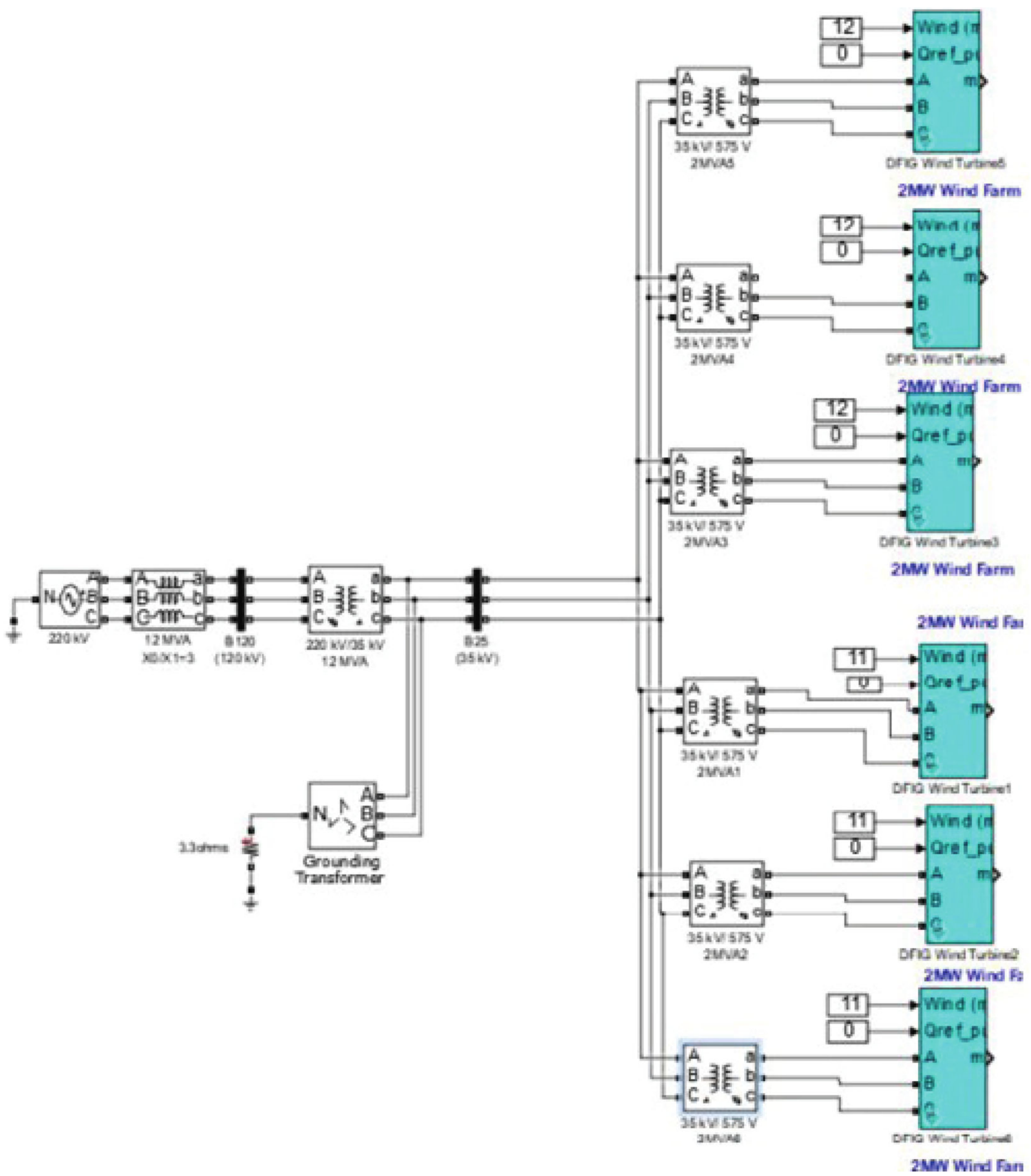

Figure 5: An example model diagram of the offshore wind farm.

Table 1: Voltage stable modal value of each node of the offshore wind farm.

Node number	Voltage stable mode value	Node number	Voltage stable mode value	Node number	Voltage stable mode value
One	0.01124	Six	0.00925	11	0.00126
Two	0.01003	Seven	0.00829	12	0.01093
Three	0.00745	Eight	0.01017	13	0.00982
Four	0.01367	Nine	0.01218	14	0.00871
Five	0.01136	10	0.00698	15	0.00115

4. Experiment and Analysis

The wind power simulation equivalent model is established in Matlab, and the whole offshore wind farm is treated with equivalent modeling scheme. See Figure 2 for the model. In this paper, the reference capacity of the system is 100 MVA, the transformer capacity of wind turbine generator set is 20 MVA, and the transformer capacity of offshore booster station is 80 MVA. Node 15 is identified as the balance node, and the remaining nodes are all designated as PQ nodes. The amount of reactive power demand compensation is greatest whenever the wind turbine is running, when the output is at full load, so the offshore wind farm set in this paper is in the case of 100 percent output state.

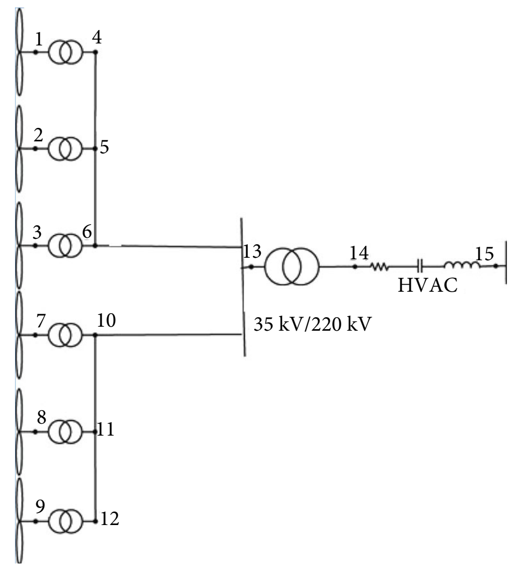

Figure 6: Node number and wiring diagram of the offshore wind farm.

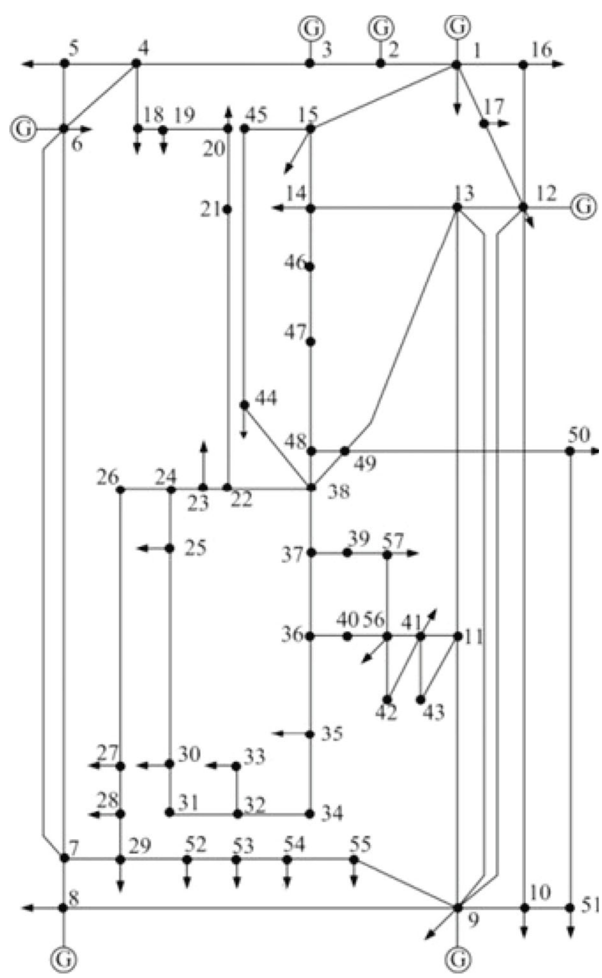

Figure 7: Node system diagram.

Table 2: Parameter setting of the improved genetic algorithm.

Encoding	The population size	Crossover operation	Crossover probability	Mutation probability	Optimal front-end individual coefficient	Maximum iteration
Real integer mixed encoding	100	New mutation operator	0.9	0.01	0.2	50

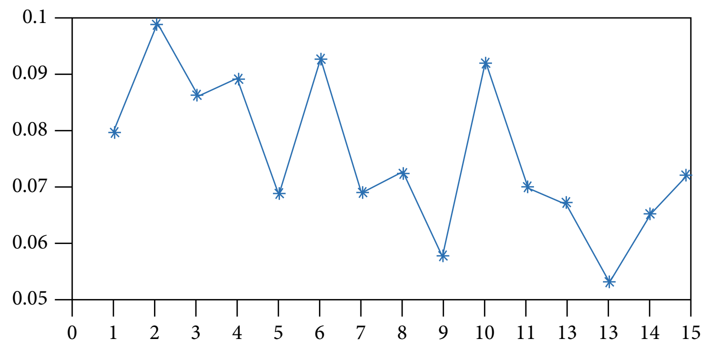

Figure 8: Voltage deviation diagram of load node.

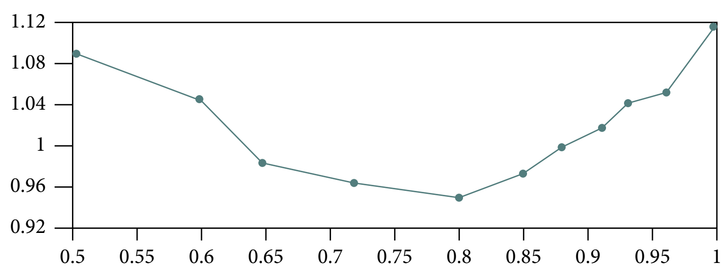

Figure 9: F minimum under different weight coefficients.

The schematic diagram of offshore wind farm example model is shown in Figure 5. The technique described in Chapter 4 is used to perform the voltage stability mode shapes of each node of an offshore wind farm, and the voltage stability modal values of each node are solved as shown in Table 1 below. Figures 6 and 7 show the node system diagram and node number with wiring diagram of the offshore wind farm.

Select the point in Figure 3 with the smallest steady-state voltage modal value as the offshore wind farm's reactive power compensation point; then, compare the quantitative value of each node in Table 1, and the voltage stability modal values of nodes 11 and 15 are the smallest, which can be used as power factor correction nodes. Using the improved fast nondominated sorting genetic algorithm with elite strategy, the Pareto optimal solution with the least power factor correction capacity and the least voltage deviation of load nodes is obtained. The genetic algorithm's parameter settings are shown in Table 2.

Comparing the data in Table 1, the voltage stability modal values of node numbers 11 and 15 are the smallest, which can be used as reactive power compensation points. The improved genetic algorithm is used to solve the Pareto optimal solution with the minimum reactive power compensation capacity and the minimum voltage deviation of load nodes. The Pareto solution is shown in Table 2, and the voltage deviation diagram of load nodes is shown in Figure 8.

Fuzzy weight method is used to optimize the objective function. From an economic point of view, firstly, the reactive power optimization goal of at least 1F of reactive power compensation capacity of wind turbine is considered and given the maximum fuzzy weight, and secondly, the reactive power optimization goal of at least 2F of voltage deviation of load node of wind turbine is considered. From the above Table 2, it can be seen that the optimal solutions of voltage deviation of load nodes are in line with the requirement that the absolute value of positive and negative voltage deviation should not exceed 10% of the nominal voltage in Technical Provisions for Wind Farm Access to Power Grid. According to the priority of objective function considered in this paper, the experimental results under different specific gravities are compared and weighed, as shown in Figure 9.

5. Conclusion

In this paper, an investment strategy based on genetic algorithm is proposed, and an improved reactive power optimization scheme is proposed for wind turbines. The effectiveness of the new algorithm in reactive power optimization of wind farms is tested in a simulation example of wind turbines, and the optimization results show good performance in voltage quality, active power loss, and node voltage deviation of wind turbines. However, the problem of complex current collection network in wind turbine has not been considered in this paper, and whether reactive power optimization of wind turbine can adapt to this scheme needs further study.

Data Availability

The labeled dataset used to support the findings of this study is available from the corresponding author upon request.

Conflicts of Interest

The authors declare no competing interests.

References

[1] W. Huang and W. Zhang, "Research on distributed wind power reactive voltage coordinated control strategy connected to distribution network," in *2021 4th International Conference on Energy, Electrical and Power Engineering (CEEPE)*, pp. 529–534, IEEE, Chongqing, China., April 2021.

[2] A. Eid, S. Kamel, and L. Abualigah, "Marine predators algorithm for optimal allocation of active and reactive power resources in distribution networks," *Neural Computing and Applications*, vol. 33, no. 21, pp. 14327–14355, 2021.

[3] J. Hao, S. Luo, and L. Pan, "Computer-aided intelligent design using deep multi-objective cooperative optimization algorithm," *Future Generation Computer Systems*, vol. 124, pp. 49–53, 2021.

[4] K. Suvarchala, T. Yuvaraj, and P. Balamurugan, "A brief review on optimal allocation of distributed generation in distribution network," in *2018 4th International Conference on Electrical Energy Systems (ICEES)*, pp. 391–396, IEEE, Chennai, India., Feb 2018.

[5] C. K. Das, O. Bass, T. S. Mahmoud, G. Kothapalli, M. A. S. Masoum, and N. Mousavi, "An optimal allocation and sizing strategy of distributed energy storage systems to improve performance of distribution networks," *Journal of Energy Storage*, vol. 26, article 100847, 2019.

[6] V. A. Morais, J. L. Afonso, A. S. Carvalho, and A. P. Martins, "New reactive power compensation strategies for railway infrastructure capacity increasing," *Energies*, vol. 13, no. 17, p. 4379, 2020.

[7] K. Mehmood, Z. Li, M. F. Tahir, and K. M. Cheema, "Fast excitation control strategy for typical magnetically controllable reactor for reactive power compensation," *International Journal of Electrical Power & Energy Systems*, vol. 129, article 106757, 2021.

[8] X. Ding, R. Yao, X. Zhai, C. Li, and H. Dong, "An adaptive compensation droop control strategy for reactive power sharing in islanded microgrid," *Electrical Engineering*, vol. 102, no. 1, pp. 267–278, 2020.

[9] A. Dhaneria, "Grid connected PV system with reactive power compensation for the grid," in *2020 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT)*, pp. 1–5, IEEE, Washington, USA., Feb 2020.

[10] M. Wang, H. Yi, Z. Yang et al., "Comprehensive control of voltage quality in distribution network based on reactive power optimization," *IEEE 9th International Power Electronics and Motion Control Conference (IPEMC2020-ECCE Asia)*, 2020, IEEE, Nanjing, China., 2020.

[11] N. Karmakar and B. Bhattacharyya, "Optimal reactive power planning in power transmission network using sensitivity based bi-level strategy," *Sustainable Energy, Grids and Networks*, vol. 23, article 100383, 2020.

[12] W. Yang, L. Chen, Z. Deng, X. Xu, and C. Zhou, "A multi-period scheduling strategy for ADN considering the reactive power adjustment ability of DES," *International Journal of Electrical Power & Energy Systems*, vol. 121, article 106095, 2020.

[13] O. D. Montoya and W. Gil-González, "Dynamic active and reactive power compensation in distribution networks with batteries: a day-ahead economic dispatch approach," *Computers & Electrical Engineering*, vol. 85, article 106710, 2020.

[14] S. Tamalouzt, Y. Belkhier, Y. Sahri et al., "Enhanced direct reactive power control-based multi-level inverter for DFIG wind system under variable speeds," *Sustainability*, vol. 13, no. 16, p. 9060, 2021.

[15] F. Chen, H. Deng, and Z. Shao, "Decentralised control method of battery energy storage systems for SoC balancing and reactive power sharing," *IET Generation, Transmission & Distribution*, vol. 14, no. 18, pp. 3702–3709, 2020.

[16] M. L. Kolhe and M. Rasul, "3-phase grid-connected building integrated photovoltaic system with reactive power control capability," *Renewable Energy*, vol. 154, pp. 1065–1075, 2020.

[17] X. Tang, Z. Huang, and M. Zhang, "An auxiliary unit with selective harmonic suppression and inherent reactive power compensation for civil distribution networks," *International Journal of Electrical Power & Energy Systems*, vol. 124, article 106323, 2021.

[18] Y. Tao and W. Yue, "Multi objective reactive power optimization of distribution network with distributed generation power uncertainty," *Journal Of Physics: Conference Series*, vol. 2023, no. 1, article 012041, 2021.

[19] Y. Muhammad, R. Khan, M. A. Z. Raja, F. Ullah, N. I. Chaudhary, and Y. He, "Solution of optimal reactive power dispatch with FACTS devices: a survey," *Energy Reports*, vol. 6, pp. 2211–2229, 2020.

[20] B. K. Jha, A. Singh, A. Kumar, R. K. Misra, and D. Singh, "Phase unbalance and PAR constrained optimal active and reactive power scheduling of virtual power plants (VPPs)," *International Journal of Electrical Power & Energy Systems*, vol. 125, article 106443, 2021.

[21] B. Kelkoul and A. Boumediene, "Stability analysis and study between classical sliding mode control (SMC) and super twisting algorithm (STA) for doubly fed induction generator (DFIG) under wind turbine," *Energy*, vol. 214, article 118871, 2021.