Microgrid Development Model and Control Strategy for Dual Carbon Target

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Abstract. In recent years, in the face of China's increasingly serious environmental pollution and energy structure problems, the country has proposed the double carbon target of "peak carbon" by 2030 and "carbon neutral" by 2060, and microgrids, as a kind of small-scale power generation and distribution system with economy and environmental protection, can better absorb distributed energy. In the context of the dual carbon target, it is important to study the development mode and control strategy of microgrids energy. This paper firstly elaborates the advantages of combining microgrid and distributed energy, divides microgrid into grid-connected microgrid and stand-alone microgrid according to the operation mode, and gives the mathematical model of distributed energy. Based on the above, this paper studies grid-connected and stand-alone microgrids. Additionally, single-objective and multi-objective models under different strategies have been presented. The single-objective model aims to minimize operating costs, while the multi-objective model aims to minimize operating costs and carbon emissions simultaneously. Genetic algorithms have been employed to solve this problem, and MATLAB simulations have been used to analyze the models. The results of the simulations demonstrate that this strategy can significantly reduce carbon emissions with only a marginal increase in costs, thus validating the correctness and effectiveness of this approach.

Keywords: Microgrid Optimized Operation, Distributed Energy, Dual Carbon Targets.

1. Introduction

In recent years, in the face of environmental pollution and energy structure and other issues, the state has promulgated a series of policies and regulations to support the development of renewable energy. In order to build a clean, low-carbon, safe and efficient modern energy system and push forward the energy revolution, China has established the goal of "striving to reach the peak of carbon dioxide emissions by 2030, and striving to achieve carbon neutrality by 2060".

Due to the increasing demand for electricity, the scale of the power grid is also expanding. Although the traditional ultra-high-voltage, long-distance power grid has solved the problem of uneven distribution of energy and loads, there are still problems such as high energy transmission loss, energy dependence, environmental pollution, and poor flexibility and sustainability. In this context, distributed generation technology has emerged [1]. Distributed generation disperses energy production to more locations, reducing the dependence on centralized power sources and therefore reducing the risk of energy supply interruptions. However, the large-scale integration of distributed energy into the distribution network will bring a large impact. In order to effectively solve this challenge and reduce the negative impact of distributed generation, multiple distributed energy sources with complementary characteristics are usually integrated into a microgrid form of operation.

Microgrid refers to a small power grid composed of distributed energy resources, loads, and energy storage systems (ESS), with a certain degree of autonomy [2]. There are two main types of microgrid operation, one is normal interconnected mode with the larger grid, and the other is disconnecting from the larger grid into an island mode in case of emergency [3]. In interconnected mode, the microgrid can complement and transfer energy through the traditional grid. In islanded mode, the microgrid can operate completely independently of the traditional grid, without relying on the external grid for power supply, generating power from a variety of energy resources including solar, wind, biomass, etc., and storing excess energy for further use through energy storage equipment [4].

In conjunction with the dual-carbon objective, there have been many studies on the optimal scheduling problem for microgrids. Literature verifies the impact of carbon emission costs on

microgrid planning [5]. Literature improves the comprehensive economic and environmental benefits of grid-connected microgrids [6]. Literature proposes an integrated scheduling optimization method to reduce the total operating costs of microgrids and distribution grids [7]. Literature reduces the total planning cost of microgrid effectively [8]. However, the above studies did not consider the operation cost and carbon emission optimization at the same time. Therefore, this paper proposes two microgrid operation strategies to verify the feasibility and effectiveness of the strategies by comparing the operation cost and carbon emission under single-objective and multi-objective optimization conditions.

2. Methodology

2.1. Distributed Energy Modeling

Microgrid refers to a small power grid composed of distributed energy resources, loads and ESS, while distributed energy is an important part of microgrids, analyzing and mathematical modeling of distributed energy is the basis for studying microgrid operation.

2.1.1. Wind power output modeling

Wind power is a renewable energy source with the advantages of extensive resources, environmental friendliness and stable energy, and at the same time, it can promote the rapid development of social economy, and it has gradually become an important form of energy to be promoted and applied in countries all over the world. The process of wind turbine output power can be expressed by equation (1).

$$P_{wG} = \frac{1}{2}\rho\pi r^2 v^3 C_p \tag{1}$$

Where, ρ, r, v and C_p represent air density, the blade radius of the turbine, the size of the tip wind speed and the wind energy conversion efficiency respectively.

2.1.2. Photovoltaic power output modeling

Solar photovoltaic (PV) power generation is a renewable energy technology that utilizes solar energy to convert light energy into electricity, with the advantages of cleanliness and environmental friendliness, low maintenance cost, long life, high reliability, flexibility and scalability. The mathematical model of its power output can be expressed by equation (2).

$$P_{pv} = P_{stc}\frac{G_t}{G_{stc}}[1 + k_c(\theta_t - \theta_{stc})] \tag{2}$$

Where, P_{pv}, P_{stc}, G_t, k_c, θ_t, G_{stc} and θ_{stc} represent the system output, the system standard output, the light intensity, the temperature coefficient, the actual operating temperature, the rated light intensity and operating temperature respectively.

2.1.3 Diesel generator output modeling

Diesel generators (DG) generate electricity by consuming diesel fuel and are widely used in microgrid operation in various scenarios due to their low operating cost, independence from environmental factors, and good economy and flexibility. The mathematical model of its power output can be expressed by equation (3):

$$F_{cs} = k_1 P_{dg} + k_2 P_{dge} \tag{3}$$

Where, F_{cs} represents the fuel consumption of the DG, P_{dg} represents DG output power, P_{dge} represents the rated power of DG, k_1 and k_2 represent the intercept coefficient of the fuel curve of DG and the slope of the fuel curve respectively.

2.2. Optimization Strategies for Economic Operation of Microgrids

Chemical remediation techniques are a relatively common means of remediating oil-contaminated land. The current classification of this technology includes chemical oxidation, chemical scrubbing, solvent extraction and photocatalysis.

2.2.1. Optimal scheduling of grid-connected microgrid economics

The economic operation strategy of grid-connected microgrid is to prioritize distributed energy generation including PV and wind power. When distributed energy generation has surplus, consider the time-of-use pricing mechanism, and charge the excess power to ESS when the main grid sale price is low. When the distributed energy supply cannot meet the load demand for electricity, compare the storage discharge price and the main grid power purchase price, and choose the one with the lower price to supply electricity.

Considering the lowest operating cost as the single objective, the total cost is shown in equation (4). Considering the environmental pollution problem, define the DG pollution cost, carbon emission and carbon emission cost as shown in equations (5)-(8). When operating costs and carbon emissions are used as multiple targets, the total costs are shown in equation (9).

$$C_{tot} = \sum_t^T C_{pv}P_{pv} + \sum_t^T C_{pw}P_{pw} + \sum_t^T C_{dg}P_{dg} + \sum_t^T C_{es}P_{cd} + \sum_t^T C_{buy}P_{grid} - \sum_t^T C_{sell}P_{grid} \quad (4)$$

Where, C_{pv}, C_{pw}, C_{dg} represent costs of photovoltaic, wind and DG respectively. P_{pv}, P_{pw}, P_{dg} represent output of PV, wind power, DG respectively. C_{es} represents charging and discharging costs for ESS. P_{cd} represents charge and discharge power of ESS. C_{buy} and C_{sell} represent purchase price and sale price of electricity for the main grid respectively. P_{grid} represents main grid power.

$$C_{dgp} = \sum_t^T C_{po}P_{dg} \quad (5)$$

$$E_{dg} = \sum_t^T \mu_{dg}P_{dg} \quad (6)$$

$$E_{grid} = \sum_t^T \mu_{grid}P_{pv_buy} \quad (7)$$

$$C_{ce} = \lambda(E_{dg} + E_{grid}) \quad (8)$$

Where, C_{dgp} represents the cost of pollution control for DG; C_{po} represents the DG pollution factor; E_{dg} represents the DG carbon emissions; μ_{dg} represents the DG carbon emission factor; E_{grid} represents the carbon emissions generated by grid purchased electricity; μ_{grid} represents the grid carbon emission factor; P_{pv_buy} represents the power purchased from the grid; C_{ce} represents the total cost of carbon emissions and λ represents the carbon price.

$$C_{sum} = k_1C_{tot} + k_2C_{ce} \quad (9)$$

Where, C_{sum} represents the total operating costs. k_1 and k_2 represent the weighting factors.

The grid-connected operation of microgrids needs to consider power balance constraints, maximum transmission power constraints of contact lines, PV output constraints, wind power output constraints, DG output constraints, and ESS constraints. Equations (10)-(18) show the constraints.

$$P_{grid} = P_{pv} + P_{pw} + P_{dg} - P_{cd} - P_{load} \quad (10)$$

$$-P_{gridmax} < P_{grid} < P_{gridmax} \quad (11)$$

$$0 < P_{pv} < P_{pvmax} \tag{12}$$

$$0 < P_{pw} < P_{pwmax} \tag{13}$$

$$0 < P_{dg} < P_{dgmax} \tag{14}$$

$$0 < P_{ch} < P_{chmax} \tag{15}$$

$$0 < P_{dch} < P_{dchmax} \tag{16}$$

$$SOC_{min} \leq SOC \leq SOC_{max} \tag{17}$$

$$SOC(0) = SOC(24) \tag{18}$$

Where, $P_{gridmax}$ represents maximum transmission power on the transmission line between the large grid and the microgrid. P_{pvmax} represents maximum output power of PV. P_{pwmax} represents maximum output power of wind turbine. P_{dgmax} represents maximum output power of DG. P_{ch} and P_{dch} represent battery charging power and discharging power respectively. P_{chmax} and P_{dchmax} represent the maximum charging and discharging power of ESS respectively. SOC_{min} and SOC_{max} represent the minimum and maximum value of SOC respectively. $SOC(0)$ and $SOC(24)$ represent the value of the charge state of ESS at moment 0 and moment 24.

2.2.2. Optimal scheduling of stand-alone microgrid economics

The economic operation strategy of an independent microgrid is based on the example of an independent wind-solar-diesel-storage microgrid. Due to environmental pollution caused by diesel power generation opportunities, the system prioritizes distributed energy for power supply to the load. When distributed energy generation can meet the load demand, excess electricity is charged to the ESS. If the capacity of the storage battery reaches the upper limit, then wind and solar energy are discarded. When the load demand is too large and distributed energy power supply cannot guarantee the load demand, the priority is given to the ESS discharge. If the ESS discharge still cannot meet the load demand, then the introduction of DG to the load power supply. Based on this, if the load demand is still cannot be met, then need to cut off part of the load.

Considering the lowest operating cost as the single objective, the total cost is shown in equation (19).

$$C_{tot} = \sum_t^T C_{pv}P_{pv} + \sum_t^T C_{pw}P_{pw} + \sum_t^T C_{dg}P_{dg} + \sum_t^T C_{es}P_{cd} + \sum_t^T p_1 P_{load-d} + \sum_t^T p_2(P_{pv-d} + P_{pw-d}) \tag{19}$$

Where,C_{pv}, C_{pw}, C_{dg} represent costs of PV, wind and DG respectively. C_{es} represents charging and discharging costs for ESS. P_{cd} represents charge and discharge power of ESS. p_1 and p_2 represent cut-load penalty factor and penalty factor for wind and solar abandonment respectively.

Due to the emergence of wind and solar power abandonment and load shedding in stand-alone microgrids, the output and load power of PV and wind power are no longer constant values. Therefore, the difference between the PV, wind power outputs and load power are defined as P_{pv-d}, P_{pw-d} and P_{load-d}. Equations (20)-(22) show the definitions. Considering the environmental pollution issue, define the DG carbon emission and carbon emission cost as shown in equations (23)-(24). When operating costs and carbon emissions are used as multiple targets, the total costs are shown in equation (25).

$$P_{pv-d} = P_{PV} - P_{pv} \tag{20}$$

$$P_{pw-d} = P_{PW} - P_{pw} \tag{21}$$

$$P_{load-d} = P_{LOAD} - P_{load} \tag{22}$$

$$E_{dg} = \sum_t^T \mu_{dg} P_{dg} \tag{23}$$

$$C_{ce} = \lambda E_{dg} \tag{24}$$

$$C_{sum} = k_1 C_{tot} + k_2 C_{ce} \tag{25}$$

Where, P_{PV}, P_{PW} and P_{LOAD} represent the given PV output, wind output and load demand respectively. E_{dg} represents the DG carbon emissions; μ_{dg} represents the DG carbon emission factor; C_{ce} represents the total cost of carbon emissions and λ represents the carbon price. C_{sum} represents the total operating costs. k_1 and k_2 represent the weighting factors.

Equation (26) shows the power balance constraints for stand-alone microgrids.

$$P_{pv} + P_{pw} + P_{dg} + P_{dch} = P_{load} + P_{ch} \tag{26}$$

Where, P_{pv}, P_{pw}, P_{dg} represent output of PV, wind power and DG respectively. P_{ch} and P_{dch} represent charge and discharge power of ESS respectively. P_{load} represents load demand power.

Due to the microgrid off-grid operation without the upper power grid for support, in order to ensure that the microgrid internal load power, when the renewable energy output is less than the load power, by the DG and ESS common power supply, no longer consider constraints of equal state of SOC at the beginning and the end of the scheduling moment of ESS and the contact line constraints.

3. Results and Discussion

Based on the optimization strategy for economic operation of microgrids given in 2.2, this chapter conducts case analysis to optimize the single objective with the lowest operating cost as the goal and the multi-objective with the lowest operating cost and carbon emissions. Finally, the optimization results under different objectives are compared to verify the optimal economic operation strategy of microgrids in offline scenarios.

3.1. Grid-connected Microgrid Economics Case Analysis

3.1.1. Parameter settings

The parameter settings for distributed energy and carbon emission price are shown in Table 1. Besides, the carbon emission factor of DG is 0.458, the carbon emission factor of main grid power purchase is 0.997 [9, 10], and the weighting factor is 0.5. The curve of the wind turbine and PV output and load prediction is shown in Fig. 1, and the time-division price of electricity is shown in Table 2.

Table 1. Distributed energy and carbon emission settings

	Maximum output power or capacity	Price
Wind turbine	100 kW	0.1 ¥/kWh
PV	200 kW	0.2 ¥/kWh
DG	100 kW	0.4 ¥/kWh
ESS	100 kWh	0.02 ¥/kWh
Carbon emission		0.28 ¥/kg

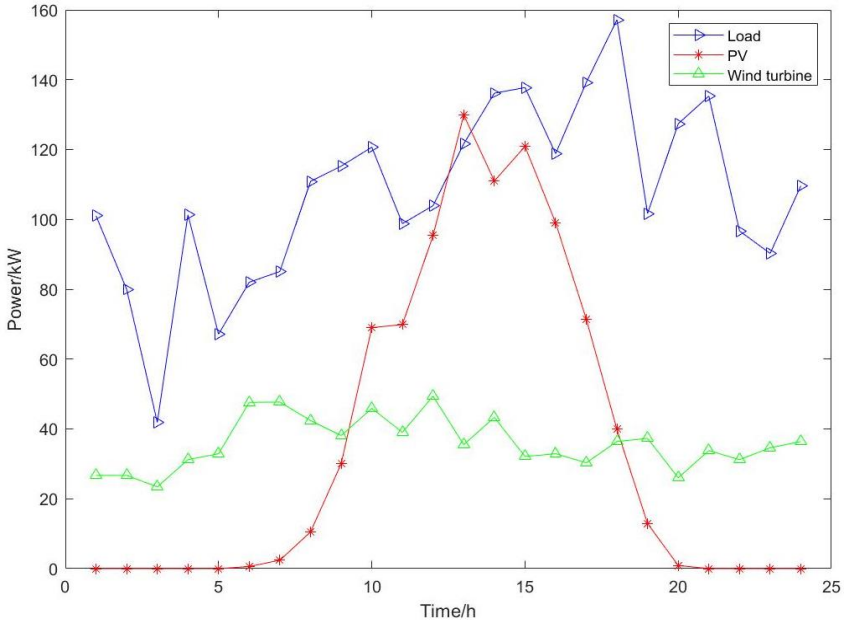


Figure 1. The curve of wind turbine and PV output and load prediction. (Picture credit: Original)

Table 2. Microgrid purchase and sale prices

Time	0:00-7:00	7:00-10:00	10:00-15:00	15:00-18:00	18:00-21:00	21:00-0:00
Purchase prices (¥/kWh)	0.22	0.42	0.65	0.42	0.65	0.42
Sale prices (¥/kWh)	0.25	0.53	0.82	0.53	0.82	0.53

3.1.2. Analysis of results

On the basis of the economic operation strategy of grid-connected microgrid mentioned above, firstly, a single-objective analysis aiming to minimize operating costs is conducted, and the outcomes are illustrated in Fig. 2. Subsequently, a multi-objective analysis targeting both the lowest operating cost and reduced carbon emissions is undertaken, with the results presented in Fig. 3.

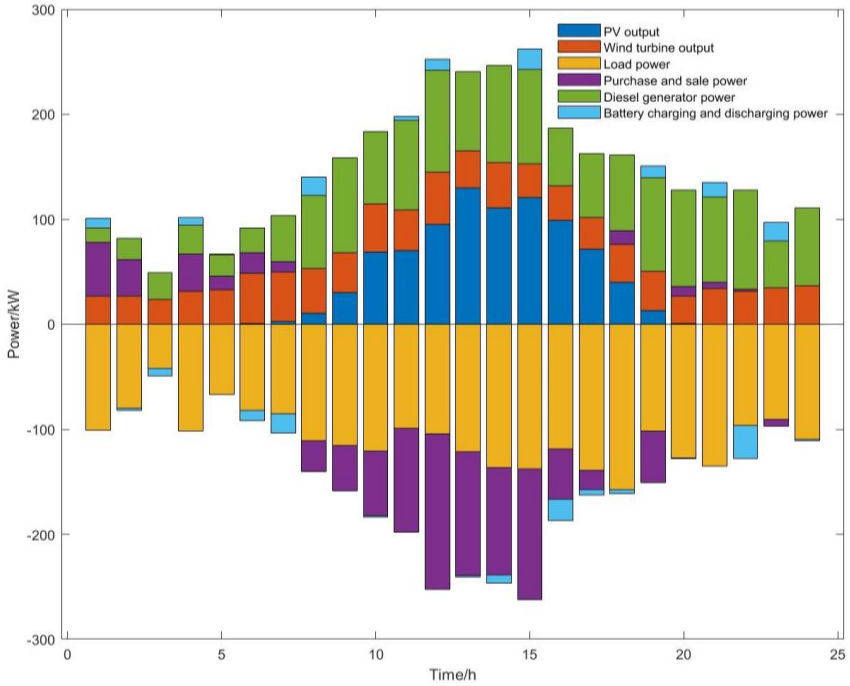


Figure 2. Results of single-objective grid-connection example. (Picture credit: Original)

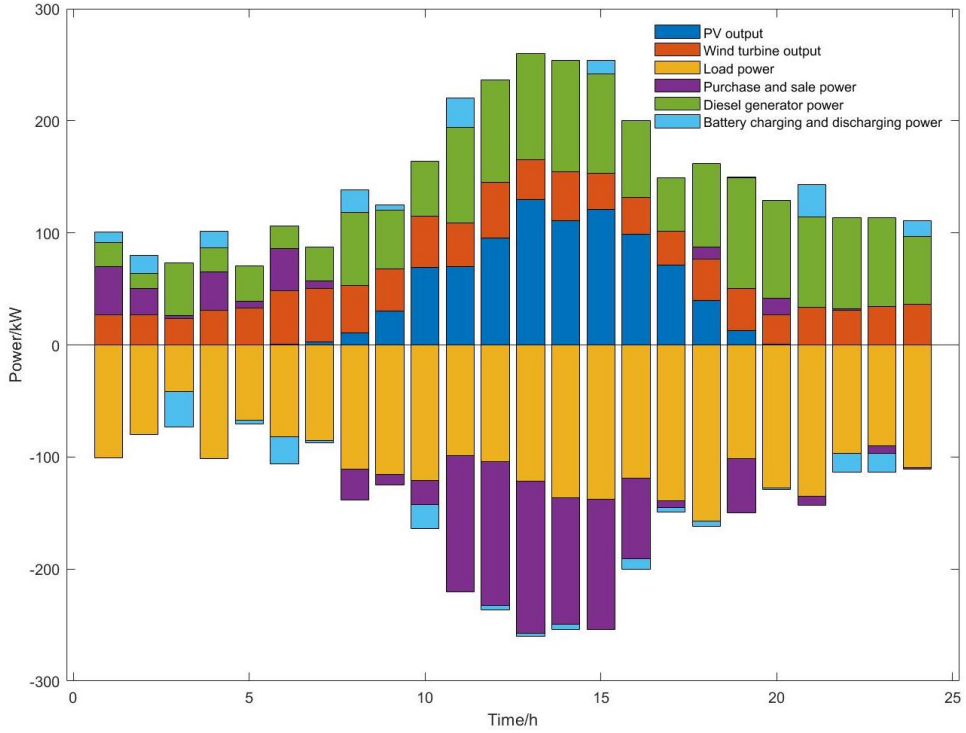


Figure 3. Results of multi-objective grid-connection example (Picture credit: Original)

The results of the grid-connected operation with the lowest operating cost as the single objective are shown in Fig. 2. The system prioritizes the power supply of the load by the wind turbine and PV output. When the wind turbine and PV output is insufficient, the lower price is selected for power supply by comparing the purchase price of the main grid with the operating cost of the DG. If the wind turbine and PV output is greater than the load demand, the excess power is charged to ESS or sold to the upper grid.

For the period from 0 to 7 hours, due to the scarcity of wind and solar resources, and in this period of power purchase price is less than the price of DG operation, and in the lowest price of the day. Therefore, in consideration of the economy of the main grid is mainly used in the form of purchasing power to supply loads, in which the DG and ESS as an auxiliary energy for power supply.

During the 7 to 10 hours, due to time-of-use price restrictions, the price of electricity purchased at this time is greater than the price of DG operation, so almost no electricity is purchased from the main grid. In the 10 to 17 hours, when the price of electricity sales is the highest, the use of DG to generate large amounts of power and sell the surplus power to the grid can get the maximum economic benefits. Therefore, at this time of the day, the DG output and power sales to the grid have reached the maximum value of the day.

At time 18:00, when the revenue from power sales is not high and the price of purchased power is low, only the DG output and purchased power are required to meet the load demand. At 19:00 to 21:00, some more power sales are made due to the increase in power sale price and discharge from storage to reduce the DG operating cost. From 21:00 to 0:00, the load is supplied by a combination of DG output and main grid purchased power, while the excess power is utilized to charge ESS to satisfy the storage SOC constraints, ensuring that the ESS has the same initial and final state of charge for one day.

The results of the grid-connected operation with the lowest operating cost and carbon emmisions as the multi-objective are shown in Fig. 3. After considering the carbon emission cost, as the carbon emission coefficient of the main grid electricity purchase is greater than that of DG, the system tries not to purchase electricity from the main grid, but mainly uses DG for power generation.

From 0 to 7 hours, compared to single target operation, there is a significant reduction in the power procured from the main grid, replaced by DG with less pollution to meet the load power requirements. At 8 to 10 hours, considering the high price and pollution of the main grid power purchase, electricity

was not purchased from the main grid during this period. In order to meet the load demand while reducing carbon emissions, a large amount of ESS was discharged at 8 hours, which reduces costs and carbon emissions.

From 11 to 16 hours, due to the high price of electricity sold in this period, a large number of DG are still used to generate electricity, and the excess electricity is sold to the main grid, but the output of DG is reduced due to the constraints on carbon emissions compared to single-objective operation.

At 16 to 0 hours, due to the low cost and no carbon emissions, ESS discharge power of the system has been improved, and electricity is almost not purchased and sold from the main network. The load demand electricity is mainly provided by DG.

The data presented in Table 3 reveals that the total cost before and after considering carbon emissions has increased by 9.96%, and the carbon emissions have decreased by 25.39%, which indicates that the strategy has achieved the goal of reducing carbon emissions by slightly increasing costs.

Table 3. Comparison of results

Time	Single-objective	Multi-objective
Operating cost/¥	443.6271	487.8342
Carbon emission/kg	1060.635	791.3693

3.2. Stand-alone Nicrogrid Economics Case Analysis

3.2.1. Parameter settings

In this paper, the parameter settings for distributed energy and carbon emission price are shown in Table 4. Besides, cut-load penalty factor and penalty factor for wind and solar abandonment are both set to be 100, and the weighting factor is 0.5. The curve of the wind turbine and PV output and load prediction is shown in Fig. 4.

Table 4. Distributed energy and carbon emission settings

	Maximum output power or capacity	Price
Wind turbine	200 kW	0.1 ¥/kWh
PV	150 kW	0.24 ¥/kWh
DG	150 kW	0.1 ¥/kWh
ESS	750 kWh	0.25 ¥/kWh
Carbon emission		0.28 ¥/kg

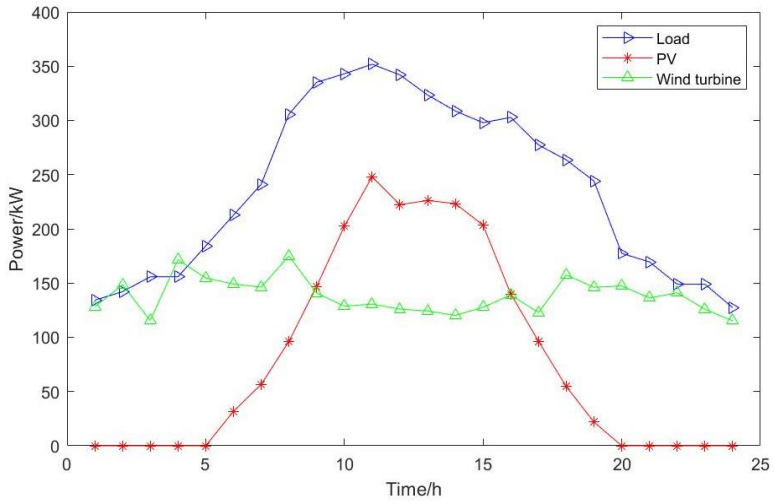


Figure 4. The curve of wind turbine and PV output and load prediction. (Picture credit: Original)

3.2.2. Analysis of results

On the basis of the economic operation strategy of stand-alone microgrid mentioned above, firstly, a single-objective analysis aiming to minimize operating costs is conducted, and the outcomes are

illustrated in Fig. 5. Subsequently, a multi-objective analysis targeting both the lowest operating cost and reduced carbon emissions is undertaken, with the results presented in Fig. 6.

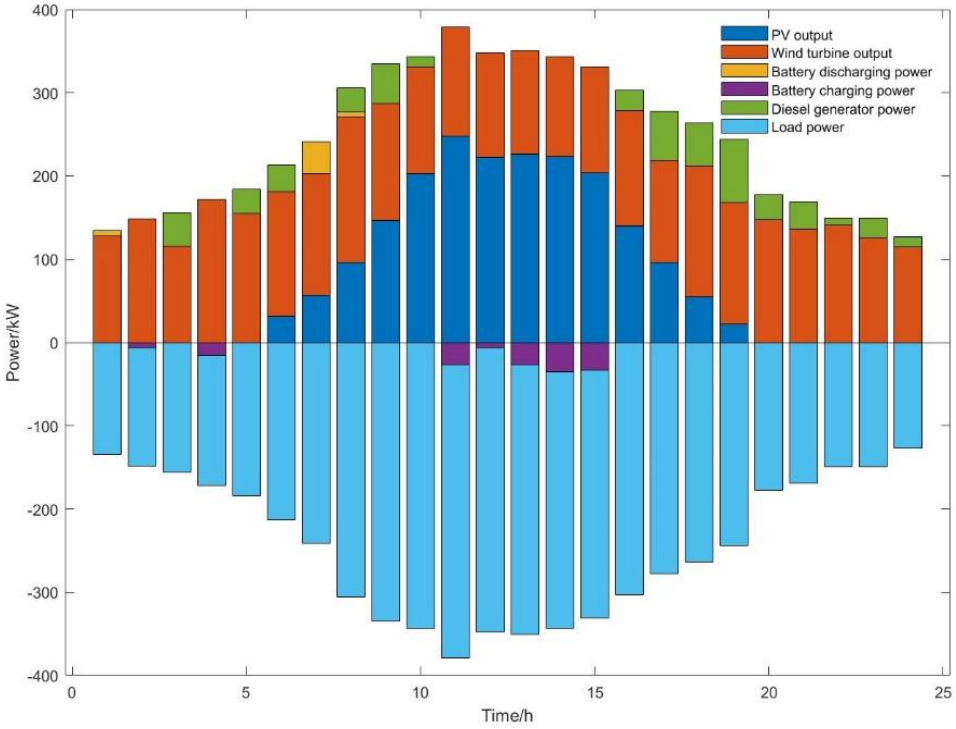


Figure 5. Results of single-objective off-grid example. (Picture credit: Original)

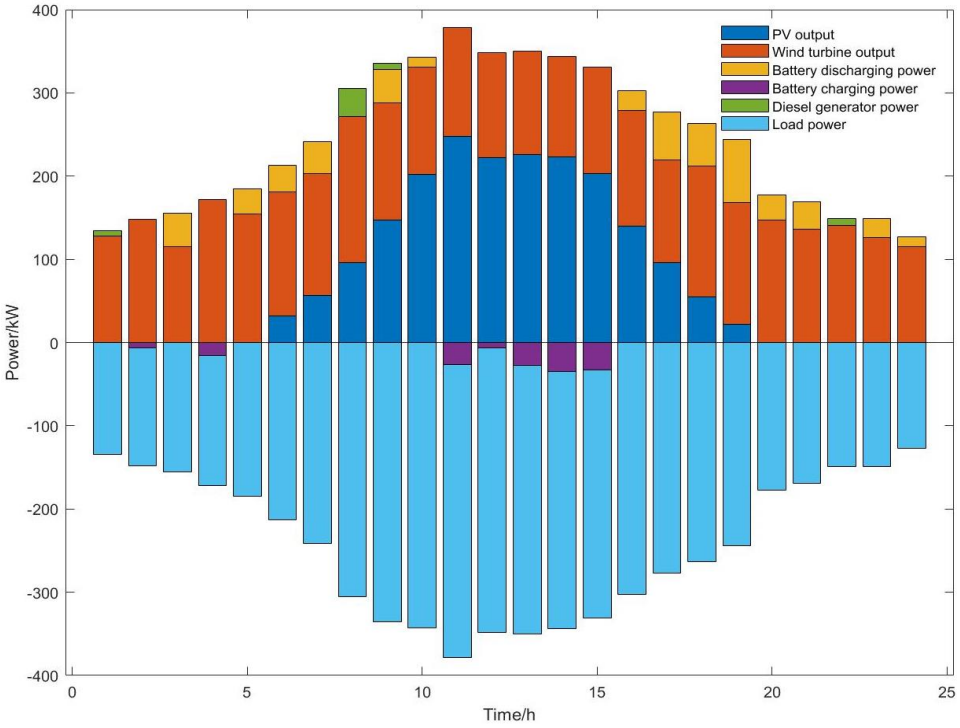


Figure 6. Results of multi-objective off-grid example (Picture credit: Original)

The results of off-grid operation with the single objective of minimizing operating cost are shown in the figures above. In the case that the renewable energy can meet the load demand, the excess power is given to ESS for charging. When the wind power cannot meet the load power, comparing the operation cost of diesel generator and ESS, the diesel generator is preferred to supply power to the load.

Fig. 7 illustrates that PV and wind turbine are both at full capacity under this operating strategy and the load demand is fully satisfied. The results shown in Fig. 5 indicate that at 3:00, 5:00 to 6:00, due to the high penalty factor for wind and solar abandonment, and the lower operating cost of DG compared to ESS the system uses DG to supply power to the load during this period. At 2:00, 4:00, and 11:00 to 15:00, the renewable energy output can meet the load demand during this period. Due to the high value of cut-load penalty factor, the excess electricity is sent to ESS for charging. To ensure that the ESS capacity does not exceed the upper limit, ESS is discharged at 1:00, 7:00 and 8:00. At 16:00 to 0:00, low-cost DG are still used to power the load.

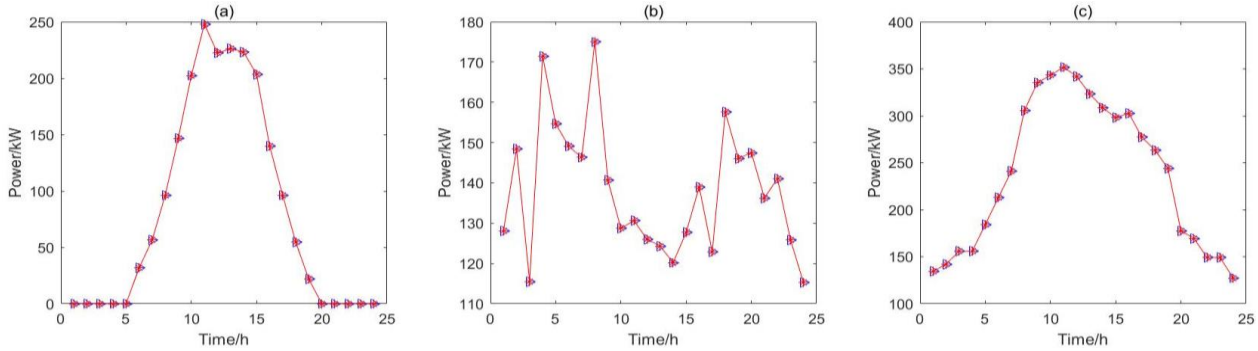


Figure 7. PV output situation (a), Wind turbine output situation (b), and Load demand curve (c) (Picture credit: Original)

The results of off-grid operation with multi-objective of minimizing operating costs and carbon emissions are shown in Fig. 6. Considering the large carbon emission factor of the DG, the system mainly supplies power to the load with ESS during operation. Due to the limitation of the lower capacity limit, ESS cannot constantly supply power to the load. Therefore, at 1:00, 8:00 and 9:00, the electricity that is not enough to meet the load demand from renewable energy is supplied by DG.

At 2:00, 4:00 and 11:00 to 15:00, due to the abundant wind and solar resources, which can meet the load demand, the surplus power is charged to ESS. At 16:00 to 0:00, the system still chooses to use ESS to supply power to the loads, taking into account the operating cost and carbon emission cost. However, at 22:00, since the storage power cannot be lower than the lower capacity limit, the power demanded by the load at that moment is supplemented by DG.

The data presented in Table 5 reveals that the total cost before and after considering carbon emissions has increased by 7.46%, and the carbon emissions have decreased by 88.95%, which indicates that the strategy has achieved the goal of reducing carbon emissions by slightly increasing costs.

Table 5. Comparison of results

Time	Single-objective	Multi-objective
Operating cost/¥	905.214	972.714
Carbon emission/kg	434.0615	47.9615

4. Conclusion

With the proposal of the dual carbon goal, the application of microgrids and distributed energy has become the main development goal in China. In order to maximize the economic and environmental protection of microgrid operation, the combination of microgrids and distributed energy operation strategy is the key to research. In this context, this paper focuses on the economic operation of microgrids, with the main purpose of reducing carbon emissions, and carries out relevant research work. The Matlab simulation analysis results indicate that the grid-connected microgrid, supported by the superior power grid, needs to consider the carbon emission brought by purchasing power from the main grid during the operation process. When the renewable energy of stand-alone microgrid cannot meet the load demand, the electricity is mainly provided by ESS and DG. Considering the carbon emissions brought by DG, ESS is mainly used for power supply under multi-objective

conditions. Finally, the example results indicate that this strategy can significantly reduce carbon emissions by slightly increasing costs, verifying the correctness and effectiveness of the proposed strategy in this paper.

References

[1] Pepermans G., Driesen J., Haeseldonckx D., et al., Distributed generation: definition, benefits and issues. Energy policy, 2005, 33 (6): 787 - 798.

[2] Marnay C., Venkataramanan G., Microgrids in the evolving electricity generation and delivery infrastructure. IEEE Power Eng Soc Gen Meet, 2006, 18 – 22.

[3] Jiayi H., Chuanwen J., Rong X., A review on distributed energy resources and MicroGrid. Renewable and Sustainable Energy Reviews, 2008, 12 (9): 2472 - 2483.

[4] Zhao W., Xu M., Ning N., et al., A Microgrid Capacity Optimization Method Considering Carbon Emission Cost,2020 IEEE Sustainable Power and Energy Conference (ispec). IEEE, 2020, 2219 - 2224.

[5] Lopes J. A. P., Moreira C.L., Madureira A.G., Defining control strategies for microgrids islanded operation. IEEE Transactions on power systems, 2006, 21 (2): 916 - 924.

[6] Zhu X., Peng C., Geng H., Multi-Objective Sizing Optimization Method of Microgrid Considering Cost and Carbon Emissions, 2022 4th International Conference on Smart Power & Internet Energy Systems (SPIES). IEEE, 2022, 2278 - 2283.

[7] Zhao K., Zhang B., Zhao G., et al., Comprehensive Dispatching Optimization for Distribution Network Containing Microgrid, 2018 2nd IEEE Conference on Energy Internet and Energy System Integration (EI2). IEEE, 2018, 1 - 6.

[8] Cheng S., Liu Z., Huang T.L, et al., Optimal planning of hybrid energy generation system in the microgrid considering direct load control, 2017 International Conference on Fuzzy Theory and Its Applications (iFUZZY). IEEE, 2017, 1 - 5.

[9] Li Z., Li Y., Wei Y., et al., Optimal operation of microgrid in the park considering carbon trading and the proportion of green electricity. Electrical Measurement & Instrumentation, 2022: 1 - 11 (In Chinese).

[10] Luo J., Zou M., Hou B., et al., Coordinated and optimal operation of wind solar energy storage system considering V2G and carbon emission. Electrical Measurement & Instrumentation, 2021, 1 - 8. (In Chinese).