Analysis of the Influence of the Spatial-Temporal Characteristics of Wind Power and Photovoltaics on the Economic Dispatch of Independent Microgrids

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Abstract. Considering the spatial-temporal characteristics of wind and solar power generation in the dispatching of new power systems can effectively improve the stability and economy of system operation. In order to investigate the impact of the spatial-temporal characteristics of wind power generation and solar power generation on the dispatch economy and robustness of independent microgrid, this research establishes a robust optimal dispatch model based on extreme scenarios. First, the uncertainty and complementarity of generation of wind and solar is analyzed with the actual wind and solar data, and the standard deviation and Spearman correlation coefficient are used to quantitatively evaluate the two characteristics. The other power generation units in the system are modeled; then, a robust optimal dispatch model with the objective function of minimizing the operating cost of each generator unit is established; finally, the simulation is divided into four scenarios, and by adjusting the robustness of the system, different comprehensive operating costs and wind and light output conditions are obtained in each scenario. The analysis shows that the spatiotemporal characteristics of wind and solar output have a significant impact on the dispatch economy and robustness of the independent microgrid.

Keywords: Uncertainty · Complementarity · Independent microgrid · Extreme scenario method · Robust optimal scheduling

1 Introduction

The increasing installed capacity of new energy such as wind and solar energy brings more uncertainties to the power system. It poses big challenges to security and economy of power system [1]. It is significant to consider the spatial and temporal characteristics of wind and solar generation in the dispatch of the power system.

The spatial and temporal characteristics of wind and solar energy are considered in the study of dispatch of power grid. [1, 2] used Weibull distribution and Beta distribution to characterize the uncertainty. [3] according to the probability density function of three

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uncertain parameters, several groups of data of solar, wind and load are obtained, then got simulated scenarios and prediction mean scenarios. [4] modeled wind speed using a two-parameter Weibull distribution and solar radiation was modeled using a log-normal distribution. [5] incorporated the complementary fluctuating properties of solar and wind energy into the distributed energy system planning process. Simulation examples showed that, compared with the single economic target model, the fluctuation complementarity ratio could be improved. [6–9] considering the complementarity of solar and wind, explored energy system planning and economic dispatch. [10] constructed the fuzzy set of the wind and solar output prediction error based on the Wasserstein metric, then the uncertainty of the net load under this processing method was obtained. Finally, a distributed robust optimization method was established for case analysis. [11] is similar to [10] in the method of constructing fuzzy sets, which adopts the method of robust stochastic optimization.

This paper discusses the impact of the spatiotemporal characteristics of generation of solar and wind on independent microgrid. Considering the uncertainty of power generation, extreme scenario method is used to establish the robust optimal dispatching model of independent microgrid. Finally, the impact analysis is carried out according to the uncertainty of comprehensive operating costs, wind and solar power generation and the complementarity of different extreme scenarios.

2 Modeling of Independent Microgrid Systems

The microgrid in this paper is consisted of one micro gas turbine, three wind turbines, three photovoltaic power generation systems, energy storage systems and loads.

2.1 Uncertainty Model Based on Extreme Scenario Method

The principle of robust optimization is to find optimal planning scheme in the uncertain set. Generally, the scheduling model is to satisfy the system constraints and equipment constraints in all the values in the uncertain set then seek the optimal system economy. The extreme scenario refers to the output when the boundary is reached. For a single wind turbine or photovoltaic power generation system, the extreme scenario is shown in Fig. 1.

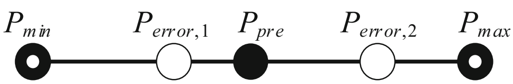


Fig. 1. The extreme scenario for a single renewable energy source.

In the figure, P_{pre} is the output of the prediction scenario; $P_{error,1}$, $P_{error,2}$ are the output of the error scenario; $P_{\min}$ and $P_{\max}$ are the output of the energy extreme scenario, respectively. The uncertainty in wind and solar energy output is constructed based on the extreme scenario method can be described by the uncertainty set shown in (1).

$$\begin{cases} P^t_{WT,i,down} \le P^t_{WT,i} \le P^t_{WT,i,up} \\ P^t_{WT,i,down} = (1-\alpha)P^t_{WT,i,pre} \\ P^t_{WT,i,up} = (1+\alpha)P^t_{WT,i,pre} \\ P^t_{PV,j,down} \le P^t_{PV,j} \le P^t_{PV,j,up} \\ P^t_{PV,j,down} = (1-\beta)P^t_{PV,j,pre} \\ P^t_{PV,j,up} = (1+\beta)P^t_{PV,j,pre} \end{cases} \tag{1}$$

In the formula, α and β are the proportional coefficients between the actual and predicted values of power generation of solar and wind in extreme scenarios, respectively. It can be seen that the larger the value is, the larger the range of uncertainty set of wind and solar energy output uncertainty is, which means that the independent microgrid can cope with the larger uncertainty with the stronger robustness.

2.2 Unit Models

The power generation cost of a micro-turbine in an independent microgrid can be represented by a linear function which can be shown as (2).

$$C_{MG}(t) = [aP_{MG}(t) + b]\Delta t \tag{2}$$

In the formula, a and b are the cost coefficients; $P_{MG}(t)$ is micro gas turbine output in t period; Δt is the scheduling step length, which is 1h. The constraint is shown in (3).

$$-P_{MG,\min} \le P_{MG}(t) \le P_{MG,\max} \tag{3}$$

The climbing constraint is shown in (4).

$$-P_{MG,down} \le P_{MG}(t) - P_{MG}(t-1) \le P_{MG,up} \tag{4}$$

The operation cost of energy storage mainly considers its investment cost and operation and maintenance cost, and the charge and discharge cost during the t period of the investment recovery period is shown in (5).

$$C_{ESS}(t) = K_{ESS}\left[P^{(}_{ESS,dis}t)/\eta + P_{ESS,ch}(t)\eta\right] \tag{5}$$

In the formula, K_{ESS} is the charging and discharging cost factor; η is the charge and discharge efficiency of the energy storage system. The constraints are shown as:

$$0 \le P^{(}_{ESS,dis}t) \le P^{\max}_{ESS,dis} \tag{6}$$

$$0 \le P^{(}_{ESS,ch}t) \le P^{\max}_{ESS,ch} \tag{7}$$

In order to ensure that the energy storage system has enough margin to make up for the power gap, its state of charge (SOC) also needs to meet the following constraints:

$$SOC(t+1) = SOC(t) + \frac{P_{ESS}(t+1)\Delta t}{E}\eta \tag{8}$$

$$SOC_{start} = SOC_{end} \tag{9}$$

$$SOC_{\min} \leq SOC(t) \leq SOC_{\max} \tag{10}$$

In the formula, E is the capacity of energy storage system; SOC_{start} and SOC_{end} are the SOC values when system starting and ending work, respectively.

3 Evaluation Index of Spatial-Temporal Characteristics

In this paper, fluctuation is selected to represent the uncertainty, that is, to quantitatively describe the output characteristics of renewable energy that change above and below the mean value over time, so the standard deviation is used for evaluation, as shown in (11).

$$\sigma = \sqrt{\frac{1}{T}\sum_{t=1}^{T}(P_t - \mu)^2} \tag{11}$$

The correlation coefficient can measure the correlation between different data. Compared with the Pearson correlation coefficient, the Spearman correlation coefficient has lower data requirements and is widely used in the correlation analysis of non-linear and non-normally distributed non-continuous data. This paper uses the Spearman correlation coefficient to measure the correlation between wind power and photovoltaics. The stronger the complementarity, the closer the correlation coefficient is to −1, as shown in (12).

$$\rho = \frac{\sum_t \left(P_{WT,t} - \overline{P_{WT}}\right)\left(P_{PV,t} - \overline{P_{PV}}\right)}{\sqrt{\sum_t \left(P_{WT,t} - \overline{P_{WT}}\right)^2 \sum_i \left(P_{PV,t} - \overline{P_{PV}}\right)^2}} \tag{12}$$

4 Robust Optimal Scheduling Model

4.1 Objective Function

The robust optimal scheduling model is the comprehensive operating cost of the system, which can be shown as:

$$\min C_{total} = C_{MG} + C_{ESS} + C_{WT} + C_{PV} \tag{13}$$

$$C_{WT} = \sum_{i=1}^{I} K_{WT,i}P_{WT,i} \tag{14}$$

$$C_{PV} = \sum_{j=1}^{J} K_{PV,j} P_{PV,j} \tag{15}$$

In the formulas, C_{MG} and C_{ESS} are the fuel cost of the micro gas turbine and the operating cost of the energy storage system; C_{WT} and C_{PV} are the maintenance costs of renewable energy power system; $K_{WT,i}$ and $K_{PV,j}$ are the maintenance coefficients of the ith wind turbine and the jth photovoltaic power generation system, respectively.

4.2 Constraints

There are equality constraints and inequality constraints. Equation constraints include (9) and the system supply and demand power balance, as shown in (16).

$$P_{Load}(t) = P_{MG}(t) + P_{ESS}^{(}t) + \sum_{i=1}^{I} P_{WT,i}(t) + \sum_{j=1}^{J} P_{PV,i}(t) \tag{16}$$

The inequality constraint should also include the output uncertainty set constraint:

$$(1-\alpha)P_{WT,i,pre}^{t} \le P_{WT,i}^{t} \le (1+\alpha)P_{WT,i,pre}^{t} \tag{17}$$

$$(1-\beta)P_{PV,j,pre}^{t} \le P_{PV,j}^{t} \le (1+\beta)P_{PV,j,pre}^{t} \tag{18}$$

$$\forall\alpha \in [5\% , 30\%] \tag{19}$$

$$\forall\beta \in [5\% , 30\%] \tag{20}$$

5 Case Analysis

The power data in this research comes from an island on a certain day. The simulation scenarios in this paper are shown in Table 1.

Table 1. Simulation scenarios.

Scenarios	Considerations
Scenario 1	Uncertainty of wind and solar output
Scenario 2	Only uncertainty of wind output
Scenario 3	Only uncertainty of photoelectric output
Scenario 4	No uncertainty

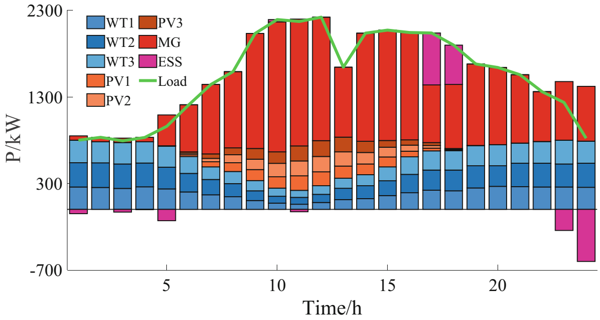


Fig. 2. Output of each unit in scenario 4.

Scenario 4 does not consider the uncertainty of scenery, and its optimal scheduling is a deterministic planning problem. Only the output of each unit in scenario 4 is shown in Fig. 2.

As can be seen from the above figure, when the wind and solar output can meet most of the load demand, the electricity generation of micro gas turbine and the energy storage system is relatively small. On the contrary, the output of the two needs to be coordinated to meet the load demand economically. The comprehensive operating cost of each scenario under different β values is shown in Fig. 3.

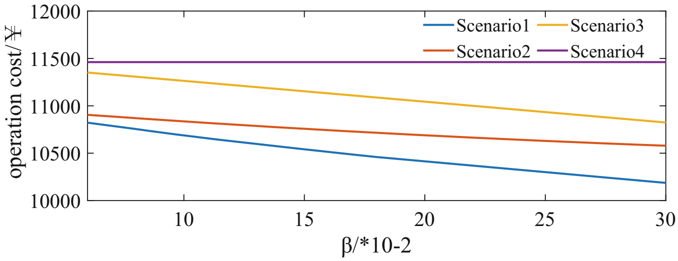
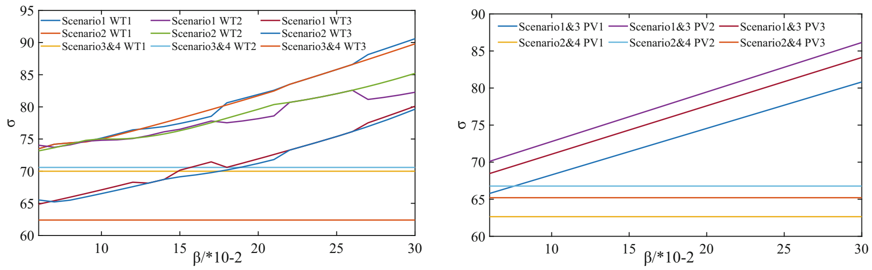


Fig. 3. Comprehensive operating cost of each scenario under different β.

As can be seen from the figure, as the β increases, the operating cost gradually decreases, indicating that under the premise that the system can absorb all wind and solar output, the enhancement of robustness can increase the economy of the system. The standard deviations of output fluctuations of three WT systems and three PV systems in each scenario is shown in Fig. 4.

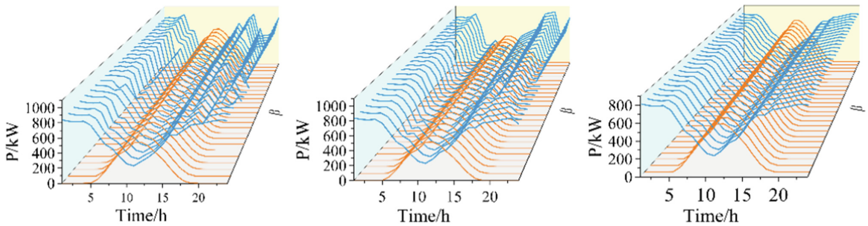
It can be seen that although the enhancement of robustness can improve the operating economy of the system, the premise is that the system can withstand higher-risk output. The output and spearman correlation coefficient under different β values of scenarios 1, 2, and 3 are shown in Fig. 5 and Fig. 6.

We can know that wind and solar output of each scene is complementary. With the increase of the enhancement of the system robustness, the ρ of scenario 1 and scenario 2 both tend to increase. The reason why the complementarity of wind and solar output in



(a) wind output fluctuation (b) solar output fluctuation

Fig. 4. Wind and solar output fluctuation of each scenario under different β.



(a) scenario 1 (b) scenario 2 (c) scenario 3

Fig. 5. Output of wind turbine and photovoltaic power system in each scenario.

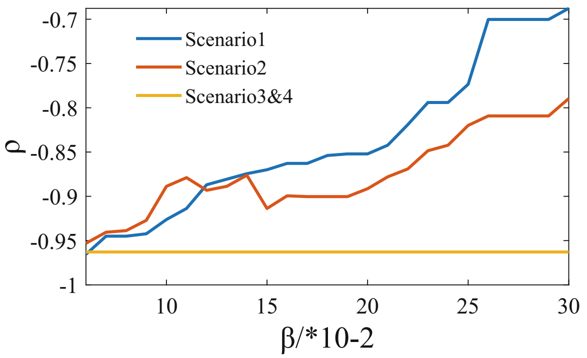


Fig. 6. The ρ of output of wind turbine and photovoltaic power system in each scenario.

scenario 3 does not change with β is because the photovoltaic power generation system in scenario 3 has always been in the extreme scenario.

6 Conclusion

Through multiple solutions of the uncertain linear programming model, the relationship between the spatiotemporal characteristics of renewable energy power generation and the economic operation of an independent microgrid is explored: the uncertainty of output is negatively correlated with complementarity. If an independent microgrid system needs to absorb more wind-solar output and improve the economics of operation, its robustness needs to be improved.

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