Economic Dispatch for Power System Considering Fuzzification of PV Output and Costs of Rotating Reserve Capacity

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Abstract. With the increasing permeability of photovoltaic power generation in the power grid, the uncertainty of its output has puts forward new requirements to the economic dispatch for power system. To achieve economic operation, dynamic economic dispatch is used in the optimization of thermal power unit output. In order to reflect the costs of the economic operation of power system more objectively, the costs of rotating reserve capacity are taken into consideration in the cost function. Then, fuzzy chance constraint is established based on credibility theory, to make the results more in line with the decision-maker's subjective intention. Traditional particle swarm optimization (PSO) algorithm is simplified, to optimize the economic operation model of power system. Through the numerical example proved the effectiveness of the proposed method.

Introduction

The energy crisis has led to the widespread concern of new energy sources, which including solar energy. One of the main use form of photovoltaic power generation is the connected operation of large-scale photovoltaic power generation. Photovoltaic power generation accessed to power grid can reduce coal consumption and pollution emissions. On the one hand, it plays a promoting role in energy conservation and green development; on the other hand, it has a negative impact on the stable operation of the power grid.

Documents' [1-13] introducing the PV output is not comprehensive enough, in terms of ambiguity involves less. In this paper, the problem of dynamic economic dispatch of power system with photovoltaic power generation is studied. Based on the fuzzy theory, the reliability distribution of the PV output is established. At the same time, the constraints of the rotating reserve capacity including the reliability distribution of the PV output are established. Finally, on the basis of spare capacity constraints, the cost model of the rotating reserve capacity is established, and it is incorporated into the cost function to reflect the economic operation cost of the power system better.

Model of Photovoltaic Power Generation with Fuzziness

Photovoltaic power generation has multiple uncertainties, and its output is affected by the factors such as light, temperature and so on. When the temperature changes, the relationship between the output and the light is approximately linear:

\[ P = \eta \frac{S}{S_{\text{ref}}} P_{\text{ref}} \]  

(1)

Because of the uncertainty of the solar irradiance, leading to the uncertainty of the output power, in this paper, from the point of view of credibility, the PV output is a fuzzy variable. By Zadeh extension principle [6], the photovoltaic output forecast as trapezoidal fuzzy variables \( \xi = (S_1, S_2, S_3, S_4) \) [2]. If
the installation capacity of PV system is $C_0$, the membership function of the predicted value of the output power is:

$$\left(\eta \frac{S_1}{S_{ref}} C_0, \eta \frac{S_2}{S_{ref}} C_0, \eta \frac{S_3}{S_{ref}} C_0, \eta \frac{S_4}{S_{ref}} C_0\right)$$

Its credibility is distributed as:

$$Cr(\xi \leq x)=\begin{cases}0, & x \leq \eta \frac{S_1}{S_{ref}} C_0 \\x - \eta \frac{S_1}{S_{ref}} C_0 \left/ \left[\eta \frac{2(S_2 - S_1)}{S_{ref}} C_0\right]\right., & \eta \frac{S_1}{S_{ref}} C_0 < x \leq \eta \frac{S_2}{S_{ref}} C_0 \\x + \eta \frac{(S_4 - 2S_1)}{S_{ref}} C_0 \left/ \eta \frac{2(S_4 - S_1)}{S_{ref}} C_0\right., & \eta \frac{S_2}{S_{ref}} C_0 < x \leq \eta \frac{S_4}{S_{ref}} C_0 \\1, & \eta \frac{S_4}{S_{ref}} C_0 < x \end{cases}$$

Rotating Standby Model and Cost of Photovoltaic Power Generation

Uncertain light will cause uncertainty PV output, in order to mitigate the negative impact of PV output uncertainty of the system and improve the reliability of the system, in this paper, the positive and negative rotation reserve capacity is introduced, with $R_u$ and $R_d$ respectively. After the photovoltaic power station is incorporated into the power grid, when the actual output is smaller than the planned value, require thermal power units to increase power generation, this part of the power as a system of positive spinning reserve; When the actual output is much more than the planned value, this time should reduce the power generation power of thermal power units instead of photovoltaic power plants to supply load, which is part of the power system as a negative amount of spinning reserve. Among:

$$R_u(t) = \sum_{i=1}^{N} R_{u,i}(t)$$

$$R_d(t) = \sum_{i=1}^{N} R_{d,i}(t)$$

$$R_{u,i}(t) = \min \left(P_{G,i}^{\text{max}} - P_{G,i}(t), \Delta P_{G,i}(t) \right)$$

$$R_{d,i}(t) = \min \left(P_{G,i}(t) - P_{G,i}^{\text{max}}, \Delta P_{G,i}(t) \right)$$

$$\Delta P_{G,i}(t) = \Delta T \cdot \delta_i$$

Incorporating the cost of spinning reserve capacity in a cost function is essential. Spare capacity cost of the system is the product of reserve cost coefficient and reserve capacity, and the reserve capacity cost coefficient also includes the positive and negative reserve capacity cost coefficient, as $K_u, K_d$ respectively. In this paper, the market bidding strategy is used [5], the positive reserve cost coefficient is the minimum value of the power generation cost coefficient of each thermal power unit, and negative reserve cost coefficient is the maximum value of the cost coefficient of power generation for each thermal power unit.
Economic Dispatch Model with PV

In view of the solar irradiance and the load uncertainty, we should adopt the dynamic economic dispatch model to deal with the problem [11-13].

Mathematical Model

Photovoltaic grid power system dynamic economic dispatch model of objective function is as follows:

\[ C_{\text{min}} = \sum_{i=1}^{T} \left[ F(t) + C_i(t) \right] \quad (9) \]

In the objective function,

\[
\begin{align*}
F(t) &= \sum_{i=1}^{N} \left[ \alpha_i P_{G,i}^2(t) + h_i P_{G,i}(t) + c_i + H_{\text{ff}} \cdot \left( \alpha_i P_{G,i}^2(t) + \beta_i P_{G,i}(t) + \gamma_i \right) \right] \\
C_i(t) &= K_u(t) \cdot R_u(t) + K_d(t) \cdot R_d(t)
\end{align*}
\quad (10)
\]

Restrictions

(1) Power balance constraints

Taking into account the balance between power supply and demand in the system, the output of the thermal power unit, the output of photovoltaic power station, the load power and the system power should meet the power balance equation in the \( t \) period, as follows:

\[ \sum_{i=1}^{N} P_{G,i}(t) + \sum_{j=1}^{N} P_{\text{PV,j}}(t) = P_{\text{load}}(t) - P_{\text{loss}}(t) \quad (11) \]

(2) The thermal power unit output constraint;

\[ P_{\text{G,i}}^\text{min} \leq P_{\text{G,i}}(t) \leq P_{\text{G,i}}^\text{max} \quad (12) \]

(3) Ramp rate constraint

\[ -\delta_{\text{G,i}} \cdot \Delta T \leq P_{\text{G,i}}(t) - P_{\text{G,i}}(t) \leq \delta_{\text{G,i}} \cdot \Delta T \quad (13) \]

(4) System rotation reserve capacity constraint

\[ C_i \left\{ \sum_{i=1}^{N} \left[ P_{G,i}(t) + R_i(t) \right] \geq \left( P_{\text{load}}(t) - P_{\text{loss}}(t) \right) - P_{\text{PV}}(t) \right\} \geq \alpha \quad (14) \]

\[ R_u \geq \omega_{\text{u,i}} \cdot P_{\text{load}}(t) + \omega_{\text{u,z}} \cdot P_{\text{PV}}(t) \quad (15) \]

\[ R_d \geq \omega_{\text{d,i}} \cdot P_{\text{load}}(t) + \omega_{\text{d,z}} \cdot P_{\text{PV}}(t) \quad (16) \]

\[ P_{\text{G,i}}^\text{min} \leq P_{\text{G,i}}(t) + R_i(t) \leq P_{\text{G,i}}^\text{max} \quad (17) \]

Equation (14), can also be written as:

\[ \left\{ 1 - C_i \left[ P_{\text{PV}}(t) \leq P_{\text{load}}(t) - \sum_{i=1}^{N} \left[ P_{G,i}(t) + R_i(t) \right] \right] \right\} \geq \alpha \quad (18) \]

By using the above mentioned, the reliability of the output power of the photovoltaic output can be relieved to satisfy the constraint.
Economic Dispatch Method Based on Simplified Particle Swarm Optimization (SPSO)

The simplified particle swarm optimization (SPSO) algorithm is improved on the basis of the basic particle swarm optimization algorithm. Each particle according to its own optimal solution $p_{i,d}$ and the global optimal solution $p_{g,d}$ to get its first $t+1$ iteration of the speed and the best location. The literature [14] proposed a simplified particle swarm algorithm, the algorithm removes the evolution of particle swarm in variable speed. Tests show that the simplified particle swarm algorithm has faster convergence speed and higher efficiency. The equation of the method can be simplified as:

$$x_{i,d}^{t+1} = \omega \cdot x_{i,d}^t + c_1 r_1 \left( p_{i,d} - x_{i,d} \right) + c_2 r_2 \left( p_{g,d} - x_{i,d} \right)$$

Example Analysis

In order to simplify the calculation, the photovoltaic power generation system is always in the maximum power output state. System uses the method of continuous prediction to predict solar irradiance and load data, interval per hour. One photovoltaic power plants with a capacity of 100MW is selected, where the rated power of each PV module is 250W, which is incorporated into the power system composed of 6 sets of conventional thermal power units to carry out a numerical example to verify. The load demand from historical data, the measured solar irradiance data from a photovoltaic power station within 24 hours of the day; Parameters of photovoltaic cells and thermal power units are derived from the literature [5], the solar irradiance and the load data below respectively.

Figure 1. PV Output forecasting curve.

Figure 2. One day load forecasting curve.
From Figure 2, we can find strong similarities between the economic operation cost curve and the load curve. This phenomenon can be attributed to two factors. On the one hand, it is low penetration of PV output. In the case of low permeability, thermal units provide the main output for power system, hence the costs of the power system are mainly determined by the thermal power units. Although PV power plant output and maximum load demand respectively reached the maximum values at the time of 12:00, but the costs did not fall. The value of the PV output is only 80MW, while the load demand actually closer to 1100MW, penetration rate of only 7.2% at 12:00 clock. Before 6:00 and after 18:00 photovoltaic power generation system has been in a state of zero output, which means the operation of the entire power system entirely dependent on the output of thermal units. They show that low permeability lead to the similarity of the both curve again; On the other hand, an inequality constraints account for this phenomenon due to large value of confidence level. Large value of confidence level can decrease the stability of PV output and weaken the impacts on the target trend function. It indicates that fuzzy constraint model proposed in this paper can enhance the system reliability. Analysis shows that as long as the change in the value of \( \frac{\alpha}{\omega} / \omega \), you can get different results of the operating costs.

Conclusion

In this paper, the problem of economic dispatch of power system with photovoltaic power generation is studied. The PV output model is established, and the reliability distribution of PV output is established. Positive and negative rotation reserve capacity constraints are introduced. The objective function includes not only the unit cost of fuel consumption and exhaust emissions but also incorporated into the cost of spinning reserve capacity cost, which makes the cost model more reasonable, and reflects the impact of uncertainty on the output of photovoltaic power system economic operation. According to the equality and inequality constraints, a simplified particle swarm optimization algorithm is used to solve the optimal solution of the objective function. An example shows that in the dynamic economic dispatch in power system with photovoltaic power generation, using the photovoltaic output proposed fuzzy model and the spinning reserve cost mentioned in this paper are reasonable. The scheduling scheme can take into account both reliability and economy, and has high practical value.

References


