Research on Network Loss of Distributed Energy Integration into Power System

Qingfeng Xu, Peng Gao, Chao Tong
State Grid Jinzhou Electric Power Supply Company, State Grid Liaoning Electric Power Supply Co., Ltd. Jinzhou, China
The corresponding author's e-mail address: xqf_jz@ln.sgcc.com.cn

Abstract. At present, the integration of clean energy into the grid has led to excessive network losses. This paper proposes a method for optimizing clean energy power generation parameters. In view of the random characteristics of intermittent renewable energy power generation such as wind power and photovoltaic power generation, the maximum likelihood estimation method is used to optimize the clean energy power generation model parameters. Then, a P-Q equation based on the integration of clean energy into the system was established. Finally, the simulation verified that the optimized power generation model effectively reduces the grid loss.

1. Introduction
In recent years, various distributed power projects have been continuously implemented. The key technologies based on distributed energy system grid connection are widely studied, and the implementation of various distributed power projects marks the gradual development of research and promotion of distributed power related technologies, which will be widely promoted in the next few years [1-3]. The rational use of distributed energy can greatly reduce the operating cost of the grid and increase the utilization rate of clean energy, and ultimately improve the overall reliability and energy quality of the grid system.

Distributed power is a new type of energy. Its biggest feature is clean, environmentally friendly, renewable, and suitable for widespread promotion [4-5]. It plays an important role in promoting the conversion of the global energy structure from non-renewable energy such as petroleum and coal to clean and renewable energy. Although distributed power has many advantages and the research is getting deeper and deeper, relying solely on distributed power has less effect and needs to be fully integrated with the current grid structure, complement each other, and rely on each other to improve the current grid structure and achieve a win-win situation [6-7]. In view of the current situation of distributed power research, this article mainly does the following work.

1. For distributed power sources, we establish a modeling process for the random probability characteristics and time series characteristics of renewable energy power generation output, and use probability statistical models and time series models to quantify the random time series fluctuation process of renewable energy power generation output;
2. For the distributed power generation system, we analyze the impact of the distributed power generation system on the system network loss when it is integrated into the grid, and establish a mathematical model for numerical analysis.
2. Mathematical Model of Clean Energy

2.1. Wind power model

Wind speed probability distribution model and parameters are important indicators for quantitatively evaluating the statistical characteristics of wind energy resources. Classical models for fitting the characteristics of wind speed probability distribution include: Weibull distribution, Rayleigh distribution, Log-normal distribution, etc. The two-parameter Weibull distribution model is the most widely used.

Weibull distribution function and its probability density function are expressed as

\[
F(V) = P(v \leq V) = 1 - \exp \left[ -\left( \frac{V}{c} \right)^{k} \right] \tag{1}
\]
\[
f(V) = \left( \frac{k}{c} \right) \left( \frac{V}{c} \right)^{k-1} \exp \left[ -\left( \frac{V}{c} \right)^{k} \right] \tag{2}
\]

where \( c \) and \( k \) are the scale parameter and shape parameter of the Weibull distribution, respectively. The scale parameter \( c \) reflects the average wind speed of the wind farm. \( k \) has a great influence on the distribution curve. If \( 0 < k < 1 \), the probability density is a decreasing function of \( V \). If \( k = 1 \), the distribution is exponential. If \( k = 2 \), it is called the Rayleigh distribution. If \( k = 3.5 \), the Weibull distribution is closer to the normal distribution. \( V \) is the given wind speed. \( c \) and \( k \) need to use historical sample data for parameter identification and estimation. This paper uses the maximum likelihood method to analyze the parameters of \( c \) and \( k \).

Construct the likelihood function according to the maximum likelihood principle:

\[
L(k,c) = \prod_{i=1}^{n} f(x_i) = \prod_{i=1}^{n} \left( \frac{k}{c} \right) \left( \frac{x_i}{c} \right)^{k-1} \exp \left[ -\left( \frac{x_i}{c} \right)^{k} \right]
\]

Take the logarithm of Equation 3, we get

\[
\ln L(k,c) = \sum_{i=1}^{n} \left[ \ln k + (k - 1) \ln x_i - k \ln c - \left( \frac{x_i}{c} \right)^{k} \right]
\]

The maximum likelihood values of parameters \( c \) and \( k \) can be solved by the following likelihood equations

\[
\begin{align*}
Y_1 &= \frac{\partial \ln L(k,c)}{\partial k} = 0 \\
Y_2 &= \frac{\partial \ln L(k,c)}{\partial c} = 0 \\
Y_1(k,c) &= \frac{\partial Y_1(k,c)}{\partial k} \quad Y_2(k,c) = \frac{\partial Y_2(k,c)}{\partial c} \\
\begin{bmatrix}
Y_1(k,c) \\
Y_2(k,c)
\end{bmatrix} +
\begin{bmatrix}
\frac{\partial Y_1(k,c)}{\partial c} & \frac{\partial Y_1(k,c)}{\partial c} \\
\frac{\partial Y_2(k,c)}{\partial c} & \frac{\partial Y_2(k,c)}{\partial c}
\end{bmatrix}
\begin{bmatrix}
\Delta k \\
\Delta c
\end{bmatrix} =
\begin{bmatrix}
0 \\
0
\end{bmatrix}
\end{align*}
\]

According to equation (3)-(6), we get
\[ \hat{c} = \left( \frac{1}{n} \sum_{i=1}^{n} v_i^k \right)^{1/k} \]
\[ \frac{1}{k} = \left[ \frac{\sum_{i=1}^{n} v_i^k \ln v_i}{\sum_{i=1}^{n} v_i} \right] - \frac{1}{n} \sum_{i=1}^{n} \ln v_i \] (7)

where \( i \) is the number of the wind speed sample; \( \hat{c} \) and \( \hat{k} \) are the estimated values of \( c \) and \( k \) respectively. \( v \) is the wind speed sample value. \( n \) is the total wind speed sample space.

### 2.2. Photovoltaic output model

The output of photovoltaic power generation is affected by external factors such as light intensity, ambient temperature, photovoltaic module installation inclination, and working voltage. In planning research, it is generally assumed that the photovoltaic module is at the best installation angle and the best working voltage, and the impact of temperature changes on the photoelectric conversion efficiency is ignored. The output of photovoltaic power plants can be expressed:

\[ P_{\text{solar}}(t) = S(t) \cdot A \cdot \eta \] (8)

where \( S(t) \) is the current irradiation intensity; \( A \) is the area of the photovoltaic array; \( \eta \) is the photoelectric conversion efficiency.

The output of photovoltaic power generation can also be approximated as Beta points. The probability density function is:

\[ f \left( \frac{P_{\text{solar}}}{P_{\text{max}}} \right) = \frac{\Gamma(\alpha + \beta)}{\Gamma(\alpha) \Gamma(\beta)} \left( \frac{P_{\text{solar}}}{P_{\text{max}}} \right)^{\alpha-1} \left( 1 - \frac{P_{\text{solar}}}{P_{\text{max}}} \right)^{\beta-1} \] (9)

where \( P_{\text{max}} = S_{\text{max}} A \eta \) is the maximum output of the photovoltaic power station.

In the time interval corresponding to the output of photovoltaic power generation, the probability distribution characteristics of the output of the photovoltaic power station are calculated section by section.

\[ x = \frac{P_{\text{solar}}}{P_{\text{max}}} \cdot B(\alpha, \beta) = \frac{\Gamma(\alpha) \Gamma(\beta)}{\Gamma(\alpha + \beta)} \] (10)

\[ f(x) = \frac{1}{B(\alpha, \beta)} (x)^{\alpha-1} (1 - x)^{\beta-1} \] (11)

Construct the maximum likelihood function as follows:

\[ L(\alpha, \beta) = \prod_{i=1}^{n} f \left( x_i \right) \]

\[ \ln L(\alpha, \beta) = \sum_{i=1}^{n} \ln f \left( x_i \right) \] (12)

Use Newton Raphson's method to solve the maximum likelihood equations:

\[ \left\{ \begin{array}{l}
Y_1 = \frac{\partial \ln L(\alpha, \beta)}{\partial \alpha} = 0 \\
Y_2 = \frac{\partial \ln L(\alpha, \beta)}{\partial \beta} = 0
\end{array} \right. \] (13)

According to equation (13)-(14), we get
3. The impact of clean energy on network loss

The network loss value is related to line parameters and power flow distribution. The integration of the clean power generation system into the power grid will affect the power flow distribution of the power grid system, which in turn will affect the power loss of the system.

The power of node $i$ is shown in equations (16)-(17):

$$P(i) = \begin{cases} 
\sum_{j=1}^{n} P_j + \sum_{j=i+1}^{n} \Delta P_j (1 < i < n) \\
\sum_{j=1}^{n} P_j + \sum_{j=i+1}^{n} \Delta P_j (i = n) 
\end{cases}$$

$$Q(i) = \begin{cases} 
\sum_{j=1}^{n} Q_j + \sum_{j=i+1}^{n} \Delta Q_j (1 < i < n) \\
\sum_{j=1}^{n} Q_j + \sum_{j=i+1}^{n} \Delta Q_j (i = n) 
\end{cases}$$

The power loss of branch $i$ is:

$$\Delta P(i) = \frac{(P(i)^2 + Q(i)^2)}{U_i^2} R_i$$

$$\Delta Q(i) = \frac{(P(i)^2 + Q(i)^2)}{U_i^2} X_i$$

When node $k$ is connected to the clean energy power generation system, the power of node $i$ is:

$$P(i) = \begin{cases} 
\sum_{j=1}^{n} P_j + \sum_{j=i+1}^{n} \Delta P_j - P_{GF} (1 < i < k) \\
\sum_{j=1}^{n} P_j + \sum_{j=i+1}^{n} \Delta P_j (i = n) 
\end{cases}$$

$$Q(i) = \begin{cases} 
\sum_{j=1}^{n} Q_j + \sum_{j=i+1}^{n} \Delta Q_j - Q_{GF} (1 < i < k) \\
\sum_{j=1}^{n} Q_j + \sum_{j=i+1}^{n} \Delta Q_j (i = n) 
\end{cases}$$

4. Simulation analysis

This article chooses IEEE 9 bus system. The load model uses a constant power model. Assume that the reactive power and total power of the system are 2400kvar and 3700kW respectively. The three-phase power and reference voltage values are set to 10000kVA and 12.66kV respectively, and the system parameters and node load values are calculated according to the above parameters. As follows:
Table 1: System node load and branch parameters

| Number | First Note | End Note | Resistance | Reactance | Terminal Active | Terminal Reactive |
|--------|------------|----------|------------|-----------|----------------|------------------|
| 1      | 0          | 1        | 0.0892     | 0.0379    | 95             | 45               |
| 2      | 1          | 2        | 0.5013     | 0.2436    | 40             | 45               |
| 3      | 2          | 3        | 0.2347     | 0.1726    | 90             | 35               |
| 4      | 3          | 4        | 0.2358     | 0.5371    | 85             | 35               |
| 5      | 4          | 5        | 0.3964     | 0.1310    | 22             | 30               |
| 6      | 5          | 6        | 1.0524     | 0.9417    | 205            | 30               |
| 7      | 6          | 7        | 0.9638     | 0.3108    | 205            | 45               |
| 8      | 7          | 8        | 0.4986     | 0.1102    | 55             | 35               |

Figure 1: IEEE 9 bus system

Figure 2: System network loss comparison chart
As can be seen from the above figure, the integration of energy power generation systems as a whole will reduce the system network loss. Due to the integration of clean energy power generation systems, the injection power of the line will be reduced, and the transmission power of the front end will also be reduced, so the overall line can be greatly reduced. Therefore, the reliability of the system can be improved.

5. Conclusion
The relay protection and power flow distribution of the power grid system will be affected by the distributed power sources integrated into the power grid. This paper establishes a clean energy power generation prediction model. This paper analyzes the influence of the network loss when the distributed power generation system is integrated into the grid, and finally the simulation verifies that the prediction model can effectively reduce the network loss rate.

References
[1] Golshan M E H, Arefifar S A. Distributed generation, reactive sources and network-configuration planning for power and energy-loss reduction[J]. IEE Proceedings - Generation, Transmission and Distribution, 2006, 153(2):127-136.
[2] Bell K, Quinonez-Varela G, Burt G. Automation to maximise distributed generation contribution and reduce network losses[J]. 2009:38-38.
[3] Mishra S, Das D, Raut U. A Simple Branch Exchange Based Network Reconfiguration Method for Loss Minimization with Distributed Generation[C], IEEE-WIECONF-ECE. IEEE, 2015.
[4] Zhang J, Bo Z Q. Research of the impact of distribution generation on distribution network loss[C], Universities Power Engineering Conference. IEEE, 2010.
[5] Pazouki S, Mohsenzadeh A, Haghipam M R, et al. Optimal allocation of wind turbine in multi carrier energy networks improving loss and voltage profile[C], International Conference on Electrical & Electronics Engineering. IEEE, 2013.
[6] Pokhrel B R, Karthikeyan N, Bak-Jensen B, et al. Loss optimization in distribution networks with distributed generation[C], 2017 52nd International Universities Power Engineering Conference (UPEC). 2017.
[7] Dent C J, Ochoa L F, Harrison G P. Network distributed generation capacity analysis using OPF with voltage step constraints[C], 20th International Conference on Electricity Distribution CIRED 2009. IET, 2009.