Distribution Network Voltage State Assessment with Distributed Generation Based on Improved Probabilistic Power Flow Method

Zhiwei Liao, Sisi Chen and Chuang Lin

ABSTRACT

In order to overcome the blind zone in the evaluation method of the operation status of the traditional distribution network caused by the high penetration of distributed power, this paper studies the state quantitative evaluation method of distribution network voltage quality which takes the random characteristics of distributed generation into account. In this paper, a method based on the invariant and Gram-Charlier series to calculate the probability power flow is introduced, and the evaluation system including the average over-limit probability of system voltage, the voltage confidence interval of node voltage and the maximum over-limit probability of node voltage are established. Then taking the distributed photovoltaic as the representative, the probabilistic model whose active output follows Beta distribution is proposed and an improved index of photovoltaic permeability that includes the photovoltaic fluctuation characteristics is defined so as to quantitatively and feasibly evaluate the influence of different photovoltaic permeability on the voltage quality of the distribution network to provide guiding reference.

Keywords: Distributed photovoltaic; probabilistic power flow method; the Gram-Charlier series; probability assessment; photovoltaic permeability

INTRODUCTION

Distributed Generation (DG) and large power grid complement each other and work coordinately, which is the best way of using existing resources and equipment comprehensively to provide reliable and high-quality power for users. However, with the large number of DG access, distribution network operation is bound to be affected. On the one hand, the trend of the traditional distribution network is changed. On the other hand, DGs are affected by the external environment easily and its output is uncertain. So the traditional deterministic power flow calculation method will no longer be applied, the theory of probability flow is introduced to analyze the influence of distributed power supply on the operation status of distribution network accurately and reliably.

At present, the impact of distributed power supply on the quality of distribution network...
has been studied. In paper [1], the influence of PV access on the network loss is analyzed on the basis of analyzing the voltage variation of the distribution network. What’s more, based on the DiGSIILENT platform, the typical line model of the medium voltage distribution network in Wuxi is simulated. In [2] a comprehensive evaluation method of distribution network with distributed power supply is proposed, and a comprehensive evaluation index system is established from different aspects. In addition, some experts have made some studies on the influence of distributed power supply on the power quality of distribution networks based on probabilistic power flow calculation. Probabilistic power flow algorithm can be divided into three categories, namely, simulation method, analytic method and approximation method [3]. In [4] a simulation method based on Monte-Carlo simulation is proposed to calculate the influence of the change of system components and network structure uncertainty. According to the probability characteristics of output random variables, a complete set of risk assessment system is established. In [5] the Monte-Carlo simulation method is applied to the micro-grid operation scene, and the conclusion that the control parameters of the micro-power inverter can effectively reduce the probability of the voltage and current of the micro-grid are analyzed. Although the above simulation method can handle uncertain factors, its calculation is large and its period is long. In [6] the C-type Gram-Charlier series expansion is introduced for the case of the probability distribution of the output random variable of type A Gram-Charlier series to simulate the impact of wind power access grid. And approximation method is mainly included the point estimation method [7-8], the second moment method [9] and the state transformation method [10]. In the current approximation method, the calculation result regarded as the mean and variance the main goal, how to choose the state variable to obtain more accurate overall probability distribution is the existence of the problem. The above method also needs to be further studied.

In this paper, combined the probabilistic power flow algorithm based on semi-invariant method with Gram-Charlier series expansion method, the distributed PV output obey Beta distribution probability model is established. The evaluation system of power grid voltage quality is defined by defining the average voltage over-limit probability with system voltage, the node voltage confidence interval and the maximum voltage-limited probability of node voltage. Finally, a numerical simulation is carried out to study the effect of distribution network voltage with PV penetration in order to provide guiding opinions for DGs planning.

THEORETICAL BASIS

Semi-invariant Concept and Solution

The basic idea of the probabilistic power flow calculation based on the semi-invariant [11] is to calculate the power flow according to the initial condition of the system and the calculation result is used as the reference run point. Then the random interference of various factors of the system is superimposed on the reference operating point and then the semi-invariants of each state variable of the system are described. Finally, the semi-invariants of each state variable of the system are calculated and the probability distribution is calculated by combining the series expansion.

Assuming that \( F(x) \) is the cumulative distribution function of the random variable, let \( t \) be any real number, then the function \( g(x) = e^{it} = \cos(tx) + jsin(tx) \) on \( (-\infty, +\infty) \) about the integral of \( F(x) \) is called as the characteristic function of \( F(x) \), which is expressed as follows:

\[
\psi(t) = E(e^{it}) = \int_{-\infty}^{\infty} e^{itx}dF(x)
\]  

(1)
The characteristic function of $F(x)$ is taken from the logarithm and expands to the Maclaurin series at $t=0$, and the following equation is arranged:

$$\log \psi (t) = \sum_{i=0}^{k} \frac{Y_i}{k!} (jt)^i + O(t^k) \quad (2)$$

Where $Y_i$ is a semi-invariant, also known as cumulative; subscript $k$ represents the order of semi-invariant.

The semi-invariant solution is mainly achieved by numerical analysis and Monte Carlo method. Numerical analysis means that when the distribution of random variables is known, the semi-invariants of each order are deduced by mathematical formula, according to the mathematical characteristics of the specific distribution. If the random variable distribution is unknown or complicated, it is difficult to use numerical analysis method, but can be solved by Monte Carlo sampling calculation of its various semi-invariant. Among them, when the Monte Carlo method is used, the moment characteristic of the random variable is calculated and then its semi-invariant is calculated, as shown in (3) and (4):

$$\alpha_i = \sum_{i=1}^{n} x_i$$
$$\begin{cases} Y_1 = \alpha_1, & k = 1 \\ Y_k = \alpha_k - \sum_{i=k}^{n} C_i \alpha_i Y_i, & k > 1 \end{cases} \quad (4)$$

Where $\alpha_k$ is the k-order origin moment of the random variable, $x_i$ represents that the i-th data point in the data sample of the random variable, $n$ indicates data sample size, $C_i$ indicates a combination of $i$ elements extracted from $(k-1)$ different elements, which satisfies $i \leq k - 1$.

**Gram-Charlier Series Expansion**

Gram-Charlier series expansion is a series expansion method based on standard normal distribution function, which is based on the semi-invariant approximate solution of the random variables in order to obtain the probability density function and cumulative distribution function of random variables. Therefore, the method needs to standardize the stochastic variables and semi-invariant of each order their variables, and then the probability distribution function of the normalized random variables is obtained. Finally, the normalized reduction is carried out to obtain the probability distribution function of the unnormalized random variables.

Assuming that the expected value of the random variable $X$ is $\mu_x$, the standard deviation is $\sigma_x$, the normalized random variable is obtained by calculating $\overline{X}= (X-\mu)/\sigma$. According to the A-type Gram-Charlier series expansion, standardized random variable probability density function (as shown in Eq.(5)) and cumulative distribution function (as shown in Eq.(6)) can be calculated, the specific formula can be expressed as follows:

$$f_{\overline{X}} (\overline{x}) = \phi (\overline{x}) + \frac{A_1 \phi^{(1)} (\overline{x})}{1!} + \frac{A_2 \phi^{(2)} (\overline{x})}{2!} + \ldots + \frac{A_n \phi^{(n)} (\overline{x})}{n!} \quad (5)$$

$$F_{\overline{X}} (\overline{x}) = \int_{-\infty}^{\overline{x}} \phi (\overline{t}) d\overline{t} + \frac{A_1 \phi (\overline{x})}{1!} + \frac{A_2 \phi^{(1)} (\overline{x})}{2!} + \ldots + \frac{A_n \phi^{(n-1)} (\overline{x})}{n!} \quad (6)$$

Where $\phi(*)$ indicates that probability density function subjected to standard normal distribution random variable, $\phi^{(n)}(*)$ is the result of the n-order derivative, $A_1, A_2, \ldots, A_n$ represent that the coefficients of A-type the Gram-Charlier series expansion, which can be calculated according to Eq. (7):
\[ A_i = 0, \quad A_i = -y_i^{(i)} \]
\[ A_2 = 0, \quad A_2 = y_2^{(i)} + 10\left(y_2^{(i)}\right)^2 \]
\[ A_3 = -y_3^{(i)} A_3 = -\left(y_3^{(i)} + 35y_3^{(i)}y_4^{(i)}\right) \]
\[ A_4 = y_4^{(i)} A_4 = y_4^{(i)} + 56y_3^{(i)}y_5^{(i)} + 35\left(y_3^{(i)}\right)^2 \]

Where \( y_i^{(i)} \) is k-order semi-invariants of normalized random variables \( \bar{X} \). In the practical application, in the practical application, the k-th semi-invariant \( y_k^{(i)} \) of the random variable \( X \) is calculated and then \( y_k^{(i)} \) is calculated according to its linear property. Finally, the function \( f_\bar{X}(\bar{x}) \) and \( F_\bar{X}(\bar{x}) \) of the normalized random variable is obtained according to Eq. (5) and (6). In order to get the function \( f_\bar{X}(\bar{x}) \) and \( F_\bar{X}(\bar{x}) \) of the random variables \( X \), a standardized reduction process is required, which can be expressed as follows:

\[
F_x(x) = P(X \leq x) = P(\delta_x \bar{X} + \mu_x \leq x) = P\left(\bar{X} \leq \frac{x - \mu_x}{\sigma_x}\right) = F_\bar{X}\left(\frac{x - \mu_x}{\sigma_x}\right)
\]

\[
f_x(x) = \frac{1}{\sigma_x} f_\bar{X}\left(\frac{x - \mu_x}{\sigma_x}\right)
\]

**MODELING OF DISTRIBUTED PHOTOVOLTAIC RANDOM CHARACTERISTICS**

On a short time scale, the random variation of solar light intensity follows the Beta distribution, which can be shown as:

\[
f_x\left(\frac{r}{r_{\text{max}}}\right) = \frac{\Gamma(\alpha + \beta)}{\Gamma(\alpha)\Gamma(\beta)} \left(\frac{r}{r_{\text{max}}}\right)^{\alpha-1} \left(1 - \frac{r}{r_{\text{max}}}\right)^{\beta-1}
\]

Where \( f_r(\bullet) \) is the probability density function of the light intensity random variable \( R \), \( r \) and \( r_{\text{max}} \) respectively represents the actual and maximum values of the light intensity during the period; \( \Gamma(\bullet) \) represents the Gamma function; \( \alpha \) and \( \beta \) respectively indicates two shape parameters of the Beta distribution, which can be calculated according to Eq. (11) and (12):

\[
\alpha = \frac{\mu_r - \mu_{r_{\text{max}}}}{\sigma_{r_{\text{max}}}} + 1 - \frac{\mu_r}{\mu_{r_{\text{max}}}}
\]

\[
\beta = \frac{\mu_r - \mu_{r_{\text{max}}}}{\sigma_{r_{\text{max}}}} + \left(1 - \frac{\mu_r}{\mu_{r_{\text{max}}}}\right)
\]

Where \( \mu_{r_{\text{max}}} \) and \( \sigma_{r_{\text{max}}} \) respectively represents the expected value and the standard deviation of the actual value and the maximum value ratio of the light intensity during the period.

When the solar light intensity distribution is known, it is assumed that the PV output active power and the light intensity are linearly related, which can be expressed as follows:

\[
P_{pv} = P_{Pv} \cdot \eta \cdot r
\]

Where \( P_{pv} \) is photovoltaic output power actual value during the period, \( A \) is the total area of photovoltaic panels, \( \eta \) indicates photovoltaic conversion efficiency. Because of the above,
the distributed photovoltaic output active power and reactive power probability model can be obtained, specifically expressed as follows:

\[
\begin{align*}
    f_{P_{\text{PV}}}(P_{\text{PV}}) &= \frac{1}{\eta_{\text{PV}}} \cdot \frac{\Gamma(\alpha + \beta)}{\Gamma(\alpha) \Gamma(\beta)} \left( \frac{P_{\text{PV}}}{P_{\text{PV,max}}} \right)^{\alpha-1} \left( 1 - \frac{P_{\text{PV}}}{P_{\text{PV,max}}} \right)^{\beta-1} \\
    f_{Q_{\text{PV}}}(Q_{\text{PV}}) &= \frac{1}{\eta_{\text{PV}}} \cdot \frac{1}{\tan \phi_{\text{PV}}} \cdot \frac{\Gamma(\alpha + \beta)}{\Gamma(\alpha) \Gamma(\beta)} \left( \frac{Q_{\text{PV}}}{Q_{\text{PV,max}}} \right)^{\alpha-1} \left( 1 - \frac{Q_{\text{PV}}}{Q_{\text{PV,max}}} \right)^{\beta-1}
\end{align*}
\]  

(14) 

(15)

Where \( Q_{\text{PV}} = P_{\text{PV}} \cdot \tan \phi_{\text{PV}} \) represents reactive power, \( \cos \phi_{\text{PV}} \) indicates photovoltaic power factor under the control of photovoltaic inverter.

**DISTRIBUTION NETWORK VOLTAGE QUALITY EVALUATION INDEX**

In order to evaluate the voltage variation of the distributed photovoltaic distribution network comprehensively and accurately, three indexes including the average voltage limit probability, the node voltage confidence interval and the maximum limit probability of the node voltage are defined, which be expressed as follows:

1. **System voltage average limit probability** \( P_{V_{\text{offlimits}}} \)

   In order to comprehensively evaluate the voltage limit of the distributed network with distributed PV, it is necessary to take the voltage limit of each node of the whole system into account, and then average limit probability of the system voltage is calculated for the purpose of better describing the overall average voltage limit of the system. Assuming that the system has \( n \) nodes and a given interval of the node voltage, then the node voltage overrun probability is expressed as, then the system voltage average probability limit can be calculated by Eq. (16):

\[
    P_{V_{\text{offlimits}}} = \frac{\sum P_{V_{\text{offlimits}}}}{n} 
\]

(16)

2. **Node voltage confidence interval** \( [V_{\text{mid}}, V_{\text{offlimits}}] \)

   Through the probability flow calculation, the voltage expectation and the standard deviation of each node can be obtained, and the fluctuation of the voltage of different nodes can be qualitatively known. In order to accurately evaluate the range of voltage variations in the steady-state operation of distribution networks with distributed PV, it is necessary to obtain quantitative information of voltage fluctuation. Given the confidence level \((1-CL)\), in the calculated voltage accumulation curve of each node, \( V_{\text{mid}} \) and \( V_{\text{offlimits}} \) were obtained separately. And it is thought that the majority of the node voltage falls on the interval \( [V_{\text{mid}}, V_{\text{offlimits}}] \).

3. **Maximum limit probability of node voltage** \( P_{V_{\text{offlimits,max}}} \)

   Due to the uncertainty of the distributed PV output and the load fluctuation, the voltage variation of the distribution network tends to be complicated. The maximum probability limit of the node voltage is defined, which is used to examine the weak position of the voltage safety of the system, and it is convenient to formulate the improvement measures. The index can be calculated by the formula (17):

\[
P_{V_{\text{offlimits,max}}} = \max \left( P_{V_{1,\text{offlimits}}}, P_{V_{2,\text{offlimits}}}, \ldots, P_{V_{n,\text{offlimits}}} \right)
\]

(17)
After the establishment of the above evaluation index system, the concrete flow chart of the distributed power distribution and the voltage quality assessment method of distribution network with distributed photovoltaic is shown as shown in Figure 1.

![Flow Chart](image)

**Figure 1. The Flow Chart of Probabilistic Power Flow Calculation and Voltage Evaluation Method of Distribution Network with Distributed Photovoltaic.**

**SIMULATION EXAMPLE**

This paper uses IEEE34 node standard test system as a distribution network simulation model. The standard test system is shown in Figure 2, the system has a reference capacity of 1MVA and a reference voltage of 24.9kV. Setting the node 1 as the balance node, the voltage per unit value is 1.03p.u., and ignoring the distribution transformer in the network, the load data and the node data are given by the IEEE node system, the PV in the picture represents the distributed PV, the dotted line can be expressed as the choice of PV access, which to facilitate the subsequent discussion and analysis of the contents.

![Image](image)

**Figure 2. The Diagram of IEEE34 Node Standard Test System.**

When the qualified voltage of the distribution network is evaluated by the evaluation index system, the qualified interval of the node voltage is $[0.95, 1.05]$, then the probability limit of the node voltage can be expressed as $P(V_i < 0.95 \cup V_i > 1.05)$; given the confidence level (1-CL) is 0.95. The confidence interval for the node voltage $i$ can be expressed as $[V_{i,pmin}, V_{i,pmax}]$.

In order to characterize the influence of distributed PV random accessing distribution network, this paper defines an improved photovoltaic permeability indicators considering fluctuation characteristics, which is calculated that by means of the ratio of the total output active of the distributed PV and active load of the system in extreme cases, and then it is
calculated from the weighted average based on a given weighting factor. Then according to the probability model characteristics of the distributed photovoltaic and load, the probability and index can be expressed as:

\[ P \left( a_i \leq \frac{\sum P_{i_k} - \sum \mu_{i_k}}{\sigma_{i_k}} \leq a_2 \right) = P \left( a_1 \leq \frac{\sum p_{i_k} - \sum \mu_{i_k}}{\sum \sigma_{i_k}} \leq a_2 \right) = 1 - CL \]  

(18)

\[ P \left( b_i \leq \frac{\sum P_{i_k} - \sum \mu_{i_k}}{\sum \sigma_{i_k}} \leq b_2 \right) = 1 - CL \]  

(19)

\[ \omega_{Ai} = m_1 \frac{b_1 \sum A \eta r_{max}}{\sum \mu_{i_k} \left( 1 + a_1 \xi_{i_k} \right)} + m_2 \frac{b_2 \sum A \eta r_{max}}{\sum \mu_{i_k} \left( 1 + a_2 \xi_{i_k} \right)} \]  

(20)

Where (1-CL) is confidence; \( b_1 \), \( b_2 \) refer to the upper and lower limits of the confidence interval of the random variable probability distribution subjected to the Beta distribution; \( a_1, a_2 \) represents the upper and lower limits of the confidence interval of the standard normal distribution random variable; \( m_1, m_2 \) represents the weight coefficient.

The maximum intensity of light intensity \( r_{max} = 1.1335 \text{kHz/m}^2 \) was obtained by the light intensity simulation data of GMT + 08: 00 in Guangzhou, China (23° 6’N, 113° 2’E) got by using HOMER software. The light intensity is approximately submitted to the Beta distribution, and the shape parameter \( \alpha \) is 0.6798 and the scale parameter \( \beta \) is 1.7788 obtained by nonlinear fitting. Given a confidence level (1-CL) of 0.95, through the table we can see \( a_1 \) is -1.96, \( a_2 \) is 1.96.

### Table I. Parameter Setting of Photovoltaic Power Supply under Different PV Permeability.

<table>
<thead>
<tr>
<th>( A_{31} ) (m²)</th>
<th>( A_{32} ) (m²)</th>
<th>( A_{33} ) (m²)</th>
<th>( A_{34} ) (m²)</th>
<th>Power factor</th>
<th>Conversion efficiency</th>
<th>Photovoltaic permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>200</td>
<td>200</td>
<td>800</td>
<td>1</td>
<td>13%</td>
<td>10.42%</td>
</tr>
<tr>
<td>400</td>
<td>400</td>
<td>400</td>
<td>1600</td>
<td>1</td>
<td>13%</td>
<td>20.83%</td>
</tr>
<tr>
<td>600</td>
<td>600</td>
<td>600</td>
<td>2400</td>
<td>1</td>
<td>13%</td>
<td>31.25%</td>
</tr>
<tr>
<td>800</td>
<td>800</td>
<td>800</td>
<td>3200</td>
<td>1</td>
<td>13%</td>
<td>41.67%</td>
</tr>
<tr>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>4000</td>
<td>1</td>
<td>13%</td>
<td>52.08%</td>
</tr>
</tbody>
</table>

According to the specific distribution of light intensity data, given \( b_1 \) is 0.00235, \( b_2 \) is 0.834, \( m_1 \) is 0.80, \( m_2 \) is 0.20. The total load of the system is 414.04kW, assuming that the situation of the load fluctuation is the same and the load fluctuation coefficient is 10%. As shown in Figure 2, the photovoltaic power supply with rated power of 200kW is connected to each of the nodes 31, 32, 33 and 34, assuming that each photovoltaic power source is operated with 1 of power factor, that is to say, the reactive power output is 0; Parallel battery array characteristics of all photovoltaic power source are the same, photoelectric conversion efficiency of 13%, then the PV permeability at this time only depends on the total area \( A_i \) of the battery array of the PV grid node. By substituting the above parameters into equation (23), and setting the total area \( A_i \) of a series of photovoltaic array, the variation of the voltage quality of the distribution network under different photovoltaic permeability can be investigated. The specific parameters are shown in Table I above. The calculation result of all distribution network voltage quality evaluation indices are shown in Table II and Table III.
Table II. Confidence Interval of Photovoltaic Grid - Connected Node under Different PV Permeability.

<table>
<thead>
<tr>
<th>PV permeability</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>node 31 without PV</td>
<td>[0.946,0.958]</td>
<td>[0.952,0.974]</td>
<td>[0.954,0.993]</td>
<td>[0.957,1.012]</td>
<td>[0.959,1.031]</td>
</tr>
<tr>
<td>node 31 with PV</td>
<td>[0.945,0.958]</td>
<td>[0.951,0.974]</td>
<td>[0.954,0.994]</td>
<td>[0.956,1.013]</td>
<td>[0.958,1.032]</td>
</tr>
<tr>
<td>node 32 without PV</td>
<td>[0.946,0.958]</td>
<td>[0.952,0.974]</td>
<td>[0.954,0.993]</td>
<td>[0.957,1.012]</td>
<td>[0.959,1.031]</td>
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<td>[0.945,0.958]</td>
<td>[0.951,0.974]</td>
<td>[0.954,0.994]</td>
<td>[0.956,1.013]</td>
<td>[0.958,1.032]</td>
</tr>
<tr>
<td>node 33 without PV</td>
<td>[0.946,0.958]</td>
<td>[0.952,0.974]</td>
<td>[0.954,0.993]</td>
<td>[0.957,1.012]</td>
<td>[0.959,1.031]</td>
</tr>
<tr>
<td>node 33 with PV</td>
<td>[0.945,0.958]</td>
<td>[0.951,0.974]</td>
<td>[0.954,0.994]</td>
<td>[0.956,1.013]</td>
<td>[0.958,1.032]</td>
</tr>
<tr>
<td>node 34 without PV</td>
<td>[0.945,0.958]</td>
<td>[0.951,0.974]</td>
<td>[0.954,0.993]</td>
<td>[0.956,1.013]</td>
<td>[0.958,1.032]</td>
</tr>
<tr>
<td>node 34 with PV</td>
<td>[0.945,0.958]</td>
<td>[0.951,0.974]</td>
<td>[0.954,0.994]</td>
<td>[0.956,1.013]</td>
<td>[0.958,1.032]</td>
</tr>
</tbody>
</table>

Table III. The Average and Maximum Limit Probability of the System Voltage under Different PV Permeability.

<table>
<thead>
<tr>
<th>PV permeability</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>average limit probability of system without PV</td>
<td>8.263%</td>
<td>8.263%</td>
<td>8.263%</td>
<td>8.263%</td>
<td>8.263%</td>
</tr>
<tr>
<td>average limit probability of system with PV</td>
<td>0.0259%</td>
<td>0.0196%</td>
<td>0.0154%</td>
<td>0.0177%</td>
<td>0.9160%</td>
</tr>
<tr>
<td>maximum limit probability of system without PV</td>
<td>28.643% (34)</td>
<td>28.643% (34)</td>
<td>28.643% (34)</td>
<td>28.643% (34)</td>
<td>28.643% (34)</td>
</tr>
<tr>
<td>maximum limit probability of system with PV</td>
<td>1.098%(34)</td>
<td>0.0689%(34)</td>
<td>0.0112%(17)</td>
<td>0.0515%(17)</td>
<td>2.218%(34)</td>
</tr>
</tbody>
</table>

Ps: The result “1.098%(34)” in the table indicates that the voltage limit probability of bus 34 is 1.098%.

In view of comprehensive analysis of the above chart, the analysis can be informed of the following conclusions:

(1) It can be seen from Table II that when the PV is connected to distribution network, the upper and lower limits of the confidence interval of the PV grid are increased, which indicates that the PV connection has a certain lifting effect on the network node voltage. In addition, with the PV permeability increasing, the voltage rising function of the grid is becoming more and more obvious.

(2) With the PV permeability gradually increasing, the network voltage confidence interval widen and the degree of volatility increase gradually. When the PV permeability increases from 10% to 50%, the width of the grid confidence interval increases from 0.022 to 0.089, the lower limit of the confidence interval is increased from 0.951 to 0.961, and the upper limit of the confidence interval increases from 0.974 to 1.050. It is shown that the increase of PV permeability not only can obviously increase the expected value of the node voltage, but also can increase the fluctuation range of the upper limit of voltage and the voltage overrun risk.

(3) It can be seen from Table III that the access of distributed PV significantly improves the overage limit probability of the system voltage and the maximum limit probability of the node voltage, at the same time, even it improves the voltage safety of the terminal node. When the PV permeability increases from 10% to 50%, both the average limit probability of the system voltage and the maximum limit probability of the node voltage are shown to decrease first and then increase, that is, the access of the low permeability PV, which is beneficial to improve the low voltage problem of the node, and the access of the high permeability PV will increase the risk of the upper limit of the node voltage. Therefore, quantitative indicators need to be quantitatively evaluated to provide recommendations for the allocation of PV access capacity.
CONCLUSION

This paper presents the evaluation system including the average over-limit probability of system voltage, the voltage confidence interval of node voltage and the maximum over-limit probability of node voltage based on improved probabilistic power flow method. The system evaluate different PV penetration have different influence on distribution network feasibly and accurately to conclude that appropriate PV access capacity which is favorable to improve the voltage of distribution network weak area.

REFERENCES