Reliability Assessment of Distribution Network System Considering Output Uncertainties of Distributed Generators

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Abstract. In view of the effect of DGs uncertainty on the reliability of the distribution network system, an integrated Markov model is put forward to evaluate the reliability of distribution network, considering the randomness of DG, DG mechanical failure rate and starting/switching refuse rate and other factors; In view of the randomness of the output of photovoltaic power, using the Cornish Fisher expansion method to generate the standard normal distribution of sample space in order to further analysis the effects of illumination intensity correlation coefficient of distribution system reliability. Through the simulation analysis of BUS6 IEEE-RBTS system, the simulation results show that the reliability of distribution network system is closely related to the distributed power access point, the DG capacity and the DG output correlation coefficient.

1. Introduction
The sustainable development of intelligent distribution network to access the grid more and more clean and renewable energy, including solar and power based distributed power (distributed generation DG) to relieve the energy pressure, protect the environment, flexible power at the same time[1], but also to the safety operation of the distribution network to bring more uncertain factors[2]. Because of the large amount of distributed power supply, the distributed network of traditional distribution network has become a complex active network [3]; In addition, the output of the distributed power supply is affected by external factors, which is stochastic and intermittent. How to quantify these uncertainties [4-5] and evaluate the impact of random events on the reliability of distribution network power supply, it is worth studying deeply.

In recent years, the reliability evaluation of distribution network with DG has been the focus of research both at home and abroad. Built without considering the storage model and method of system under the condition of DG distribution network reliability evaluation literature [6-7] Monte Carlo simulation; Literature [8-9] to study the influence of the energy storage system on reliability of the new distribution system; Literature [10] research on reliability of distribution network with distributed generation and fault reconstruction evaluation algorithm; literature research literatures the determined between distributed power and the reliability of the relationship, established a distribution network reliability point estimation model.
2. Output state model of distribution network generation system

The traditional distribution system reliability assessment and evaluation of different DG need to measure the load capability of distributed power distribution network reliability, namely ignoring network element constraints, impact analysis and output of DG random outage fault.

2.1. Output reliability model of distributed power supply

The output reliability of the distributed power supply can be simulated as two states of normal operation and mechanical failure, and the transition relation between the two states is shown in Figure 1, where lambda m and m respectively indicate the rate of failure and the rate of repair.

![Fig.1 two-state transition model of DG](image)

As can be seen from above, the mechanical failure rate of each DG in the distribution network can be expressed as:

\[ \lambda_{DG} = \frac{\lambda_m}{\lambda_m + \mu_m} \]  

(1)

When the access station DG is in the distribution network, the running state of DG can be expressed as a dimension state vector:

\[ s = (s_j), \; j = 1, 2, \cdots n \]  

(2)

Among them:

\[ s_j = \begin{cases} 1 \\ 0 \end{cases} \]  

(3)

0-1 indicate the station j DG is in fault and normal state respectively. Assuming that the operating state of DG is independent of each other, the probability index is:

\[ \Pr\{s\} = \prod_{j=1}^{n} \lambda_{DG}^{1-s_j} (1-\lambda_{DG})^{s_j} \]  

(4)

2.2. PV stochastic output model

The output power of photovoltaic power generation system \( P_s \) depends on the radiation intensity \( r \), the total area of photovoltaic panels \( S \) and the photoelectric conversion efficiency \( \eta \). If the shadowing effect is neglected, the PV system power generation can be expressed as:

\[ P_s = r \sum_{i=1}^{N_s} \eta_i S_i \]  

(5)

Where: \( \eta_i \) and \( S_i \) express photoelectric conversion efficiency and area for PV modules, \( N_s \) expresses components of photovoltaic cells. Statistical studies show that the radiation intensity can approximately obey the Beta \(^{[14]}\) distribution in a given period of time. In combination (5), the probability density function of PV active power is obtained:

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

(6)

Where: \( P_{\text{max}} \) expresses Output power of photovoltaic power generation system under maximum illumination; \( \alpha \) and \( \beta \) are two shape parameters of the Beta distribution.
2.3. Random output model of wind power

The variation law of the output power $P_w$ of wind turbines depends on wind speed $v$, and the mathematical relationship between the two can be approximately represented by the following piecewise functions [15]:

$$
P_w = \begin{cases} 
0, & v \notin [v_{ci}, v_{co}) \\
k_1v + k_2, & v \in [v_{ci}, v_r) \\
P_r, & v \in [v_r, v_{co}] 
\end{cases}
$$  \quad (7)

Where: $P_r$ is the rated power of fan; $v_{ci}$, $v_r$ and $v_{co}$ respectively indicate cut in wind speed, rated wind speed and cut out wind speed; $k_1 = P_r / (v_r - v_{ci})$; $k_2 = -k_1v_{ci}$. From the formula (6), it can be seen that wind speed distribution is the basis of wind energy resources assessment.

Research data show that the two parameter Weibull distribution function fitting of actual wind speed approximation is the highest, and most of the time, the wind speed is maintained between $v_{ci}$ and $v_{co}$. Therefore, combined (6) to the probability density function for $P_w$:

$$
f(P_w) = \frac{k}{k_c} \left( \frac{P_w - k_2}{k_c} \right)^{i-1} \exp\left[-\left( \frac{P_w - k_2}{k_c} \right)^i\right] \quad (8)
$$

In the formula, $c$ and $k$ are the scale parameters and shape parameters of wind speed Weibull distribution, which can be estimated from the wind speed sample data based on maximum likelihood method.

3. Reliability evaluation method of distribution network

3.1. Sample space generation of random variables

According to the above analysis, the wind speed and light intensity respectively obey Weibull distribution and Beta distribution, so the corresponding distributed power output obey the non-normal distribution. At present, it is not mature for the sample space sampling method to deal with the non-normal distribution random variables. In the process of correlation analysis, the normal random variables need to be generated to generate the standard normal space. The advantages of Cornish-Fisher series expansion method is capable of any distribution into the normal distribution function form, the specific performance of the unknown distribution of normal distribution by quantile and higher-order expression. In this paper, the Cornish-Fisher series of 5 order expansion is used to transform the DG output sample space conforming to the normal distribution.

3.2. Reliability evaluation method based on Markov model

The object of the Markov model is a repairable system, and its reliability is analyzed by studying the probability that the system shifts from one state to another. Reliability evaluation of distribution system with distributed power, considering the need to convert between different DG system model, load probability model and distribution system within the various components of the rate, so as to establish the Markov model.

DG system failures need to consider the following factors: DG switching failure, DG mechanical failure, DG capacity deficiency. The success rate of DG startup and handover can be expressed by index $P_{ss}$:

$$
P_{ss} = \frac{N_s}{N_t} \quad (9)
$$

Where: $N_s$ indicates the number of successful startup DG; $N_t$ indicates the total number of attempts to operate DG.

The most common index used in the adequacy evaluation of DG power supply is the load loss probability (LOLP), that is, the probability that the DG output can not meet the demand for power consumption:

$$
LOLP = \sum_{i=1}^{n} P \sum_{j=1}^{m} P(C_j < L_i) \quad (10)
$$
In the formula, \( m \) and \( n \) respectively indicate the DG capacity level and the load demand grade; \( C_j \) represents the DG capacity of the \( j \) level, and \( L_i \) represents the load power of the \( i \) grade.

Each state between the state transition diagram as shown in Figure 2, where \( \lambda_{DS} \) and \( \mu_{DS} \) respectively by EMCS analysis of failure rate and repair rate of the income distribution system; \( \lambda_{xy} \) and \( \lambda_{yx} \) said the transition between the state and \( Y \) respectively, under normal circumstances, in general, \( \lambda_{xy} \) can be expressed as:

\[
\lambda_{xy} = \frac{N_{xy}}{D_y} = \sum_{i=1}^{n} \lambda_{xy}^i P_i = \sum_{i=1}^{n} \frac{N_{xy}^i}{D_y} P_i
\]  

(11)

In the actual system, the reliability level of the DG itself is not up to 100% and \( P_{ss} < 1 \), the reliability model of actual distribution system can be improved on this basis, the improved Markov state transition diagram should be eliminated form as shown in Figure 2.

According to the state transition diagram, the state transition matrix can be write as formula (13):

\[
\begin{bmatrix}
0 & \lambda_{00} & \lambda_{01} & \lambda_{02} & \lambda_{03} & \lambda_{04} & \lambda_{05} & \lambda_{06} & \lambda_{07} & \lambda_{08} & \lambda_{09} & \lambda_{010} \\
\lambda_{10} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\lambda_{20} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\lambda_{30} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\mu_{00} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\mu_{10} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\mu_{20} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\mu_{30} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \mu_{10} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \mu_{20} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \mu_{30} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \mu_{40} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \mu_{50} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \mu_{60} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\end{bmatrix}
\]  

(12)

o sum up, the reliability evaluation index system of distribution network system based on the integrated Markov model is as follows:
4. Example analysis

In order to validate the Improved Markov model in reliability evaluation of distribution network with DG system, based on IEEE-RBTS BUS6 feeder, adding distributed power and switch, simulation analysis of the proposed method. The type and characteristics of feeder load points are consistent with document [14]. Assuming that the fault isolation time is 1h, the weight coefficients of 1, 2, and 3 load levels are 0.5, 0.3, and 0.2.

The parameters of the two distributed power sources are as follows:

a. WTG: \( v_{\text{ci}} = 3 \text{m/s}; \ v_{\text{ci}} = 14 \text{m/s}; \ v_{\text{c0}} = 25 \text{m/s}; \ c = 10.7; \ k = 3.97 \).

b. SDG: Shape parameter of Beta distribution: \( \alpha = 0.3; \ \beta = 1.2 \).

4.1. Adaptive algorithm analysis

In order to analyze the influence of distributed power on the reliability of distribution system, the test system is evaluated in four different scenarios.

Scene 1: the distribution system does not access the distributed power supply, and ignores the reliability of the switch in the distribution network.

Scene 2: the distribution system is not connected to the distributed power supply, and the rejection of the switch in the distribution network is also considered.

Scene 3: in node 15 access to a WTG, node 25 access to a SDG, rated power of 1MW.

Scenario 4: ignore the DG capacity limit based on scenario 3.

The average outage rate index of each load point is shown in figure 4. The partial load reliability index and the system reliability index are shown in table 1 and table 2 respectively.
### Table 1: Reliability indices of some load points

| Scene | $r(h)$ | LP1 | LP8 | LP11 | LP14 | LP19 |
|-------|--------|-----|-----|------|------|------|
| 1     |        | 3.3879 | 5.0064 | 5.0064 | 3.9024 | 5.0016 |
| 2     |        | 3.3912 | 5.1453 | 5.1417 | 4.1315 | 5.1407 |
| 3     |        | 3.3807 | 4.9146 | 4.3581 | 4.1067 | 4.5612 |
| 4     |        | 3.3713 | 2.7523 | 4.0472 | 4.0647 | 4.2136 |

### Table 2: Reliability indices of the system

| Scene | SAIFI | SAIDI | ENSI/MW | ASAI/% |
|-------|-------|-------|--------|--------|
| 1     | 1.6548 | 6.8534 | 30.641 | 99.9629 |
| 2     | 1.7836 | 7.3951 | 36.257 | 99.9514 |
| 3     | 1.5187 | 6.1949 | 29.485 | 99.9764 |
| 4     | 1.3902 | 4.8615 | 22.573 | 99.9785 |

According to the simulation results, the following conclusions can be drawn:

1. Fig. 4 Comparison in scenario 2 and scenario 3 curves in the distribution network fault, distributed power supply area to non-fault nearby, so the average outage rate in distributed power near the load point ($\lambda$) significantly decreased; By comparing the curves of Scene 3 and Scene 4, we can see that the outage rate can be further reduced without considering the DG capacity limitation.

2. Compare the reliability evaluation results of scenario 1 and scene 2, scene 2 is less than the scene 1, this is because the switch rejection will change the islanding operation scheme, therefore, considering the reliability of the switch action, the evaluation results will be more real and effective in the reliability evaluation of the distribution network.

3. Compare each data in table 3, DG access can significantly reduce the average outage time near the load point ($r$) and the average outage time ($U$); for LP1, LP8 and LP14 and other non-distributed power supply area load, DG access to the outage rate index ($\lambda$) had no obvious effect, but the outage time index ($r, U$) has certain influence, the influence size depends on the correlation between the output and the load of the distributed power supply.

#### 4.2. Analysis of influence of DG correlation on reliability of distribution network system

In the test system, PV generators with rated capacity of 1MW are maintained at nodes 13, 15, 18, 20, 21 and 25 to keep the load power constant. Define parameters $k = \frac{\sum P_{DG}}{\sum P_L}$ to indicate the size of the DG output. Study on the relationship between the average photo number $P$ effect rate and average power outage time of $R$ on load.

![Fig.5 Relationship between annual average outage rate of LP14 and illumination correlation coefficient](image.png)
Table 3 Relationship between annual average outage duration of load point and illumination correlation coefficient

| k   | Load point | 0.2  | 0.4  | 0.6  | 0.8  |
|-----|------------|------|------|------|------|
| 0.5 | LP8        | 4.5716 | 4.5716 | 4.5716 | 4.5716 |
|     | LP14       | 4.1884 | 4.1267 | 4.0651 | 4.0184 |
|     | LP21       | 7.5376 | 7.5376 | 7.5376 | 7.5376 |
|     | LP8        | 4.2049 | 4.1852 | 4.0827 | 3.9542 |
| 0.8 | LP14       | 3.2681 | 3.0427 | 2.9153 | 2.8834 |
|     | LP21       | 5.0149 | 5.1672 | 5.3129 | 5.4473 |
|     | LP8        | 2.7318 | 2.8064 | 2.8748 | 2.9452 |
| 1.2 | LP14       | 1.7462 | 1.8049 | 1.8634 | 1.9173 |
|     | LP21       | 1.9769 | 2.1473 | 2.2961 | 2.5283 |

Figure 5 shows the influence of the correlation coefficient of illumination intensity on the average outage rate index of the load point LP14; Table 3 lists the different distributed photovoltaic power output under the condition of three typical load node average outage time changes with the light intensity correlation coefficient. From the above results, we can draw a conclusion:

1. When the DG output coefficient of k is small, with the increase of light intensity correlation coefficient, the higher reliability of the load. This is because when the correlation coefficient is small, due to insufficient DG reserve capacity, any insufficient DG output will result in the demand for electricity in the vicinity of the non-fault zone load is not met; With the increase of correlation coefficient, DG output with good consistency, DG the problem of insufficient capacity to improve, improve the reliability of load transfer.

2. When the DG output coefficient of K is large, with the increase of light intensity correlation coefficient, the reliability of part load decreased. This is because the DG enough spare capacity, a single DG output deficiency does not affect the power supply; on the contrary, when the relationship between the large number of photo, DG output has a strong consistency, there will be DG at the same time all output is insufficient, some of the load power supply shortage, reduce reliability. This is because the DG enough spare capacity, single DG insufficient output does not affect the load power supply. On the contrary, when the number of photo contacts is large, the DG output has a strong consistency, and all the DG output is insufficient at the same time, which makes some load point power shortage and reduces the reliability.

5. Conclusion
In order to study the effect of uncertain factors on distributed power distribution system reliability, considering the distributed power machinery fault, switch tripping and the output of other factors, to establish a comprehensive assessment of the reliability of Markov model. Cornish-Fisher series expansion method is used to generate DG output sample space, which is consistent with normal distribution. The influence of light intensity correlation on reliability of distribution network is studied. Calculation analysis shows that the access of distributed power supply can effectively improve the reliability of load point and distribution network system, and the reliability evaluation result of switch rejection and DG mechanical fault is more practical; The greater the output of the distributed power supply, the higher the reliability of the distribution network, but the influence of output correlation on reliability is complex, so the output size of the distribution network should be considered comprehensively.

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