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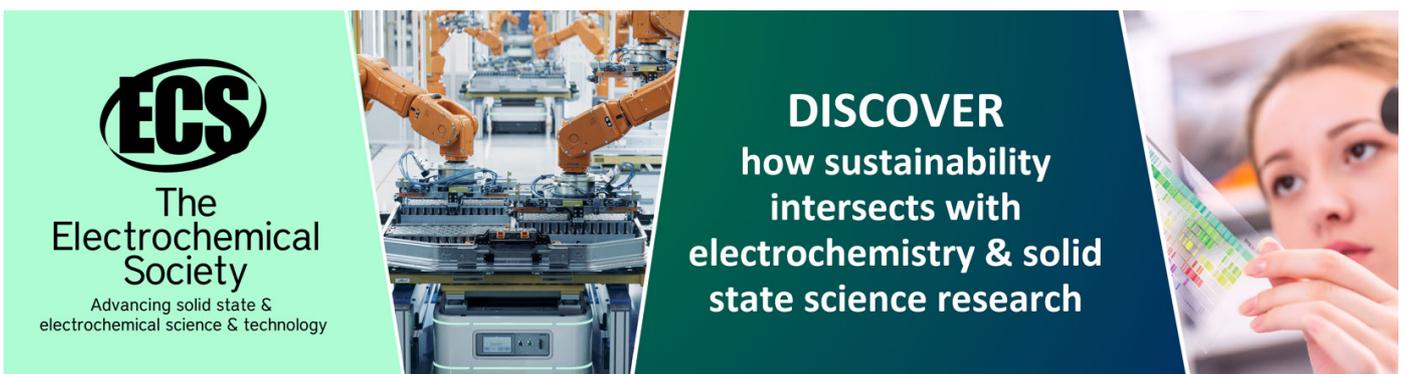
## A method for evaluating the uncertainty of short-circuit current in power system with photovoltaic power generation

To cite this article: Jiafang Wu *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **546** 022025

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# A method for evaluating the uncertainty of short-circuit current in power system with photovoltaic power generation

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**Abstract.** Short-circuit current of power system with photovoltaic power generation is related to the fault current provided by the photovoltaic power supply. In this paper, based on the analysis of low voltage ride-through uncertain region of photovoltaic power generation, the random model of low voltage off-grid is constructed. Further combining with the system fault information, based on the monte carlo simulation, a probabilistic assessment method of short-circuit current in power system is proposed, which takes into account uncertainty of photovoltaic low voltage ride-through. Finally, an example is given to verify the proposed method. The method in this paper comprehensively considers the random factors of power grid failure and photovoltaic power generation low voltage off-grid, and the short-circuit current result can accurately reflect actual short-circuit current level of the system.

## 1. Introduction

The continuous expansion of the scale of photovoltaic power generation will have a certain impact on the power grid. For example, due to the different types of photovoltaics and control strategies, there will be differences in the low voltage ride-through capabilities of photovoltaics, resulting in uncertainty [1].

Moreover, the randomness of grid faults will also cause uncertainty in the short-circuit current of photovoltaics.

Existing literatures have tested photovoltaic power plants, thus establishing their low-voltage ride-through model and analyzing the short-circuit current characteristics of photovoltaic generators [2-4]. However, there is no relevant literature to study the uncertainty of low-voltage ride-through capability of photovoltaic power generation.

At present, the probabilistic assessment method has been applied to power grid voltage stability [5], voltage sag [6] and power flow analysis [7], etc. By integrating the random modeling of power grid fault, the calculation of short-circuit current of photovoltaic power generation and the uncertain modeling of low voltage crossing, the probabilistic assessment of short-circuit current level of power system containing photovoltaic power generation can be carried out.



## 2. Probability model of low voltage off-grid for photovoltaic power generation

### 2.1. Uncertainty region of low voltage ride-through curve

There are differences in the types of photovoltaic inverters and manufacturers, so it can be considered that the low-voltage ride-through capability of each photovoltaic is different. In actual operation of photovoltaic equipment, the low-voltage ride-through curve exists in an uncertain area near the national standard curve, such as Figure 1.

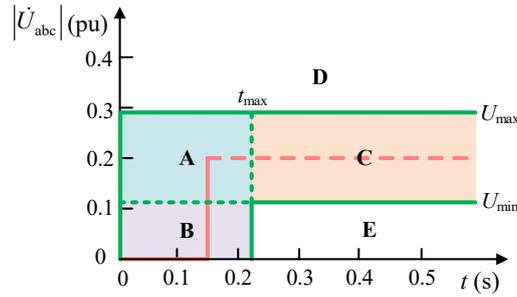


Figure 1. Uncertainty region of low voltage ride-through curve

In the figure,  $t_{\max}$  represents the maximum time for the terminal voltage to fall to 0pu,  $U_{\max}$  and  $U_{\min}$  represent the maximum and minimum voltage for the terminal voltage to fall to 0pu, respectively. The area surrounded by the solid green line is the uncertainty area. The uncertainty area includes three areas ABC, and D is the non-off-grid operation area, and E is the off-grid operation area. The parameters in the figure are determined by the test data.

### 2.2. Random modeling of photovoltaic power generation low voltage off-grid

It can be seen from the foregoing that the amplitude and duration of the voltage of the photovoltaic power generation terminal determine whether it is off-grid and can be converted into a probability problem in an uncertain area. Consider the randomness of photovoltaic low voltage ride through capability, and evaluate the probability of photovoltaic off-grid operation.

In Figure 1, the photovoltaic in area D remains on-grid and the probability of disconnection is 0. While in area E, the photovoltaic will be disconnected from the grid and the probability of disconnection is 1. The probability of photovoltaic off-grid in the uncertain area ABC is determined by both  $t$  and  $U$ .

In this paper, the randomness of  $t$  and  $U$  is characterized by the normal distribution function, based on the relevant research of load voltage tolerance curve [8].  $f_x(t)$  and  $f_y(U)$  represent the probability density functions of B and C regions, respectively, which are expressed as follows:

$$f_x(t) = \frac{1}{\sqrt{2\pi}\sigma_1} \exp\left[-(t-0.15)^2 / (2\sigma_1^2)\right] \quad (1)$$

$$f_y(U) = \frac{1}{\sqrt{2\pi}\sigma_2} \exp\left[-(U-0.2)^2 / (2\sigma_2^2)\right] \quad (2)$$

where,  $t \in [0, t_{\max}]$ ,  $U \in [U_{\min}, U_{\max}]$ ,  $\sigma_1$  and  $\sigma_2$  are the distribution densities of region B and region C, respectively. Since  $t$  and  $U$  are two independent random variables, the joint probability density function of random variables  $t$  and  $U$  in region A can be expressed as:

$$\begin{aligned} f_{x,y}(t,U) &= f_x(t)f_y(U) \\ &= \frac{1}{2\pi\sigma_1\sigma_2} \exp\left\{-\frac{1}{2}\left[\frac{(t-0.15)^2}{\sigma_1^2} + \frac{(U-0.2)^2}{\sigma_2^2}\right]\right\} \end{aligned} \quad (3)$$

According to 3  $\sigma$  principle, the values of  $\sigma_1$  and  $\sigma_2$  can be further solved:

$$\begin{cases} \sigma_1 = (0.15 - 0)/3 = 0.05 \\ \sigma_2 = (0.2 - U_{\min})/3 \end{cases} \quad (4)$$

The values of  $t_{\max}$ ,  $U_{\max}$  and  $U_{\min}$  are obtained through multiple experiments. By substituting equation (4) to solve for  $\sigma_2$ , the probability density function in the whole uncertain region can be obtained by combining equations (1) and (3).

As shown in Figure 2, there are five types of events, of which s1 and s2 are located in area D and area E, respectively, and the probability of photovoltaic off-grid is 0 and 1, respectively.  $U_3$  and  $t_3$  are the voltage sag amplitude and duration of s3 respectively,  $t_4$  is the voltage sag duration of s4, and  $U_5$  is the voltage sag amplitude of s5.

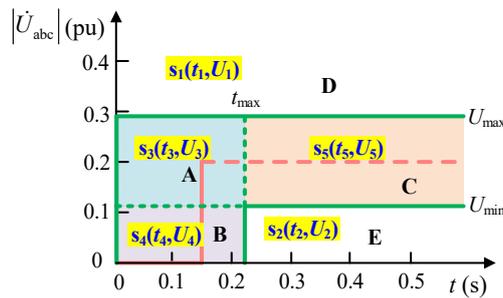


Figure 2. Evaluation of off-grid operation for photovoltaic power generations

When s1~s5 occurs, the photovoltaic off-grid probability is expressed as:

$$\begin{cases} P_{s_1}(U_{\max} \leq U) = 0 \\ P_{s_2}(t_{\max} \leq t, U \leq U_{\min}) = 1 \\ P_{s_3}(0 \leq t \leq t_3, U_3 \leq U \leq U_{\max}) = \int_0^{t_3} \int_{U_3}^{U_{\max}} f_{x,y}(t, U) du dt \\ P_{s_4}(0 \leq t \leq t_4) = \int_0^{t_4} f_x(t) dt \\ P_{s_5}(U_5 \leq U \leq U_{\max}) = \int_{U_5}^{U_{\max}} f_y(U) du \end{cases} \quad (5)$$

### 3. Probabilistic assessment method of short circuit current in power system under uncertainty of photovoltaic low voltage ride-through

The occurrence of faults in the power system is random, so it is necessary to evaluate whether the photovoltaic power generation is off-grid for each fault, and then evaluate the short-circuit current level of the system.

In summary, the method proposed in this paper comprehensively considers uncertain factors such as the probability of disconnection of photovoltaic power generation and system failure. Among them, the system failure factors include the faulty line, fault type, and fault duration.

This paper assumes that the failure rate of each line is proportional to its length, and the failure probability of each point on a line follows [0,1] distribution.

It is difficult to obtain the true values of various types of failure probabilities in power systems. Therefore, this paper assumes that the probability of occurrence of various types of failures in the network is the same as in literature [6].

Assume that the fault duration follows the normal distribution of the expected value of 0.18s and the standard deviation of 0.06s, and the fault transition impedance follows the normal distribution of the expected value of 5Ω and the standard deviation of 1Ω.

This paper uses the Monte Carlo method to deal with the above random problems. Iterative calculation is based on the value of random variables, and the probability of short-circuit current is further evaluated in conjunction with the probability of low-voltage off-grid of photovoltaic power generation.

The program mainly follows the following steps:

- (1) Set the sampling times and randomly sample to obtain fault information such as fault line, fault location, fault type, fault duration, etc.
- (2) According to the  $n$ th sampling value, calculate the voltage amplitude of the PV grid-connected terminal and the maximum current  $I_{pvn}$  of the photovoltaic output during a fault.
- (3) According to the terminal voltage amplitude and the duration of the fault, obtain the photovoltaic generation off-grid probability  $P_{pvn}$  at the  $n$ th sampling, and then calculate the expected value of the photovoltaic injection current  $(1-P_{pvn}) \cdot I_{pvn}$ .
- (4) Substitute the above expected value into the short-circuit calculation program to calculate the short-circuit current at the fault point;
- (5) After sampling  $n$  times, the short-circuit current value of each fault point under different fault conditions is obtained, and finally the probability distribution diagram of the short-circuit current is formed.

#### 4. The example analysis

The structure of a 10kV feeder network in an area is shown in Figure 3. The red node is the photovoltaic power generation access point, with a minimum photovoltaic capacity of 0.5MW and a maximum of 1.5MW.

After sampling 1000 times, the probability distribution of short-circuit current at each point of the system is shown in Figure 4 and Figure 5, respectively.

The red and purple areas in Figure 4 represent the probability distribution results of the short-circuit current at the fault point when the photovoltaic is connected to the grid. It can be seen from the figure that photovoltaic grid connection will increase the short-circuit level of the system, and the short-circuit current at the fault point is the largest.

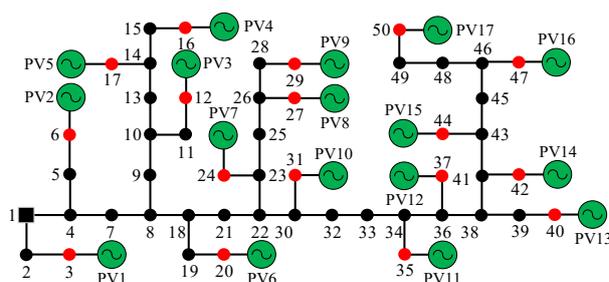


Figure 3. Network structure with 50 nodes

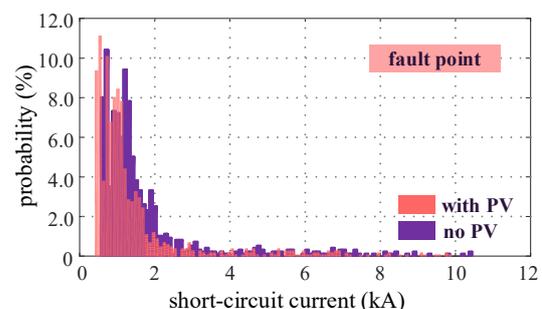
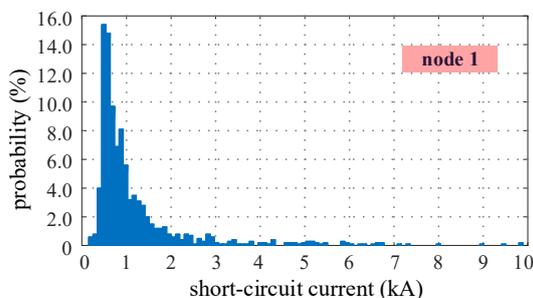
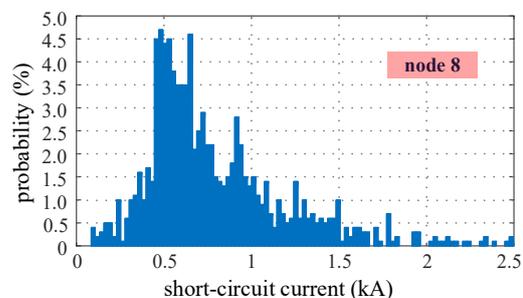


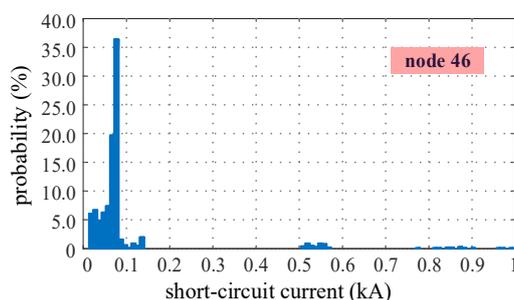
Figure 4. Probability distribution at fault points



(a) Probability distribution at node 1



(b) Probability distribution at node 8



(c) Probability distribution at node 46

Figure 5. Probability distribution of short-circuit current at some nodes

Since the short-circuit current provided by the conventional power supply on the system side is much larger than that of photovoltaic power generation, it can be seen from Figure 5 that the maximum short-circuit current and the maximum probability short-circuit current sustained by node 1 to node 46 both show a downward trend, that is, the closer to the conventional power supply, the greater the short-circuit current.

In addition, it can be seen from Figure 5 that probability distribution of short-circuit current varies from node to node, in which the probability distribution of node 1 and node 46 is relatively concentrated, while the short-circuit current distribution of node 8 is relatively dispersed.

In the system topology, node 1 is located at the head of the network and closest to the conventional power supply, while node 46 is located at the end of the network. Node 8 is an intermediate node, which is affected by both conventional power supply and photovoltaic power generation. Therefore, the short-circuit current distribution at this node is more dispersed.

This method can not only estimate the maximum short-circuit current of the system, but also obtain the maximum probability current and the probability interval of the system short-circuit current.

## 5. Conclusion

In this paper, considering the uncertainty of the low voltage crossing curve, the random evaluation model of photovoltaic low voltage off-grid is established. At the same time, a probabilistic evaluation method of short-circuit current of the system is proposed based on fault information of power system.

Compared with the conventional accurate calculation method, the method in this paper is helpful to give more objective results, present the probability distribution of the system short-circuit current, and provide an effective basis for the selection of equipment.

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