

# Analysis of Short-circuit and Protection Failure Risk Considering Random Output of Distributed Photovoltaics

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**Abstract.** Distributed photovoltaics (DPV) will increase or shunt the fault current as a branch of the power supply. The random outputs of DPV will also cause a random distribution of fault current, while the breaking capacity of the breaker and the setting value of the current protection is pre-set value, and cannot flexibly change, so DPV will bring a certain degree of influence on the breaking margin and the sensitivity of protection. This paper makes probability distribution calculating model of fault current containing DPV, and takes IEEE 33-node system as an example, simulated the probability distribution of fault current at different penetration of DPV. Finally, from the two indicators of the breaking margin of breaker and the sensitivity of protection, analysed the protection failure risk after the access of DPV.

## 1. Introduction

Conventional current protection is configured in a single-sided power-supply mode, while DPV will provide fault current as a branch of the power supply, and with the different distance between the fault point and the access point, fault current provided by DPV current will play a role of increase, shunt or reverse, making different influence on protection, even lead to protection misoperation or rejective-operation [1-4]. In [5-8], the fault current is simulated to analyze the protection misoperation or rejective-operation of different locations, and new protection setting methods after DPV access are proposed. However, in the above literature, DPV uses a constant power model, without considering the influence of randomness of DPV output on fault current and protection.

This paper develops the probability distribution model of fault current according to the random output of DPV, and taking IEEE 33-node system as an example, simulated the probability distribution of fault current at different penetration of DPV. Finally from the two indicators of the breaking margin of breaker and the sensitivity of protection, analyzed the protection failure risk after the access of DPV.

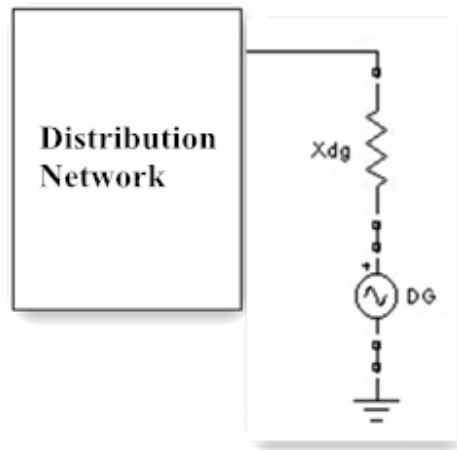
## 2. Probability Distribution Calculating Model of Fault Current containing DPV

In the system with DPV, DPV will provide part of the fault current, so it can transfer to one voltage source and reactance, as shown in figure 1. Compared with the impedance matrix of the original system, the access of DPV is equivalent to an increase of a ground branch with internal impedance of  $X_{DPV}$ [9].

The greater the output of the DPV before the fault, the greater the fault current provided by DPV after the fault, equivalent to the smaller internal impedance  $X_{DPV}$ ; Conversely, the smaller the output of the DPV before the fault, the smaller the fault current provided by DPV, equivalent to the greater internal impedance  $X_{DPV}$ . Therefore, the fault current provided by DPV is different when different



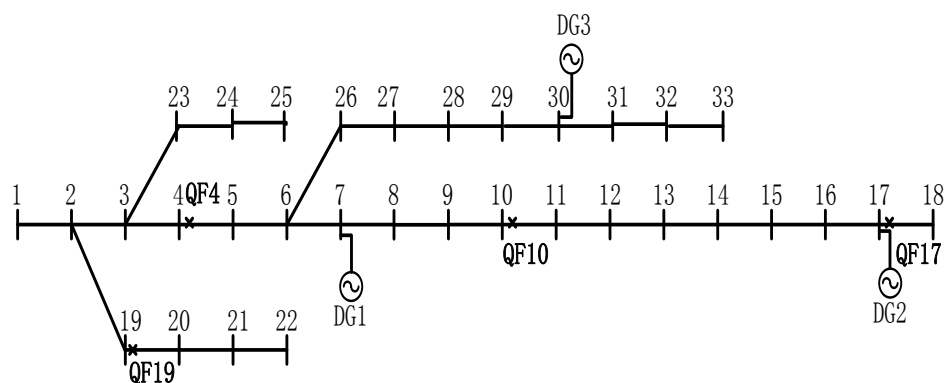
output; When multiple DPVs access, DPVs at different positions have different effects on fault current. Thus it's needed to calculate the probability distribution of fault current.



**Figure 1.** Fault current calculating model of DPV

### 3. Analysis of Breaking Margin

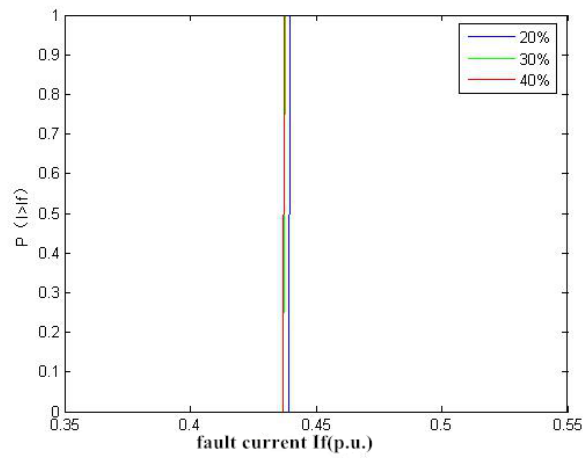
This paper takes IEEE33 node system as example to analyze breaking margin, the figure 2 shows its schematic, the node and branch parameter is referred in [10].



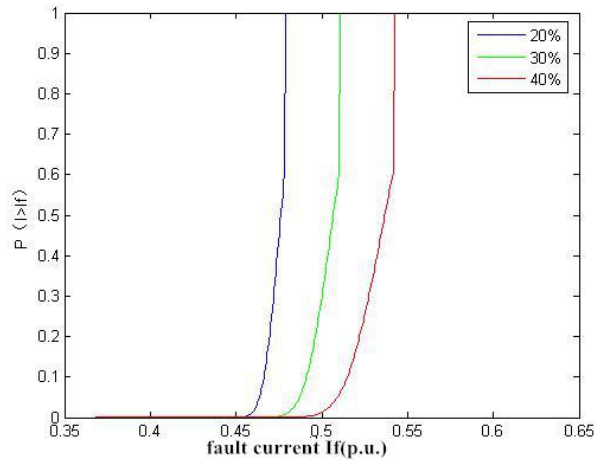
**Figure 2.** Schematic of IEEE33 node system

This part chooses node 7, 17 and 30 as access point and analyzes breakers QF4, QF10, QF17, QF19 on line 4-5, 10-11, 17-18, 19-20.

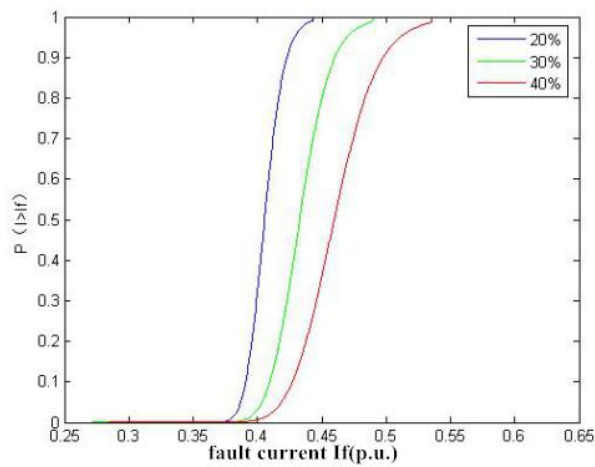
When three-phase short-circuit happens at downstream of circuit breaker, the fault current is largest, which can check the breaking margin of breakers. Setting penetration of DPV at 20%, 30%, 40%, and three-phase short-circuit at the downstream outlet of QF4, QF10, QF17, QF19, the probability distribution of fault current is shown in figure 3.



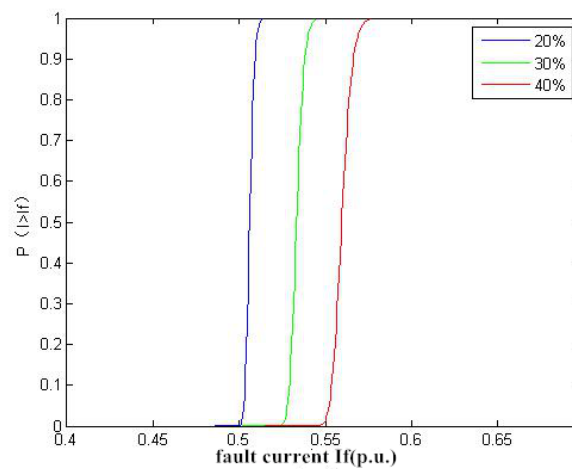
(a) Fault current of QF4



(b) Fault current of QF10



(c) Fault current of QF17



(d) Fault current of QF19

**Figure 3.** Probability distribution of fault current

The breaking margin (The maximum fault inrush current/maximum breaking current) of each breaker is shown in table 1.

**Table 1.** Breaking margin of each breaker at different penetration

	10%	20%	30%	40%	60%
<b>QF4</b>	55.99%	55.98%	56.03%	56.01%	56.01%
<b>QF10</b>	59.09%	51.87%	48.67%	45.44%	37.23%
<b>QF17</b>	64.93%	55.40%	47.74%	41.14%	31.34%
<b>QF19</b>	54.28%	48.07%	44.71%	41.40%	36.86%

It can be drawn from figure 3 and table 1:

1). The fault current provided by DPV doesn't flow through QF4, so the maximum fault current flowing through the breaker QF4 does not change with the penetration of DPV, whose breaking margin isn't affected by penetration;

2). QF10, QF17, and QF19 can flow through the fault current provided by DPV when short-circuit at the downstream outlet, so the higher the penetration, the greater the fault current, and the stronger the dispersion, leading the breaking margin becoming smaller;

3). Comparing breakers QF10 and QF17, the former only flow through the fault current provided by two of the three DPVs, while the boosting fault current from all the three DPVs can flow through QF17. Therefore, the fault current flowing through the breaker QF 17 is highly dispersive, and the breaking margin increases more rapidly with the increase of the penetration.

#### 4. Analysis of Sensitivity of Protection

The analysis of section 3 shows that the random output of DPV makes the fault current dispersive, even the same nature of short-circuit at the same node, fault current will be different. As the current protection settings are mostly based on the maximum value of fault current as a benchmark (section 3 is based on the maximum load current). The minimum fault current can be used to check the sensitivity, so the access of DPV will bring a certain degree of influence on the sensitivity of protection.

In this part, sensitivity analysis is carried out with current protection section 2 as an example. The sensitivity coefficient of section 2 is defined as follows,

$$K_{sen}^{II} = \frac{I_{k.end.min}^{(2)}}{I_{set}^{II}} \quad (1)$$

Where,  $I_{k.end.min}^{(2)}$  is the minimum 2-phase short-circuit fault current that may occur at the end of the line;  $I_{set}^{II}$  is the setting value of current protection section 2. If the calculated  $K_{sen}^{II} \geq 1.4 \sim 1.5$ , indicating that the setting value is in line with the sensitivity index.

According to the above principle, the sensitivity coefficient of protection at QF4, QF10, QF19 is calculated and analyzed for different penetration of DPV, whose results are shown in table 2- table 4

**Table 2.** Sensitivity coefficient of QF10 at different penetration

	10%	20%	30%	40%	60%
$I_{set}^{II}$ (A)	192.35	250.33	278.08	305.84	332.62
$I_{k.end.min}^{(2)}$ (A)	278.38	309.61	321.03	331.29	340.78
$K_{sen}^{II}$	1.447	1.237	1.154	1.083	1.024

**Table 3.** Sensitivity coefficient of QF19 at different penetration

	10%	20%	30%	40%	60%
$I_{set}^{II}$ (A)	234.37	272.44	299.52	327.20	353.78
$I_{k.end.min}^{(2)}$ (A)	311.15	342.71	357.76	371.44	385.56
$K_{sen}^{II}$	1.327	1.258	1.194	1.135	1.090

**Table 4.** Sensitivity coefficient of QF4 at different penetration

	10%	20%	30%	40%	60%
$I_{set}^{II}$ (A)	214.12	214.32	214.15	213.98	214.07
$I_{k.end.min}^{(2)}$ (A)	299.52	299.58	299.17	299.38	299.26
$K_{sen}^{II}$	1.401	1.398	1.397	1.399	1.398

It can be drawn from table 2- table 4:

The random output of DPV makes the fault current dispersive, the large range of fault current may occur when short-circuit at the same node. As the current protection settings are mostly based on the maximum value of fault current as a benchmark, and the minimum value of fault current to check the sensitivity, the increase of the penetration of DPV will make the protection sensitivity decrease;

The degree which the protection sensitivity is affected is related to the relative position between the protection and the access point of DPV. If the protection is located upstream of all DPVs, the sensitivity is not affected, for example, QF4; If the protection is located downstream of the DPV, the sensitivity changes greatly, such as QF10; If the protection is located in other branches without DPV, the change of sensitivity is small as the fault current provided by DPV is small, such as QF19.

## 5. Conclusion

In this paper, the variance of the internal impedance  $X_{DPV}$  of DPV in the short-circuit calculation model is used to reflect the randomness of the DPV output, which can simulate the probability distribution of the fault current and analyze the protection failure risk. Taking the IEEE33 bus system as an example, the calculation results show that the bigger the DPV penetration and the closer the

protection from the access point, the greater the dispersion of the fault current, leading the smaller breaking margin and protection sensitivity.

## 6. Acknowledgments

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