

## Technical Article

# How to Calculate Effective and Low-impedance Grounding for Power Systems

June 08, 2020 by [Lorenzo Mari](#)

**This article illustrate the impact of effective and low-impedance (reactance or resistance) grounding on the power system.**

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The best method to control overvoltages is effective, or solid, grounding. It's important to properly calculate the resistors required for this type of grounding. This article shows how to calculate effective and low-impedance grounding through a step-by-step example.

[These methods](#) supply phase-to-neutral connected loads without the risk of finding dangerous neutral-to-ground voltages when a ground-fault arises. An effectively grounded system also has the highest values of ground-fault currents, which may range from zero to three times the three-phase short-circuit current.

In the USA, low-resistance grounding is the most popular method utilized to limit ground-fault current. The value of resistance is much lower than that of the high-resistance method and ranges from 5% to 20% of the three-phase fault current. Some applications limit the ground current to around 50A to 600A.

A typical resistor of 400A will allow enough current flow to operate the protective relays for fast fault clearing. These resistors are also time-rated. A standard figure is 10s because, like in effective grounding, the branch will shut down after the first ground-fault.

## Effective and Low-impedance Grounding Calculations

The example below will illustrate the impact of effective and low-impedance (reactance or resistance) grounding on the power system.

**Note:**

$X_d''$  = Direct-axis subtransient reactance (a synchronous generator parameter)

$V_{LL}$  = Voltage line-to-line

$Z_b$  = Base impedance (This is part of the per-unit system used to analyze power systems)

A symmetrical synchronous generator operated at no load (i.e., with the main circuit breaker open), and rated 500 MVA, 22kV, is wye connected and solidly grounded.

Generator constants:

$$X_d'' = X_1 = X_2 = 15\% ; X_0 = 5\%$$

- Find the subtransient single line-to-ground fault current in the generator windings.

Base values  $kV_b = 22$  and  $MVA_b = 500$

$$Z_b = (kV_b)^2/MVA_b = (22)^2/500 = 0.968 \Omega$$

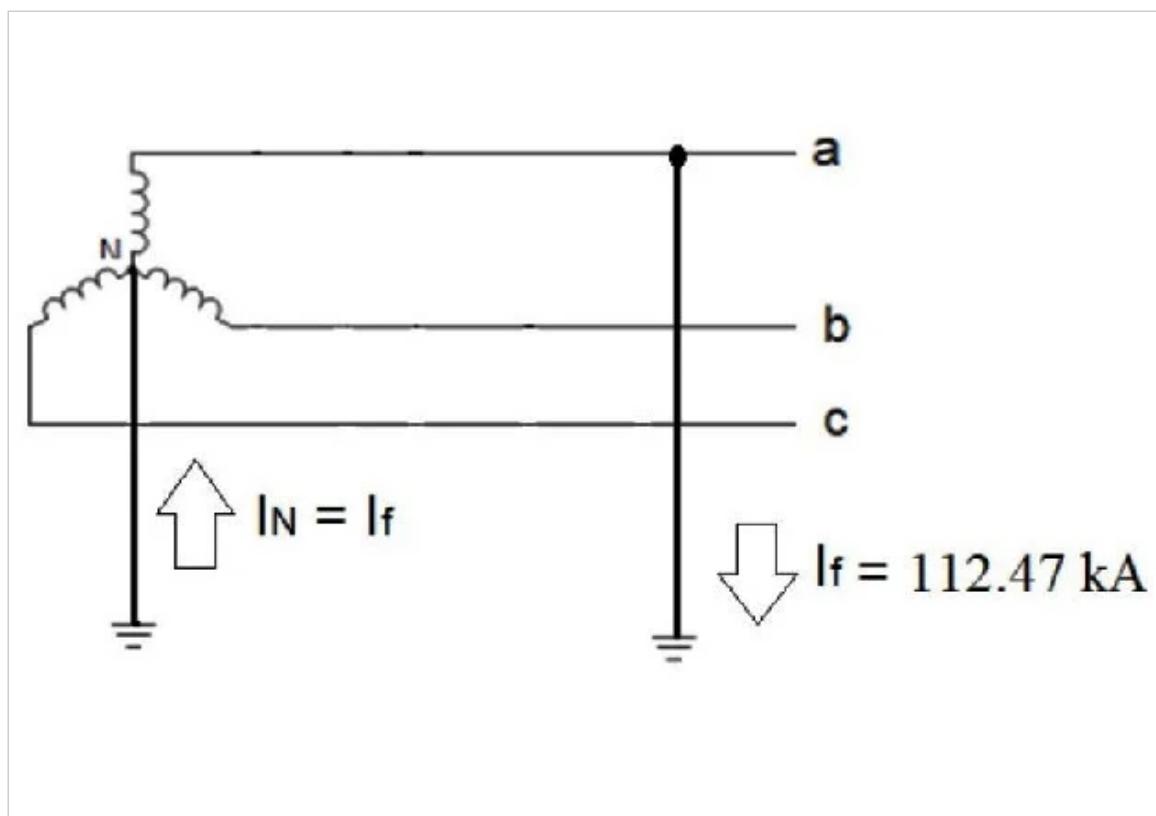
$$X_d'' = X_1 = X_2 = 0.15 \cdot 0.968 = 0.1452 \Omega$$

$$X_0 = 0.05 \cdot 0.968 = 0.0484 \Omega$$

$$I_0 = V_{LN}/(X_1 + X_2 + X_0) = (V_{LL}/\sqrt{3})/(X_1 + X_2 + X_0)$$

$$I_0 = (22/\sqrt{3}) \text{ kV}/(0.1452 + 0.1452 + 0.0484) \Omega = 12.7 \text{ kV}/0.3388 \Omega = 37.49 \text{ kA}$$

$$I_{f1\phi} = 3 \cdot I_0 = 3 \cdot 37.49 = \mathbf{112.47 \text{ kA}}$$



**Figure 1.** Unloaded, solidly grounded generator with a line-to-ground fault on phase a

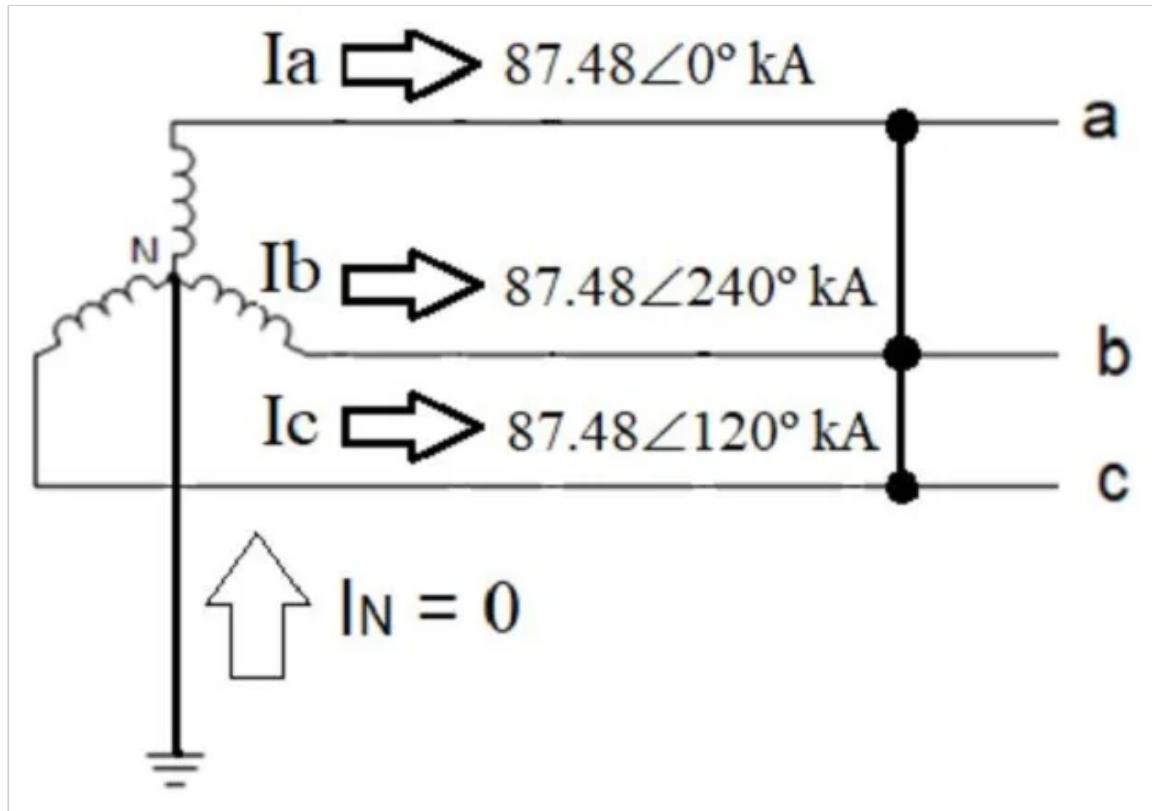
- Find the ratio  $X_o/X_1$

$$X_o/X_1 = 5\%/15\% = 0.333$$

Note:  $X_o/X_1 < 3 \rightarrow$  system effectively grounded

3. Find the subtransient three-phase fault current in the generator windings.

$$I_{f3\phi} = V_{LN}/X_1 = (V_{LL}/\sqrt{3})/X_1 = (22/\sqrt{3}) \text{ kV}/0.1452 \Omega = 87.48 \text{ kA}$$



*Figure 2. Unloaded, solidly grounded generator with a three-phase short circuit at its terminals*

4. Find the ratio  $I_{f1\phi}/I_{f3\phi}$ .

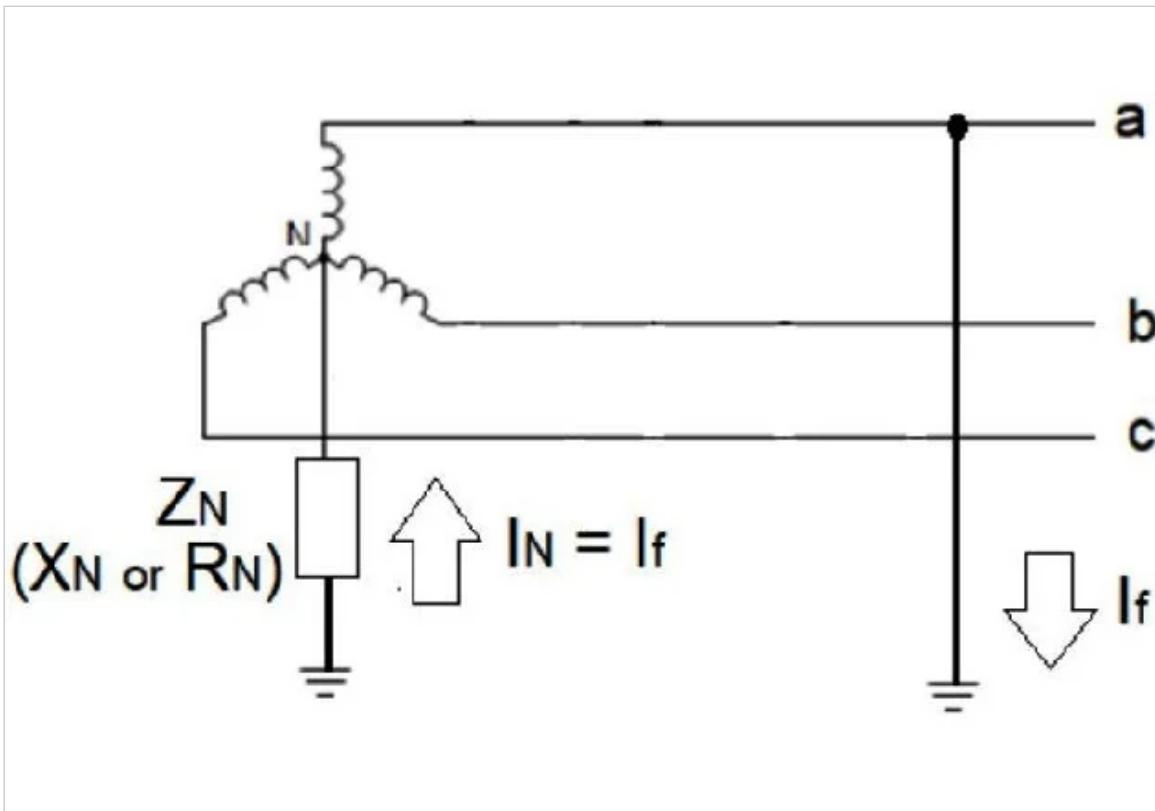
$$I_{f1\phi}/I_{f3\phi} = 112.47 \text{ kA}/87.48 \text{ kA} = 1.286$$

Note: The line-to-ground fault current is 28.6% higher than the three-phase fault current. It may damage the generator.

5. Find the reactance of a neutral grounding reactor to limit the line-to-ground fault current to 100% of the three-phase fault current.

$$\begin{aligned} I_{f1\phi} &= 3 \cdot I_0 = I_{f3\phi} = 87.48 \text{ kA} = 3 \cdot V_{LN}/(X_1 + X_2 + X_0 + 3 \cdot X_N) = (\sqrt{3} \cdot \sqrt{3} \cdot V_{LL}/\sqrt{3})/(X_1 + X_2 + X_0 + 3 \cdot X_N) = \sqrt{3} \cdot 22 \\ \text{kV}/(0.1452 + 0.1452 + 0.0484 + 3 \cdot X_N) \Omega &= 38.106 \text{ kV}/(0.3388 + 3 \cdot X_N) \Omega \Rightarrow X_N = 0.03226 \Omega \end{aligned}$$

Note:  $X_0 + 3 \cdot X_N = X_1 = X_2$  when  $I_{f1\phi} = I_{f3\phi}$ .



*Figure 3. Unloaded, low-impedance grounded generator with a line-to-ground fault on phase a*

6. Find the ratio  $X_0/X_1$  with the neutral grounding reactor of question 5.

$$3 \cdot X_N = (3 \cdot 0.03226 \Omega / 0.968 \Omega) \cdot 100 = 10\%$$

With the neutral grounding reactor inserted in the zero-sequence circuit  $X_0 = 5\% + 10\% = 15\% = X_1$

$$X_0/X_1 = 15\%/15\% = 1$$

Note 1: The fault current contribution of one winding of this generator to a line-to-ground fault, outside the machine, will not be higher than the three-phase fault current of the generator.

Note 2:  $X_0/X_1 < 3 \rightarrow$  By definition, the system is not low-reactance grounded, despite having a reactance inserted in the neutral.

7. Find the reactance of a neutral grounding reactor to limit the line-to-ground fault current to 60% of the three-phase fault current.

$$I_{f1\phi} = 3 \cdot I_0 = 0.60 \cdot I_{f3\phi} = 0.60 \cdot 87.48 \text{ kA} = 52.49 \text{ kA} = 38.106 \text{ kV} / (0.3388 + 3 \cdot X_N) \Omega \Rightarrow X_N = 0.1291 \Omega$$

8. Find the ratio  $X_0/X_1$  with the neutral grounding reactor of question 7.

$$3 \cdot X_N = (3 \cdot 0.1291 \Omega / 0.968 \Omega) \cdot 100 = 40\%$$

$$X_0 = 5\% + 40\% = 45\%$$

$$X_o/X_1 = 45\% / 15\% = 3$$

Note: 60% of  $I_{f3\phi}$  is the maximum ground-fault current for the system to be low-reactance grounded.

9. Find the reactance of a neutral grounding reactor to limit the line-to-ground fault current to 25% of the three-phase fault current.

$$I_{f1\phi} = 3 \cdot I_0 = 0.25 \cdot I_{f3\phi} = 0.25 \cdot 87.48 \text{ kA} = 21.87 \text{ kA} = 38.106 \text{ kV} / (0.3388 + 3 \cdot X_N) \Omega \Rightarrow X_N = \mathbf{0.4679 \Omega}$$

10. Find the ratio  $X_o/X_1$  with the neutral grounding reactor of question 9.

$$3 \cdot X_N = (3 \cdot 0.4679 \Omega / 0.968 \Omega) \cdot 100 = 145\%$$

$$X_0 = 5\% + 145\% = 150\%$$

$$X_o/X_1 = 150\% / 15\% = \mathbf{10}$$

Note: To control transient overvoltages, the ground-fault current with a reactor should not be less than 25% of the three-phase fault current

11. Find the resistance of a neutral grounding resistor to limit the line-to-ground fault current to 100% of the three-phase fault current.

$$I_{f1\phi} = 3 \cdot I_0 = I_{f3\phi} = 87.48 \angle \text{kA} = 3 \cdot V_{LN} / j(X_1 + X_2 + X_0) + 3 \cdot R_N = 38.106 \text{ kV} / j(0.3388) + 3 \cdot R_N \Omega$$

$$|87.48 \angle 1 \text{kA}| = |38.106 \text{ kV} / j(0.3388) + 3 \cdot R_N \Omega|$$

$$|j(0.3388) + 3 \cdot R_N| = \sqrt{(0.3388)^2 + 9 \cdot (R_N)^2} = 38.106 \text{ kV} / 87.48 \text{ kA} = 0.436 \Omega$$

$$(R_N)^2 = 0.00836 \Omega^2$$

$$R_N = +/- \sqrt{0.00836} = +/- 0.0914 \Omega$$

Take the positive root  $R_N = \mathbf{0.0914 \Omega}$

12. Find the resistance of a neutral grounding resistor to limit the line-to-ground fault current to 400 A.

$$I_{f1\phi} = 3 \cdot I_0 = 0.4 \angle \text{kA}$$

$$|0.4 \angle 1 \text{kA}| = |38.106 \text{ kV} / j(0.3388) + 3 \cdot R_N \Omega|$$

$$|j(0.3388) + 3 \cdot R_N| = \sqrt{(0.3388)^2 + 9 \cdot (R_N)^2} = 38.106 \text{ kV} / 0.4 \text{ kA} = 95.265 \Omega$$

$$(R_N)^2 = 1008.32 \Omega^2$$

$$R_N = +/- \sqrt{1008.32} = +/- 31.75 \Omega$$

Take the positive root  $R_N = \mathbf{31.75 \Omega}$

13. Repeat question 12 applying the expression  $R_N = V_{LN}/I_{f1\phi}$ .

$$R_N = V_{LN}/I_{f1\phi} = 22/\sqrt{3} \text{ kV}/0.4 \text{ kA} = \mathbf{31.75 \Omega}$$

Note: when the resistance value is significant compared with the system impedance, its value can be computed directly as  $R_N = V_{LN}/I_{f1\phi}$ .

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