Grounding the Neutral of Electrical Systems Through Low-Resistance Grounding Resistors: An Application Case

Massimo Mitolo, *Senior Member, IEEE*

***Abstract*—It seems common knowledge that three-phase short-circuit currents are the worst possible scenario for electrical systems. In reality, single-phase ground-fault currents may be significantly more intense than three-phase fault currents. With the occurrence of high single-phase fault currents, severe damage could be caused to the iron cores of electric machines included in the zero-sequence fault loop. The method of neutral low-resistance grounding will be discussed by applying a step-by-step calculation procedure to an actual case, in order to properly size the grounding resistor, thereby limiting the fault current.**

***Index Terms*—Complex numbers, ground-fault current, low-resistance neutral grounding resistor (LRG), positive-, negative-, and zero-sequence impedance, short-circuit current, Thevenin equivalent impedance.**

CONVENTIONS

1) Underlined capital letters designate complex numbers (e.g., $\underline{Z}$).
2) Absolute sign symbol (e.g., $|\underline{Z}|$) designates magnitude of complex numbers.
3) Indexes 0, 1, 2 applied to a complex number (e.g., $\underline{Z1}$) designate, respectively, zero-, positive-, and negative-sequence impedance.
4) Superscript and subscript can be applied to a complex number (e.g., $\underline{Z1}_{XF1}^{7500\ MVA}$) to indicate the reference base (i.e., 7500 MVA) and the component name (i.e., XF1).

I. INTRODUCTION

LOW-RESISTANCE grounding resistors (LRGs) appear to be a preferred choice for power distribution systems where no neutral-connected load are fed through a delta–wye transformer, particularly when motors are directly supplied at transformer bus. Low-resistance grounding is suitable when continued operation of processes is not critical in the event of a fault.

The state of the neutral of the system is of the essence in determining the magnitude of single-phase ground-fault (SLG) currents. This type of fault occurs most frequently, and three-phase faults are usually an evolution of SLGs. The main purpose of grounding with LRG is to limit the maximum fault current to a predetermined value which will not damage any equipment in the power system yet allowing sufficient circulation of fault current to effectively operate protective relays to clear the fault.

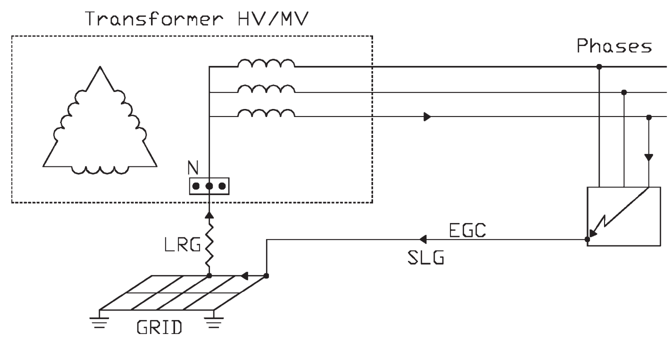

Fig. 1. General fault loop including LRG.

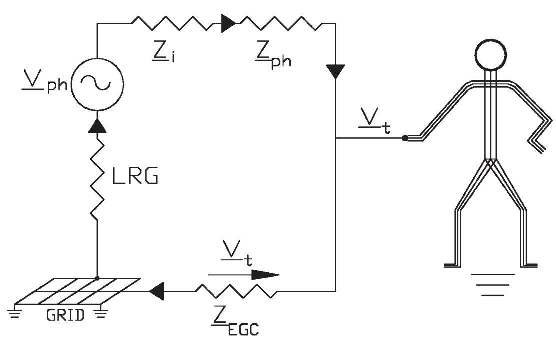

Fig. 2. Touch voltage is proportional to $\underline{Z}_{EGC}$ and not to LRG.

The minimum ground-fault current must be large enough to activate the ground-fault protection device and relay "off" the faulted portion of the system. In other words, current intensity must not be of the same magnitude as the "normal" unbalanced capacitive charging currents, coming from healthy phases, during the regular functioning of the plant. This is necessary in order to avoid nuisance trips of the protection devices.

LRGs are installed as shown in Fig. 1. SLG goes back to the source through the equipment grounding conductors, part of the grounding grid, and the neutral resistance.

It is clear how the actual earth is not included in the fault loop. The presence of the LRG does not pose any particular safety issues. The touch voltage $\underline{V}_t$ for a fault on equipment on the secondary side of the substation (e.g., medium-voltage

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The author is with Chu & Gassman, Middlesex, NJ 08846 USA (e-mail: mmitolo@chugassman.com).

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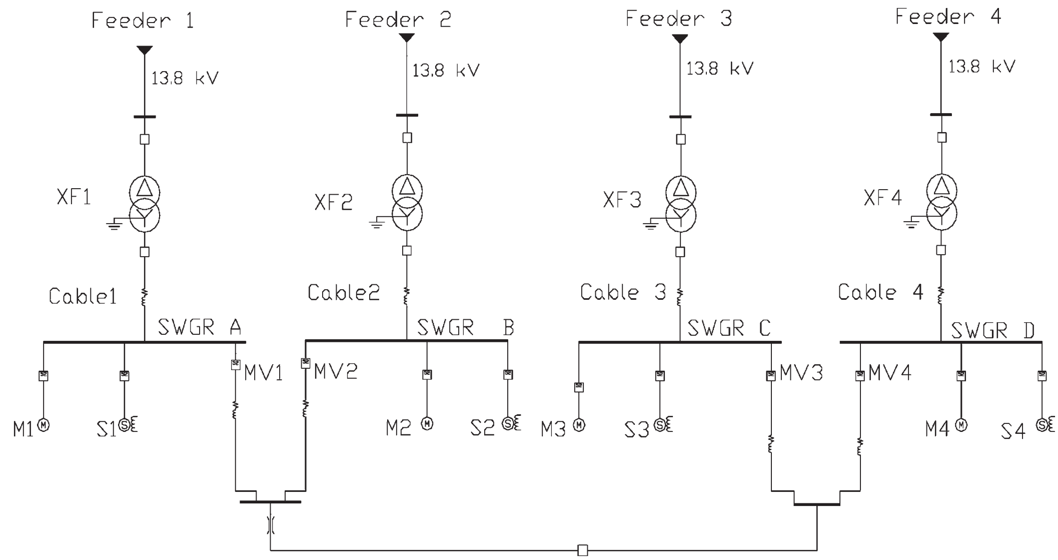

Fig. 3. Oversimplified electrical distribution one-line diagram.

motors), in fact, is proportional to the equipment-grounding-conductor impedance $\underline{Z}_{EGC}$ and not to LRG, as shown in Fig. 2.

In general, $\underline{Z}_{EGC}$ is very small if compared to the neutral grounding resistor (e.g., fraction of ohms) and, thus, so is the touch voltage.

In addition, the medium-voltage loads are, generally, protected by zero-sequence impedance relays, which instantaneously trip, limiting the exposure time to the fault potential.

Reference [2] calls for neutral grounding resistors' size of at least 100 A but considers more usual a range from 200 to 1000 A. In some unusual circumstances, the resistors may even allow a fault current as high as 1200 A. This range of currents safeguards the electric machines' ferromagnetic cores included in the zero-sequence fault loop, by containing both the thermal stress and the ground-resistor copper loss. The rule of thumb proposed by Beeman [3] is to limit the level of ground-fault currents to values from 5% to 20% of the three-phase short-circuit current at the same point of fault.

The ratings of current transformers and type of relays must be chosen accordingly once the SLG's minimum value has been determined.

Neutral grounding resistors are rated in line-to-neutral volts (the line-to-neutral rating of the system), initial current in amperes, maximum temperature rise, and allowable "on" time in seconds. They must be capable of carrying rated current for the allowable "on" time, without exceeding the permissible temperature rise established in [1]. The most common "on" time is 10 s, but also 60 s can be specified.

Grounding resistors, suitable for outdoor service, are customized by manufacturer, according to the electrical designer's specifications.

II. Method of Symmetrical Components

Method of symmetrical components, as described in [4] by its inventor, allows an effective evaluation of the ground-fault currents, once the Thevenin equivalent impedance at the fault point has been calculated. By Thevenin impedance, we mean the impedance as seen at any couple of points of the distribution system once their circuital connection has been opened and the system has been "passivated," i.e., all the voltage generators have been short circuited and all the current generators have been opened. This method utilizes positive-, negative-, and zero-sequence impedances of all the components involved in the fault.

It can be proved that the general expression (1) yields the aforementioned SLG current, involving any of the phases, in amperes

$$\underline{I_{\mathrm{SLG}}} = \underline{3I_0} = \frac{3\underline{E}}{\underline{Z1} + \underline{Z2} + \underline{Z0} + 3\underline{Z_{\mathrm{G}}}} \tag{1}$$

where $\underline{E}$ represents the line-to-neutral voltage phasor in volts; $\underline{Z1}$, $\underline{Z2}$, and $\underline{Z0}$ are, respectively, positive-, negative-, and zero-sequence impedances in ohms per phase; $\underline{Z}_G$ is the limiting impedance of the neutral grounding equipment, if present; and $\underline{I}_0$ is the zero-sequence current.

III. Application Case

Make reference to the oversimplified one-line diagram shown in Fig. 3.

The 4.16-kV system (Fig. 1), constituted by a permanent parallel-of-four solidly grounded main substations, directly supplies four induction motors (M_1, M_2, M_3, and M_4, 2500 hp each) and four synchronous motors (S_1, S_2, S_3, and S_4, 800 hp each). Let us calculate the fault current at Switchgear A, assuming to isolate the Switchgear A from the rest of the distribution system, by opening the breaker MV1.

The electrical utility, upon request of the designer, communicated the following values as positive-, negative-, and zero-sequence impedances at the 13.8-kV property-line supply box

$$\underline{Z1}_{\mathrm{Utility}} = \underline{Z2}_{\mathrm{Utility}} = 0.89 + j1.26 \text{ p.u.} \tag{2}$$

$$\underline{Z0}_{\mathrm{Utility}} = 2.16 + j3.89 \text{ p.u.} \tag{3}$$

Calculation *Base Values* used for the earlier quantities were also communicated by the utility to be $V_{\mathrm{B}} = 13.8$ kV e,