LOW ZERO-SEQUENCE IMPEDANCES ON GENERATORS

Date: August 30, 2000
Revision:0
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INTRODUCTION

When considering the AIC rating of switchboards and other components, it is important to remember the source of the fault current and the nature of that source. In a recent study performed by Power Systems Engineering, a generator-fed switchboard was determined to be underrated due to line-to-ground fault magnitudes. The engineer specifying the equipment had used three-phase fault calculations to select the ratings for the equipment.

DISCUSSION

Good design practice dictates that short circuit calculations be performed to ensure that the AIC rating specified for equipment is higher than the anticipated fault currents. Properly rated equipment is not only a code requirement but can impact the cost of a project. Equipment that is underrated must be replaced, and overrated equipment costs more than properly rated equipment.

Short circuit calculations during the design phase require some assumptions and generalizations, which are validated or corrected when a detailed study is completed. The detailed study is usually completed prior to the review of equipment submittals. Underrated equipment identified in the study can be changed before orders are released or factories prepare the equipment for shipment.

In the case study mentioned in the introduction, the detailed short circuit study was not completed until after the equipment had been installed. Since the engineer had used the positive sequence impedance of the generator for his calculations (or used generator decrement curve data, which is based on the positive sequence impedance), some of the equipment was underrated. As will be discussed below, the lower zero sequence impedance of a generator can result in line-to-ground fault currents that can be as high as one and a half times the phase fault currents.

ANALYSIS

To graphically illustrate the variation in magnitude between line-to-ground faults and phase faults, we will begin by looking at the one-line diagram for a typical installation. This is shown in Figure 1. The service transformers are 2500 kVA and the generators are 1500 kW.

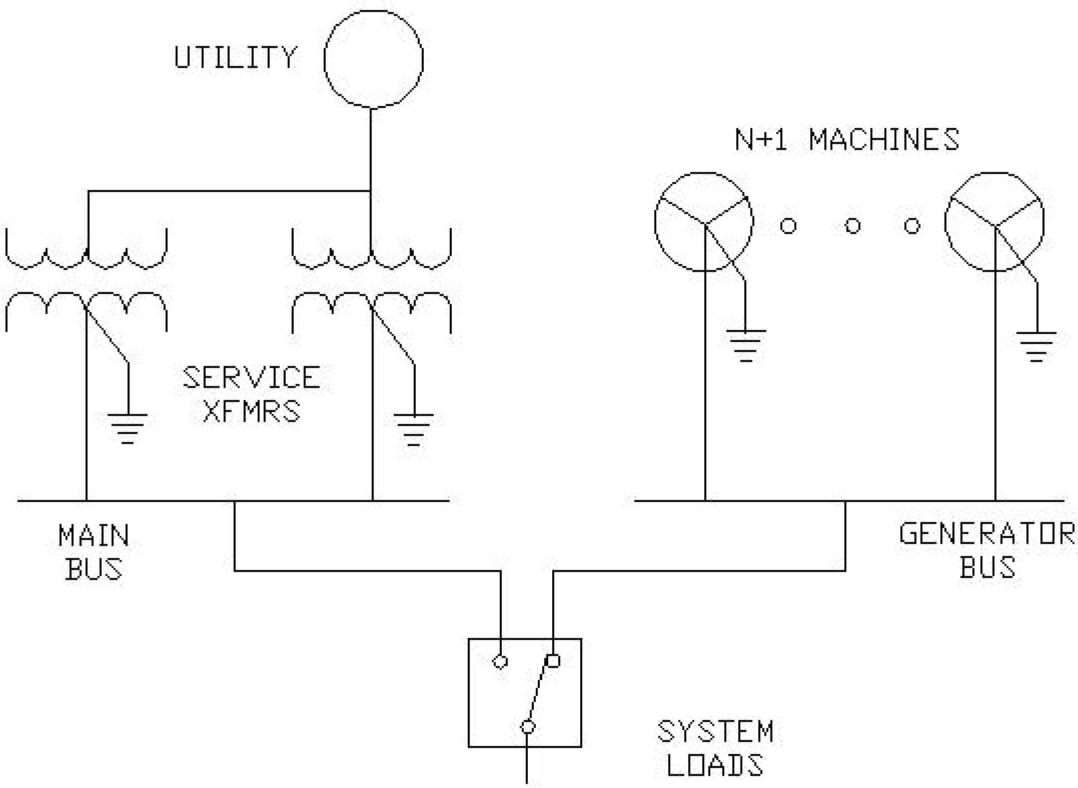

Figure 1 – One line Diagram

Table 1 summarizes the impedance values for the transformers and generators shown. All values are shown in per unit for each phase. The kVA base is 10,000 and the kV base for the primary is 13.8 and 0.48 for the secondary. Note that the values for the generator reactance are subtransient values.

As can be seen by observation, the generator zero-sequence X(0) impedance is somewhat lower than the positive-sequence X(+). This contrasts markedly with the transformers and the utility source impedance, where the zero-sequence impedance X(0) is essentially the same as the positive sequence impedance X(+)..

	GENERATORS AND UTILITY					
	R(0)	R(-)	R(+)	X(0)	X(-)	X(+)
GEN1	7.46E-02	7.46E-02	7.48E-02	3.63E-01	1.40E+00	1.25E+00
GEN2	7.46E-02	7.46E-02	7.48E-02	3.63E-01	1.40E+00	1.25E+00
UTIL 1	8.20E-05	8.20E-05	8.20E-05	4.10E-04	4.10E-04	4.10E-04
UTIL 2	8.20E-05	8.20E-05	8.20E-05	4.10E-04	4.10E-04	4.10E-04

	TRANSFORMERS					
	R(0)	R(-)	R(+)	X(0)	X(-)	X(+)
XFMR1	3.24E-02	3.24E-02	3.24E-02	2.27E-01	2.27E-01	2.27E-01
XFMR2	3.24E-02	3.24E-02	3.24E-02	2.27E-01	2.27E-01	2.27E-01

Table 1 – Source and Transformer Impedance Values

For the purpose of this analysis, we will assume that the utility and generators will never be paralleled. As such, there is no need to consider the implications of the lower generator zero-sequence impedance being in parallel with the utility transformer zero-sequence impedance. (See related paper, "Beware of Hand Calculations for Short Circuit Studies", available at www.powerstudies.com).

To determine the available three-phase fault currents, the pre-fault voltage (usually taken to be the nominal voltage) would be divided by the equivalent positive sequence impedance of the network, as seen from the faulted bus.

Using the impedance values for the conductors shown in Table 2, for a fault at the ATS, the positive sequence network, with the generator as the source, would be as shown in Figure 2. (Since the line-to-ground fault current magnitudes for

	CONDUCTORS					
	R(0)	R(-)	R(+)	X(0)	X(-)	X(+)
GEN1 TO GSB	4.40E-02	1.27E-02	1.27E-02	3.75E-02	1.87E-02	1.87E-02
GEN2 TO GSB	4.40E-02	1.27E-02	1.27E-02	3.75E-02	1.87E-02	1.87E-02
GSB TO ATS 1	3.47E-02	1.16E-02	1.16E-02	3.08E-02	1.41E-02	1.41E-02
XFMR1 SEC TO MSB	2.47E-02	1.62E-03	1.62E-03	2.86E-03	1.39E-03	1.39E-03
XFMR2 SEC TO MSB	2.47E-02	1.62E-03	1.62E-03	2.86E-03	1.39E-03	1.39E-03
MSB TO ATS1	3.47E-02	1.16E-02	1.16E-02	3.08E-02	1.41E-02	1.41E-02

Table 2 – Conductor Impedance Values

the transformer source are the same as the phase fault current magnitudes, we will confine our analysis to the generator source.)

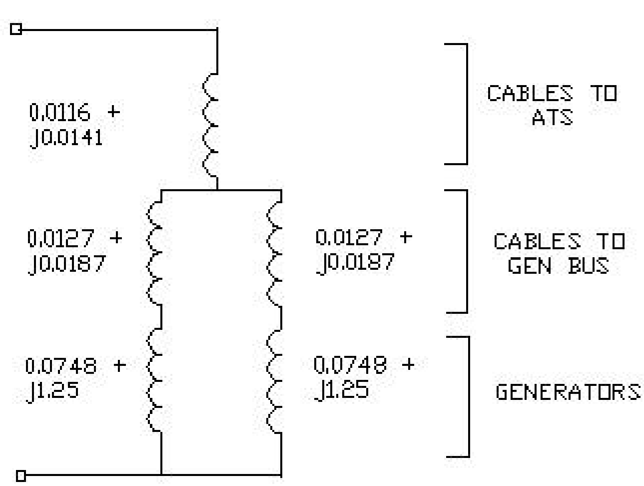

Figure 2 – Positive Sequence Diagram

The equivalent impedance of the positive sequence network would then be the parallel combination of the series combination of generators and their conductors in series with the conductor to the ATS.

Neglecting the impedance of the conductors, neglecting the resistance of the generators, and using only the positive sequence impedance would yield the following results:

$$I_{FAULT,PU} = \frac{V_{LL,NOM,PU}}{Z_{POS-SEQ,PU}\sqrt{3}} = \frac{1\angle 0^o}{\left(\frac{j1.25}{2}\right)\sqrt{3}} \approx 0.924\angle -90^o$$

$$\Rightarrow I_{FAULT} = I_{FAULT,PU} I_{BASE} = I_{FAULT,PU}\left(\frac{S_{BASE}}{V_{BASE}\sqrt{3}}\right) = 0.924\angle -90^o\left(\frac{10{,}000kVA}{480V\sqrt{3}}\right) \approx 11.1kA\angle -90^o$$

We now turn our attention to the available <u>line-to-ground fault currents</u>. For this calculation, the pre-fault voltage would be divided by the equivalent zero-sequence impedance of the network, as seen from the faulted bus. Looking at the impedance seen at the ATS for a line-to-ground fault, the following sequence network is generated.

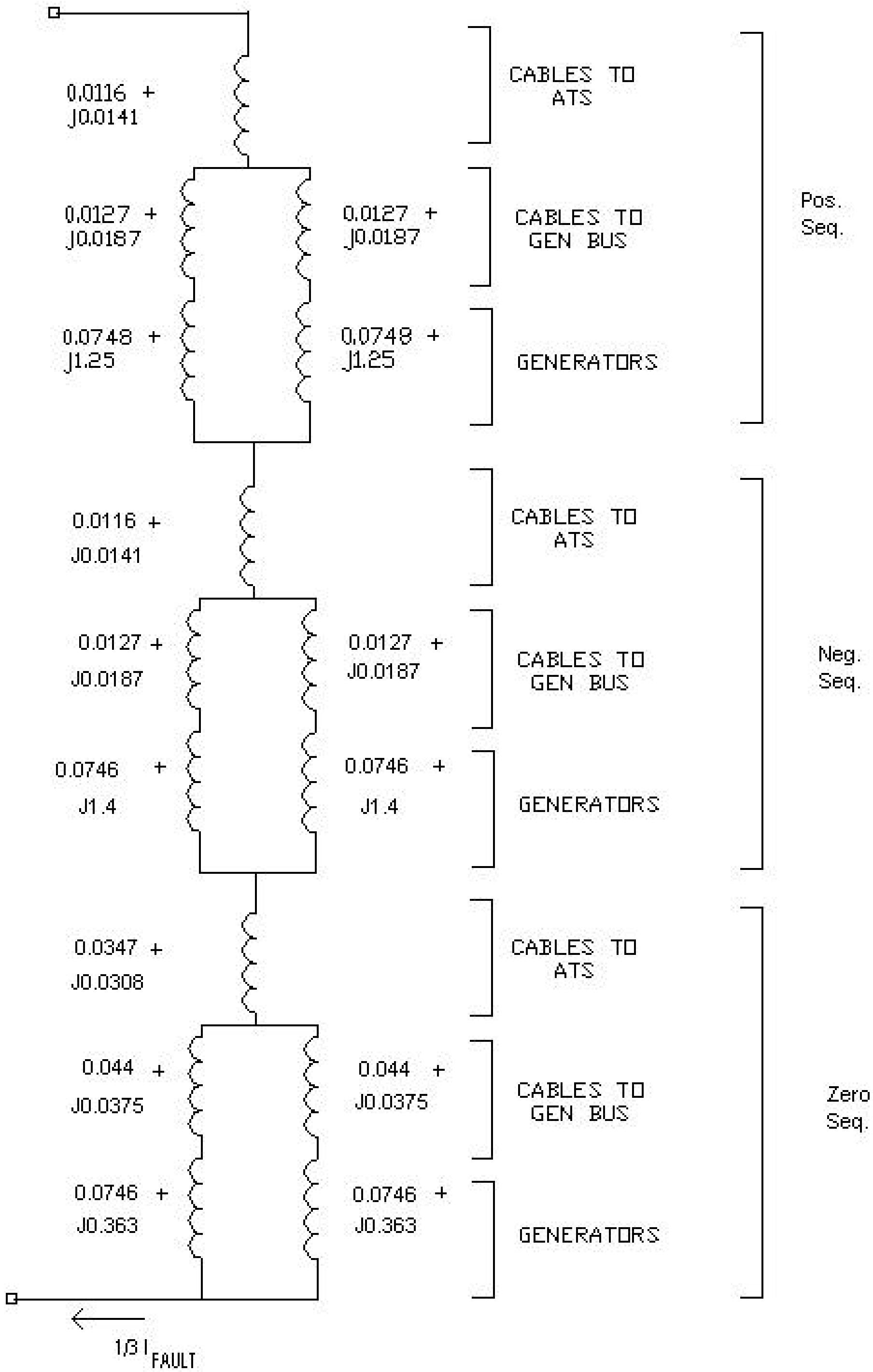

Figure 3 – Sequence Network for Line-to-Ground Faults

As before, we will neglect the impedance of the conductors and the resistance of the generators. This would yield the following results:

$$I_{FAULT,PU} = \frac{V_{LL,NOM,PU}\sqrt{3}}{Z_{SEQ,PU}} = \frac{1\angle 0^o \sqrt{3}}{\left(\frac{j1.25}{2} + \frac{j1.4}{2} + \frac{j0.363}{2}\right)} \approx 1.15\angle -90^o$$

$$\Rightarrow I_{FAULT} = I_{FAULT,PU} I_{BASE} = I_{FAULT,PU}\left(\frac{S_{BASE}}{V_{BASE}\sqrt{3}}\right) = 1.15\angle -90^o \left(\frac{10{,}000kVA}{480V\sqrt{3}}\right) \approx 13.8kA\angle -90^o$$

As can be seen from this calculation, the line-to-ground fault current is almost 125% of the three-phase fault current.

If the model were expanded to include five generators, the three phase fault current would be approximately 27.75 kA and the line-to-ground fault current would be 34.5 kA. If the AIC rating of the equipment to be used were based on the three phase currents, the equipment would be underrated.

Of course, in a case with fewer and/or smaller machines, the disparity between the phase fault currents and the ground fault currents may not be a problem, that is, 125% of the phase fault currents may still be well below the minimum AIC rating of equipment in a given voltage rating. However, it is always important to check before the equipment is approved for manufacture and shipment.

CONCLUSIONS

This simple, two machine model demonstrates the higher magnitudes that can be anticipated for line-to-ground faults when a facility is fed from a generator source. When specifying the AIC rating of equipment, it is important to consider the source of the fault and the nature of that source.

Although simple installations with small machines may not be affected, good design practice would dictate that consideration be given to the calculation of line-to-ground fault currents. Failure to compare the equipment short circuit ratings to the calculated line-to-ground fault currents can cause construction delays and expensive equipment replacement.

ABOUT THE AUTHORS

John Merrell is an electrical engineer at Power Systems Engineering, P.S. Mr. Merrell graduated from the University of Washington with a B.S.E.E. degree in 1999. Prior to graduating, Mr. Merrell worked at ALSTOM ESCA in Bellevue, WA. There he assisted in the development and testing of a graphical user interface for web based power software.

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At Power Systems Engineering, they are responsible for performing short circuit, harmonic, load flow, and protection device coordination studies for industrial, commercial, and utility clients. Based outside of Seattle, Washington since 1986, Power Systems Engineering is an electrical engineering consulting firm specializing in power systems studies, power quality, and commissioning services. Customers include Boeing, Microsoft, University of Washington, General Electric, Siemens, Square D, Cutler-Hammer, and many others. Our web page address is www.powerstudies.com.