International Journal of Current Innovations in Interdisciplinary Scientific Studies

Volume 1, Issue 1, (2017) 01-07

www.ij-ciss.eu

Modelling the influence of generator's location on the value of sustained short circuit current

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Suggested Citation:

Bucatariu, I., Baloi, F., Bere, C. & Jigoria-Oprea, D. (2017). Modelling the influence of generator's location on the value of sustained short circuit current. *International journal of Current innovations in Interdisciplinary Scientific Studies*. *1*(1), 01-07. Available from: www.ij-ciss.eu

Received from August 12, 2017; revised from Ocotber 15, 2017 ; accepted from December 11, 2017.
Selection and peer review under responsibility of Prof. Dr. Huseyin Uzunboylu, Near East University, Cyprus.

Abstract

This research aimed to analyze the influence of generators position in relation to the fault location on the value of sustained short-circuit current. Power management times where solar abound, electricity has been adopted on almost every household appliance and equipment. Supplementes have had to be acquired to handle the deficient power needed at urgent times. With these in mind generators have been adopted as a means to innovatively solve power defiicency issues. Research however, has revealed that voltage stability and power quality of electrical systems depend on proper operation of the Automatic Voltage Regulators (AVR) of generators . In this paper, we used a case study approach to present the method for calculating the sustained short circuit currents, taking into account the mode of representation of the synchronous generators according to the fault location. In general, synchronous generators are equipped with automated voltage controllers and their representation in equivalent circuit of positive sequence system depends on the electrical distance (impedance) between the fault location and terminals of the synchronous generator.

Keywords: short circuit current; synchronous generators; automated voltage regulator; critical distance;

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1. Introduction

In contemporary times, the increased adoption of renewable power has called for the need for more distributed generators (DGs) in the distribution networks. The merger of large-scale distributive generators into the distribution network amends power distribution flow and short-circuit currents and creates the short-circuit current contribution of the distribution generators to influence the power system protection and reclosing. Various methods are used to assess the short-circuit current of induction generators, including real-time simulation tools, dynamic simulation software and physical experiments (Wang, Li and Li 2018). In their research however, they discussed in-depth an on-line fault identification method based on Volterra kernel which uses a stator branch voltage and stator unbalance branch current acquired from the generator as input and output signals of the series model.

The sustained short-circuit currents are used for the checking of electrical equipment at thermal short-circuit current strength (Song, Kim, Choi, Kim, and Choi, 2018). The sustained short-circuit current occurs after the decay of all transient processes in synchronous generators. Its value depends on the excitation current, the excitation system and the saturation of synchronous generator (Li, Yang, Mu, Le Blond, and He, 2018). In the case of the synchronous generators possessing an automatic voltage regulator (AVR), the excitation current is increased during the short circuit. The rise of the excitation current hinges on the electrical distance between the synchronous generator and the fault location. If the synchronous generator is close to the fault location, the voltage at its terminals drops and the automatic voltage regulator commands the rise of the excitation current up to the limit. On the other hand, if the synchronous generator is far from fault location, the voltage at its terminals drops slightly and the automatic voltage regulator commands the increasing of the excitation current which did not reach the limit value [1]. In special literature, the position of the synchronous generator in relation to the fault location is determined by the ratio between the initial three phase short circuit current and the rated current of the generator (Jiang, Feng, Zhang, Zhang, and Zhang, 2018). The synchronous generator is considered nearby short circuit if the ratio is greater than or equal with 2. The sustained short-circuit currents are calculated by multiplying the rated current of the generator by a factor that depends on the ratio between the initial three phase short circuit current and the rated current of the generator, the excitation and the type of synchronous generator (Boutsika, and Papathanassiou , 2008).

The aim of this study is to present the method of calculation of the sustained short-circuit currents using the power sources electromotive forces and the reactance. The findings reveal the mode of representation of the synchronous generator in the equivalent circuit of positive sequence system according to the presence of the automatic voltage regulator. In addition, in order to evidence the influence of the AVR and of the generator position in relation to the fault location on calculation of sustained short-circuit current, a study case is adopted.

2. Representation of the synchronous generator for the calculation of the sustained short-circuit current

This section initially begins by displaying the computation of the sustained short-circuit current, the formulae identification and the revealing information of the generator's location to the fault locations using the case study approach. In the equivalent circuit, for the calculation of sustained short-circuit current, the mode of representation of the synchronous generator is different depending on the presence of the AVR. The generator without AVR is represented in the equivalent circuit by the excitation electromotive force E_{ef} for the load regime before the short-circuit and synchronous generator reactance X_d [4], [5], [6].

The excitation electromotive force E_{ef} is calculated using the equation (1):

$$E_{ef} = \sqrt{(U_f \cos\varphi)^2 + (IX_d + U_f \sin\varphi)^2} \tag{1}$$

where: U_f is the voltage at terminals of generator in load regime; I – the load current before the short-circuit; φ – the phase angle between U_f and I.

If the generator is with AVR, then its representation in the equivalent circuit for positive sequence system, depends on the electrical distance (reactance) between the generator and the fault location. Prior to the innovation of the three phases short-circuit, if the generator is far from fault location (X_{ext} is high) and the voltage at the generator terminals is equal to the rated voltage, then due to the short circuit, the voltage at terminals of generator will decrease slightly. AVR turns into operation and gives command of the excitation system to increase the excitation current, and the voltage at terminals of generator returns at the rated voltage. In this case, the operating mode of the synchronous generator during the steady state short circuit is called the operating mode with rated voltage to the terminals. The generator is represented in the equivalent circuit for positive sequence system by an electromotive force equal to the rated phase voltage of the generator. The self-reactance is insignificant.

If the generator is close to the fault location (X_{ext} is small), at the appearance of the three phases short-circuit, the voltage to the terminals of the generator drops and the AVR gives command of the excitation system to increase the excitation current up to the limit, but the voltage to the generator terminals do not return at the rated voltage. In this case, the operating mode of the synchronous generator during the steady state short circuit is called the operating mode with excitation current limit. The generator is represented, in the equivalent circuit for positive sequence system, by the maximum electromotive force of excitation E_{ep} and synchronous reactance.

The results of the study reveals that there is an electrical distance discovered (measured by X_{ext}), which occurs when the three phases short-circuit and the automatic voltage regulator operates and gives command to the excitation system to increase the excitation current up to the limit value. This will inadvertently cause the voltage at the generator's terminals to be moved to its rated value. This electrical distance is called "critical distance". If the short circuit occurs even at the critical distance, then the generator delivers a current called critical current (I_{kcr}). Further information can be seen from Figure 1 below, which establishes the critical reactance and the critical current.

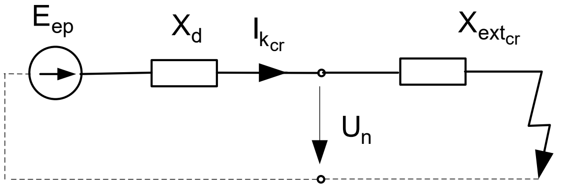

Figure 1. Equivalent circuit diagram to the determining of the critical reactance and the critical current

The critical reactance (X_{cr}) and the critical current (I_{kcr}) can be calculated from relationships:

$$X_{cr} = X_{ext_{cr}} = \frac{U_n}{E_{ep} - U_n} \cdot X_d \tag{2}$$

$$I_{k_{cr}} = \frac{E_{ep} - U_n}{X_d} \tag{3}$$

where: E_{ep} is electromotive force of ceiling excitation per phase; U_n - rated phase voltage; X_d - synchronous reactance.

To determine the position, synchronous generator in relation to the fault location is compared with the reactance measured between the generator terminals and the place of short circuit (X_{ext}) with the critical reactance: for near to generator short circuit $X_{ext}>X_{cr}$ and for far from generator short-circuit $X_{ext}<X_{cr}$,. On the contrary, the research of Wang, Li and Li (2018) using Volterra series model, revealed that their third method improved the accuracy such that after the inter-turn short circuit fault occurs, the absolute average of first-order kernel and third-order rises. The third-order kernel rises with the growth of the short circuit ratio. When the inter-turn short circuit fault ratio is low, they opined that it could be diagnosed by third-order kernel. Their findings also found that the three-dimensional surface of the second-order kernel has more positive peaks in normal situation. Their study rather recommended that when inter-turn short circuit fault occurs, there are more negative peaks on the surface. Therefore, this method bolsters the accuracy of fault diagnosis and has strong anti-interference ability and good robustness.

3. Computation of the sustained short-circuit current

In order to determine the generator position in relation to the fault location, the method of critical distance can be used only in circuit diagrams with one synchronous generator. This method is not used in circuit diagrams with more generators because it is difficult to determine the reactance between the generator terminals and the fault location.

In the following, the calculation method of the sustained short circuit current in circuit diagrams with more generators having automatic voltage regulators is described. For each synchronous generator from the circuit diagram, the critical current is calculated and a hypothesis is proposed about its position in relation to fault location. In the equivalent circuit for positive sequence system, each generator is inserted in accordance with the adopted hypothesis. The sustained short circuit full current is calculated and the current delivered by each generator to fault location is also calculated. It compares the current delivered by each generator to fault location with the critical current of the respective generator. The generator is considered nearby the short circuit location if the current delivered by generator is higher than the critical current ($I_K>I_{Kcr}$) and if the current delivered by the generator is lower than the critical current ($I_K<I_{Kcr}$), then the generator is far from short circuit. If the results of the comparisons between the delivered sustained short circuit currents generators and their critical current show that assumptions adopted are not correct for some generators, then the calculations are repeated with initial assumption changed accordingly. The calculations end when all assumptions adopted are correct. The sustained short circuit current at the fault location and currents on the sides of the circuit diagram are those resulted from the calculation that check all the assumptions adopted.

4. Analysis of case and findings

The illustration of the calculation procedure of sustained short-circuit current is presented in the network diagram from Figure 2. The influence of the fault location on the representation of synchronous generator in the equivalent circuit can be analyzed considering three phase short circuit in the locations *k1* and *k2*. In order to simplify the calculation, the resistances of all the equipment from the diagram network are neglected. Consumers CG1 and CG2 are considered complex consumers that contain motors and static loads.

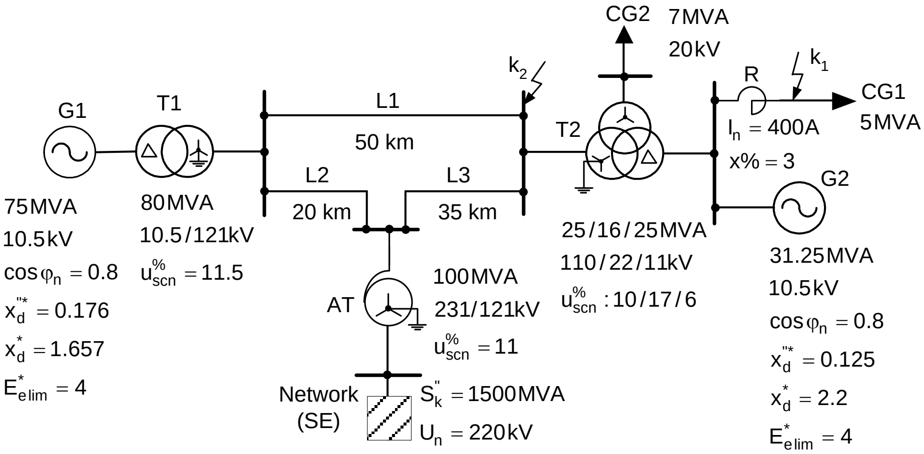

Figure 2. Diagram network for the study case

In the equivalent circuit for calculation of sustained short-circuit current are inserted the equipment, as follows: the complex consumer by the reactance $X=1.2 \cdot Z_n$, the network (SE) by electromotive voltage ($E_{SF}=c \cdot U_n/\sqrt{3}$) and the reactance ($X_{SF}=c \cdot U_n^2/S_k''$), the electrical line, transformer and the choke coil by positive sequence reactance. The representation of synchronous generator in the equivalent circuit depends on what is considered near or far from the short circuit location. The generator G1 is supposed near to the short circuit and is introduced in the equivalent circuit by the maximum electromotive force of excitation ($E_{epf}= E_{ep}^* \cdot U_n/\sqrt{3}$) and the synchronous reactance. The generator G2 is considered far from short circuit and in the equivalent circuit is introduced by an electromotive force equal to rated phase voltage. The parameters of all the equipment are calculated in relative units, by relation to a base system ($S_b=100$ *MVA*). In Figure 3 is shown the equivalent circuit for the calculation of sustained short circuit current at three phase short circuit in *k1*.

The critical current value for each generator is calculated using relationship (3), thus: $I_{kcrG1}=7.47$ *kA* and $I_{kcrG2}=2.34$ *kA*.

After the calculation, the values of sustained short circuit total current in the case of fault in *k1* ($I_{k1}=7.43$ *kA*) and the contribution of the two generators ($I_{k1G1}=2.23$ *kA* and $I_{k1G2}=2.83$ *kA*) are obtained. If the critical currents of the two generators with their delivered currents are compared, is observed that $I_{k1G1}<I_{kcrG1}$ and $I_{k1G2}>I_{kcrG2}$, it follows that the assumptions made about the position of the two generators in regard to the short-circuit location are correctly.

If the short circuit occurs in *k2* and remain the same assumptions about the position of the two generators in regard to the short-circuit location (Figure 4), the following results are obtained: the total current in the case of fault in *k2* ($I_{k2}=3.85$ *kA*) and the contribution of the two generators ($I_{k2G1}=21.32$ *kA* and $I_{k2G2}=2.84$ *kA*). It is observed that the delivered current of generator G1 at the fault location is greater than its critical current. The hypothesis that G1 is near the short circuit location is false.

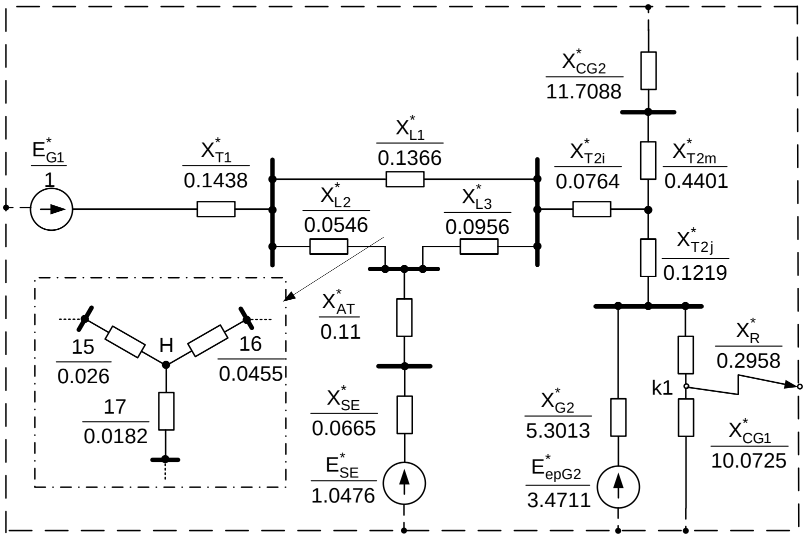

Figure 3. Equivalent circuit for the calculation of sustained short circuit current in k1

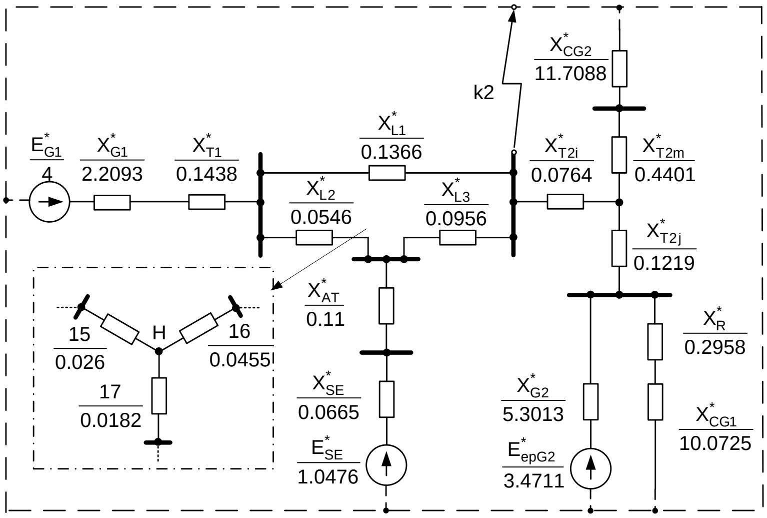

Figure 4. Equivalent circuit for the calculation of sustained short circuit current in k2

In these conditions the generator G1 is considered near the short circuit and is inserted in the equivalent circuit by the maximum electromotive force of excitation and the synchronous reactance (Figure 4). Whereas this change in the equivalent circuit and after the calculations, the following results are obtained: the total current at fault in *k2* ($I_{k2}=2.96\ kA$) and the contribution of the two generators ($I_{k2G1}=8.65\ kA$ and $I_{k2G2}=2.84\ kA$). In this case if the critical currents of the two generators are compared with their delivered currents, is observed that $I_{k1G1}>I_{kcrG1}$ and $I_{k1G2}>I_{kcrG2}$, it follows that both generators are near the short circuit location.

5. Conclusions

This paper was based on a case study to reveal the method for computing sustained short-circuit currents by equipping synchronous generators with automated voltage controllers. The method of calculation of the sustained short-circuit currents considering the representation of generator in the equivalent circuit diagram in positive phase sequence through the electromotive force and the synchronous reactance allows the determination of both the total current at the short circuit location and the partial currents flowing through the longitudinal branches of the system. The findings reveal that there is an electrical distance discovered (measured by X_{ext}), which occurs when the three phases short-circuit, and the automatic voltage regulator operates and gives command to the excitation system to increase the excitation current up to the limit value. This method helps students understand the AVR roll and the influence of the synchronous generators position in relation to the RMS value of short-circuit current at the fault location. This is an innovation in the method of computing sustained short-circuit currents. The research therefore recommends further study from other researchers in this regard

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