RESEARCH ARTICLE

Modeling Features of a Single Phase-to-Earth Fault in a Medium Voltage Overhead Transmission Line

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Received: 16-09-2020 **Accepted:** 17-10-2020 **Available online:** 31-12-2020

ABSTRACT

The modeling and calculation of a single phase-to-earth fault of 6 to 35 kV have specific features when compared with circuits with higher nominal voltages. In this paper, a mathematical analysis and modeling of a 3-phase overhead transmission line with distributed parameters consisting of several nominal T-shaped, 3-phase links with concentrated parameters replaced by 1 nominal T-shaped link were carried out. Further analysis showed that not accounting for the distributed nature of the line parameters did not cause significant errors in the assessment of the maximum overvoltage in the arc suppression in single phase-to-earth faults, and that sufficient accuracy insures the representation of the line by only 1 nominal T-shaped, 3-phase link. Such a modeling technique makes it impossible to identify the location of single-phase faults, which is the property of higher harmonic amplification of individual frequencies. Chain equivalent schemas with constant parameters are valid for a single frequency, thereby providing an opportunity to study the nature of the wave process by the discrete selection of parameters. Next in the mathematical representation, we consider the overhead transmission lines as lines with distributed parameters.

Keywords: Power system, Single phase-to-earth fault, Overhead transmission lines, Matlab Simpower Simulink

1. INTRODUCTION

Fault is simply defined as a number of undesirable but unavoidable incidents that can temporarily disturb the stable condition of the power system, which occurs when the insulation of the system fails at any point. Moreover, if a conducting object comes into contact with a bare power conductor, a short circuit, or fault, is said to have occurred. Single phase-to-earth faults are the most frequent failures in medium and high voltage systems. The values of the currents and of the temporary overvoltage with the power frequency in the case of a single pole earth fault depend on the neutral point treatment, earth capacitances of the overhead lines or cables connected to the network, voltage level, the value of the fault resistance, and the distance between the supply busbars and the fault location (Komen et al., 2007).

Access this article online

DOI: 10.25079/ukhjse.v4n2y2020.pp127-138 **E-ISSN:** 2520-7792

Mahanty and Gupta (2007) created a methodology for fault analysis utilizing current samples with the help of fuzzy logic. In this technique, only 1 end of the 3-phase current samples was considered to have achieved the fault classification (Mahanty and Dutta, 2007). Shashi et al. (2012) developed a scheme to detect the line-to-ground fault by using fuzzy logic. The developed method requires current samples after the fault at 1 side of the transmission line only (Shashi et al., 2012). Ashok et al. (2013) proposed discrete wavelet transform (DWT) for classification of faults in transmission systems. A solution for the protection of a 3-terminal transmission system using DWT for fault classification was presented by

Dileep Kumar and Raghunath Sagar. Simulation studies are carried out in power systems computer-aided design software in combination with electromagnetic transients including direct current on 400 kV, 300 km transmission line models designed for different types of single phase-to-ground faults (Dileep and Raghunath, 2014). Prasad et al. (2015) have implemented a new approach using 2 fuzzy rule systems, whereas Prasad and Belwin Edward (2016) implemented a new method using currents at 1 end of the overhead line with the help of DWT (Prasad and Belwin, 2016). Muhammad (2016) located different faults in high voltage transmission lines in the Kurdistan power system, which was proposed and carried out in order to determine which artificial neural network (ANN) fault locator structure delivered the best performance (Aree, 2016). Abdulrahman (2019) presented fault location recognition in the Kurdistan Regional power transmission system using ANN.

This paper proposes a mathematical model for a single phase-to-ground fault using a 3-phase overhead transmission line model with distributed parameters. For the network under consideration, the following factors had to be taken into account. First, the level of the current of the sustained metallic single phase-to-ground fault in all cases had to be taken into account with the exception of circuits with low ohmic grounded neutrals with lower rated currents. Second, the network depends significantly on the total length of the electrical circuit connected to the common busbar of the supply center. Third, even with a metallic ground fault, it cannot be calculated according to the usual technical handbook data because the technical literature only provides the total capacitive currents or conductance of overhead transmission lines and cables. In high ohmic neutral grounding, the value of the resister does not depend on the mode of operation and is chosen on the basis of the condition of the extinguishing arc for the half period of the industrial frequency.

In order to describe the behavior of the network during single phase-to-earth faults, a simulation model was created using MATLAB SimPowerSystem software. SimPowerSystems provides component libraries and analysis tools for modeling and simulating electrical power systems (Ćućić et al., 2008).

2. MATHEMATICAL MODELS

Consider an electrical sub-circuit in which a single phase-to-ground fault occurred through a resistance R_g as shown in Fig. 1, where capacitor C is shown between phase conductors and the ground and R_N indicates the neutral grounding resistance.

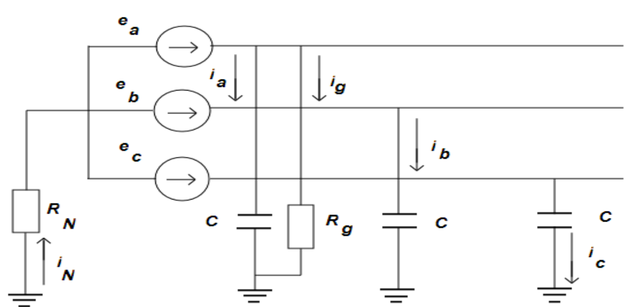

Figure 1. Equivalent circuit for an overhead transmission line with a single phase-ground fault

The differential equation for the voltage balance via capacitance C for 1 of the phases is:

$$e_a - \frac{1}{C}\int_0^t i_a dt = R_N i_N \quad (1)$$

In order to get rid of the integral, a derivative of the left and right side of the equation is used. Using this technique on the remaining 2 phases, as well as writing down the voltage balance equation for the resistance circuit of the single-phase ground fault R_g, we get:

$$\frac{de_a}{dt} - \frac{i_a}{C} = R_N \frac{di_N}{dt}, \quad (2)$$

$$\frac{de_b}{dt} - \frac{i_b}{C} = R_N \frac{di_N}{dt}, \quad (3)$$

$$\frac{de_c}{dt} - \frac{i_c}{C} = R_N \frac{di_N}{dt}, \quad (4)$$

$$e_a - R_g i_g = R_N i_N, \quad (5)$$

$$i_a + i_b + i_c + i_g = i_N \quad (6)$$

Adding together the left-hand side and right-hand side of equations (2) to (4) and taking into account that

$$e_a + e_b + e_c = 0 \quad (7)$$

we obtain a new system of 2 equations:

$$(p_t 3R_N + {}^1/_C) i_N - ({}^1/_C) i_g = 0 \quad (8)$$

where $p_t = {}^d/_{dt}$

The characteristic equation of the system of equations (5) and (8) will be:

$$p3R_g R_N C + R_g + R_N = 0$$

From here we have:

$$p = -\frac{R_g + R_N}{3R_g R_N C}$$

That is, the current of the single phase-to-ground fault contains a periodic component of:

$$i_\tau = I_\tau e^{-t/T_a} \quad (9)$$

where,

$$T_a = \frac{3R_g R_n C}{R_g + R_N} \quad (10)$$

According to equation (10), the lower the time constant T_a, the lower the resistance of the ground arc fault R_g. It is therefore believed that $R_g \rightarrow \infty$, which increases the time constant to its maximum value and, accordingly, aggravate the condition of the extinguishing of the arc. If it is just the case that should be considered as a calculated, then,

$$T_a = \frac{3R_N C}{1+{R_N}/{R_g}} = 3R_N C \quad (11)$$

If in expression (9), $T_a = {t}/{3}$ is inserted, then for the time t the current i_τ drops to less than 5% of the initial value, which guarantees the extinguishing of the arc. At the same time, there is a requirement that such an extinguishing should occur during the first half period of the main frequency, which means the first current transition through zero, therefore implying $t = 0.01s$. Thus, we have $T_a = {0.01}/{3}\, s$. Based on equation (11), we obtain a calculated expression for determining the required value of the ground resister:

$$R_N = \frac{T_a}{3C} = \frac{0{,}01}{3\times3\times C} = \frac{1}{900C} \quad (12)$$

It is important that in formula (12) C is the phase capacitance of the networks line in relation to the ground rather than the total phase capacitance. Fig. 2 gives the necessary explanation of how to distinguish between the phase-to-phase conductance between conductors and the phase conductance of the conductors in relation to the ground.

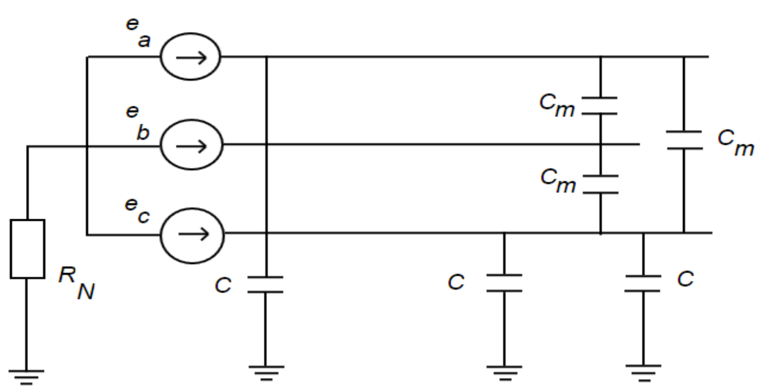

Figure 2. Capacitive conductance of the power line

Fig. 2 shows the capacitive conductance between conductors and the ground (C) and between the phase conductors (C_m). The latter is connected in delta. We transform it into star in Fig. 3.

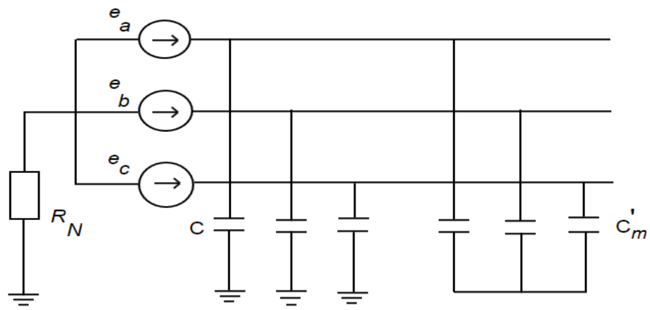

Figure 3. Conversion of the capacitive conductance of the power line

It is obvious that in the symmetrical load mode the neutral points of capacitive star C and capacitive star C'_m have equal potentials, and, accordingly, the line possesses a total phase capacitance of $C_{ph} = C + C'_m$, which is cited in technical catalogues as per 1 km or per 100 km lines. In the single phase-to-ground mode, the capacitance star C'_m does not affect the level of the fault current because its neutral is isolated from the ground. Therefore, phase-to-phase capacitances should not be included in the calculations. However, the reference literature does not provide the necessary data for the capacitance of conductors relative to the ground. Certain features are provided by the Simulink software product in which the geometric size of the supports and conductors can calculate the capacitance of the overhead transmission lines in relation to the ground. Approximate values can be calculated based on the recommendations made by F.A lekhachev who proposed to use the following ratios between capacitances in relation to the earth and between phases:

$$\text{for cables: } \frac{C_m}{C} = \frac{1}{3} \text{ and for overhead transmission lines: } \frac{C_m}{C} = \frac{1}{5} \qquad (13)$$

When converting the delta to the star, we obtain $C'_m = 3C_m$. Therefore, the total capacity of the line equal to:

$$C_0 = C + C'_m = C + 3C_m$$

Here, taking into account equation (13) we obtain:

$$C_0 = C + 3C_m = C + \frac{3}{3}C = 2C \text{ for cables, and}$$

$$\text{for overhead transmission lines: } C_0 = C + 3C_m = C + \frac{3}{5}C = \frac{8}{5}C \qquad (14)$$

When using the reference (catalog) values for the total capacitance C_0, we can determine the desired capacitance of phase conductors in relation to the ground

For cables, $C = \frac{1}{2}C_0$; (15)

For overhead transmission lines, $C = \frac{5}{8}C_0$. (16)

The ratios (15) and (16) are extremely important because they clearly show how different the capacity of the line relative to the ground is from its total (full) capacity. These same expressions should serve as a basis for calculating the ground fault current I_g when examining a designed electrical network project according to the permissible level of ground fault current. For networks of 6 kV, this current should not exceed 30A; for 10 kV networks, it should not exceed 20A; and for 35 kV networks, it should not exceed 5A. The ground fault current should be calculated by taking into account the capacitance values of formulas (15) and (16) as follows:

$$I_g = \sqrt{3}U_{rated}\sum_{n=1}^{N}\omega C_{0n} l_n \quad (17)$$

where N is the number of lines supplied by the common bus, l_n is the length of the nth line, and C_{0n} is the total phase capacitance related to the ground for the nth line.

When a resistive ground is installed, the fault current to the ground I_g in a steady state mode is determined by the total capacity of the network related to the ground C, transformer parameters R_t and X_T, and the resister R_N and will be calculated using the following formula:

$$I_g = 3I_o = U_{ph}\left\{j3\omega C + \frac{3}{3R_T + jX_T}\right\} \quad (18)$$

3. SIMULATION AND RESULTS

The system modeling is shown in Fig. 4. The simulation model consists of a 3-phase, 6 kV source, network transformer, and overhead transmission.

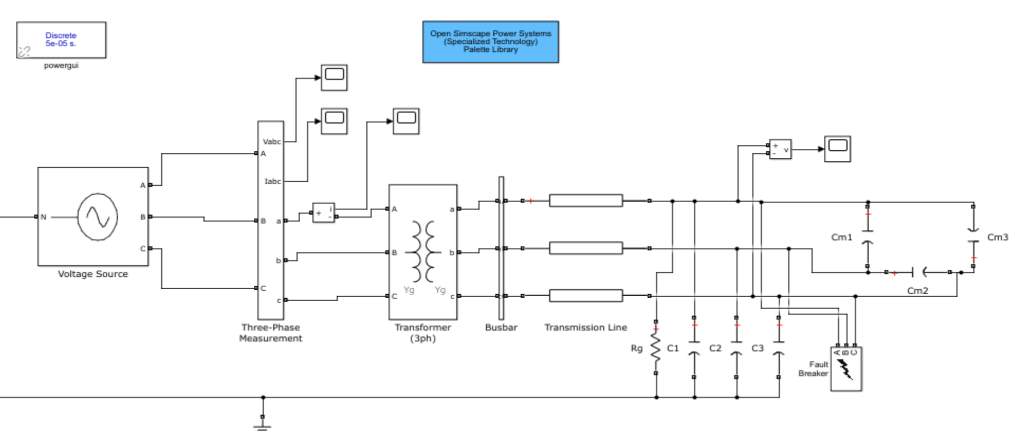

Figure 4. Simulation diagram of the proposed system model

Table 1 shows all the simulation parameters used for this work. The resistance (R_g) and each capacitor (C) are connected to the ground. The 3-phase source is connected in Y with a grounded neutral resistance (R_n). This block generates a 3-phase sinusoidal 6 kV line voltage. A single pole fault with earth is represented as a 1-phase circuit breaker connected to the ground.

Table 1: Simulation Parameters

Simulation component	Parameter value
Three-phase source	Vrms=6kV/√3, f=50Hz.
Three-phase transformer	R=0.002pu, L=0.08pu.
Transmission line	D=100km, r=0.01273pu, L=0.9337e-3pu, c= 12.74e-9pu.
Fault breaker	Switching times=[1/50 5/50] se, Ron=0.001Ω, Rg=1Ω, Rs=inf, Cs=inf.

Fig. 5 and Fig. 6 show the balanced 3-phase root mean square (rms) sine wave voltages and currents under normal and steady-state condition, respectively.

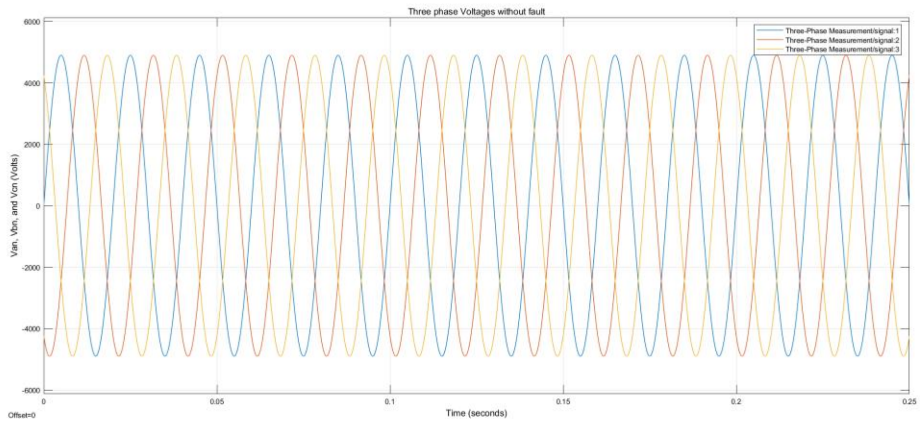

Figure 5. Three-phase voltages without fault

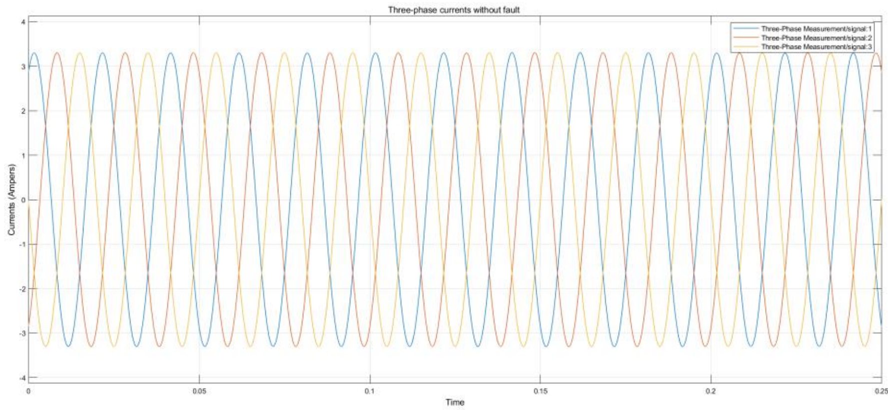

Figure 6. Three-phase currents without fault

Fig. 7 shows all phase voltages at a single phase A-to-ground fault. It shows that phase voltage A drops down to approximately zero voltage after the fault has been cleared and all phase voltages return back to the rated value.

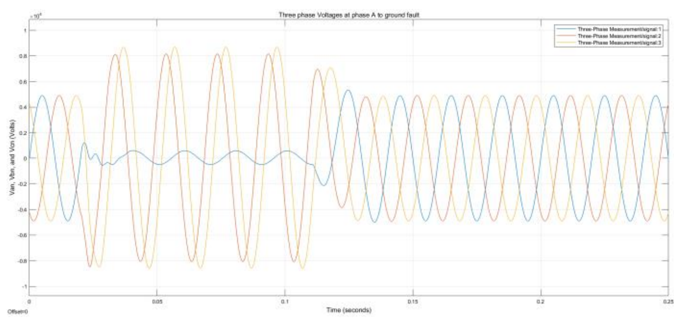

Figure 7. Three-phase voltages with occurrence of a phase A to ground fault

Fig. 8 to Fig. 11 show the response of all phase currents at a single phase A-to-ground fault in various cases, which shows the effect of disconnecting and connecting capacitance, neutral resistance, and ground fault resistance in the system. Figure shows the change in the time constant T_a with increase in the ground resistance R_g. It is seen that the time constant of the system is 5 ms and it will be constant even if R_g is increased above 500 ohms.

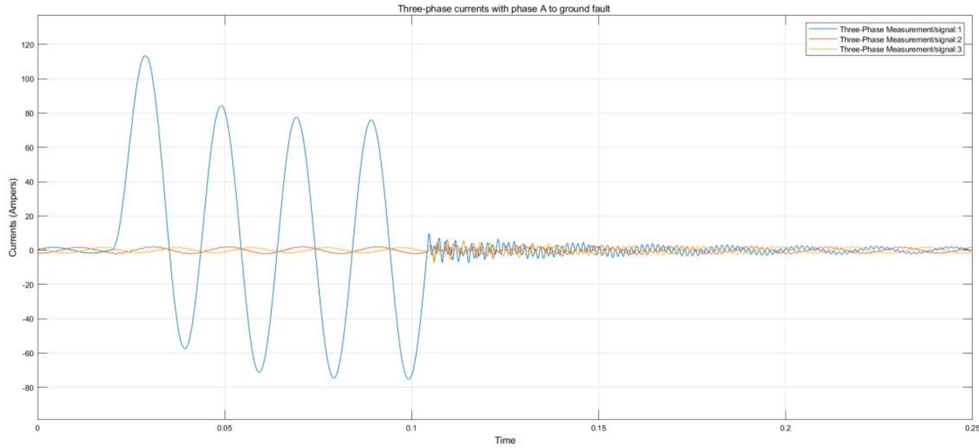

Figure 8. Three-phase current when a phase A-to-ground fault occurs without connecting C, Rn, and Rg.

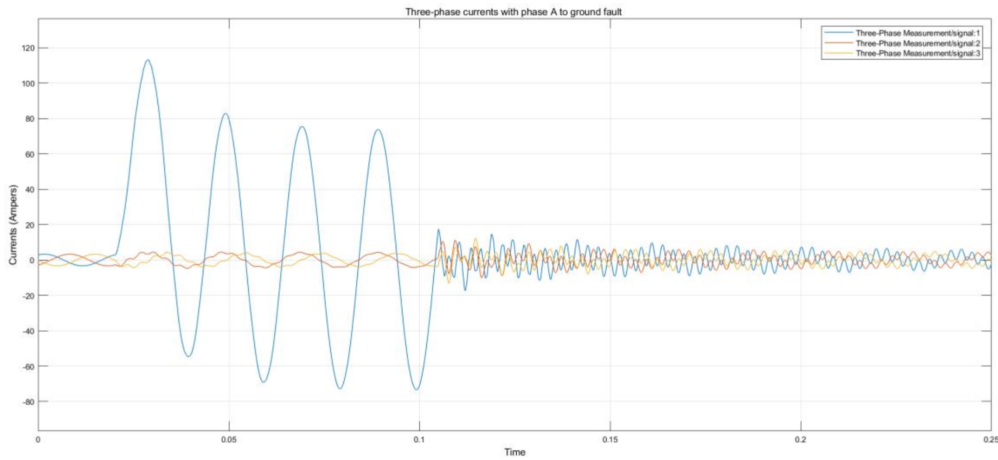

Figure 9. Three-phase current when a phase A-to-ground fault occurs with connecting C but without connecting Rn and Rg.

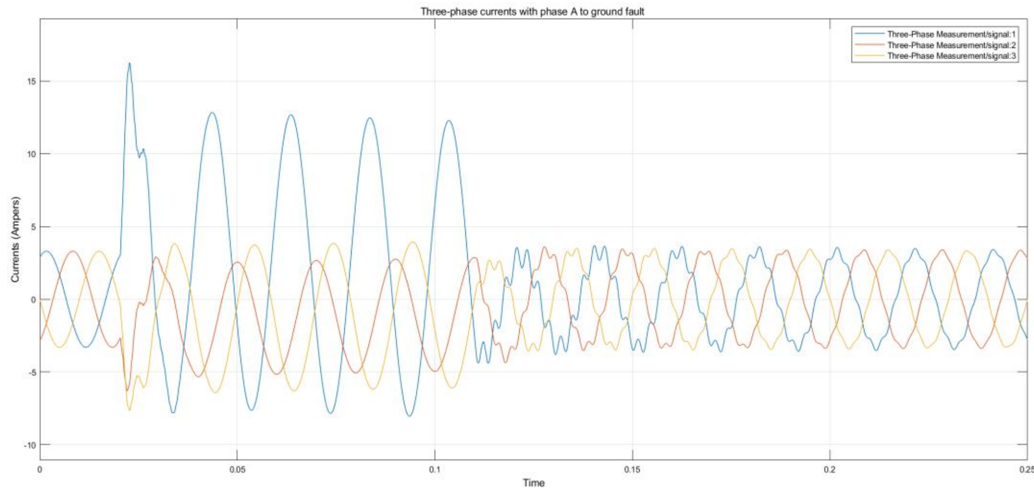

Figure 10. Three-phase current when a phase A-to-ground fault occurs with connecting C and Rn but without connecting Rg.

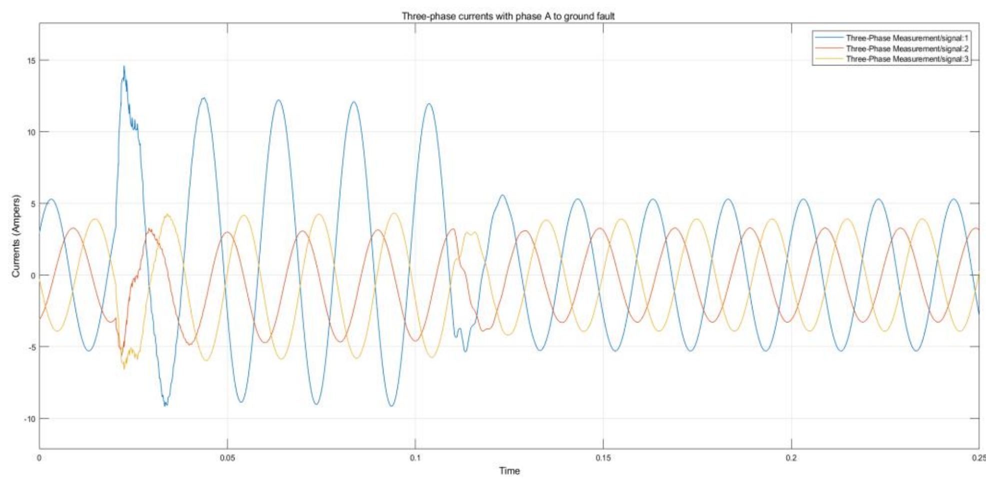

Figure 11. Three-phase current when a phase A-to-ground fault occurs with connecting C, Rn, and Rg.

The asymmetric fault currents obtained from the simulation were compared for each case of disconnecting C, R_n, and R_g and connecting C, R_n, and R_g. It simulated and analyzed the harmonic of the current in phase A by using fast Fourier transform analysis as shown in Fig. 12. It can be seen that when connecting C, R_n, and R_g, the total harmonic distortion (THD) became very allowable according to all THD power system standards, and it was reduced from 20.47% to 0.04%.

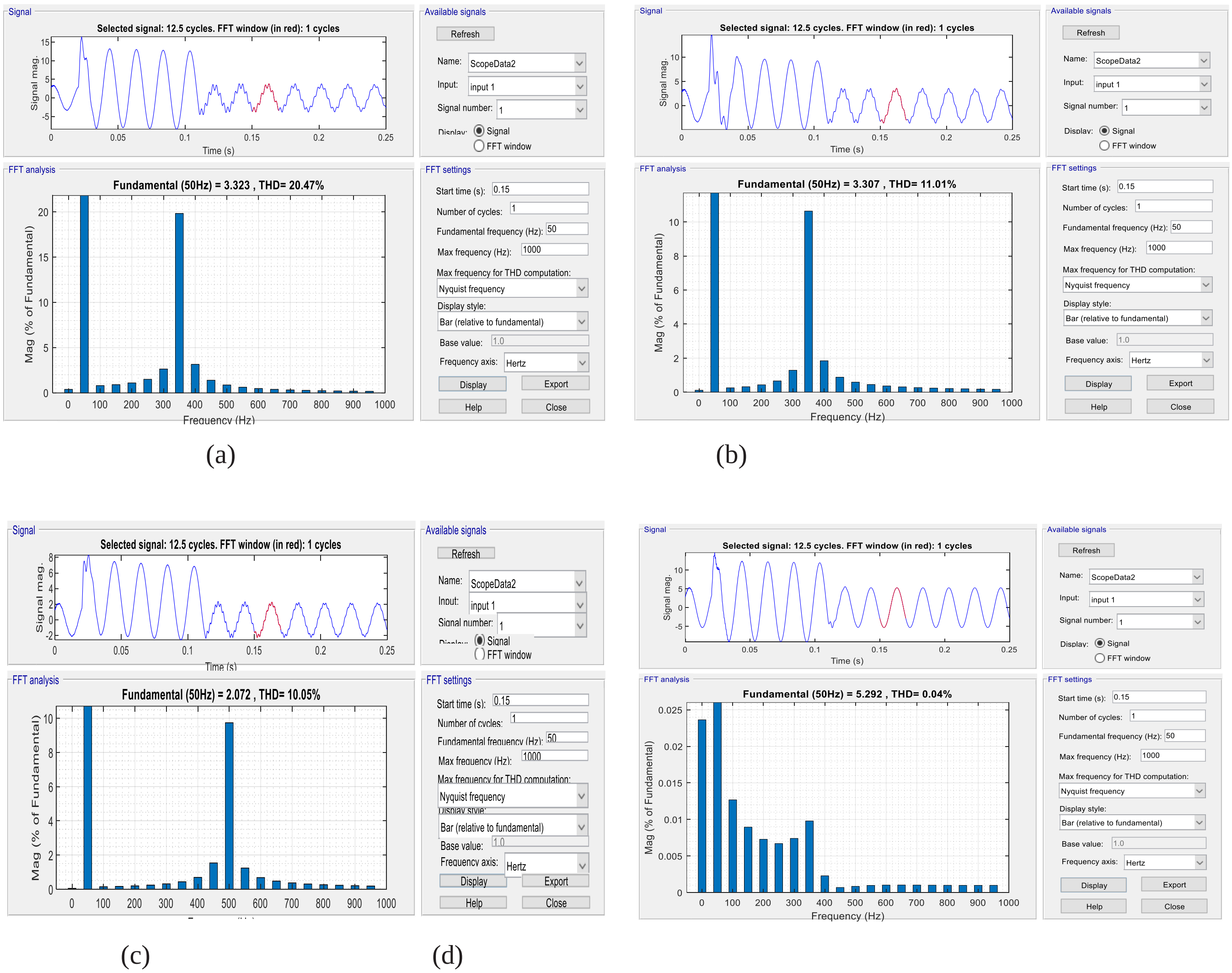

Figure 12. Harmonic analysis of phase current A when a phase A-to-ground fault occur (**a**) without connecting C, R_n, and R_g, (**b**) when connecting C, but R_n and R_g are not connected, (**c**) when connecting C and R_n, but R_g is not connected, and (**d**) when connecting C, R_n, and R_g

4. CONCLUSIONS

Transmission lines are used to transmit a huge amount of power over a long distance. However, because these lines are located in the open atmosphere, they are highly affected by different types of abnormal conditions or faults. This study starts with a thorough analysis of a high resistance ground fault condition. From a detailed fault analysis, it has been concluded that the lower the time constant, the lower the resistance of the ground arc fault, and, therefore, by increasing the ground arc fault resistance, the time constant to its maximum value is increased and, accordingly, the condition of the extinguishing the arc is aggravated. At the same time, there is a requirement that such an extinguishing should occur during the first half period of the main frequency; this means during the first current transition through zero. This study presents the desired capacitance of the phase conductors in relation to the ground for both cables and overhead transmission lines. It has been proven from the simulation results that the proposed methodology is not affected by the presence of high resistance in the faulted path. The proposed scheme has been simulated in MATLAB/SIMULINK software. Furthermore, it is highly accurate because it measures the correct values of resistance and reactance of the faulted portion of the transmission line. From the simulation results, it has been proven that the proposed scheme measures the fault impedance very precisely. The proposed scheme is based on the response of the fundamental quantities of the voltage and the current signals with all system parameters, neutral resistance ground arc fault resistance, and phase capacitors. It also provides a better stability against close-in faults.

REFERENCES

Abdulrahman, M. A. (2019). Fault bus identification in Kurdistan Power Systems using artificial neural network. *Zanco Journal of Pure and Applied Sciences*, 31(s3), 410-416.

Ashok, V., Bangarraju, K. G. V. S. & Murthy, V. V. N. (2013). Identification and classification of transmission line faults using wavelet analysis. *ITSI Transactions on Electrical and Electronics Engineering*, 1(1), 117-122.

Ćućić, R., Komen, V., & Živić Đurović, M. (2008). Neutral point concept in distribution networks. *Engineering Review,* 28(2), 77-89.

Dileep, A., Kumar, S., & Raghunath, S. (2014). Discrimination of faults and their location identification on a high voltage transmission lines using the discrete wavelet transform. *International Journal of Education and Applied Research,* 4(1), 107-111.

Fedotov, A., Vagapov, G. & Abdullin, L. (2019). Identification of feeder with single-phase ground fault. IEEE International Conference on Industrial Engineering, Applications and Manufactoring.

Komen, V. & Cucic, R. (2007). Fault resistances in medium voltage distribution networks. Annals of DAAAM & Proceedings, DAAAM International Vienna.

Krasnykh, A. A., Krivoshein I. L., & Kozlov A. L. (2016). Single-phase Earth fault location in a branched distribution network 6–35 kV overhead lines. 2nd International Conference on Industrial Engineering, Application and Manufacturing.

Mahanty, R. N. & Dutta Gupta, P. B. (2007). A fuzzy logic based fault classification approach using current samples only. *Electric Power Systems Research,* 77(5-6), 501-507.

Muhammad, A. A. (2016). Fault location estimation of Kurdistan Power System using ANN. *Zanco Journal of Pure and Applied Sciences*, 28(2), s137-s145.

Prasad, A. & Belwin Edward, J. (2016). Application of wavelet technique for fault classification in transmission systems. *Procedia Computer Science*, 92, 78-83.

Prasad, A., Belwin Edward, J., Shashank Roy, C., Divyansh, G. & Kumar, A. (2015). Classification of faults in power transmission lines using fuzzy-logic technique. *Indian Journal of Science and Technology*, 8(30), 1-6.

Shashi, R., Neelam, L., Nidhi, C., Richa, N. & Ramesh, P. (2012). Fuzzy-logic-based fault classification for transmission line protection. *International Journal of Research and Engineering, Application and Science,* 2(2), 281-291.

Wang, B., Dong, X., Lan, L. & Xu, F. (2013). Novel location algorithm for single-line-to-ground faults in transmission line with distributed parameters. *Generation, Transmission & Distribution,* 7(6), 560–566.

Zhi, X. X. & Huang J. D. (2008). New research based fault location on a distribution network. China International Conference on Electricity Distribution.