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COMPARISON OF EARTHING TECHNIQUES FOR SINGLE LINE TO GROUND FAULT IN 11 kV DISTRIBUTION SYSTEM USING SIMULINK

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Abstract: In this paper, a new smart earthing method was proposed to reduce the current magnitude of single line to ground fault and thus reduce the damage caused by this fault. Traditional methods of earthing system were studied and compared with the proposed new method using simulation in the MATLAB program to show the superiority of the new method and its economic benefit. The power system characteristics depending on the selection of earthing methods such as charging current magnitude, overvoltage, insulation level, mechanical and thermal damage and fault clearing time are discussed. In this smart technique, a bank of earthing resistors is used according to the characteristics of the earthing fault (fault resistance value), which leads to the passage of a low electric current, but it is detectable regardless of the faults characteristics. Fuzzy Logic Controller technique is used to solve control problem.

Keywords: *earthing methods, single line to ground fault (SLG), bank of earthing resistances, charging current, fuzzy logic controller (FLC), Low resistance grounding (LRG), High resistance grounding (HRG), Neutral grounding resistance (NGR)*

مقارنة تقنيات التأريض للخط الارضي ذو الخط الواحد في نظام التوزيع 11 كيلو فولت باستخدام المحاكاة

الخلاصة: في هذا البحث تم اقتراح طريقة تأريض ذكية جديدة لتقليل قيمة تيار الخطأ الارضي ذو الخط الواحد وبالتالي تقليل الاضرار المتسببة بواسطة ذلك الخطأ. تم دراسة ومقارنة الطرق التقليدية لنظام التأريض مع الطريقة الجديدة المقترحة باستخدام المحاكاة في برنامج الماتلاب موضحا افضلية الطريقة الجديدة وفوائدها الاقتصادية. تم مناقشة خصائص نظام القدرة التي تعتمد على اختيار تقنيات التأريض مثل قيمة تيار الشحن، والجهد الزائد، ومستوى العزل، والضرر الميكانيكي والحراري، ووقت إزالة الأخطاء. في هذه التقنية الذكية، تم استخدام مجموعة من مقاومات التأريض وفقا لخصائص الخطأ الارضي (قيمة مقاومة الخطأ)، الأمر الذي يؤدي إلى مرور تيار كهربائي قليل ولكنه قابل للكشف بغض النظر عن خصائص الأخطاء. تم استخدام متحكم المنطق المضبب لحل مسألة السيطرة.

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1. Introduction

During the operation of electrical power system, the very important issues are the safety and the reliability of the system. To improve the power system safety and reliability, the suitable earthing system type must be properly choose and applied. An earthing system type means that how the neutral point of the system connected to the earth. The main purpose of an earthing system is to improve the protection of the system equipment's during single line to ground fault (SLG) and other fault types. The single line to ground fault are the most type of the faults occurs in power system. The occurrence percent of this fault type approximately is 95% [1]. In general, there are many goals for earthing system such that:

1. Limited the magnitude of transient over voltages.
2. Simplified earth fault location.
3. Improving of system and equipment fault protection.
4. Reducing of maintenance time and expense.
5. Provide greater safety for personnel.
6. Improving of lightning protection.
7. Reduction in frequency of faults.

Many considerations determine the selection of what earthing system method is suitable for earthing the neutral of 11 kV distribution system. These considerations are short circuit fault current withstand capability, the amount of thermal damage, the amount of mechanical damage, the magnitude of an over voltage, the insulation level, needing for alarm or trip, allocation of the fault location, the pickup setting of an over current protection device and the clearing fault time [2]. There are many researchers tended to study this area because of its importance and great effect on the protection of electrical networks and their employees. For examples, the main neutral grounding methods that including un-grounding neutral method, neutral grounding by using a Peterson coil method and neutral grounding by using low resistance value method are discussed in [3]. Addressing the significance and influence of neutral grounding resistance method in 30kV Western Libyan power system network and explain the effect of this method in limiting and determining of the bolted single line to ground fault currents for a network fed by a single or multi sources in [4]. The methods which used to ground the neutral point of Shanghai Fengxian 35 kV and 10 kV power grid are discussed in [5]. Discuss the phasor diagram and flow directions of the faulted current in case of single phase to ground bolted fault when the HRG method is used in power system be done in [6]. In this paper study the SLG fault in different types of earthing methods are addressed. Also, suggestion a new method to earthing the neutral of the 11 kV distribution power system and testing of this method through a SLG faults are addressed. This study will execute by using test Simulink model in matlab simulation.

2. Earthing Methods

The methods of earthing system may be used in 11 kV medium voltage system are unearthing method, solidly earthing method and low resistance grounding method (LGR). For each of these methods there are many advantages and disadvantages. So, studding of applying these methods in 11 kV system will addressed and the testing Simulink model of the power system is earthed by using these methods.

2.1. Unearthing Method

In this system, the neutral point doesn't connect to the earth but the system is grounded through earthing capacitance [7]. The current in faulted phase doesn't return directly from the earth to neutral point. The fault current returned through capacitive impedance which leads to reduce this current to very small value. So, one way to reduce the earthing fault current is to leave a transformer neutral unearthed [8]. The faulty equipment voltage is decrease to very small value which improves a safety. The mechanical and the thermal damage are very small because there is little increasing in faulted current.

2.2. Solidly Method

Earth solidly means that a neutral point of distribution system is connected to earth directly without any intentional impedance that connected in series between generator or transformer neutral to ground [9]. During the earthing fault, very high current will return to the system through solid earthing conductor. Due to high faulted current, the amount of thermal and mechanical damage is very high and there must be cleared the fault immediately. Therefore, the allocating of the fault location is impossible in spite of simplicity of fault detection due to high faulted current magnitude.

2.3. Resistance Earthing Method

To resolves many of the problems related with using of solidly earthing and unearthing systems, resistance earthing has been used in distribution power system. The earthing resistance system is used to limit high fault current to a value which will doesn't cause damage to the equipment in the power system. The two main techniques or methods of connecting medium voltage system neutrals to earth point are both carry out by using neutral grounding resistance. These two main categories of earthing resistance are:

(1) Low resistance grounding (LRG)
(2) High resistance grounding (HRG)

These both types are connected to reduce the earth fault current and separated by the level of earth fault current allowed to flow. When applying the resistance in earthing system, many issues must be explained such that in [10].

2.3.1. Charging Current

The value of an earthing resistance should be smaller than the capacitance existing between a phase conductor and the earth [11]. So, there is necessity to know the relation between the current passes through neutral ground resistance, the charging current passes through the capacitance exist between line conductor and the earth and the current passes through point of earthing fault. The relation between these three current magnitudes is the same for low resistance earthing system and high resistance earthing system in case of single line to earth fault.

During normal system operation condition, an earthing capacitance doesn't cause any problem because that the charging current per each phase are equal in magnitude [12]. But it displaced by 120 degree compared to charging current of other phases, the total charging current equal to vector summation of three current components of three earthing capacitance. These currents sum to zero and the neutral does not carry any stray capacitance currents [13].

During single line to earth fault, the current 3Ico of the two health phases and the current passes through earthing neutral resistance (I_{RN}) will contribute to the path between point of fault and the earth.

$$I_{gf} = \sqrt{{I_{RN}}^2 + 3{I_{CO}}^2} \quad (1)$$

$$I_{RN} = V_{RN}/RN = V_{LN}/RN \quad (2)$$

RN is chosen so that $I_{RN} \geq 3I_{CO}$, where I_{gf} Is the current component passes in the path between point of fault and the earth, I_{RN} Is the current component passes through neutral ground resistance (NGR), $3I_{CO}$ is the total system capacitive charging current during fault, V_{RN} is the NGR voltage, *RN* is the NGR value and V_{LN} is the line to ground voltage. So, the total charging current must be known to apply an earthing resistance. The charging current is estimated less than 15 A for 11 kV power system [13, 14, 15]. This means that the NGR setting is normally selected so that the NGR let-through current greater than the total capacitive charging current, 3Ico, of the system when there is occurrence of an earthing fault. HRG applied to reduce the faulted current value to less than 10 A. this charging current value provided to the system voltage less than 5 kV. The charging current problem doesn't exist for application of low resistance value method because it allows to hundreds of amperes to passes through it and return to the power system equipment's. This range of faulted current is dangerous due to the damage of the high value of this current and there is necessity to clearing the earthing fault in very short time (cycles) [16]. Also there is difficulty to allocate the earthing fault location.

2.3.2 Insulation level

Another very important issue is the insulation level of the power system. The insulation level is affected when there is earthing fault in the system depending on the method of the neutral connected to earth. During earthing fault, the two non-faulted phase voltage increase or over voltage. When using the resistance (LRG or HRG) to connect the neutral point to earth the over voltage is the same value approximately. During earthing fault, the line to ground voltage of the two non-faulted phases will reach to line-to-line voltage. The insulation level of the electrical insulation materials is promptly failure when subjected to overvoltage magnitude that reaches to 600% to 700% of the rated line to ground voltage value [1]. But the increasing of the overvoltage that subjected to the insulation materials during earthing fault for long time decrease the service life of the insulation materials. When using the LRG technique, the earthing fault is cleared in cycles resulting in there is no necessity to increase the insulation level.

2.3.3. Pickup Setting

The important condition is that the earthing resistance must not passes the faulted current of value less than the pickup current for over current device. So, the pickup setting should be greater than the value of the current passes through neutral earthing conductor by a safety factor.

3. New Smart Earthing Method

After study the above mentioned earthing methods, a new smart earthing technique is suggested to detect and reduce SLG fault. This method can be applied by using 12 resistances of different value connected in parallel (bank of resistances) to connect the neutral point to earth. The operation of these resistances can be controlled by using FLC and controller to limit the faulted phase current to low level that is greater than the charging current by a safety factor. The magnitude of the SLG fault changed according to the value of fault resistance. The control circuit detects current magnitude in earthing conductor and selects appropriate resistance to limit this current to low level. This leads to neglect the parameters that affect the magnitude of a SLG fault such as location of fault and its resistance.

3.1. Fuzzy logic Controller

In this technique, there needs to control an operation of the bank of earthing resistances by changing the output signal of FLC according to measured current by ammeter located in the return path of faulted current. The simplest model of FLC is applied. This model is single input single output (SISO) Mamdani Fuzzy System. For the purpose of studying the characteristics of MF, the universe of discourse for both input and output variables are selected which are normalized to intervals (0 to 6500) A and (0 to 5) V respectively. The basic SISO Mamdani fuzzy inference model consists of input variable which represent the current reading and output variable which represent the controlling signal received by controller block. Several parallel If-Then rules make up the inference mechanism. The input variable has 12 membership functions to represent the input current from ammeter. The input membership is triangle functions. Totally the antecedent of If-Then rule has 12 kinds of possibilities; therefore defuzzification process consists of 12 membership functions to represent the output of FLC which greatly fits the requirement of editing complete and symmetric rules. The output membership functions are trapezoidal functions. The selection of triangle functions and trapezoidal functions for input and output functions respectively is done due to linearity of these types of function.

4. Test System Study

The testing Simulink model consists of three phase voltage source of 33 kV, three phase transformer 33 to 11 kV of 15 MVA in which the primary winding are connected in delta and the secondary winding in Y neutral connection, three phase distribution line of 4 km, three phase transformer 11 to 0.4 kV in which the primary winding are connected in delta and the secondary winding in Y neutral connection and three phase series load of current value of 405 A in 11 kV side.

5. Simulation Results

This section will divided into many cases of Simulink results for applying the traditional techniques of earthing system and the proposed smart technique in power models.

- *Case 1: Test system with unearthing technique*

In non- earthing technique, the neutral of the secondary winding of 33 to 11 kV transformer in the test power model doesn't earthed as shown in "Fig. 1".

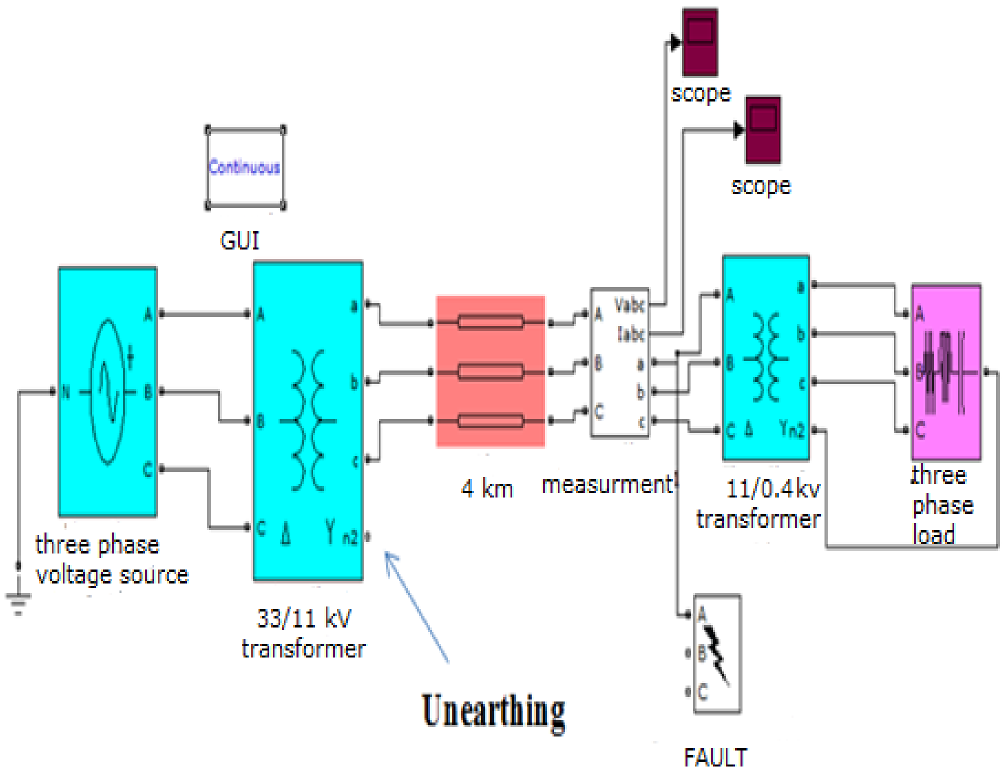

Figure 1. Unearthing method for test model

The charging current of the 11 kV model adjusted at 15 A for the worst case as it is estimated. So, the faulted phase current must be increased to this magnitude or less depending on the fault resistance and location, but the result of three phase current waveforms doesn't show this increase due to location of the fault as shown in "Fig. 2".

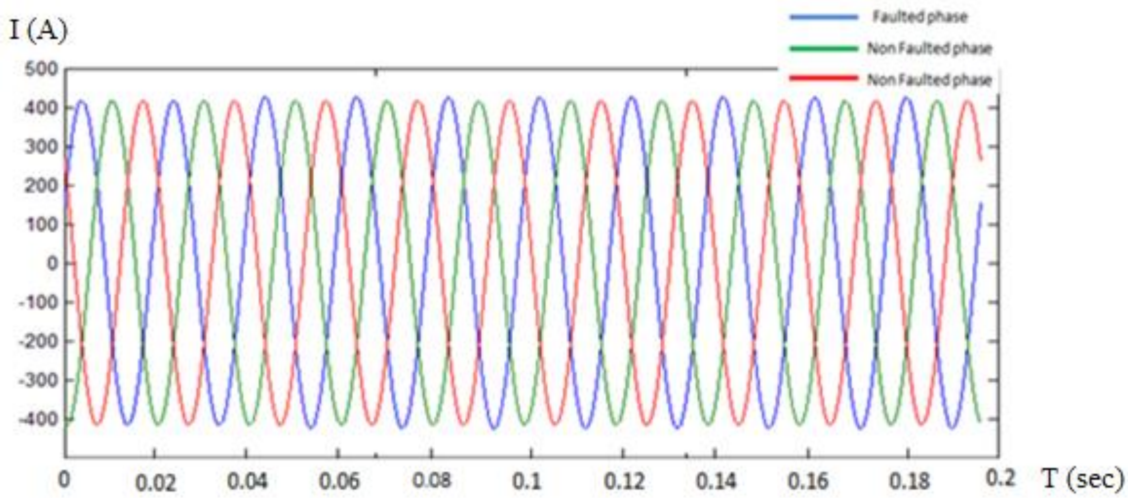

Figure 2. Three phase current waveforms under SLG fault occurs at 0.04 sec with fault resistance equal to 0.001 ohm

During fault, the voltage of the two healthy phases will increase from line to ground voltage to line to line voltage because the neutral ground voltage increase from 0 V (at normal operation) to phase to ground voltage (at earthing fault) as shown in "Fig. 3".

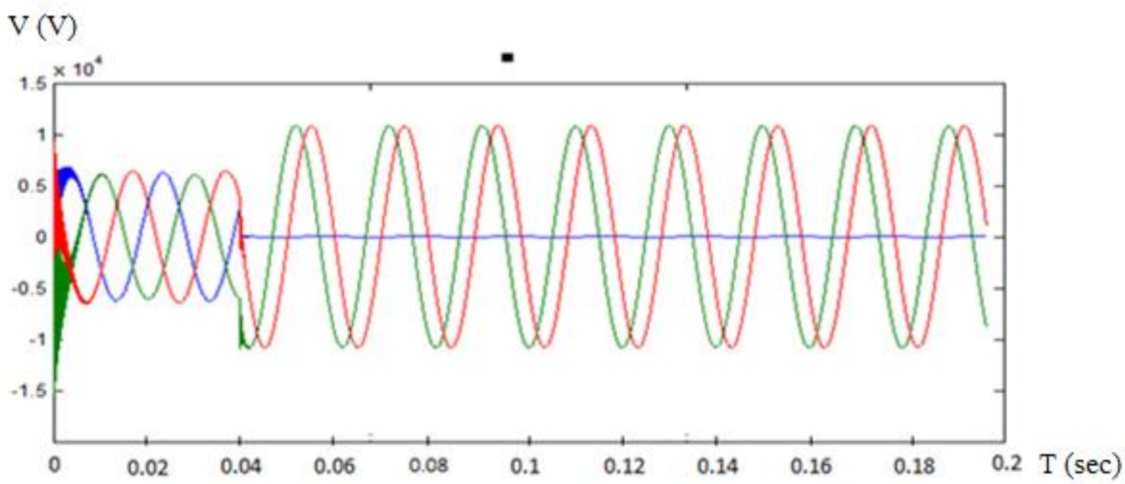

Figure 3. Three phase voltage waveforms under SLG fault occurs at 0.04 sec with fault resistance equal to 0.001 ohm

- *Case 2: Test system with solidly earthing technique*

In solidly earthing technique, the neutral of the model is connected directly as shown in "Fig. 4". The fault phase current is increased to 2800 A as shown in "Fig. 5". This dangerous magnitude results because there is not any impedance to limit the fault current.

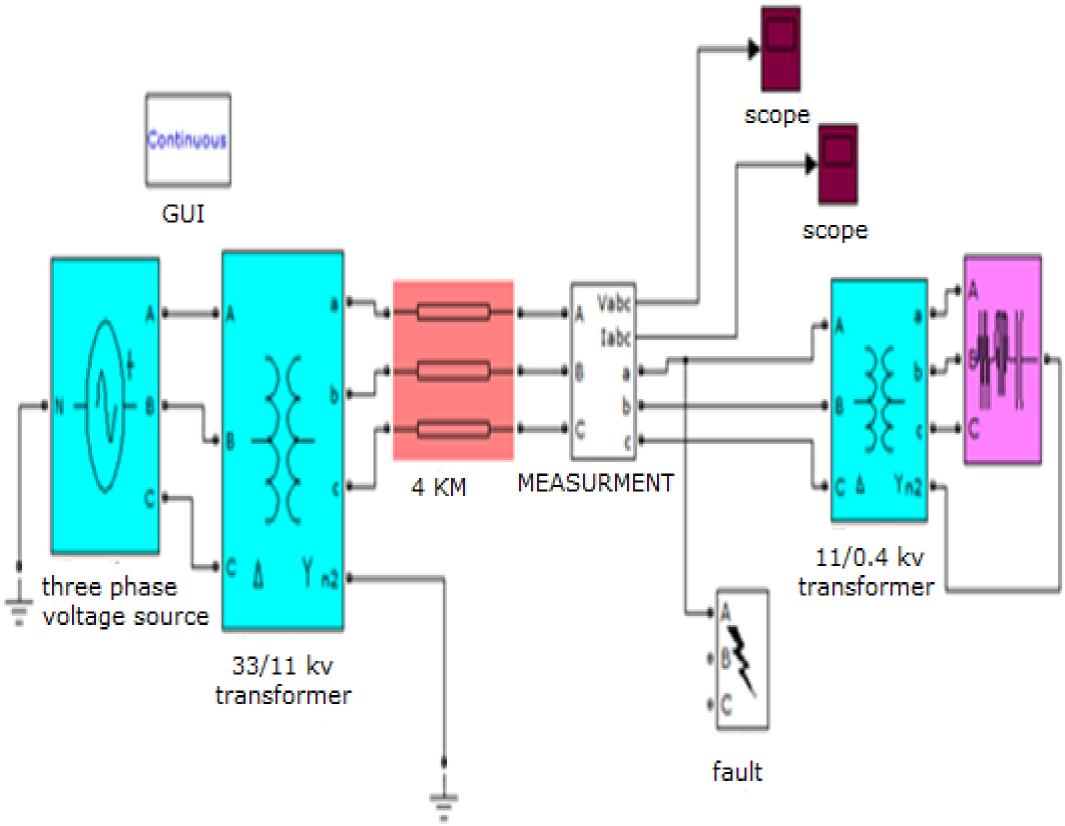

Figure 4. Solidly earthing for test model

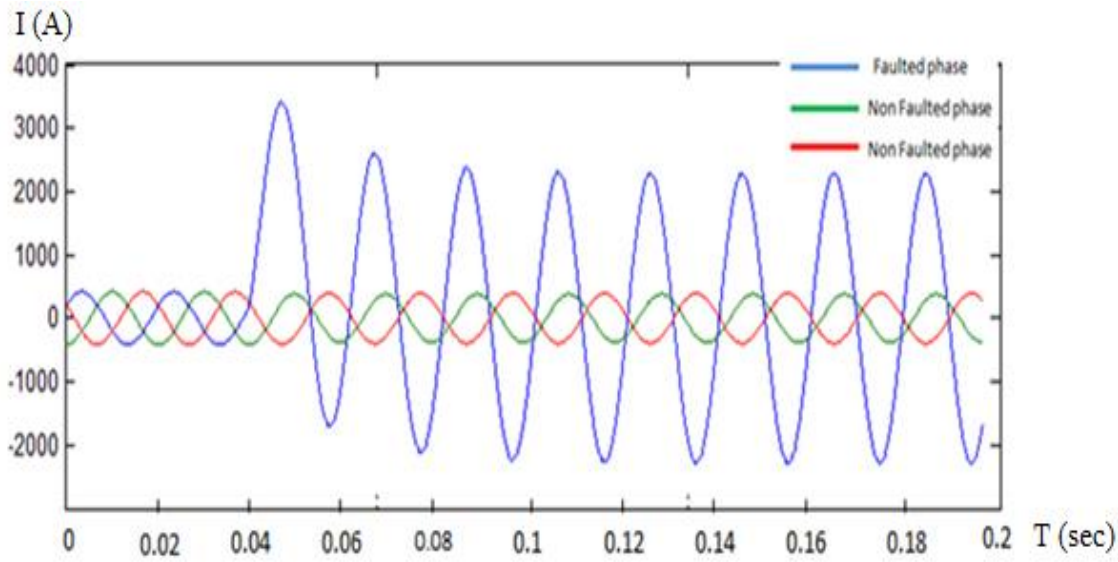

Figure 5. Three phase current waveforms under SLG fault occurs at 0.04 sec with fault resistance equal to 0.001 ohm

This method reduces the over voltage for the two healthy phases during SLG fault compared with line to line voltage as shown in "Fig. 6". Due to clearing the fault immediately and the over voltage are very small, there is no needing to increase the insulation level of the insulation material.

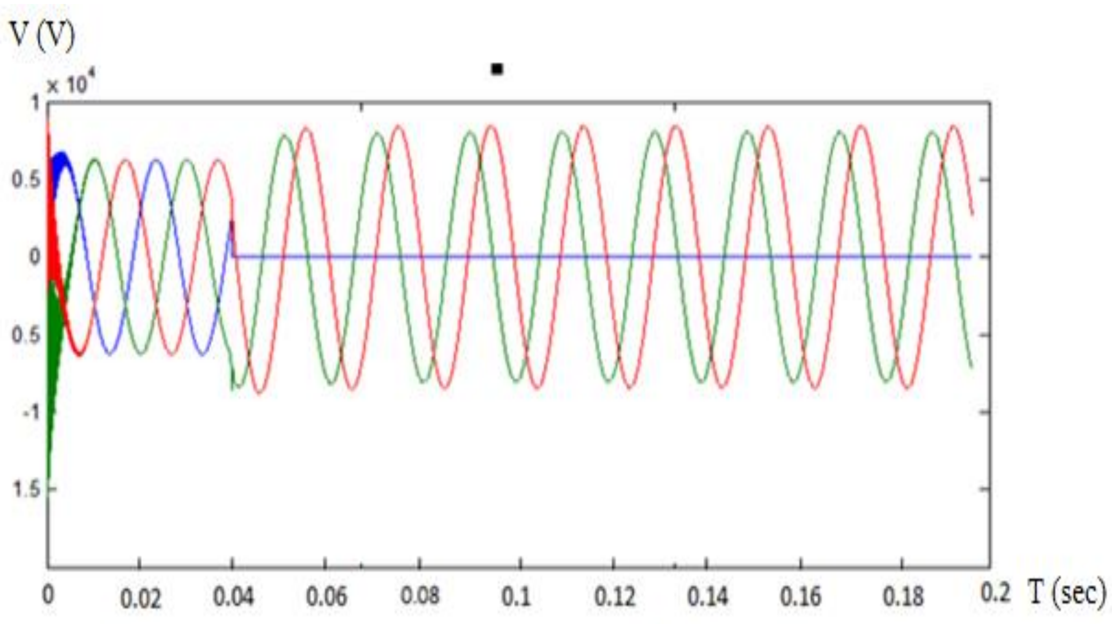

Figure 6. Three phase voltage waveforms under SLG fault occurs at 0.04 sec with fault resistance equal to 0.001 ohm

- *Case 3: Test system with low resistance value technique*

In LGR earthing technique, the neutral point of the model is connected to the earth by using low value of 21.4 Ohm as shown in "Fig. 7".

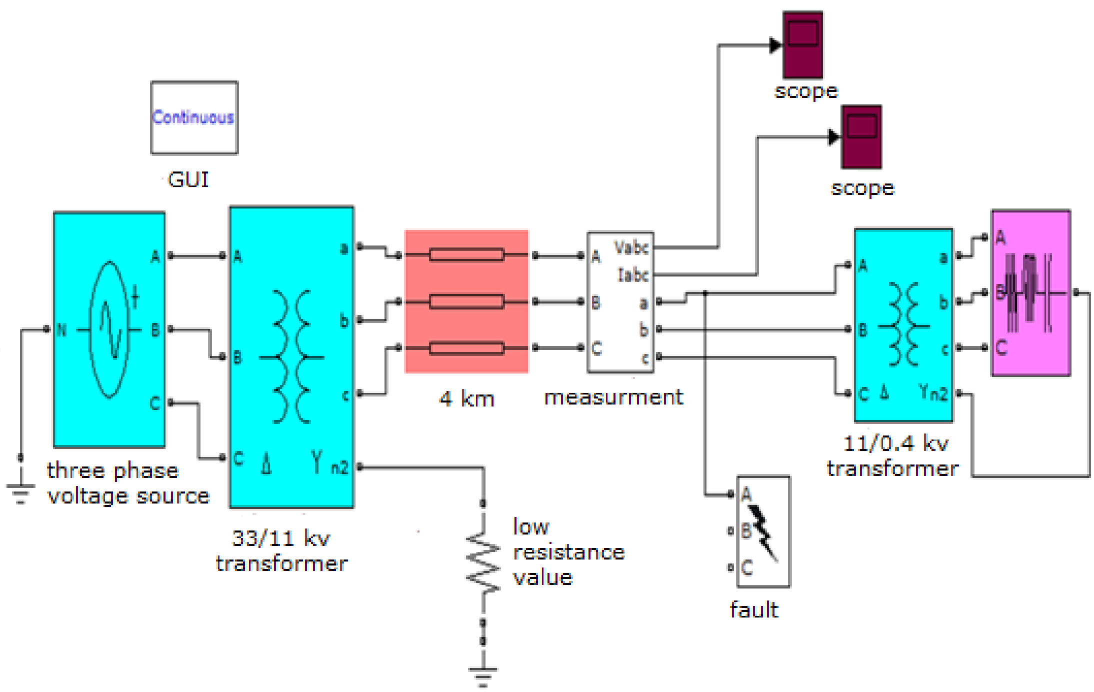

Figure 7. Low resistance earthing for test model

The fault current returns through this resistance and causes damage to the system equipment due to its high magnitude (700 A) as shown in "Fig. 8".

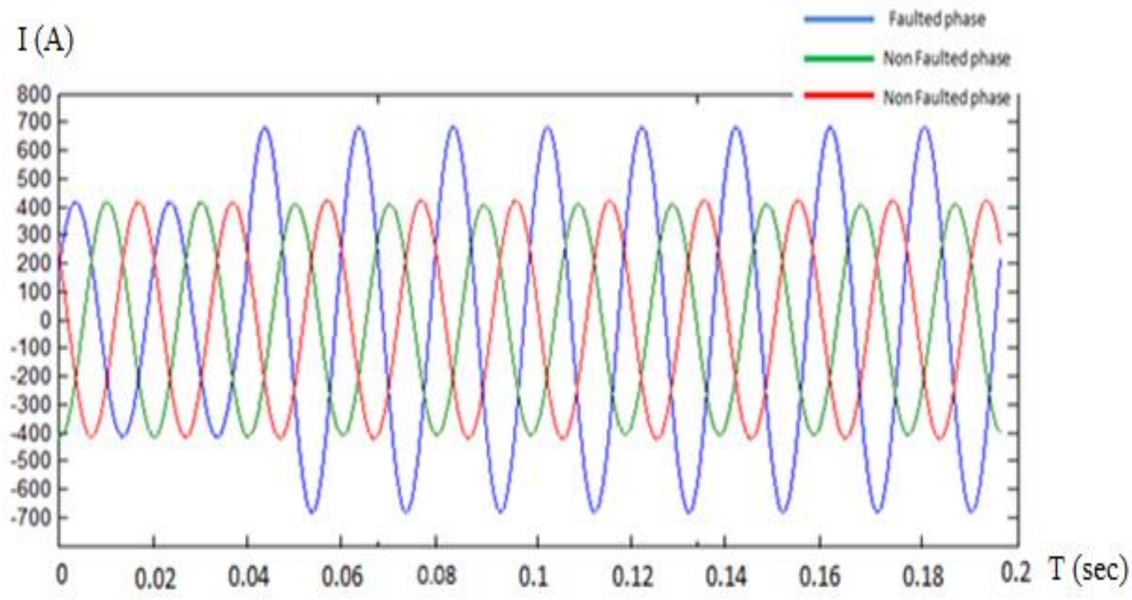

Figure 8. Three phase current waveforms under SLG fault occurs at 0.04 sec with fault resistance equal to 0.001 ohm

The voltage of faulted phase is reduced to very low value and the two non-faulted phase voltage magnitude is increased to line-to-line magnitude as shown in "Fig. 9".

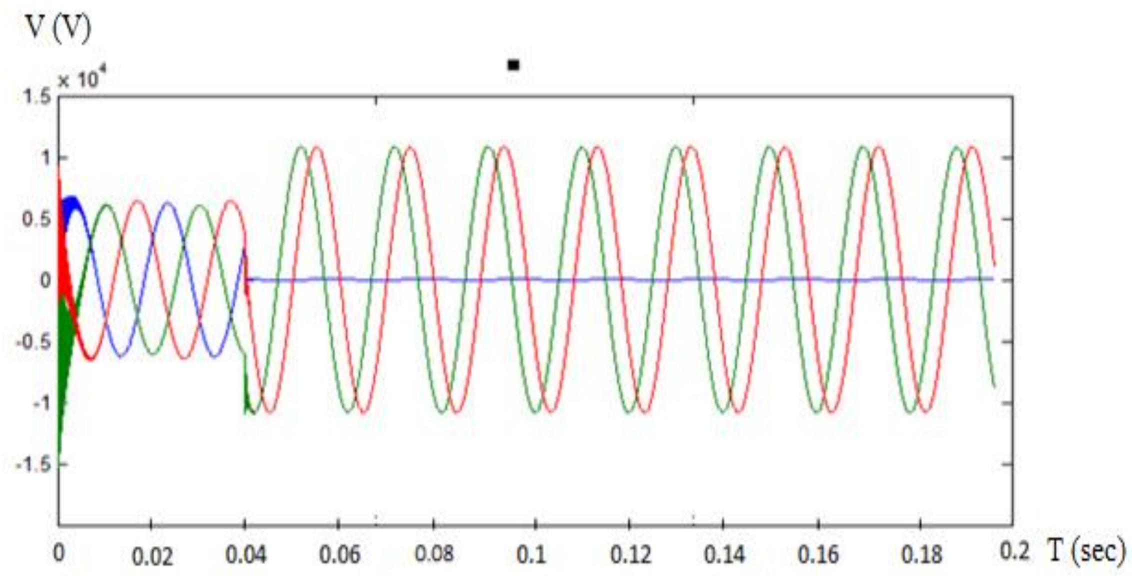

Figure 9. Three phase voltage waveforms under SLG fault occurs at 0.04 sec with fault resistance equal to 0.001 ohm

- *Case 4: Test system with proposed smart earthing technique*

After discussing the results of traditional earthing techniques, a new smart earthing technique is proposed to detect and limit the earthing fault. This technique is applied by using 12 resistances of different values which are connected in parallel (bank of resistances) and the power model neutral is connected to the earth through it as shown in "Fig. 11".

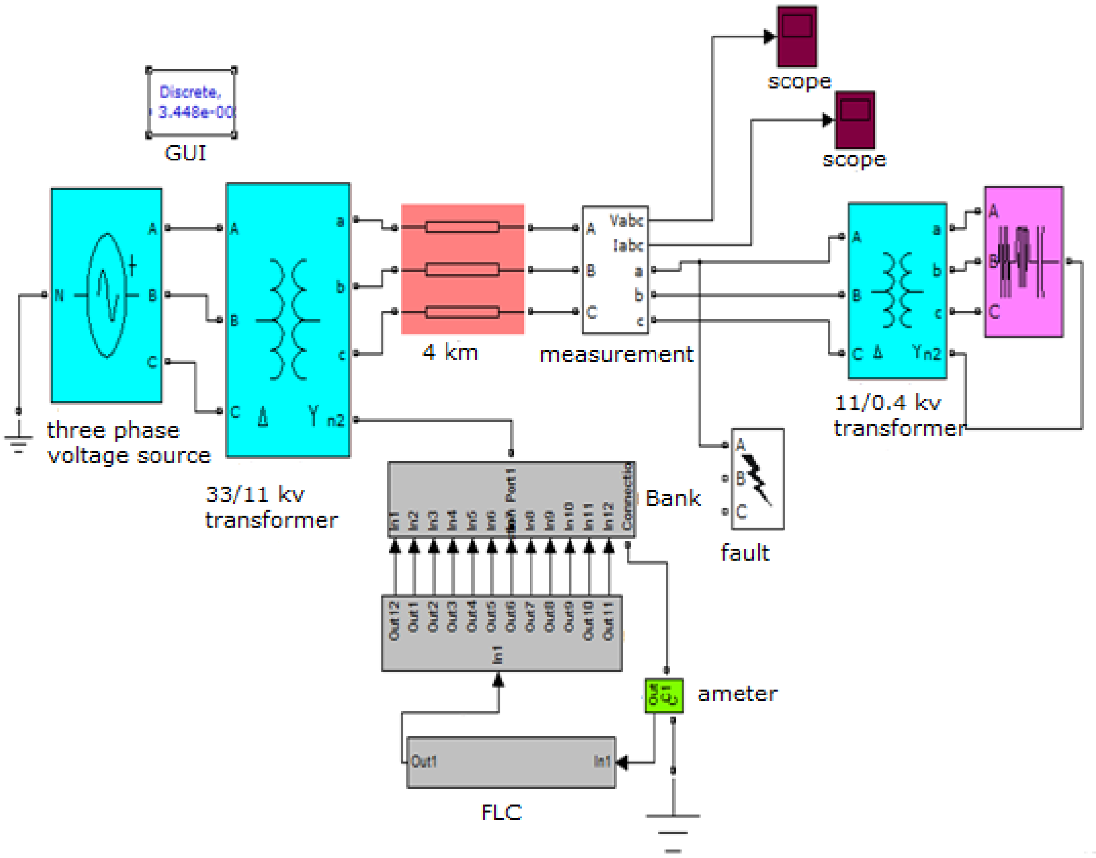

Figure 10. New earthing method for test model

The SLG faults are applied to test this technique by using many fault resistance values and by changing occurrence time of the faults as shown in "Figs. 11-22". These faults are simulated in location of 4 km from the neutral point of 11 kV side. In each case of these faults, the faulted current is returned to the system and limited to low magnitude which reduces the damage.

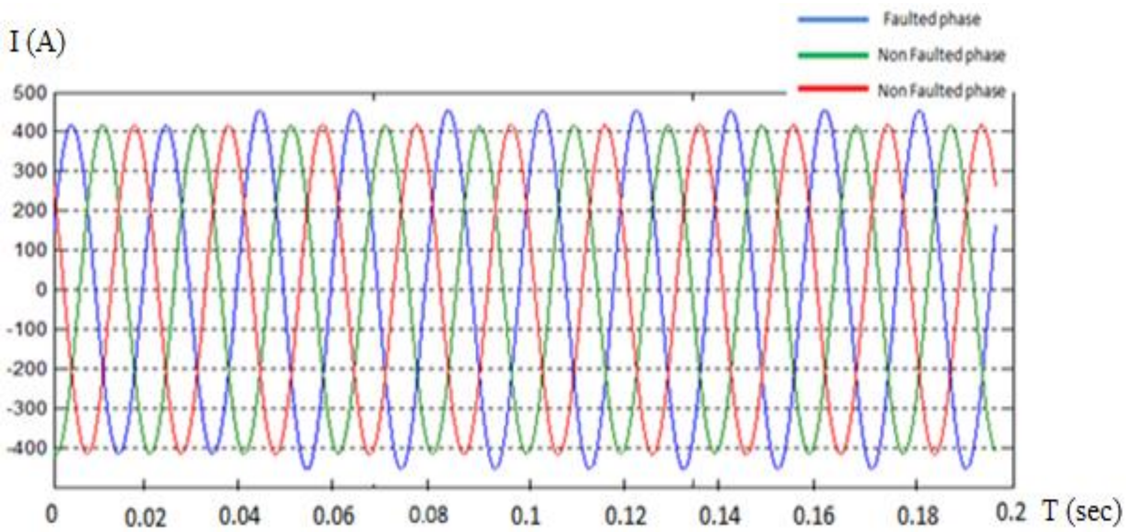

Figure 11. Three phase current waveforms under SLG fault occurs at 0.04 sec with fault resistance equal to 0.001 ohm

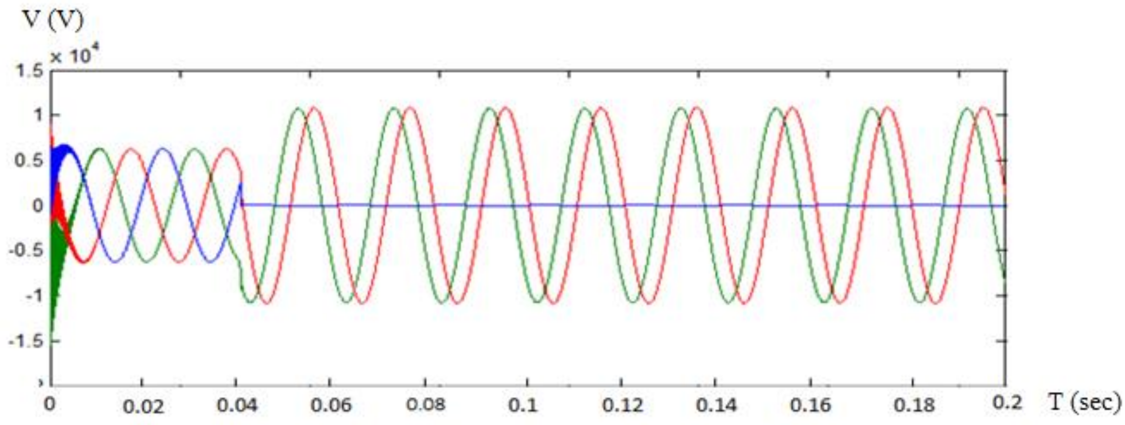

Figure 12. Three phase voltage waveforms under SLG fault occurs at 0.04 sec with fault resistance equal to 0.001 ohm

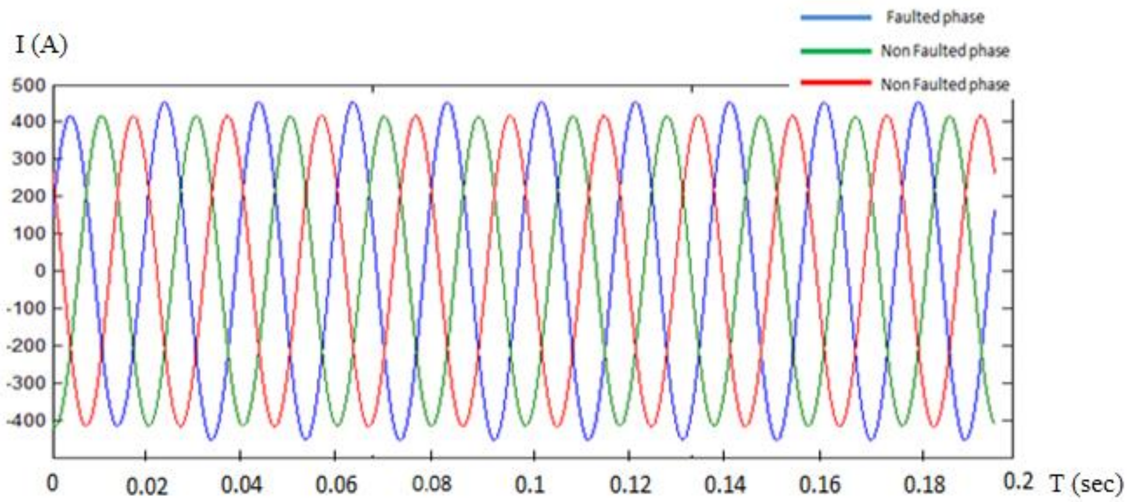

Figure 13. Three phase current waveforms under SLG fault occurs at 0.02 sec with fault resistance equal to 5 ohm

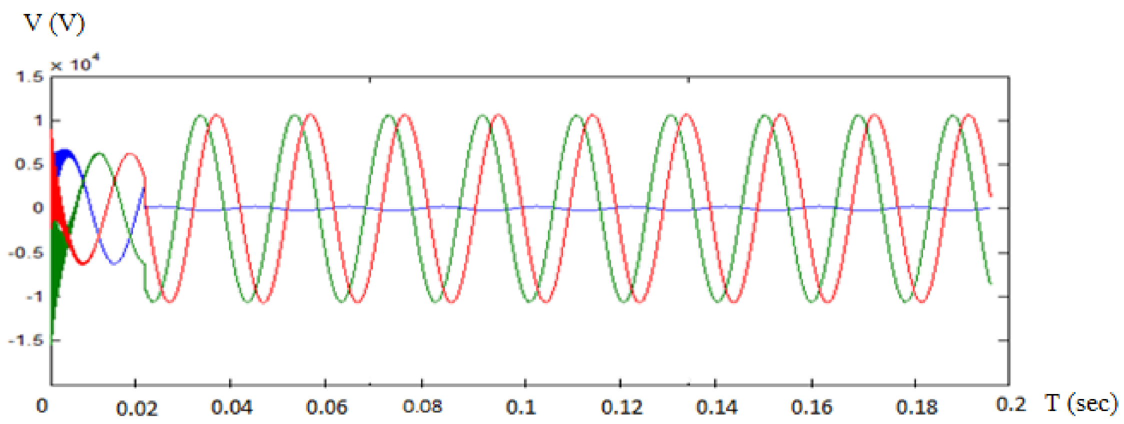

Figure 14. Three phase voltage waveforms under SLG fault occurs at 0.02 sec with fault resistance equal to 5 ohm

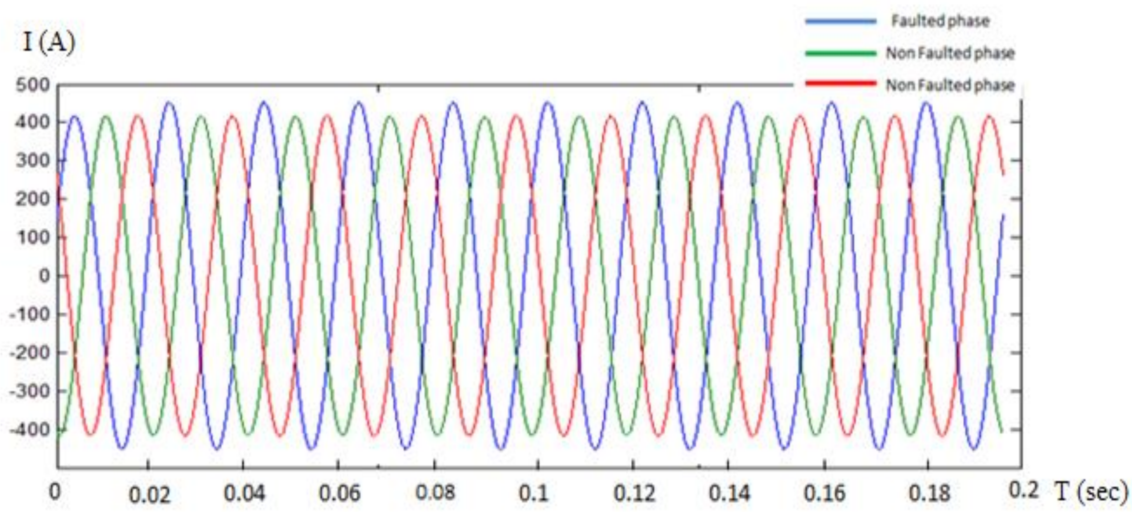

Figure 15. Three phase current waveforms under SLG fault occurs at 0.01 sec with fault resistance equal to 12 ohm

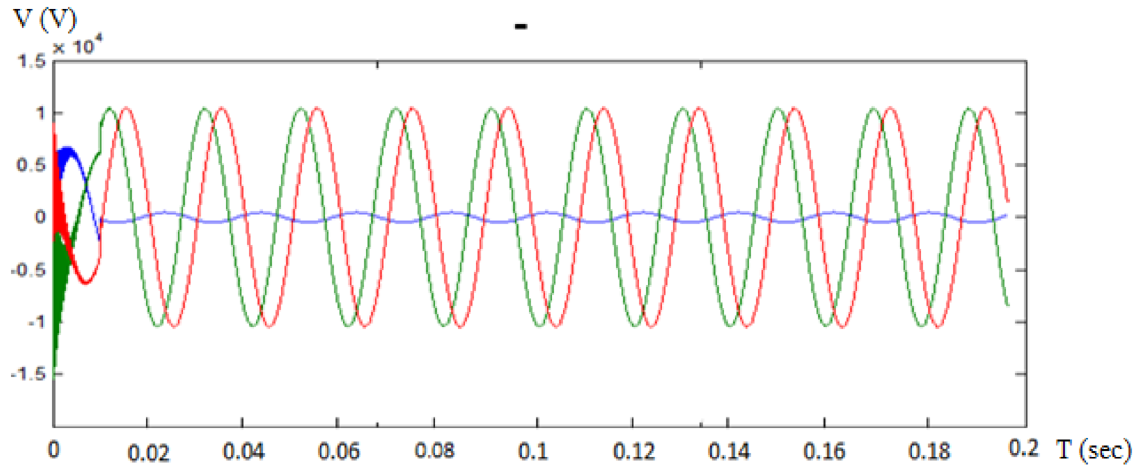

Figure 16. Three phase voltage waveforms under SLG fault occurs at 0.01 sec with fault resistance equal to 12 ohm

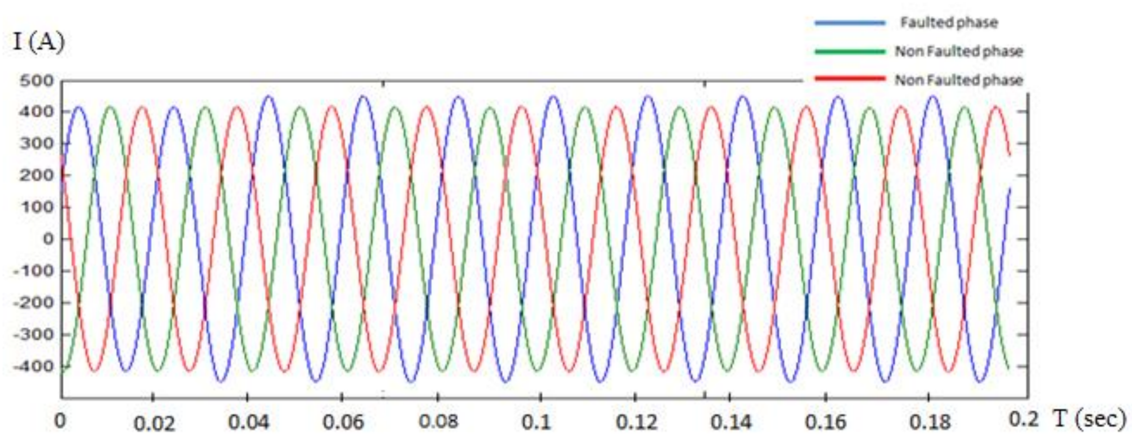

Figure 17. Three phase current waveforms under SLG fault occurs at 0.03 sec with fault resistance equal to 23 ohm

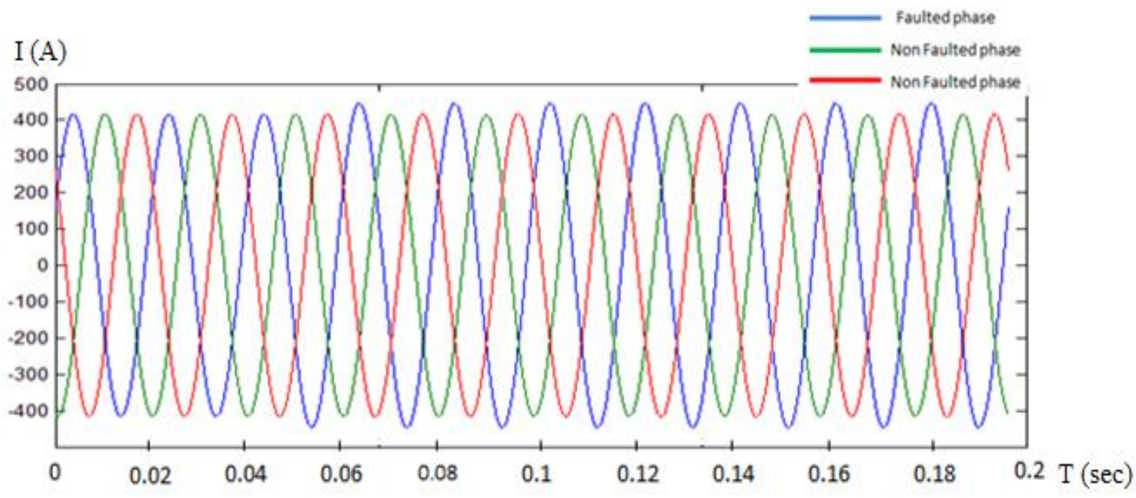

Figure 18. Three phase current waveforms under SLG fault occurs at 0.05 sec with fault resistance equal to 39 ohm

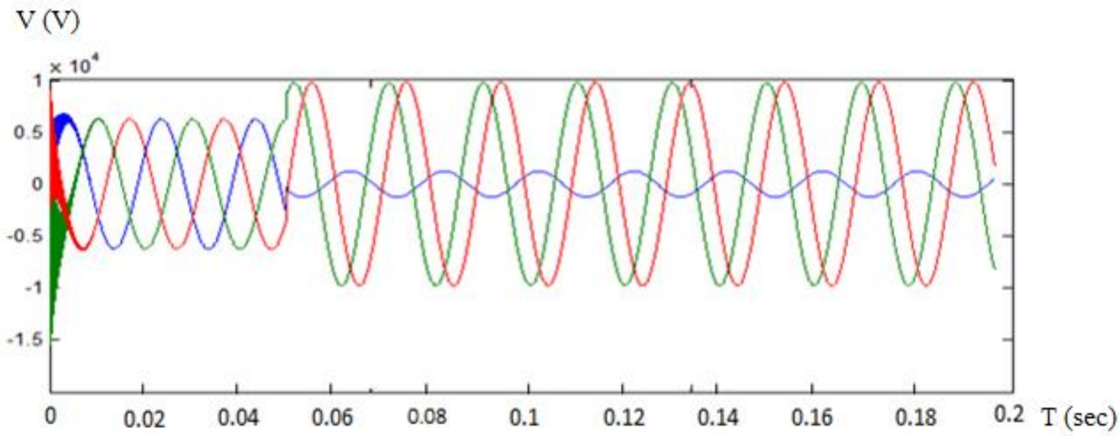

Figure 19. Three phase voltage waveforms under SLG fault occurs at 0.05 sec with fault resistance equal to 39 ohm

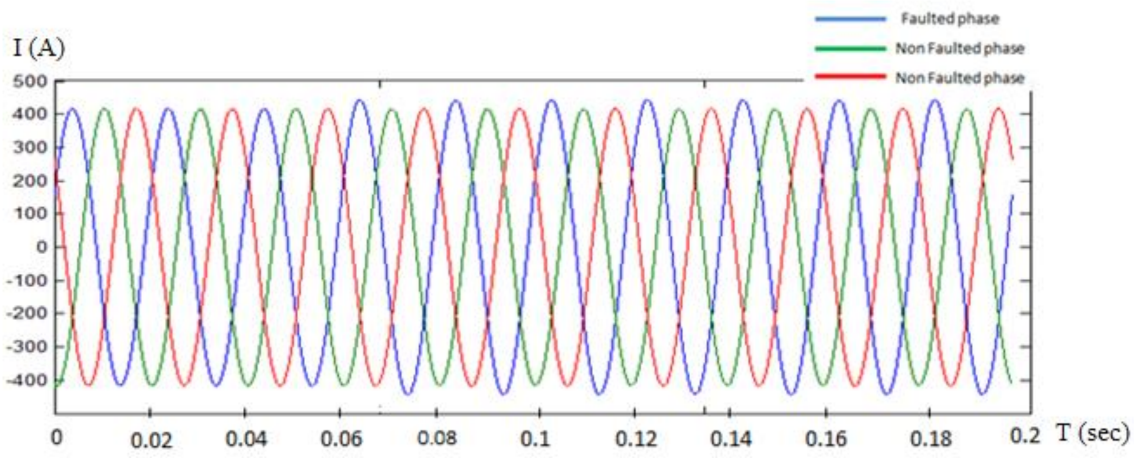

Figure 20. Three phase current waveforms under SLG fault occurs at 0.06 sec with fault resistance equal to 75 ohm

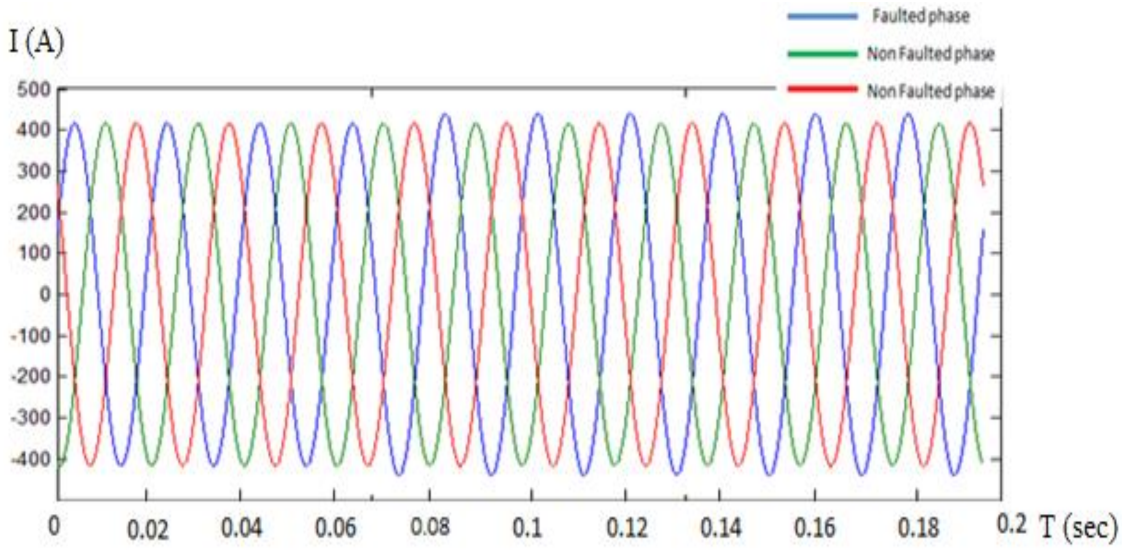

Figure 21. Three phase current waveforms under SLG fault occurs at 0.07 sec with fault resistance equal to 110 ohm

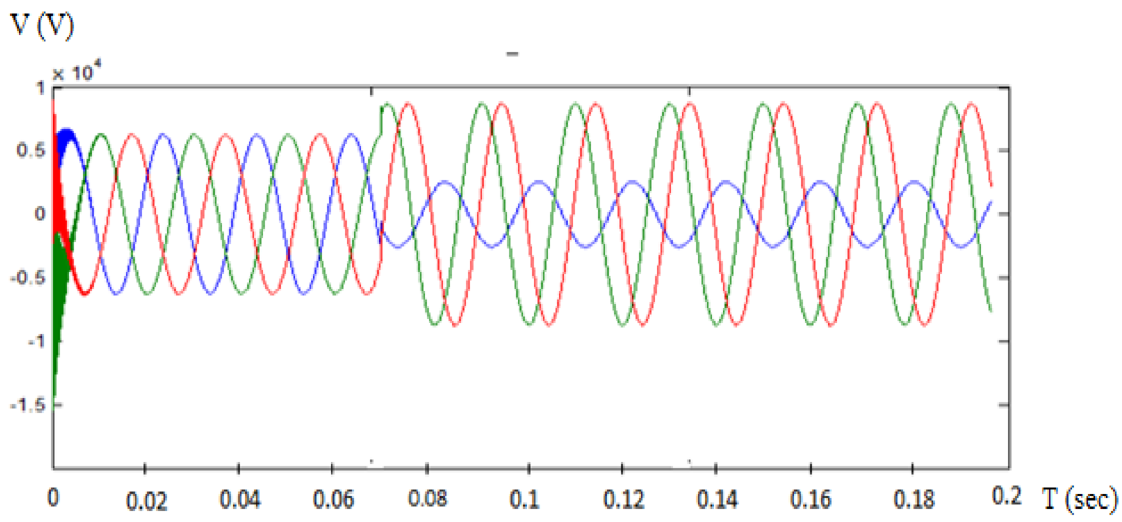

Figure 22. Three phase voltage waveforms under SLG fault occurs at 0.07 sec with fault resistance equal to 110 ohm

The simulation results of this new technique show that the fault current passes through earthing neutral resistance are decreased to low level of current approximately equal to 40 A with any value of the fault resistance. So the faulted phase current have a current more than the two healthy phases current by this low level of 40 A. This reduce the damage to the system equipment's and this allow to increase the fault clearing time another some cycles compared with fault clearing time at the low resistance value. This help in locating the earthing fault and the insulation level doesn't increase because that the clearing time stay in second compared to clearing time in hours such that in HRG system. The economic advantage of using smart earthing technique instead of traditional method (LRG method) to earthing the neutral point of 33/ 11 kV substation is accepted because the smart technique have very low damage cost of NGR while the LRG method have a high damage cost which represented by replacement cost i.e. in LRG technique, all earthing resistances operate in the same time without selector and if damage of NGR occurs, the NGR must be replaced by a new NGR. This problem doesn’t exist in smart earthing technique. In this technique, only one earthing resistance is in operation and all other earthing resistances are disconnected. So, only one earthing resistance in NGR may be damage in the same time leading to reduction in the damage cost of NGR.

6. Conclusions

1- A new smart earthing method was proposed to ground the neutral point of the 11 kV system model in SIMULINK and it contains different values of earthing resistances which are selected to compensate any change that occurs in fault resistance. FLC is used to control an operation of these earthing resistances based on characteristics of SLG fault. The several methods of the grounding system have been studied and compared by using SIMULINK (the new method is found to be the best due to many reasons such that it reduces the mechanical and thermal damage, more safety in failure of the protection device, it allow to increase the fault clearing time for some seconds making the allocation of the earth fault easier, there is no need to increase the insulation level and it considers economical earthing technique).
2- Unearthing method is used to limit the fault current but there is problems concerns with the over voltage magnitude, difficult to detect the fault and there is need to increase the insulation level.
3- In solidly earthing method, the faulted phase current is very high which causes big damage to the system equipment’s. So, there is necessity to clear this fault immediately. Also, allocate of the fault are very difficult. This method reduces the overvoltage problem.
4- Low resistance method reduce the fault current to approximately 400 A. this magnitude damages the system equipment’s. There is line to line over voltage but the insulation level doesn’t increase due to clearing the fault in cycles. Allocating of the fault location is difficult.

7. References

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