Effect of Increasing the Grounding Grid Resistance of a Ground System at a Substation on the Safety and Transient Overvoltage on the Interior Equipments

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Abstract—**In substations, protective equipments such as arresters and neutral transformer are being connected to substation ground grid to protect them against transient overvoltage, firing and other damages. But unfortunately, lack of grounding connection of electrical equipments or high resistance of grounding grid is one of the main reasons which cause risk for staffs and electrical equipments. In this paper, effect of increasing in grounding grid resistance on transient overvoltage which is caused by short circuit, switching and lightning on the interior equipments and safety in a grounding grid at substation is investigated. Effect of transient overvoltage with different short circuits is another subject that is considered. In this paper, indices for ground grid safety are expressed and grounding grid analysis will be done with CYMGrd software. Transient analysis simulations are carried out using DigSilent software and the results of investigation on a real system are presented**

Keywords: Grounding Grid, Transient Overvoltage, Safety, Grounding Grid Resistance.

I. INTRODUCTION

Between the years 1880 and 1892 transmission and distribution lines were constructed without the neutral grounding point and no part of the equipments were connected to the ground. The problems such as electric shock, fire in homes and public places were existed and protective fuses could not recognize these faults. In 1924, Electrical Engineers in England forced factories and housing for using an earthing system in their products. In 1935, standards for protecting persons and equipments developed and earthing became public [1]. The further consideration of these standards is IEEE 80-2000, that most of the substation grounding grid designed according to this standard [2].

In some substations, after occurring some events like a short circuit fault in the output lines and breaker opening, despite the use of arresters, protective devices, earthing system and some of the interior equipments that feed from the interior consumption transformer of substation are damaged.

One of the factors that can cause by this problem is grounding grid resistance. In this paper, the effect of increasing in grounding grid resistance on amplitude of transient voltage and safety of grounding grid in different conditions is investigated.

Many researches have been done on grounding system. In [3], a calculation method of grounding system using analytical approaches is introduced, in which the soil is considered as uniform and the electrodes are considered as symmetric. The analysis of performance and design of a power station grounding system is usually performed using computer programs based on two-layer soil equivalent models [4]. Recently, Finite Element Method (FEM) has been used as an excellent numerical method to calculate the grounding system [5].

In this paper, CYMGrd software is used for analysis safety of grounding grid of substation. This software uses FEM for calculating grounding indices [6]. It is necessary to know some terms for designing the grounding grid in substation. Some of them are [7]:

1- Touch Voltage: it is the voltage between the energized object and the feet of a person in contact with the object.

2- Step Voltage: it is the voltage between the feet of a person standing near an energized grounded object.

3- Ground Potential Rise: it occurs when large current flows to earth through grounding grid impedance.

CYMGrd software can calculate resistance, touch potential distribution and step potential and other parameters of grounding grid. In this paper, DigSilent software is used for transient analysis.

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Transient voltage caused by three and single phase faults, switching and lightning with and without increasing in the grounding resistance are considered.

Effect of increasing the resistance of the ground grid on amplitude of transient voltage is expressed. Furthermore, some counter measures for reducing the effect of increasing the grounding resistance on transient voltage are introduced.

II. GROUNDING GRID

In each substation, the grounding grid is used for earthing electrical equipments. All of the electrical equipments in substation are connecting to grounding grid as a two objects [9]:

1- Electrical grounding

2- Protection grounding

The guide for designing the grounding systems in substation introduced by standard ANSI / IEEE 80 and developed gradually. In this standard, equations for designing of a simple grounding system are introduced.

The importance of well-designed grounding systems appears at the performance of power systems and safety of persons and operators. The main criteria for the design of grounding systems are:

1- Safety for the person works near or in the substation

2- Minimize the ground potential rise

The risk that threatens the person who works at substation, mainly due to touch and step voltages, that created when a short circuit or other phenomena occurs in the power system. Touch and step voltages are proportional to the ground potential rise and proportionality coefficient depends on quality of grounding system.

Electric current that flows into the earth causes increasing in ground potential rise and potential distribution on the ground surface. This potential distribution on ground determined as touch and step voltages. Whenever touch and step voltages do not exceed the permissible amount, the system is called safe. According to the standard ANSI / IEEE 80 in the study of the grounding grid following should be considered [2]:

1- Determine the resistivity of soil

2- Calculation of the ground potential rise

3- Calculation of touch and step voltages

4- Evaluation of safety

In this paper, CYMGrd is used for analysing the effect of the increasing in grounding grid resistance on safety of grounding grid. Following a brief explanation is given about CYMGrd.

A. CYMGrd

CYMGrd is designed according to the standard ANSI / IEEE 80. It is possible to design grounding grid in three-dimensional in this software [10].

Often in the design grounding grid, the soil model considered uniform and single layer but due to different strains in soil, accuracy of this model is not high.

CYMGrd has soil analysis part, which can design a two-layer model in addition to single-layer model for determining a resistivity of soil. Also the surface layer model of soil is considered in this software. CYMGrd uses Wenner method for

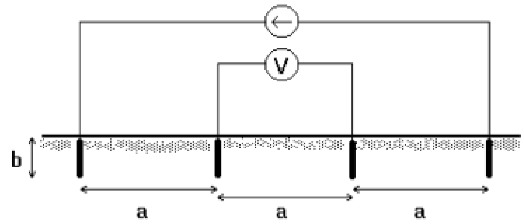

Fig. 1: Wenner method

determining soil resistivity as shown in Fig. 1.

In general, three-phase or line to line short circuit does not cause maximum ground potential rise. It is important to determine the maximum ground potential rise for grounding system. Often a single phase to ground short circuit at a specific location causes maximum ground potential rise to the grounding system which is called the worst short circuit. CYMGrd uses amplitude of single to ground fault current for determining ground potential rise.

Maximum touch and step voltages are determined in CYMGrd according to standard ANSI / IEEE 80. This criterion is defined in terms of human body tolerable current. It means the average amount of electrical current that persons can handle without electric shock. At standard ANSI / IEEE 80, permissible touch and step voltages, for a 70 kg person expressed according to the following equations [2]:

$$V_{permissible\ Touch} = \frac{0.157(1.5C_s\rho + 1000)}{\sqrt{t}} V \qquad (1)$$

$$V_{permissible\ step} = \frac{0.157(6C_s\rho + 1000)}{\sqrt{t}} V \qquad (2)$$

In these equations, ρ is soil resistivity of the below upper layer in Ohm meter, t is time that shock passes in second and 1000 is human body resistance in Ohm. C_s is the correction factor and is used due to non-uniform soil. C_s is calculated from equation (3) [2]:

$$C_s = 1 - \frac{0.09(1 - \frac{\rho}{\rho_s})}{2h_s + 0.09} \qquad (3)$$

Where, ρ_s is resistivity of upper layer and h_s is upper layer depth in meter. The suitable grounding system is a system in which the maximum touch and step voltages are less than or equal to permissible values introduced in the related standards.

Usually the maximum voltages are multiplied by a reduction factor, which are presented in Table 1. After determining the permissible touch and step voltages CYMGrd determines maximum of step and touch voltage and touch voltages distribution for safety analysis of grounding grid [6].

Table 1: Reduction factor in terms of shock duration

Shock duration	Reduction factor
0.0008	1.65
0.1	1.25
0.25	1.10
More 0.5	1.00

III. EFFECT OF INCREASING IN GROUNDING GRID RESISTANCE ON TRANSIENT VOLTAGE

In order to investigate the effect of increasing in grounding grid resistance on transient voltage caused by short circuit, switching and lightning on the interior equipments and safety in a grounding grid at the substation, a 132/20 kV substation is considered as an example. Fig. 2 shows the schematic equipments of substation.

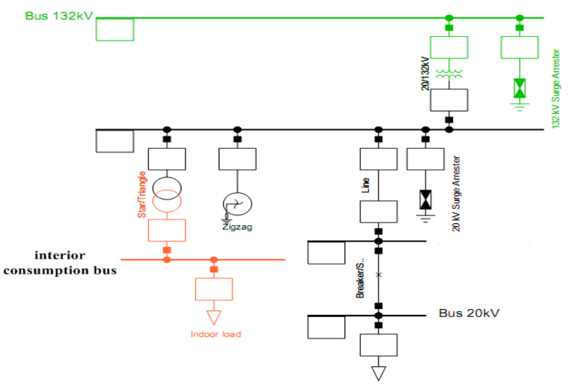

Fig. 2: Schematic of substation equipments

In this substation, transformer for interior consumption is 20/0.4 kV with type Δ / Y, and a zigzag transformer used for protection system. Two arresters are considered on both sides of the main transformer. These equipments are considered in DigSilent software. All neutral point of protection equipments and transformers are connected to the ground grid. Maximum interior consumption and output power of substation are considered to be 0.25 and 34 MW respectively, with power factor 0.85 (lag).

In this paper, the effect of increasing in grounding grid resistance on transient voltage is considered in different states. In states 1 and 2, for different value of grounding grid resistances three and single-phase short circuit occurs on 20 kV bus then breaker opens and transient voltage on the interior consumption bus of substation and safety of grounding grid are taken into account. In state 3, lightning meets the arrester and goes to grounding grid. In state 4, methods for reducing the effect of increase in grounding grid resistance on transient voltage at interior consumption bus is introduced.

The grounding grid of substation is shown in Fig. 3 and design in CYMGrd software. Other data of grounding grid is shown in Table 2. Soil model considered as single layer and maximum permissible touch and step voltages, ground resistance and reduction factor are shown in Table 3. Conductors type are Copper Anneal Soft Drawn and rods type are Copper-Clad Steel 20%.

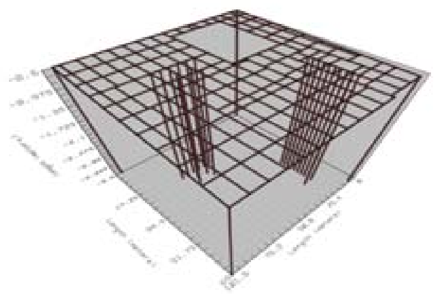

Fig. 3: Schematic of Grounding grid in CYMGrd

Table 2: Data of grounding grid

Layer Thickness	100 meters
Layer Resistivity	100 Ohm-m
Body Weight	70 kg
Surface Layer Thickness	0.15 meters
Surface Layer Resistivity	3000 Ohm-m
Shock Duration	1 sec
Ambient Temperature	50 centigrade

Table 3: Result of soil and Grid analysis

Maximum Permissible Touch Voltage	705.9 V
Maximum Permissible Step Voltage	2352.58 V
Ground Resistance	0.55 Ω
Reduction Factor (Cs)	0.776

The grounding grid that is considered for substation can provide staffs safety, and in various events amplitude of transient voltage on interior consumption bus is on the allowable range.

A. State 1

Often, the current that passes through the electrical equipments and switches in three-phase short circuit is more than other short circuit current, thus transient voltage due to this short circuit and breaker opening is higher than the others. Three-phase short circuit occurred on 20 kV bus at 0.1 second and after three cycle breaker opened. Three-phase short circuit is symmetrical therefore the current flow to ground due to this short circuit is zero. in order to check safety of grounding grid of substation in this state, maximum current that flows to ground from zigzag transformer and arrester at a time is used to evaluate the grounding grid. Another thing which should be mentioned is one meter step considered for grounding analysis.

Simulation was done for grounding grid resistance 0.55 and 1.1 Ohms. The maximum current that flow to ground at grounding grid resistance 0.55 and 1.1 Ohm are 0.72 and 0.7 kA respectively. Maximum bus voltage and grounding grid voltage are shown in Tables 4 and 5. The voltage of interior consumption bus when grounding grid resistance is 1.1 Ohm and three-phase short circuit occurs is shown in Fig. 4.

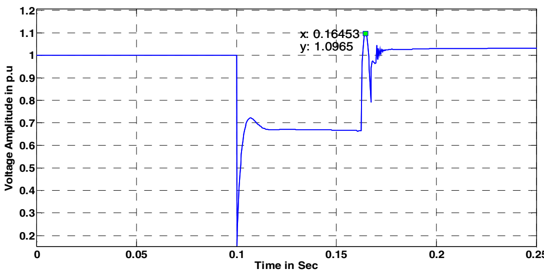

Fig. 4: Interior consumption bus voltage

Table 4: Maximum voltage in a symmetrical three- phase short circuit at interior consumption bus

Grounding Grid Resistance (Ohm)	Bus Voltage (p.u)
0.55	1.033
1.1	1.096

Table 5: Grounding grid voltage with grounding grid resistance 1.1 Ohm at three-phase short circuit

Ground Potential Rise	569.77 V
Maximum Step Voltage	18.24 V
Maximum Touch Voltage	114.17 V

At the symmetrical three-phase short circuit, when the resistance of grounding grid increase twice than suitable value, maximum voltage increases 6% in compares to the state that the grounding resistance is 0.55 Ohm and despite the increase in grounding resistance, maximum touch and step voltages are lower than the permissible value. So, in this state when grounding grid resistance is twice time bigger than the suitable value of transient voltage on the interior consumption bus which is created by three phase short circuit and switching can damage the electrical equipments of substation, but there is no problem in grounding grid indices.

B. State 2

The most of the short circuit in the distribution system is a single phase to ground. In this state, the effect of the increasing in grounding grid resistance on transient voltage at the interior consumption bus caused by single-phase to ground short circuit and switching is investigated. Unlike three phase short circuit, fault current of single phase to ground short circuit which flows to ground is not zero. So the maximum current of this short circuit that flows to ground from zigzag transformer and arrester at a time is used for grounding grid analysis.

Similar to state 1, single-phase to ground short circuit occurred on 20 kV bus at 0.1 second and after three cycles, breaker opened. Simulation was done for grounding grid resistance 0.55 and 1.1 Ohms. The maximum current that flows to ground at grounding grid resistance 0.55 and 1.1 Ohm are 1.6 and 1.4 kA respectively. Fig. 5, Tables 6 and 7 are shown the result of simulation.

The results show an increase in grounding grid resistance that is twice time bigger than the permissible value in single-phase to ground fault which causes 2.95% increase in maximum amplitude of transient voltage on the interior consumption bus. Similar to state 1, indices of grounding grid are lower than the permissible value.

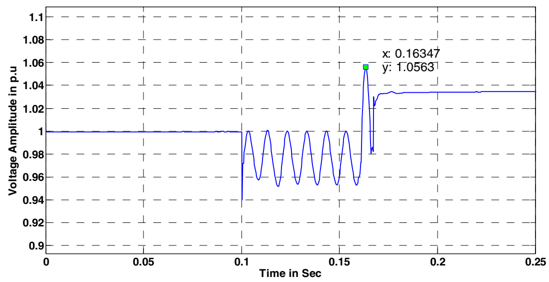

Fig. 5: Interior consumption bus voltage

Table 6: Maximum voltage in a symmetrical single- phase short circuit at interior consumption bus

Grounding Grid Resistance (Ohm)	Bus Voltage (p.u)
0.55	1.025
1.1	1.056

Table 7: Grounding grid voltage with grounding grid resistance 1.1 Ohm at single-phase short circuit

Ground Potential Rise	1019.05 V
Maximum Step Voltage	32.63 V
Maximum Touch Voltage	204.2 V

Due to high current amplitude in single-phase to ground short circuit, in this state also forth increases in grounding grid resistance is investigated. The grounding grid resistance is considered 2.2 Ohm and the results of simulation are shown in Fig. 6, Tables 8 and 9. The maximum amplitude of transient voltage increases 8.09% in compares to the state that grounding resistance is 0.55 Ohm. This voltage can damage the electrical equipments in substation. The grounding indices are lower than permissible value with no problem at safety of grounding system.

C. State 3

According to the British standard, with probability 50%, the lightning current is 25kA [11]. It is assumed that lightning meets the arrester and lightning current flows to grounding grid. Grounding grid resistance is considered twice higher than suitable value. The results of grounding system analysis are shown in Fig. 8 and Table 10. Interpretation of each color is expressed in Fig. 7.

In this state, maximum step voltage is lower than allowable value but the maximum touch voltage is 83% higher than the permissible value. So, the grounding grid is not able to provide safety for staff in substation.

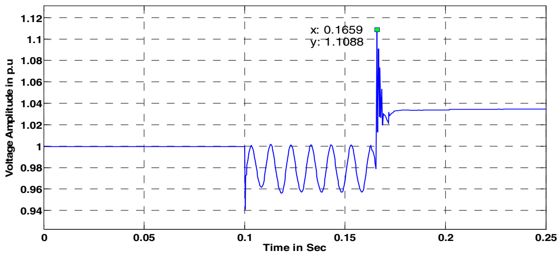

Fig. 6: Interior consumption bus voltage

Table 8: Maximum voltage in a single- phase short circuit at interior consumption bus

Grounding Grid Resistance (Ohm)	Bus Voltage (p.u)
2.2	1.108

Table 9: Grounding grid voltage with grounding grid resistance 2.2 Ohm at single-phase short circuit

Ground Potential Rise	1629.92 V
Maximum Step Voltage	59.79 V
Maximum Touch Voltage	378.17 V

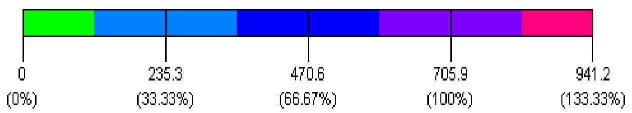

Fig. 7: The range voltage of each color

D. State 4

There are several methods for reducing the effect of the increase in grounding grid resistance on transient voltage such as install other auxiliary grounding grids beside main grid and connecting two grids together that cause decreasing in resistance of grounding grid.

Table 10: Grounding grid voltage with Grounding Grid Resistance 1.1 Ohm

Ground Potential Rise	5986.9 V
Maximum Step Voltage	191.68 V
Maximum Touch Voltage	1199.73 V

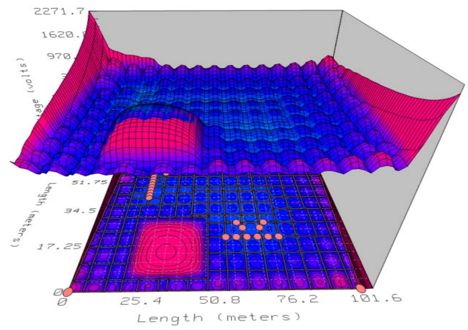

Fig. 8: Touch potential distribution at lightning current with grounding grid resistance 1.1 Ohm

For example, in the state that the grounding grid resistance of substation increases to 1.1 Ohms, an auxiliary grounding grid with dimension 30*30 is considered besides main grid and connect to main grid from two places. It assumed that lightning meets the arrester and lightning current flows to grounding grid. In this state touch potential distribution and indices of grounding grid is shown Table 11and Fig. 9.

In this state, an auxiliary grounding grid causes decreases in grounding grid resistance 0.11 Ohms. Maximum touch voltage is reduced, but it is still more than permissible touch voltage, and maximum step voltage is in the allowable range. So another auxiliary grid should be used besides other grids.

Table 11: Grounding grid indexes with decreasing in grounding grid resistance

Ground Resistance	0.99 Ω
Ground Potential Rise	4890.3 V
Maximum Step Voltage	171.68 V
Maximum Touch Voltage	850.73 V

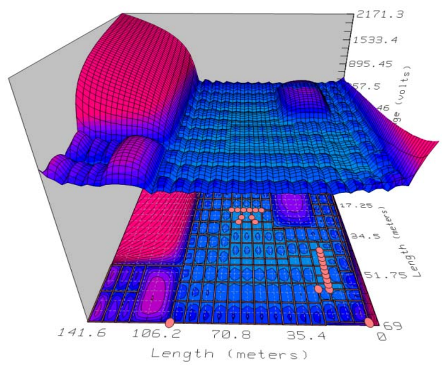

Fig. 9: Touch potential distribution at lightning current with decreasing in grounding grid resistance

IV. CONCLUSION

In this paper, the effect of increasing in grounding grid resistance on transient voltage at interior consumption bus and safety of grounding grid are investigated. The results of simulation show increasing in grounding grid resistance twice times more than the allowable value, at three-phase and single-phase to ground fault cause 6% and 2.95% increase in transient voltage on the interior consumption bus respectively that can damage the electrical equipments in substation but in these states, the safety of grounding grid indices are suitable. In the event of lightning, if the grounding resistance will be twice of suitable value, he maximum touch voltage increase 83% more than permissible value. This overvoltage can harm the substation staffs. So, in high fault current increase in grounding grid resistance at substation cause increase in maximum amplitude of transient voltage and remove safety of grounding grid. The effect of increase in grounding grid resistance on transient voltage can be reduced by decreasing grounding grid resistance with using auxiliary grid beside main grid.

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