Significance of Step and Touch Voltages

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***Abstract*— Abstract: Step and touch voltages play an important role when designing high voltage substation. Step and touch potentials near high voltage substation due to severe ground faults present a hazard to anyone in proximity to substation when a fault occurs. A primary issue of concern is hazardous step and touch voltage is that arise during fault situations, hence a reliable and efficient solution to the problem is essential. Although personnel safety is of primary concern, effect of electric current, resistance of the human body and tolerable voltage criteria considerations are also essential in the design system to ensure the protection of personnel and equipment. This study will briefly explain the significance of step and touch voltages.**

***Index Terms*— Step and Touch Voltages, Grounding System, Substation, Safety**

I. INTRODUCTION

The design for substation grounding system is considered for worker's safety in normal state and in fault of high current flow to substation grounding or approached area. The fault of high current flow to substation grounding may be the phenomenon of lightning or short-circuit grounding system. It causes potential difference and the result of potential difference causes electrical current paths through human body (between the two feet or between foot and hand). If the current is higher than tolerable human, the result may shock him to death. Good design of substation grounding system should have low grounding system resistance with considerable touch and step voltages in tolerable human. The purpose of this paper is to explain how the step and touch voltages are significant while designing of substation grounding [1-3].

II. PURPOSE OF GROUNDING SYSTEM

The purpose of a grounding system at a substation includes the following:

i. To provide the ground connection for the grounded neutral transformers, reactors and capacitors.
ii. To provide the discharge path for lightning rods, surge arrestors, spark gaps and other similar devices.
iii. To ensure safety to operating personnel by limiting potential differences that can exist in a substation.
iv. To provide a means of discharging and de- energizing equipment to proceed with maintenance on the equipment.
v. To provide a sufficiently low resistance path to ground to minimize rise in ground potential with respect to remote ground. The substation grounding system is connected to every individual equipment structure and installation in the substation so that it can provide the means by which grounding currents are conducted to remote areas.

III. EFFECT OF ELECTRIC CURRENT

In order to achieve safety criteria, it is vital to investigate the effect of current on the human body. There may be various consequences that may occur, depending upon the severity of shock, which depends on a number of factors that need to be examined. Human bodies are very sensitive to electric current at frequencies of 50Hz-60Hz therefore, a small magnitude of fault current may be dangerous. The two body functions that are vital for survival of human beings are: breathing (lungs) and blood circulation (heart beat). Hence, if either of these functions loses their ability to perform for more than a few minutes, the brain is starved of oxygen, and will result in catastrophic damage, eventually causing death.

If an electric current passes through the body, the current can disrupt the tiny electrical impulses that travel through the body's nervous system to control the heart and lung muscles. The amount of interference depends on the magnitude of the current, the duration of flow and the path of the flow. Current which flows through the brain or chest region, in the vicinity of where the heart and lungs are, more dangerous than a current passing through two fingers or from one foot to the other. If breathing ceases after an electric shock, the heart can go into ventricular fibrillation, which basically refers to the result of electrical impulses from the brain controlling the heart are confused enough to be out of step, making the heart rapid and eventually stop pumping blood leading to the termination of organs ability to function, ultimately causing loss of life. Furthermore, an electric current can also cause severe burns and causes muscles to tighten acutely. Death and injury do not necessarily occur as a direct result of electric shock but also indirectly. This is supported by evidence of people falling from energized ladders and power poles, and various other incidences. At the standard power supply frequency of 50 Hz, the passage of an electric current through the human body may cause:

Asphyxia: Muscles in the respiratory system function for inhaling and exhaling of air by the lungs. Electric shock causes these muscles to undergo contraction, in turn; the affected person may die as a result of suffocation.

Ventricular fibrillation: It is a condition that entails a lack of coordination of the contraction of the muscle tissue of the large chambers of the heart and therefore, causing uneven pumping of the heart, eventually causing the heart to cease. Fibrillations are usually fatal because all the heart muscle cells move independently.

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Cardiac fibrillation: The human heart is a pump that, with the coordinated and rhythmical contraction and expansion of its muscular fibers ensures circulation of blood throughout the body. When an electric current enters these fibers, the heart rate becomes irregular with increasingly uneven contractions, which may cause total cardiac arrest.

Muscular contraction: This can occur as a result of sufficient enough current flowing through a person at a time where they are in contact with a live part of a transmission line. Muscular contraction occurs when the part of the body in contact to the live part concerned does not have enough strength to release them self from the grasp.

Burns: These are caused by electrocution is due to heating of tissues.

Effects of a current passing through a human body depend on a number of inter-related factors those are:- (i) Current Path (ii) Frequency (iii) Current magnitude (iv) Duration of time (v) Body impedance (vi) Body sensitivity

It is evident through extensive research that electric current of frequencies of 50Hz and 60Hz imposed on a human body is very harmful. Even a small magnitude of current of 0.1A can be harmful. However, current frequencies of 3000Hz to 10000Hz are not as hazardous, and in some cases the human body is able to tolerate very high currents due to lightning surges (Dalziel and Mansfield; Dalziel, Ogden, and Abbott). The International Electro technical Commission provides curves for the tolerable body current as a function of frequency and for capacitive discharge currents [IEC 60479-2 (1987-03)] [4].

It is recommended that currents should be kept below the fibrillating threshold through a particularly good designed earthing system, in order to avoid death due to an electric shock. The values of current that flows during an electric shock are dependent on two factors. First is the potential difference across the body causing the shock and second the body's resistance. Hence, safety limits need to be predetermined in order to attain safety. These are known as the step and touch potential limits. The type of voltage also has different effects, because an alternating voltage changes its polarity at regular intervals and does not have the same effect on the muscles as a direct voltage. A shock with a direct voltage causes the muscles to contract, making it almost impossible to let go of the live conductor. An alternating voltage may allow an individual to let go, although this depends on the magnitude of the current. The total resistance is a result of the combination of contact resistance between the skin and the live conductor as well as the resistance of the body. Wet conditions provide a better surface for conduction of current since the resistance is decreased. Thus, the current can flow more easily on wet surfaces from the point of contact through the body and to the ground. Hence, standing barefoot is obviously very dangerous. The threshold of fibrillation was determined by Dalziel et al. (Dalziel, Lagen, and Thurston [10]; Dalziel and Massogilia [11]).

According to Dalziel et al. [10-11] the nonfilbrillating IB current of magnitude at durations ranging from 0.03-3 s is related to the energy absorbed by the body as described by the equation.

$$SB = (IB)^2 \times ts \quad (1)$$

Where, IB: R.M.S. magnitude of the current through the body in amperes; ts::The duration of the current exposure in seconds; SB : Empirical constant related to the electric shock energy tolerated by a certain percent of a given population. Therefore from the equation given above and the current magnitude, the duration of tolerable current can be attained.

IV. RESISTANCE OF THE HUMAN BODY

The magnitude of current that flows through the human body is directly related to the electrical resistance of the human body. The internal resistance of the human body is approximated as 300Ω. The resistance of the human body varies under different situations, that is, under dry conditions the resistance of can reach up to 100,000 Ω, conversely, under wet conditions or damaged skin the resistance may drop down to 1000 Ω. Since water is a good conductor, any wet conditions may significantly increase the chances of electrocution. Extensive tests were conducted by Dalziel to determine the safe let-go currents. From the test results the following values were obtained: the hand to hand contact resistance is equal to 2330 Ohms, and the hand to feet resistance is equal to 1130 ohms, based on Dalziel's experiment. For the purpose of safety, the resistance of a human body was assumed to be taken as 1000 Ohms. The electrical resistance of the human body depends on a number of factors listed below:

(i) The age and sex of the individual.

(ii) The state of the skin that is in contact with the energized object.

(iii) Type of insulation (shoes, etc.) .

(iv)Voltage difference of contact.

(v) The mechanical pressure with which the contact is made.

(vi) The individual's composition of blood (salt, alcohol etc.).

However, at high voltages the skin is punctured, typically causing deep burns and therefore, only the internal impedance of the body can be applied to limit the shock current. Dalziel conducted experiments on animals in order to establish the threshold of fibrillation. Dalziel's experiments proved that for shocks of 3 second duration; there was a relationship between body weight and fibrillating body shock currents for animals of the same species. From Dalziel's investigation and results, a mathematical equation for the threshold of ventricular fibrillation was developed:

$$I_B = \frac{k}{\sqrt{t}} mA \quad (2)$$

Where, IB: Body shock current at the threshold of fibrillation; t: Duration of the flow of that current; k: Constant that varies according to human body weight.

Dalziel's research was based on individual body weights of 50kg and 70kg. Thus, the design should be based on these weights.

According to Dalziel's study, at a frequency of 60Hz, for 0.05% of persons that are vulnerable against shock current; the minimum value of the body shock current at the threshold of fibrillation was 95mA for 70 kg body weight and 67mA for 50 kg body weight. Hence, the shock energy can be determined. This results in a value of SB = 0.0135. Thus, k50 = 0.116 and the formula for the allowable body current is given by the relation:

$$I_B = \frac{0.116}{\sqrt{t}} mA \qquad \text{for 50 kg body weight} \quad (3)$$

As mentioned earlier, Equation (3) is only based on durations of (0.03– 3s) and thus, is not valid for shorter or longer durations. Further studies by Dalziel and other researchers lead to alternate values of k, eventually, k = 0.157 and SB = 0.0246 was confirmed as being applicable to persons weighing 70 kg, as a result:

$$I_B = \frac{0.157}{\sqrt{t}} mA \qquad \text{for 70kg body weight} \quad (4)$$

V. STEP AND TOUCH VOLTAGES

A person walking on the surface of the ground will experience a voltage between his/her feet. This voltage will generate electric body currents. In this case, the voltage to which the person is subjected is called step voltage.

A person touching a structure which has a potential that is different from that of the point of ground at which the person is standing. In this case, the person is subjected to a voltage that will generate an electric current through his or her body. The voltage to which the human body is subjected is called the touch voltage [1]-[2].The three most likely paths for current to flow through the body are:

(i) Hand-to-hand through the chest area
(ii) Hand-to-foot
(iii) Foot-to-foot

The magnitude of these voltages depends on the following factors:

(i) The value of fault current (ii) Upper and lower resistivity of the soil (iii) Area of the grid

Step and touch voltages, which occur when a short - circuit current flows through the grounding electrodes of power lines and substation, may be causes of dangerous electric shocks. An accurate estimation of the values of these voltages can be obtained by field measurement [3]. In any of the following cases including earth faults, switching and lightning over voltages prove to cause hazardous earth potentials that are produced by power frequency and transient earth currents. There are a number of ways in which power safety voltages and transient voltages are generated.

Power safety voltages are generated via conduction of fault currents and induced voltages. Conduction of fault currents substantially contributes to safety issues that are linked with voltage rises that result from power frequency earth fault currents into the ground. Therefore, hazardous situations arise due to step, touch and transfer voltages. These voltages may induce electromagnetically in fences, pipelines, conveyors and communication cables due to the flow of current in high voltage power lines, or electro statically in case of when an item of equipment runs parallel to a transmission line for a distance . Transient voltages occur due to atmospheric origin such as lightening strikes to ground or due to man made origin, which are created during switching that eventually cause arcing between isolator and disconnected contacts. Although, lightning surge to earth elapses for a short period of time, it may in turn have greater consequences as a result of a 'follow through' of a power frequency current [4].

VI. SEASONAL INFLUENCES ON STEP AND TOUCH VOLTAGES

In rainy season, the low resistivity soil layer leads the grounding resistance and the step voltage smaller than the respective values in normal condition, it is good for the safety of human beings, but the raining season perhaps leads the touch voltage higher than its limit value, so the influence of raining on the safety of grounding grid should be considered. The touch voltage of the ground surface increases with the thickness or the resistivity of the freezing soil layer. When the thickness of the freezing soil layer exceeds the burial depth of the grounding system, touch voltage sharply increases. If the resistivity of the freezing soil layer reaches 5000Ω.m, then the touch voltage will increase to 12 times of the respective value in normal condition. Then high resistivity soil layer would lead step voltage higher than the respective value of the grounding system in normal condition. The step voltage increases with resistivity of the freezing soil layer. Even if a granite layer is added, the limit of touch voltage is still smaller than the actual touch. Adding vertical grounding electrodes can effectively decreases the touch voltage to improve the safety of grounding system. In high freezing areas, the design of grounding grid should strictly analyze the influence of freezing soil layer on the safety of the grounding system [5].The limits of step and touch voltages in different seasons are shown in Table 1.The limits of step and touch voltages decrease in rainy season and increase in freezing season.

However, in normal conditions, the grounding grid is buried in homogeneous soil with resistivity of 200Ω.m , the maximum step and touch voltages are 547 and 1481 V respectively, if the surface material is not used, and the limits of step and touch voltages are 316 and 187 V, the maximum step and touch voltages exceed their respective limits. If a granite layer is used, the limits of tolerable step and touch voltages are 9131V and 2390 V, hence, the grounding system is safe. This proves that surface granite layer should be used to raise the tolerable safety limits, and therefore, the grounding system in any condition will be safe. An accurate method for calculating the Thevenins resistance of step, touch and transferred voltage should be considered [13].

Table 1. Limits of step and touch potentials in different seasons

Resistivity of the soil layer affected by different season	Without granite layer		With granite layer	
	Step voltage limit (V)	Touch voltage limit (V)	Step voltage limit (V)	Touch voltage limit (V)
10 Ω·m	152.5	146.0	3123.5	888.8
40 Ω·m	178.4	152.5	3130.8	890.6
100 Ω·m	230.2	165.5	3148.1	894.9
200 Ω·m	316.5	187.0	9130.6	2389.9
500 Ω·m	575.5	251.8	9208.3	2410.1
1200 Ω·m	1179.8	402.9	9396.1	2456.9
5000 Ω·m	4460.3	1223.0	10412.6	2711.1

VII. TOLERABLE VOLTAGE CRITERIA (FOR STEP AND TOUCH VOLTAGES)

The human body can tolerate a considerable amount of current for a short period of time. For the human body to be safe, this value of current must be kept below a certain level that may cause ventricular fibrillation. The values of maximum allowable step and touch voltages for a person weighing 50 kg and 70 kg are given as follows:

$$E_{Step} = I_B(R_B + 2R_f) \quad (5)$$

Thus, applying Dalziel's relationship to Equation (5) and assuming the resistance is of a human body is 1000Ω. The step voltage limit is given as:

For a 50 kg person:

$$E_{Step50} = \frac{0.116}{\sqrt{t}}(1000 + 6C_s\rho_s) \quad (6)$$

For a 70 kg person:

$$E_{Step70} = \frac{0.157}{\sqrt{t}}(1000 + 6C_s\rho_s) \quad (7)$$

Similarly, the touch voltage limit is given as:

For a 50 kg person:

$$E_{Touch50} = \frac{0.116}{\sqrt{t}}(1000 + 1.5C_s\rho_s) \quad (8)$$

For a 70 kg person:

$$E_{Touch70} = \frac{0.157}{\sqrt{t}}(1000 + 1.5C_s\rho_s) \quad (9)$$

Where,

C_s: Derating factor to surface layer thickness and resistivity; C_s: (=1) Crushed rock resistivity is equal to soil resistivity; ρ_s: Resistivity of surface material in Ω.m; t: Duration of shock current in seconds.

VIII. MESH VOLTAGE

Mesh voltage is the potential between the surface of the earth in the center of a grid mesh and grid voltage. In other words it is the maximum touch voltage within a mesh of a ground grid. As the mesh voltage is usually the worst possible touch voltage inside the substation (excluding transferred potentials), thus, mesh voltage may be used as the basis of designing a high voltage substation. For equally spaced ground grids, the mesh voltage will increase along meshes from the center to the corner of the grid. The rate of this increase will depends on the size of the grid, number and location of ground rods, spacing of parallel conductors, diameters and depth of the conductors, and the resistivity profile of the soil. However, the mesh voltage may not be the worst-case touch voltage if ground rods are located near the perimeters, or if the mesh spacing near the perimeters is small. In these cases, the touch voltage at the corner of the grid may exceed the corner mesh voltage. The area of the grounding system, the conductor spacing, and the depth of the round grid have the most impact on the mesh voltage, while parameters such as the conductor diameters and the thickness of the surfacing material have less impact. If the mesh voltage is higher than tolerable touch voltage then high voltage substation design needs modification. If the mesh voltage is lower than tolerable touch voltage then high voltage substation design has achieved the safe design [6]-[7].

The design of main ground grid for gas insulated switchgear (GIS) indoor substation and air insulated switchgear indoor substation is same. The design criteria will be met when the ground potential rise (GPR) is lesser than tolerable touch voltage, otherwise the mesh and step voltage must be lesser than the tolerable step and touch voltage. The reduction of mesh and step voltage can only be achieved by the addition of ground rods to main ground grid [8].

In the field of grounding system design the quality means that how these grounding system safe guard those people from dangerous electrical shock as well as minimizing the cost of design to satisfy optimization. An evolutionary algorithm in combination with a field computation tool is used as new method that helps not only in designing of grounding system but also in getting its optimum parameters [9]. A new method and instrument for measuring touch and step voltages near a grounding system, for example in and around a substation may be used [12].

IX. CONCLUSION

The step and touch voltages are dangerous for human body. Human body may get electric shocks from step and touch voltages. From the safety point of view it is necessary to calculate step and touch voltage.

When high voltage substations are designed step and touch voltages should be calculated and must be in specified standard. The expected shock current IB caused by touch voltage can be effectively limited by applying inexpensive insulating layers on the earth's surface .The limits of step and touch potentials varies in different seasons because the resistivity of the soil layer is affected by different seasons .The step and touch voltage calculations are very significant while designing gas insulated switchgear (GIS) indoor substation and air insulated switchgear (AIS) indoor substation.

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