TRANSFERRED POTENTIAL - A HIDDEN KILLER OF MANY LINEMEN

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Abstract – Causes for electrical accidents which occur during maintenance of power line are sometimes not traceable. Unfortunately, a grounding practice which has been widely adopted in the utility industry in India, Britain and some other countries, unintentionally causes so many fatal accidents every year. The conclusion was arrived after analyzing some fatal accidents. This practice of protective grounding is still continued by many distribution companies without realizing the hazards involved.

For de-energized line maintenance, grounding the line at source end is commonly practiced for the purpose of personal protection. The paper explains, how this safety practice turns into hazard by transferring substation ground grid potential to worksite, and why this transferred potential, cannot be controlled by any means, in 3 wire overhead distribution system which runs with no separated ground wire.

The paper suggests, the solution to avoid the transferred potential and to describe it in the IEEE Std 1048 - Guide for Protective Grounding of Power Lines, IEEE Std 80-2000 - Guide for Safety in AC Substation Grounding, British Std 7430 - Code of Practice for Earthing and Indian Std 3043 - Code of Practice for Earthing, to bring an end to the accidents caused by this safety practice.

Index Terms - Electrostatic induction, Equipotential bonding, Ground Potential Rise, Let-go current, Magnetic induction, Metal-to-metal voltage, Personal protective grounding and Transferred potential.

I. INTRODUCTION

The discussion in this paper is confined only to *3phase 3wire (3ph, 3w) neutral solidly grounded systems* with overhead radial distribution lines run with no dedicated neutral or ground conductor. This kind of distribution system is widely adopted in many countries including India.

For de-energized line maintenance, a common practice in India and some other countries is to ground the line both at the source end and at the work site. This practice is being followed in transmission as well as distribution networks. The distribution lines, 11kV, 22kV & 33kV are normally 3ph 3wire with no separate neutral or ground wire. In actuality, during maintenance, the practice of grounding the distribution line at the source end, which is intended to safeguard the worker, causes uncontrollable transferred potential at the work site.

This paper discusses modifications required in the personal protective grounding practices to prevent accidents caused by the transferred potential.

II. PROTECTIVE GROUNDING CURRENTLY PRACTICED

Normally, maintenance works are carried out on a distribution line only after providing personal protective grounding either at the worksite alone or both at the source end and at the worksite. The advantages of each method are discussed below.

A. Protective Grounding at Worksite Alone

Work on a de-energized overhead line can be considered safe only if, in the event of any voltage being accidentally imposed on the line, the body current caused by the voltage should be well within the human *let-go* magnitude.

Attempt to control the voltages by temporarily grounding the line at the worksite fails, because the grounding does not bring down the *line - Earth* resistance sufficiently to divert hazardous voltages. But, it does aid in causing the source which energizes the line to trip [1]. Hence grounding at worksite alone cannot be considered as an effective safety measure to control the voltages. In addition to grounding at the worksite an equipotential zone should be established to overcome the effects of the hazardous voltages.

B. Benefits of Grounding at Source end, in Addition to Grounding at the Worksite, and its Limitations

Providing protective grounding on the distribution lines at the source end in addition to the worksite grounding is being practiced in many distribution companies. Though it has some advantages, it has a strong limitation for those advantages as listed below.

1) *Re-energization*: If the voltage source which has been disconnected to carry out a maintenance work is mistakenly reconnected, all the phase voltages of the source get shorted with the neutral, through the metallic path offered by the grounding connection made at the source end. Hence the inadvertent voltage appearing on the line due to reconnection of the source can be controlled within a safe limit.
2) *Energization from a Different Source*: If any accidental extension of supply from another source occurs, the

grounding made at the source end will offer a path of minimum possible impedance to the grounded neutral of the source which energizes the line thereby diverting the voltage effectively.

3) *Controlling the effects of Electrostatic Induction*: The grounding connection made at the source end, effectively shorts the capacitance formed between the de-energized line and the Earth, thereby divert the voltage which may develop on the line with respect to ground due to electrostatic induction.

4) *Limitations*: Above stated reasons justify the practice of grounding the line additionally at the source end. But this practice minimizes the hazards and ensures safety only if the ground potential of the substation always remains at zero. A ground fault can raise the ground potential at any time and hence this practice only maximizes the hazards to the line worker. This accounts for the lack of a good safety record with the accepted maintenance practice in 3 wire systems with no grounding wire.

III. GROUND POTENTIAL RISE IN DISTRIBUTION SUBSTATIONS

In solidly grounded system the substation ground grid potential is always at neutral potential of the power transformer. The neutral potential remains at Earth potential only during normal conditions. Whenever a current passes through resistance offered by the substation ground grid, the potential of the neutral and hence the ground grid rises with respect to the remote Earth. This rise in voltage will reflect on the enclosure of all the equipments, metallic structures, which are connected to the substation ground grid, and also reflect on the soil in and around the substation.

Figure 1 illustrates a single line to ground fault on a distribution line of a substation (fault is shown as a closed switch). Power transformer in the distribution substation is Delta/Wye connected and the wye point is solidly grounded. The fault is developed on the low voltage (LV) side due to direct contact of the line conductor with the supporting metallic pole outside the substation area at a remote location (impedance formed between the line and metallic pole is neglected). Since there is no neutral or ground wire, the entire fault current is driven into the Earth at the fault location through the grounding resistance of the metallic pole (R_P). The current then spreads in the Earth and finally reaches the power transformer neutral through the substation ground grid. Along the path of current, area offered by the soil is confined at the fault location (entry into the Earth) and at the substation (exit from the Earth). The fault current encounters significant resistance at both these locations and results in *Ground Potential Rise (GPR)* both at the substation and at the fault location. Other than at these locations, the Earth offers an enormous area to the fault current, therefore the resistance is negligible and hence the ground potential remains at zero.

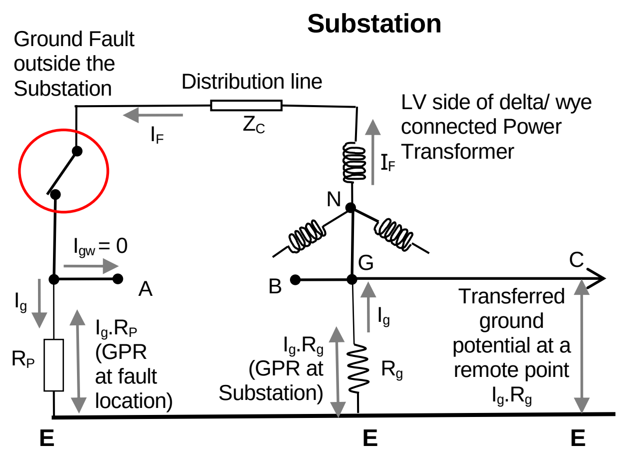

Figure 1: Transfer of Substation Ground Potential during Ground Fault in a 3w System

Z_C - Combined impedance of source and the faulty line,
R_P- Grounding resistance of the pole,
R_g - Substation ground grid resistance,
I_g - Fault current through R_g,
I_{gw} - Fault current through ground wire,
I_F -Total fault current.
G - Ground grid
E - Remote Earth

The GPR of a substation is the product of substation ground grid resistance (R_g) and the portion of the ground fault current which returns to the power transformer neutral through the substation ground grid (I_g). So, the GPR at substation is $I_g \times R_g$. Similarly GPR at faulty pole is $I_g \times R_P$, where R_P is the grounding resistance of the pole.

The effects of GPR are step potential and touch potential. Since the substations are designed to overcome these effects, GPR at the substation is not considered as serious in comparison to the GPR at fault location. But the effect of the substation GPR is also dangerous whenever the ground grid potential of the substation is permitted to transfer outside the substation area. Figure 1 illustrates how the raised ground grid potential gets transferred outside the substation area through a grounded conductor (GC).

IV. AN ACCIDENT DURING A DE-ENERGISED WORK

A maintenance work was being carried out on an overhead distribution line by two linemen after de-energizing, isolating and grounding the line at substation end. The line has no neutral or ground conductor. Additional grounding was provided at the worksite using temporary ground rods, but without establishing equipotential bonding at worksite. During the work, the workers suddenly experienced a severe shock. One of them was electrocuted and the other sustained severe injuries.

Generally if the cause of such an accident is not revealed by usual methods of analysis, it is determined to be an accident caused by an induced potential from an adjacent live line. But the effect of electrostatic or electromagnetic induction is significant only in parallel feeders and the effects are not normally significant in lower voltage (< = 33kV) distribution feeders which are normally run in single circuit.

A. *Preliminary Analysis :*

On examining the substation and the worksite after the accident, the personal protective grounding was found to be undisturbed. No incorrect operations had been carried out. There was no live line crossing or passing adjacent to the line under maintenance. Therefore possibility of any physical contact or induction from any adjacent line was ruled out. But, during the time of the accident another feeder breaker in the same sub-station which fed the line being worked on tripped due to a ground fault.

The coincidence of this fault event and the accident was not considered relevant in the preliminary analysis.

On further analysis, the cause for the accident and the relevancy of the substation feeder ground fault trip were revealed. What follows is a detailed analysis of the causes of the accident.

B. *Accident in Detail:*

The power transformer in the distribution substation was 10MVA capacity, 110 kV/ 11kV ratio, Delta / Wye connected with solidly grounded neutral. All the outgoing feeder lines were overhead line with no dedicated neutral or ground conductor. Ground wire of 110kV incoming feeder was kept isolated from the substation ground grid.

The work was carried out on the line (see Figure 2) after grounding the line (feeder-A) at the substation end. During the work a ground fault occurred in another line (feeder-B). It raised the ground potential of the substation. The grounding connection made on the de-energized line at the source end for personal protection effectively transferred the raised substation ground grid potential to the worksite through the de-energized line. Since there was only temporary grounding and no equipotential bonding connection provided at worksite, the supporting pole remained at remote ground potential. Therefore the entire transferred voltage appeared across the worker's body. The body current and its duration, caused by this transferred voltage exceeded the tolerable limit and resulted in a fatality. Some of similar accidents, which had been "closed" without finding the real cause, were also analyzed. From the records it was noted that during the time of these accidents feeder breakers in the substations had tripped due to ground faults as well. The protective grounds on the isolated line also remained undisturbed both at the substation and at the worksite in all the cases. A record of establishing equipotential bonding was found in none of the cases.

V. DISTRIBUTION OF GROUND FAULT CURRENT

The GPR of a substation depend upon both ground grid resistance and ground grid current. For a distribution substation, normally, the ground grid resistance is high and the ground grid current which is a portion of the ground fault current is also high, relative to the transmission substation. Let us see why it is so, by comparing the grid current of these substations, for a ground fault external to the substations, in detail.

1. A transmission line normally interconnects many sources. For a ground fault on a transmission line, multiple sources feed the fault and hence the current which returns to an individual source is only a small portion of the total fault current.

   But the distribution feeders (non grid feeders) are normally fed by a single source. Hence the entire fault current has to return to that particular source.
2. The transmission towers are steel structures and the lines always run with ground wires whose ends are normally connected to the source neutrals. For a ground fault outside the substation, only a small portion of the fault current returns to the source neutral through the ground grid, the remaining portion returns through the ground wires of, both the faulty line and other transmission lines, which offer metallic paths to the source neutral.

   But the distribution feeders normally run without any neutral or ground conductors. Also the ground wire of the incoming transmission line of a distribution substation is usually isolated from the substation ground grid to avoid transfer of the substation ground potential to nearby tower bases. Therefore, for a ground fault on a distribution line outside the substation, entire portion of the fault current is fed into the Earth at the fault location and the entire portion has to return only through the substation ground grid to the source neutral.
3. Auto transformers in transmission substation are normally wye connected and the neutral point is solidly grounded. For a ground fault on LV side in any one of the transmission lines outside the substation area, the auto transformer LV contributes some fault current and the HV side draws an equivalent current from its source. The substation ground grid offers a common path for both the LV and HV currents. Since both the currents are almost opposite to each other, the net ground grid current (difference between the LV and HV, grid currents) is still lesser than the LV grid current.

   The power transformer in the distribution substations are normally delta / wye connected. For ground fault on LV side, the entire fault current returns to LV neutral through the ground grid, but, the current drawn by the delta connected HV from its source(equivalent to LV fault current), circulate through the line conductors, and not through the ground grid. Hence the ground fault current, which is entirely fed by LV side, is the net ground grid current.

In the figure 1, the non-availability of the ground wire is shown as open circuit between the points A&B and hence I_{gw} is equal to zero.

Since $I_{gw} = 0$ and the supply is fed by single source through delta/star connected power transformer,

$I_g = I_F$. Therefore,

$$GPR = I_F \times R_g \text{ ………………. (1)}$$

Since entire quantity of the fault current accounts for the GPR, the GPR and its effects are normally very high in distribution substations in comparison to a transmission substation.

The following sections explain in detail, how the transferred ground potential causes a hazard in a distribution system having no ground conductor, during a de-energized line maintenance.

VI. EFFECT OF GROUNDING AT SUBSTATION

Grounding a de-energized line at the substation end to carry out a maintenance work outside the substation does not raise any problem if the ground grid potential of the substation remains within the tolerable limit of the line worker. Controlling the ground grid potential within this limit during the work is practically impossible because it requires isolation of the entire substation from all sources of supply. We shall discuss the hazards of the transferred potential caused by the grounding practice in detail.

A. The Transferred Potential Vs Step and Touch Potentials

During ground fault a rise in potential possibly in the order of thousands of volts for a fraction of a second is permitted on the metallic enclosure of the substation equipments with respect to remote Earth. This raised ground potential causes potential gradient in and around the substation and results in step and touch potentials. The design of the substations should control the step and touch potentials and its effects, within a tolerable limit at substation area. But the substation design does not ensure safety from the raised ground potential which may get transferred outside the substation area by other means. This is also not practically possible.

To control the effect of step and touch potentials, a layer of high resistivity material, such as gravel, is often spread on the Earth's surface above the ground grid to increase the contact resistance between the soil and the feet of persons in the substation [4]. The increased resistance supports to keep the body current caused by the step and touch potential within the tolerable limit.

But unlike step and touch potentials at a substation, the effect of the transferred *ground potential* cannot be controlled by design features of the substation because;

1. The magnitude of the transferred potential on the line conductor with respect to the supporting pole which is at remote ground potential can be as much as GPR.
2. The Transferred potential is not always a touch voltage; it becomes a *metal to metal touch voltage* if the supporting pole is a metallic one. For the *metal to metal touch voltage*, the current through the worker's body has to be limited by the resistance of the worker's body (in the order of 1000Ω) alone.

B. Transferred Potential Vs Direct Extension of Supply

Grounding a de-energized line at the source end is considered as an essential safety measure to overcome the effects of accidental reconnection of supply from the source end. But it transfers the ground grid potential to the worksite. To ascertain the relative risk associated with the accidentally reconnected supply and the transferred potential, let us compare these effects in detail.

1) *Effects of Accidentally Reconnected 3ph Voltage:* Let us consider a line which is de-energized and grounded at worksite and not grounded at substation, is energized with three phase supply from the substation end mistakenly.

For the accidental voltage at substation, the interconnection made for grounding the three line conductors at the worksite, forms a wye connected load. The interconnected portion act as a neutral and the line conductors themselves act as the load impedance. The worksite grounding establishes connection between this neutral point and Earth. Since the value of the resistance offered by the worksite grounding is significant, it does not play any major role in controlling the neutral voltage at worksite. The neutral voltage at the worksite will be zero if all the phase voltages which are mistakenly extended at the source end and impedances offered by the line conductors are balanced. Only any unbalance (caused by difference in switching time of individual phases or unbalance in supply voltage or unbalance in impedance, etc.) will result in development of some voltage at the neutral point and therefore on the line conductors at the worksite.

Since high short circuit currents are stimulated by the worksite grounding, the protective relay quickly operates and trips, the breaker, through which the voltage got extended accidentally.

Hence both the magnitude and duration of the voltage which is mistakenly extended to the worksite can be controlled within safe limit by grounding with equipotential bonding at the worksite alone.

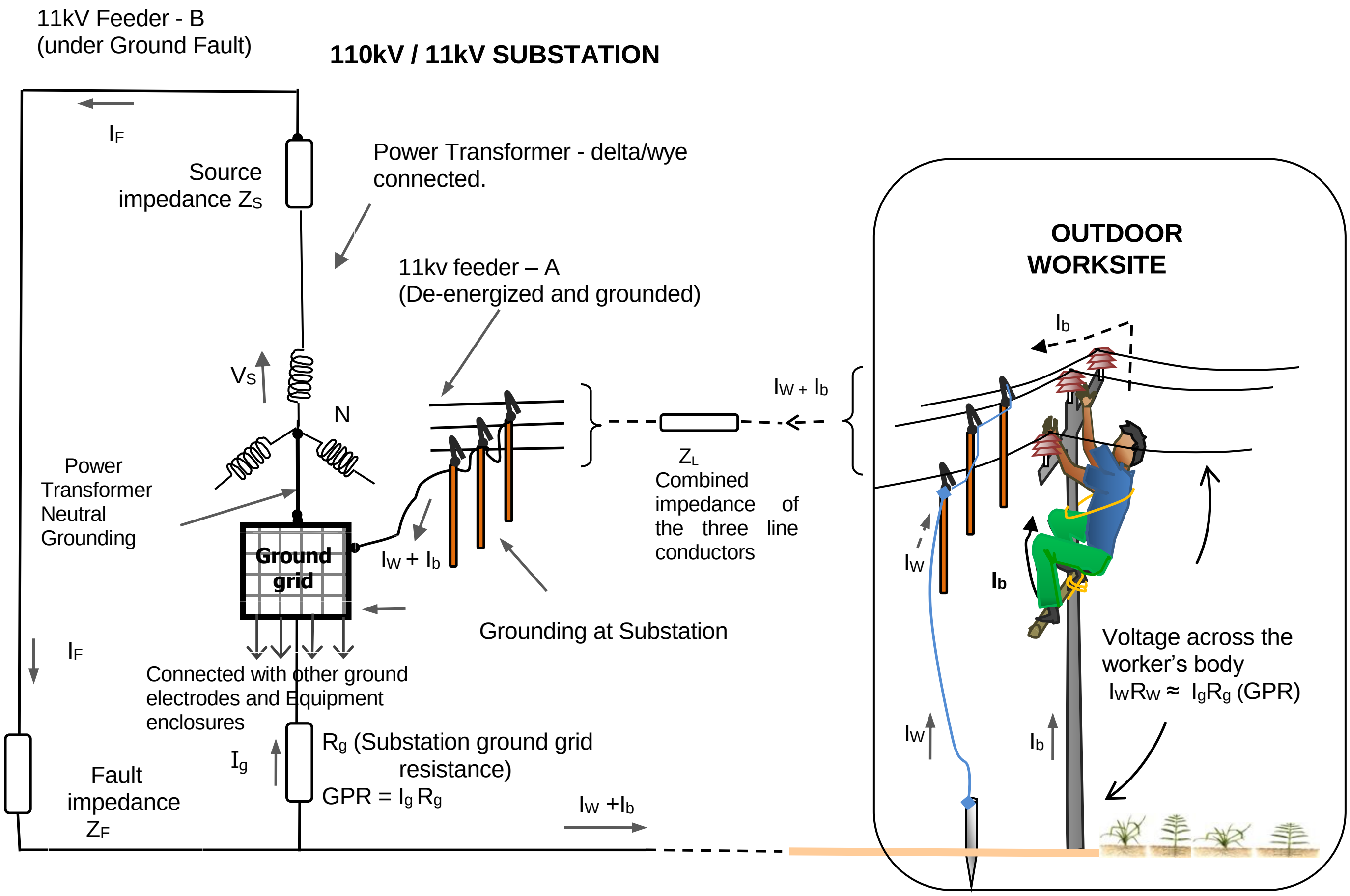

Figure 2 : The Accident - Transfer of Ground Grid Potential to Worksite
R_B - Resistance of human body
I_F - Total fault current,
I_g - Current through substation ground grid
I_W - Current through the Temprarary grounding,
I_B - Current through the worker's body

2) *Effects of the Transferred Ground Potential: Grounding the* line at the substation end in addition to the worksite bridges the two locations and transfers the *substation ground grid potential* to the worksite by direct conduction through the metallic path offered by the three paralleled line conductors (see Figure 3*)*.

The severity and probability of the hazard caused by the transferred potential are high in comparison to the direct extension of voltage caused by inappropriate three-phase energization of the line. Details are as follows;

1. In distribution substations, the ground grid resistance is normally high and the ground fault on distribution lines occurs frequently. Hence the magnitude of ground potential which gets transferred to the worksite and its frequency of occurrence are also high.
2. As the transferred ground potential appears on the line only with respect to the mass of *Earth*, grounding the line at work site cannot offer low impedance path between the line and the Earth to effectively divert the transferred voltage.

At substation end, distribution feeders are normally provided with isolating switches on both sides of the circuit breaker. The line can be completely isolated from the supply by opening of, these two line switches in addition to opening of the circuit breaker. The isolated line requires three separate operations for re-energization. Therefore probability for an unintentional or negligent reconnection of the line with the source is very low and can be eliminated totally by reasonable procedures. But the probability for GPR in the distribution substations due to ground fault in any of a distribution lines while carrying out de-energized line work in another feeder of the same sub-station is very high. Grounding the lines at the substation presents a greater hazard than if the lines are not grounded at the substation though this seems counterintuitive. The other dangerous effects of grounding the de-energized line at the source end are detailed in the following discussion.

C. Can Worksite Grounding Control the Transferred Potential?

Let us analyze the role of protective grounding on controlling the transferred potential.

Transferred potential at worksite on a line, which is grounded both at substation and worksite, due to a ground fault in another distribution line of the substation is illustrated in Figure 2. The equivalent circuits are also shown in figures 3 & 4.

V_S - Phase voltage of the power transformer.
Z_S - Impedance of the source
Z_F - Fault impedance
Z_C - Combined impedance of source and fault.
Z_L - Net impedance offered by the 3 paralleled line conductors between the substation and at worksite.
R_W - Resistance of the grounding made at worksite.
R_g - Resistance of the substation ground grid.
R_B - Resistance of the worker's body.
I_g - Fault current through the ground grid from the surrounding Earth.

Let us calculate the maximum transferred voltage while carrying out the line work. To find out the maximum transferred voltage, the worksite is considered to be out of GPR zone.

1) *Without Protective Grounding at the Worksite:* The ground potential transferred to the worksite without protective grounding at worksite is illustrated in the Figure 1.
From equation (1)
$GPR = I_F.R_g$

Therefore Transferred Potential = $I_F.R_g$ = GPR

Since there is no protective grounding at the worksite (the line is open circuited at worksite), the maximum transferred ground potential will be as much as GPR of the substation.

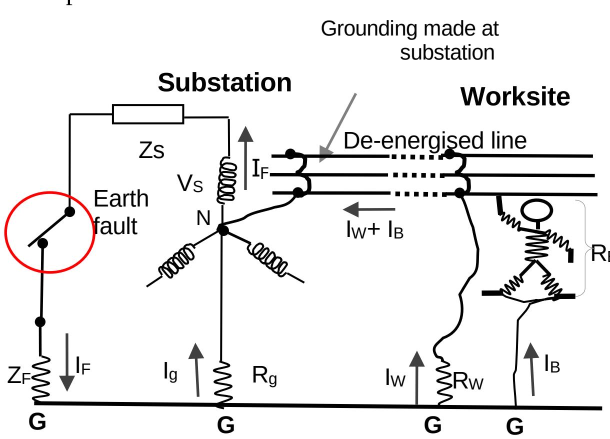

Figure 3: The Accident - Equivalent Circuit

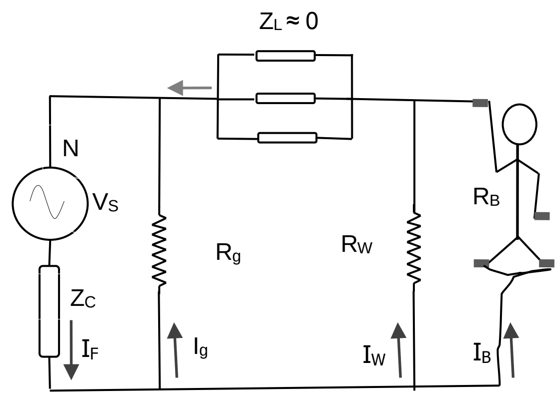

Figure 4: Simplified Equivalent Circuit

2) *With Protective Grounding at the Worksite*: Figure 2, 3 & 4 illustrate the effect of introducing the worksite grounding on controlling the transferred potential, and therefore controlling the body current (I_b).

a) *Net impedance of the line conductors* (Z_L): The line impedance (Z_L) is neglected for the calculation of transferred potential, due to the following reasons.

For line maintenance far away from the substation, apart from opening the line switch at the substation, another switch if available nearby the worksite towards the substation, is also opened. Therefore, substation ground potential does not get transferred to worksite.

If the worksite is not far away from the substation, no other line switch can be found other than the one at the substation itself. Hence only for the line maintenance which is carried out within a few kilometers distance from substation, the isolation and grounding at substation is practiced, in addition to grounding at worksite. The interconnections made for grounding the line conductors at the substation end and at the worksite offer three parallel paths between these locations. Hence the net impedance (Z_L) of the short portion of three paralleled line conductors is significantly smaller in comparison to the impedance offered by the protective grounding (R_W) at the worksite (see Figure 4) and hence Z_L is neglected in the calculations.

b) *Thevenin voltage*: Thevenin voltage between the points A & B can be calculated by simplifying the circuit (see Figure 5). Since Z_L is very small, it is omitted in the circuit.

$I_g + I_W = I_F$

Since $R_W >> R_g$, $I_W << I_g$. Hence I_W can be neglected.

Therefore $I_g = I_F$.

Now, the Thevenin voltage, $V_{th} \approx I_F \times R_g = GPR$.

c) *Thevenin impedance*: Between the points A & B, Thevenin impedance (Z_{TH}) is the parallel combination of, R_W, R_g & Z_C (see Figure 6), whose net value is very less (less than the least among the three).

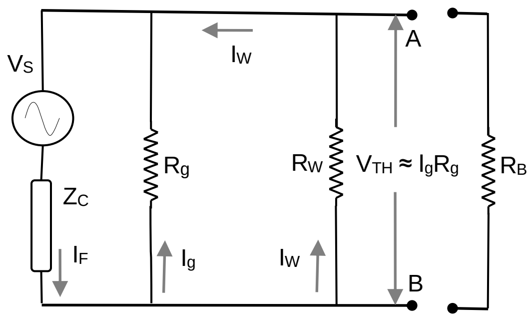

Figure 5: Thevenin Voltage

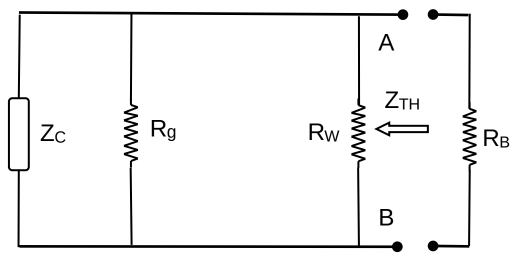

Figure 6: Thevenin Impedance

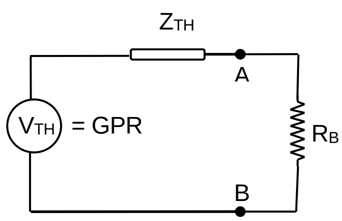

Figure 7: Thevenin equivalent circuit

d) *Thevenin equivalent circuit*: In the Thevenin equivalent circuit (see Figure 7), since $Z_{TH} << R_B$, almost the entire ground potential of the substation gets transferred without any drop and applies across Worker's body (R_B).

Hence the protective grounding at the worksite does not ensure protection against the transferred potential.

3) *Numerical Example*: Let us verify this with a numerical example (see Figure 8).

Let,

The substation ground grid resistance, $R_g = 1\ \Omega$.
The worksite grounding resistance $R_W = 10\ \Omega$.
The worker's body's resistance $R_B = 1000\ \Omega$.
Ground fault current $I_F = 1101$ A

a) *Without worksite grounding: Since there is no* worksite grounding and Z_L is neglected, R_g & R_B are parallel.

$$GPR = I_F. (R_g\ ll^{le}\ R_B)$$
$$= 1101 \times 0.999 = 1100V$$

Under this condition, the entire ground potential (1100V) transfers and applies across the worker.
Body current = 1100V / 1000Ω = 1.1A

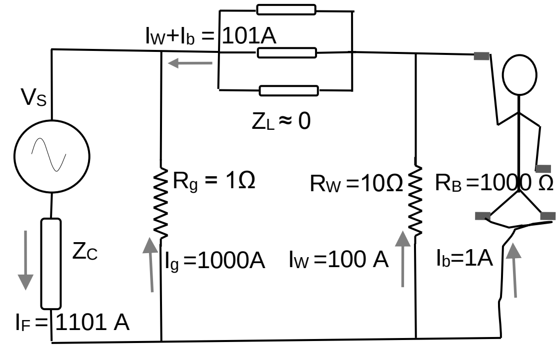

Figure 8: Fault Current with Numeric values

b) *With worksite grounding*: Under this condition, same fault current ($I_F = 1101$ A) is assumed. This fault current, split among the parallel resistances 1 **Ω**, 10 **Ω** and 1000 **Ω** along the return path to the source neutral.

Combined value of resistances (R_C) = 0.908 Ω
$GPR = I_F.R_C = 1101 \times 0.908 = 1000$ V

Here, the protective grounding at the worksite diverts a portion of the fault current (100 A) and lowers the voltage at the worksite, but not sufficiently. The voltage on the line is still 1000V, even after introducing the worksite grounding.

Body current (I_b) = 1000V / 1000Ω = 1A.

The body current is still 1 A. After introducing the worksite grounding it is reduced only by 100 mA.

Since the potential transferred to the worksite does not appear between the line conductors, and appears on all these line conductors with respect to the Earth, it is impossible to offer sufficiently low impedance path by providing temporary grounding at worksite to divert the transferred voltage.

D. Can this Transferred Potential Cause Electrocution?

Ground faults on distribution lines are frequent. Some of the ground faults are temporary and persist only for a brief period. So, after a fault, before proceeding for line patrol, the line is normally test charged which again leads to GPR if the fault persists. Hence the probability of transferred potential when carrying out de-energized work on a distribution line which is grounded at the source end is increased.

Since the transferred potential normally disappears within a fraction of a second, the important question is whether the ground potential transferred to the worksite is capable of causing electrocution? The answer is yes. The tolerable limit of electric shock depends on the body current and its duration.

Consider de-energized line work carried out on a metallic pole; under this condition, the transferred potential at worksite is a metal to metal touch voltage; the body resistance (1000Ω) is the main resistance in the circuit.

During a ground fault, a transferred potential in the order of 1000V is common. Assuming these values of voltage and resistance,

Current through the body, I = 1000V/1000Ω = 1A.

For a current of I through the body, the maximum tolerable duration ***t*** can be calculated by using Dalziel's formula.

I = 116 /√t (I in mA and t in seconds)……………… (3)

Let us apply the value of 1000 mA in this relation.

1000 = 116/√t which gives, t = 13.4 milli seconds.

For the transferred voltage not to be lethal, the protective gear should clear the fault within this small duration. But normally it takes more than 250 milli seconds, so, a fatal accident is probable.

Now, let us calculate the tolerable body current for this fault clearing time of 0.25 seconds.

I = 116 / √0.25 = 232 mA

For this value of tolerable body current, let us calculate the tolerable transferred voltage. Since the body resistance is 1000Ω, the maximum tolerable transferred potential for 250 ms duration is 232 mA x 1 K Ω = 232 V.

Therefore a transferred potential of above 232 V (for example 240V) is sufficient to cause electrocution within the fault clearing time of 250 ms.

IEEE Guide 80-2000 states: "In the 9–25 mA range, currents may be painful and can make it difficult or impossible to release energized objects grasped by the hand" [4].

So, a transferred potential of 25V (25mA x 1kΩ) is sufficient to induce a person to lose control while working on a line supported by a metallic pole and can cause fatal accidents due to mechanical injuries if the worker is not fall protected. Then, how is it possible to keep the GPR less than the 25V in the design of a substation?

E. Effect of Grounding on Magnetically Induced Voltage

The grounding made on a line at the source end for personal protection, can effectively suppress the electrostatically induced voltages. But, on the other hand, it offers a ground reference to the electromagnetically induced voltages.

Let us consider a radial line, which is isolated from supply at a substation and runs parallel to another live line. The isolated line will have some voltage between its ends due to the magnetic field induction. For any fault on the live line, the induced voltage, which depends upon the current in the adjacent live line, will be very high.

If the isolated line is grounded at the substation end for line maintenance outside the substation, a difference in potential which exists on the line conductor at worksite with respect to the substation end will now get transferred and appear on the line conductor at the worksite with respect to the local ground. This transferred voltage cannot be sufficiently diverted by providing safety grounding on the line additionally at the worksite.

In IEEE 1048[2], the effects of induced voltage at the worksite arising due to the provision of protective grounding on the line at the source end is detailed.

Hence to safe guard the worker from the effects of electromagnetically induced voltage during the de-energized line work, grounding shall not be provided at the source end. On the other hand, the voltage if any, due to electrostatic induction as well as the electromagnetic induction can be effectively controlled by establishing equipotential zone in addition to the grounding at the worksite.

VII. SAFETY PROCEDURE INCREASES THE HAZARDS

Applying of Hierarchy of Hazard Control Measures provided in *American National Standard Institute* (ANSI) Z10 for Arc flash hazard is detailed by Marcelo E. Valdes in his paper [3]. Similarly it can be applied for the transferred potential hazards also.

ANSI Z10 identifies a ranking for specific types of hazard mitigation methods. At the top of the list is "*elimination of the* hazard". A total elimination of the activity, equipment, environment, system or situation that creates the hazard could fall in this category. Since line conductors which are isolated from supply and grounded at the substation becomes live for every GPR, handling these grounded conductors should be treated as a live work and for *elimination of the* hazard, the work should not be carried out on the line with protective grounding at the source end. But presently, work on the line which is grounded at the substation is treated as a de-energized line work and hence the work is normally carried out without wearing insulating devices such as boots and gloves. Here the entire safety against shock rests only on how effectively the equipotential zone can be established at worksite.

IEEE Guide 80-2000[4] states:

1. "People often assume that any grounded object can be safely touched. A low substation ground resistance is not, in itself, a guarantee of safety".
2. "It is impractical, and often impossible, to design a ground grid to control the touch voltage caused by external transferred voltages".

Handling the line conductors which are grounded at the source end is equivalent to touching the ground grid from the remote Earth.

Again, it is clearly stated in [5], as "the amount of rise in potential on the line at the worksite is a function of the relative conductor and earth impedances".

In a 3w system having no ground conductor, the impedance offered by the worksite grounding is very high in comparison to the line impedance from the substation to the worksite, and hence the potential transferred is not controllable by adopting any methods at the worksite.

The need for removing protective grounding at source end to isolate worksite from the transferred potential while carrying out de-energized cable work is detailed in [6].

The distribution of power using only 3 line conductors (without ground wire) is a common practice in many countries. Surprisingly, this problem unique to the widely used 3w distribution system discussed in this paper has not been highlighted in any safety codes. The authors believe that this specific distribution system and the associated hazard caused by transferred potential needs to be specifically addressed in the relevant industry standards. Addressing this situation in the relevant standards can prevent accidents and fatalities that are occurring now. It is the hope of the authors that this paper initiates this discussion and results in the standards addressing this hazard being modified so lives can be saved in the future.

VIII. CONCLUSIONS

The practice of grounding an isolated distribution line at the source end, effectively suppresses the voltages arising out of accidental extension such as physical contact with another live line. On the other hand this practice transfers the *substation ground potential* to the worksite during GPR. The first one is a rare event and its effects can further be minimized. The second one of transferring substation ground potential is severe because GPR is a daily event in a distribution substation and the transferred voltage can be as high as GPR. Hence grounding at the source end, which has been considered as an essential and obviously appropriate safety practice, has an unintended consequence that is a greater hazard than the hazard it seeks to prevent.

Many distribution companies have framed a rule of practice to provide protective grounding on the line at source end before carrying out a de-energized line work. Hence this paper proposes that

1. The practice of providing protective grounding at the source end during de-energized line work shall be discarded to prevent the transferred potential. The protective grounding at the worksite alone should be practiced along with equipotential bonding connection as per the IEEE standard 1048[2].
2. To avoid accidents, the dangerous effects of transferred potential caused due to the provision of protective grounding at the source end shall be described in IEEE Std 1048 - Guide for Protective Grounding of Power lines, IEEE Std 80-2000 - Guide for Safety in AC Substation Grounding, British Std 7430 - Code of Practice for Earthing and Indian Std 3043 - Code of Practice for Earthing, etc.

Establishing an equipotential zone at the worksite is indeed a very good safety measure. It can help to overcome the effect of accidental voltages including the transferred potential. But it cannot prevent the transferred potential. It is not possible to establish an equipotential zone if the worker is handling the line conductors when supporting his body over a wooden or concrete pole or when standing on the ground.

The three wire distribution network running with no neutral or ground wire becomes live during every GPR if grounding the de-energized line at source end is practiced. Hence for *elimination of the hazard* which is ranked at the top of the list for hazard mitigation identified by ANSI Z10, practice of grounding the line at source end needs to be discarded.

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DISCUSSION

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Grounding is one of the most miss-understood aspects of electrical power systems and the transferred earth potentials component of power system grounding is even less understood. I read this paper with great interest and wish to commend the authors for tackling the subject - especially as it relates to worker safety within their country and it is counter to existing practices. Having been in 30 different countries and observing installations world-wide, it is very apparent to me that safety grounding is commonly misunderstood world-wide. The reference to investigating other accidents that had been "closed" without finding the cause, speaks to this point.

The authors correctly identified the transferred earth potential and that it was the greater risk (I called it "transfer by grounded conductors" in reference 5). This speaks to the need for insulated boom trucks, always using insulated gloves, bonding the metal pole below their feet to the temporary ground and working through practices that involve the equi-potential bonding mentioned. Further details addressing wood and cement poles are a logical extension of their work. It is my hope that the Authors can leverage their work with this paper to educate and affect real change in safety practices within India and elsewhere.

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Proper grounding during maintenance of circuits that could, accidentally become live is a key factor in maximizing safety for maintenance personnel. It is critically important that practices employed in any specific situation be evaluated routinely to ensure they truly are optimal mitigating solutions for the possible hazards that may be encountered. The research and evaluation provided by the authors seem to indicate that practices that may be appropriate in some parts of the world under one set of conditions seem to not be optimal for the conditions under which work is performed where the authors acquired their data.

This writer believes it is incumbent on authorities that regulate this work and the safety professionals that formalize the required procedures that they take the conclusions the authors of this paper have reached into consideration and re-evaluate current practices against the reality of current work practices, recent accident records and the reality of how work is actually done by maintenance personnel, versus how maybe it should be done in an ideal situation. The analysis the authors have provided seems to clearly indicate that the current practices are less than optimal and a new set of procedures is needed. It seems to me that actual grounding practices at the substation need to be re-examined, how bonding and safety grounding is performed where the work is being carried out and potentially PPE practices need to be re-evaluated, adjusted and enforced.

XI. VITA

K.Suresh, working as Assistant Executive Engineer in Special Maintenance, Dharmapuri, TANGEDCO, Tamilnadu, India. He is a Certified Energy Auditor and is currently conducting research on “Hazards in the Present Protective Grounding Practices” and making efforts to incorporate the safety aspects in relevant standards. The research gains importance because, within a year, over five fatal accidents were caused by the grounding practice in a small region (within 50-km radius) of a distribution company, and the hazardous practice is still continued by many countries, including India.