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Electrical Isolation of Two Earthing Systems under Lightning Conditions with TiO_2 Nano Fluid Barrier

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***Abstract*— A Titanium dioxide (TiO_2) nano fluid based potential barrier is proposed to separate two earthing systems which are in the proximity with each other, yet, should not have a transfer of potential between them. Such systems are often required in MV/LV transformers that have delta-star configuration. The TiO_2 in the nano-fluidic form extruded into the cavity in the ground, get mixed with surrounding soil to form an extremely high resistive medium that prevents the electrical continuity between the two electrode systems via soil. Laboratory experiments show that depending on the resistivity and nature of the surrounding soil the resistivity of the TiO_2-soil mixture could have resistivity that vary from about 10^5 Ωm to 10^{12} Ωm. By extruding to ground a 5 cm thick, semi cylindrical TiO_2 nano-fluid mix of resistivity 10^7 Ωm, having a radius of 2 m and depth of 1 m below the electrode length, the potential at a boundary point of the barrier could be reduced from 75 kV to 1.85 kV when 100 kV impulse is injected to the earthing electrode.**

Keywords*— *Earthing, lightning, transient, potential gradient, Titanium dioxide, soil

I. INTRODUCTION

Either in transient or steady conditions, one of the serious challenges that an earthing system designer encounters is the human/animal safety of the possible bystandards or bypassers [1, 2]. The secondary issue is the transfer of potential from one system to another which may cause both human injuries and equipment damage. The latter may involve heavy financial losses and down time. Thus many standards have set forth design criteria to minimize step potential, touch potential and potential transfer, especially in the cases of grounding HV or MV systems [1-6]. These design criteria also play a vital role in risk analysis and management, and electrical safety related policy development [7].

Most often, the hazards due to potential rises are mitigated by keeping a minimum ground seperation between the injection of electrical energy and the position of potential victim [1-4]. However, there could be many instances where the site space does not permit ground spacing stipulated in standards due to practical reasons. Such space-restricted sites impose many limitations on both achiving low earth resistance and prevention of potential transformer from one system to a another [8]. There are many attempts made to achive low earth resistance in a space restricted site, adopting such as deep driven electrodes, earth conductivity enhancement materials, soil conditioning etc. [9, 10], however, such attempts on reducing the transfer of potential have not been found in abundance in the literature. One of the key area with respect to this phenomena, yet to be investigated in detail is to develop systems for substations that transfer MV to LV (where Delta-Star transformation is usually used). In this paper we produce the preliminary results of a latest technique that has been tested for barriering potential from being transferred from one earthing system to another.

II. ISOLATION OF EARTHING SYSTEMS AT A SUBSTATION

At an MV transformer site (eg. 11 kV/0.415 kV) it is customary to isolate the neutral earthing of the star point of the secondary from the other earthing systems at the site [1, 2]. The other earthing systems at the site are the transformer body earth and the earth of the lightning protection system (LPS) of the primary. Typically it is allowed to integrate the transformer body earth and the LPS earth of the primary. This scenario is depicted in Figure 1.

There are two issues of interconnecting the neutral eath (E1) and the body +LPS Earth (E2). In the event of such integration;

a. If there is a significant neutral current that raise the neutral potential it will be transferred to the transformer body (transfer of neutral potential). Thus, in the event of a person or animal touching the transformer body, he or it may be subject to touch potential.
b. In the event of a lightning strike to the primary, the transient overvoltage (due to finite impedance of the earthing system), will be transferred to all the consumers via the neutral wire.

These effects will be minimized by seperating the two earthing systems. However, unless they are seperated by a considerable distance, the potential transfer could still be possible due to the finite conductivity of the soil. This issue is addressed in vaious standards and also by various power companies by stipulating a certain minimum seperation distance which could vary from 4 m to 12 m. Most of these fixed values are rules of thumb rather than a numerical figure based on scientific findings. The amount of potential transfer at a given distannce is based on the electrode configuration and most importantly the soil resistivity profile of the site. Thus, a fixed value of seperation of the two earthing systems may not work well in most of the cases. Additionally, the space restriction of the site may limit the ability of the designer to stipulate large values of seperation.

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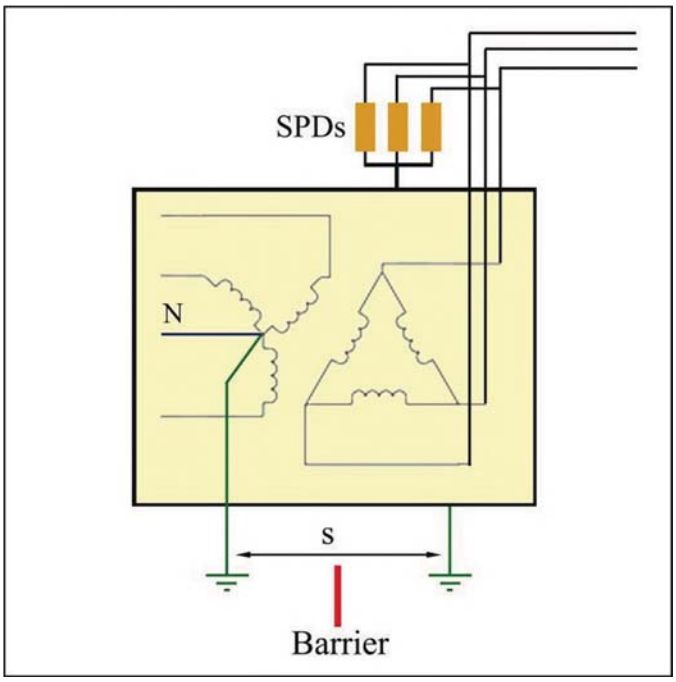

Figure 1. Two earthing systems of a delta-star transformer. S is the seperation distance recommended to prevent transfer of earth potential rise at one electrode system.

III. TiO_2 NANO-FLUIDS

Titanium dioxide (TiO2) is the naturally found xide of Titanium, usually found in the excavation of minerals such as anatase,brookite and rutile. It is also known as Titania. In the last decade, TiO2 became a hot focus among scientist as they invented titanium dioxide nanoparticle dispersed distilled water, which is now popularly known as Titanium nano-fluid. The material first caught the attention of the researchers due to its interesting behavior of thermal conductivity and several other mechanical properties [12]. It also became a point of interest to electrical engineers as it has an extremely high electrical resistivity which can vary in the range of $10^{10} – 10^{12}$ Ωm [13]. Such high resistivity, together with its viscosity, thermal properties and other mechanical characteristics make it highly suitable for many electrical applications where good insulation properties are demanded. Thus, in this study we used, for the first time in the literature, TiO_2 nano-fluid as a medium to be introduced in between electrical grounding systems to prevent electrical potential gradient extending from one electrode to another in the event of injecting transient currents to one of them (Figure 1).

IV. METHODOLOGY

The behavior TiO_2 nano fluids as it is extruded into a ground cavity is under investigation at present. The change of resistivity of the TiO_2 depends on the resistivity of soil, its particle size and moisture level. The preliminary results of such investigation on the range of resistivity of TiO_2 nano fluid – soil has been used as a simulation input in this study. The details of such measurements and outcomes will be published as a separate paper.

A typical single deep driven rod earthing configuration was simulated in 3-Dimensions in the ANSYS Maxwell software (Figure 2). A copper rod of length 4 m and circular cross-section (of cross-sectional area of 100 mm^2) was buried vertically in soil that has a resistivity of 500 Ωm (0.002 S/m). Then the potential gradient was calculated along the radial distance from the electrode by injecting a 100 kV lightning impulse (1.2/50 μs) in to the electrode.

Then the same procedure was repeated by introducing the semi-cylindrical potential barrier of depth 5 m surrounding the electrode (Figure 3). The potential at a point adjacent to the other side of the barrier (labelled as observation point) has been calculated. The observation point is 2 m + the barrier width (eg. 2.5 m for barrier width of 0.5 m) away from the electrode. The resistivity of the TiO_2 nano fluid-soil was varied over a range of realistic values.

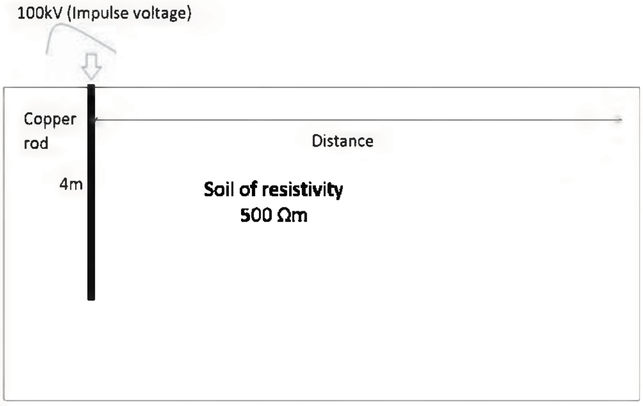

Figure 2. The electrode arrangement for the computation of potential along radial distance (in 3-D)

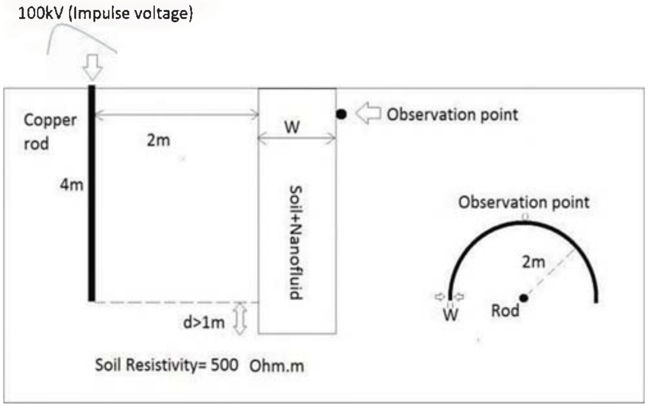

Figure 3. The electrode arrangement with the semi-cylindrical barrier with TiO2 nano fluid and soil. The left hand side diagram provides the cross sectional view whereas the right hand side diagram depicts the plan view

V. RESULTS AND DISCUSSION

Figure 4 depicts the variation of the peak value of the transient potential, radially away from the electrode in the absence of the barrier. Figure 5 shows the 2-dimensional distribution of the potential around the electrode. We considered a typical soil resistivity values in both countries where this work has been conducted; Iran and South Africa. The zero potential boundary was considered as a cylindrical surface, 100 m away from the electrode. It can be seen that the potential at a distance of 2.5 m is about 76 kV and the potential gradient is slightly greater than 3 kV/m. Even at 15 km away the potential is nearly 59 kV and the potential gradient is about 1 kV/m. If such potential is developed in the body earth due to a lightning to the primary (passed into earth via SPDs), then the potential transferred to the neutral earth which is few meters away could be lethal to the equipment of the consumers fed by the transformer irrespective of the LV wiring system. In the presence of coordinated SPDs at the consumer end the effects could be minimized, however, it is not mandatory in many countries for the consumers to have SPDs at their LV installations.

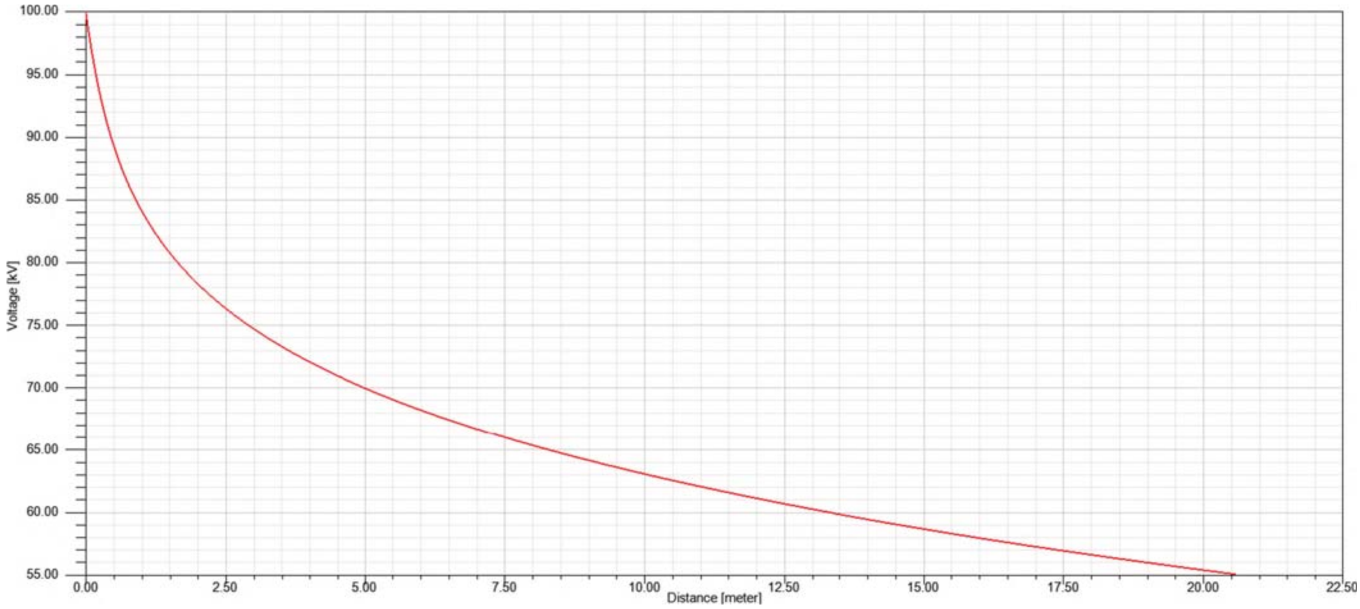

Figure 3. Potential distribution along the radial direction away from the electrode which is subjected to a transient potential of peak value 100 kV

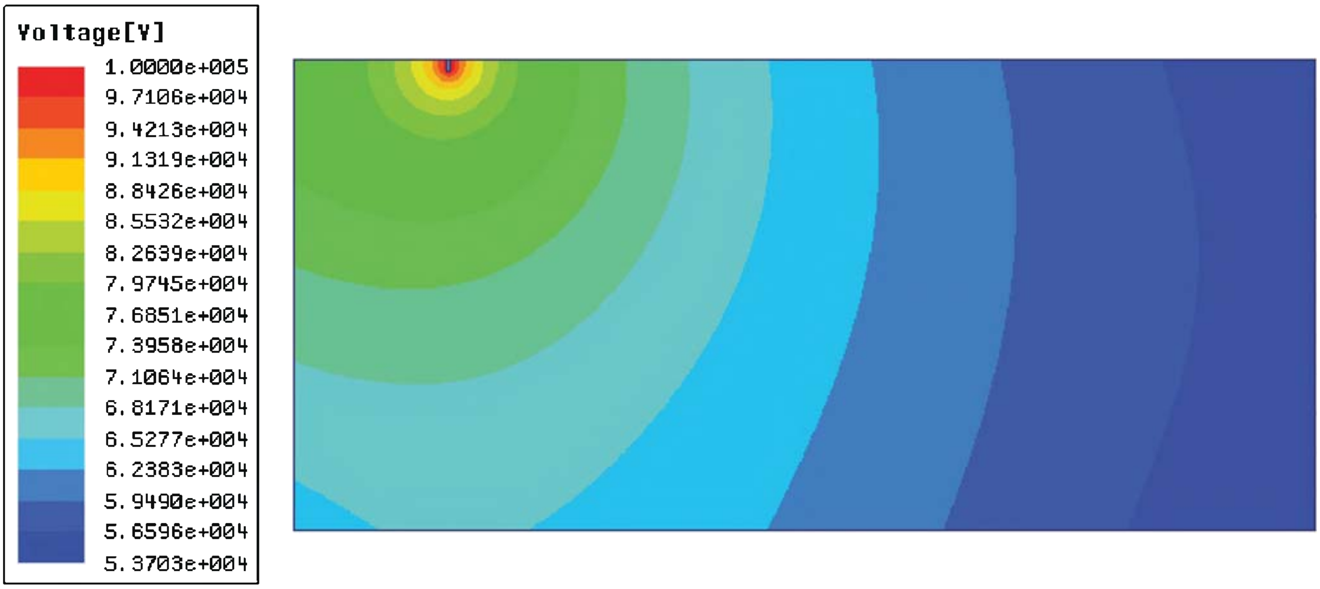

Figure 4. The 2-D distribution Patten of the potential as the earth electrode is subjected to 100 kV transient impulse.

Table I shows the potential and potential gradient at the observation point for a barrier width of 50 cm. Thus the observation point is 2.5 m away from the electrode. The resistivity of the TiO_2 nano fluid – soil was varied from 105 Ωm to 10^{12} Ωm. At 2.5 m away from the electrode the potential now reduces to approximately 1 kV when the material resistivity of the barrier is around 10^7-10^8 Ωm. This value is well below the voltage protection level (U_p) value of most LV surge protective devices and also is much lower than the impulse withstanding voltage (U_w) of a majority of LV equipment and components [14]. The potential gradient at the same point is also negligibly small in relation with human or animal safety.

Table II shows the simulation output for the poetical and potential drop beyond the barrier (2.05 – 2.7 m away from the electrode) for the material resistivity of the barrier of 10^7 Ωm. This confirms that even a 5 cm thick barrier could appreciably reduce the potential and potential gradient due to transient earth potential rise of a nearby electrode. Thus, we can firmly conclude that a TiO_2 barrier of practically reasonable dimensions could completely eliminate the damage/injury risk of potential transfer to the neutral wire of a MV/LV substation and human/animal injury due to step potential.

Table I. Variation of potential and potential gradient at the observation point with resistivity of the barrier material. Width of the barrier (w) is 50 cm

Resistivity of TiO_2 nano fluid – soil mix (Ωm)	Potential at observation point (kV)	Potential gradient at the observation point (kV/m)
10^5	1.78	0.24
10^6	1.43	0.18
10^7	1.18	0.13
10^8	0.99	0.11
10^9	0.95	0.09
10^{10}	0.94	0.09
10^{11}	0.93	0.09
10^{12}	0.90	0.09

Table II. Variation of potential and potential gradient at the observation point with the width of the barrier. Resistivity of the barrier material is 10^7 Ωm

W: Width of Barrier Material (cm)	Potential at observation point (kV)	Potential gradient at the observation point (kV/m)
5	1.85	0.32
10	1.82	0.27
20	1.78	0.24
30	1.53	0.20
40	1.22	0.15
50	1.18	0.13
60	1.15	0.12
70	1.14	0.12

The next step of this study is to investigate how the potential barrier will affect the earth resistance of each electrode of a set of two earthing systems in the proximity. It is important that the barrier should not significantly increase the earth resistance of the system while it provides the potential barrier effect. The preliminary investigations reveal that the semi-cylindrical arrangement of the barrier has almost negligible impact on the overall earth resistance values.

VI. CONCLUSSIONS

It has been shown that an insulation barrier made by extruding TiO_2 into a ground cavity can successfully reduce the extension of potential gradient beyond the barrier. Even for a 5 cm wide barrier with rather low resistivity of the mix (compared to the resistivity of pure TiO_2 nano fluid) the potential drops from nearly 80 kV to below 2 kV. Such drastic drop will make the barrier technology highly applicable in the earthing practices of substations, where more than one separate earthing systems are demanded.

The above results clearly shows that the dimensions of the barrier that requires for an appreciable potential reduction is very much realistic and practically viable. The availability of material and cost of both material and installation seems feasible, however a detailed study should be done in this regard before making firm conclusions.

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