

Effectiveness of Neutral Grounding on Power System Application

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1. INTRODUCTION

Protection of network installation and appliances, safety of man-power, and users are some very

important aspects of the power systems. The installation and operation of circuit breakers protect the system from damage due to short circuit and over-voltages, however, other safety considerations exist that cannot be handled by the circuit breakers. An example is the failure of insulation of an installed equipment, which has no efficient connection between the frame and the ground, in such a situation a large amount of current would flow through the installation frame. If there is a contact between a human being and such a frame, the current on the frame would flow through the person and would lead to injury or in an extreme situation, death. But with an efficient grounding system, the installation would be on the same potential with the earth and hence be capable to send such straying currents to the ground and avoid completely or reduce to a great extent the effect of shock on a body that might have contact with the frame [1].

Power installations and operations are some capital intensive investments. It is also a vital aspect that determines the success of other industries and the nation's economy as a whole. The effective protection of such installations as it had to do with neutral grounding is what this work seeks to establish. In this work, the main aim is to establish the effectiveness of neutral grounding on power system applications as against the ungrounded and also: (i) to

Abstract: In Power system networks and installations, it is of absolute necessity to consider the safety of personnel and the entire installation right from the planning and design stages. Thus, plans are made to provide for situations of over current in a short-circuit situation and means of isolation of faults between connected systems to avoid unending propagation. Two primary concerns in mind are: Safety of personnel, and property against overvoltage mishaps. Neutral-grounding is a System used to connect power system equipment and devices to the earth using devices that suits a particular method and situation. It is of different types and implementation and the choice of system depends mostly on what the designing or installation Engineer seeks to achieve. In this work, the ungrounded as well as different methods of neutral grounded systems were studied. The work showed in simple terms the effectiveness of neutral grounding and its advantages over the ungrounded. The results obtained are thorough research from different works that had been carried out on this subject and also from results and experiences obtained from the field. For an efficient practical neutral grounding result, the space between the earth rods must be the same or slightly greater than the length of the individual rods.

Keywords: Power System Network, Effectiveness, Neutral-grounding, Personnel, and Safety.

investigate the Voltage ratings and degree of surge-voltage protection available from surge arresters. (ii) to understand the Limitation of transient line-to-ground overvoltage.

It is becoming usual for us, in power systems to discuss more often, the importance of different types of neutral grounding system either directly or through an intermediate device. It is a process achieved by using some specific pieces of power-system apparatus, including, but not limited to, power transformers and generators to affect an effective system of neutral grounding. Figure. 1 depicts in a concise form, the different methods or modes of grounding in power systems. It is a neutral grounding if the neutral point of the equipment winding is connected to the grounding conductor.

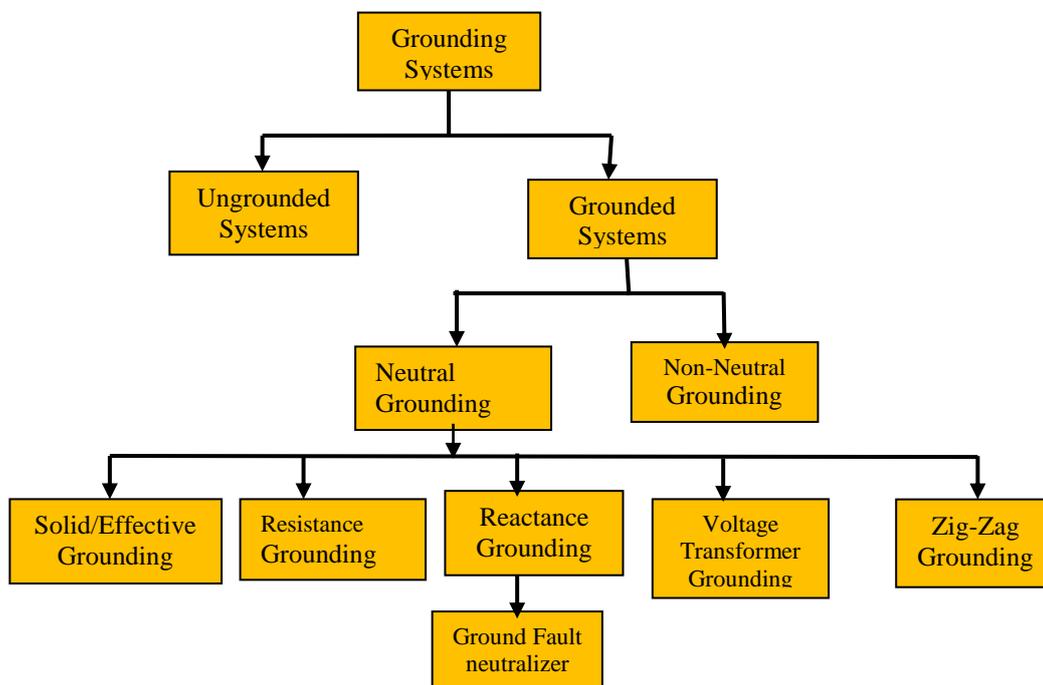


Figure 1: Methods of Grounding System

2. METHODS & FACTORS AFFECTING THE SYSTEM

a) *Methods of neutral-grounding Systems*

The mode or ways of designing a neutral-grounding system may defer from one location to the other, as a result of system voltage, cost, and geography of the site on which implementation is to be carried out. An instance is a situation where the system, on which the neutral grounding is to be applied, is carrying a high voltage, in this kind of situation, there is the need to apply a system that can eliminate arcing ground. The site's soil composition and type is also an important consideration, this is basically due to the great effect of soil resistance on a grounding system resistivity. It is relatively difficult to classify system grounding in such a way that it will be totally free from ambiguity. Hence, we would

in this paper want to classify grounding systems based on the operating voltage level of the system.

i) Ungrounded Systems: These, were for some time, seen and considered to be the best type of grounded system in terms of stability, because as it would seem; low potentiality is only obtained in a grounded situation which would increase the likely hood of some very high fault current. Hence, to insulate the system from fault currents of such magnitude, the option of an ungrounded system became saleable. In other words, for the fact that harmonics will eventually die out within an ungrounded system on its own, the effects of harmonics on an ungrounded system was regarded as something that can be ignored. More-over still, an ungrounded system is completely isolated from disturbance from nearby grounded systems. These seemly advantages, notwithstanding, ungrounded systems do not have the ability of shielding the system from overvoltage that is transient in nature, and in effect has a lot of disadvantages that made it unattractive to today's installations.

ii) Grounded Systems: Basically, there exist two methods in which a system could be grounded. These are the neutral grounded and non- neutral grounded methods. Neutral Grounded is more often used among the two methods. Neutral grounding can be applied in grounding a system as a composite whole and could still be applied to individual machines and equipment; such as transformers, generators, and high tension lines [2]. They are applied mostly on a power generating stations and distribution substations. Non-neutral grounded method is applied not solely for the power generation and distribution systems. The applications of this grounding system include, but not limited to, grounding to buildings and substations. Installations, where the equipment is grounded as a unit, are all considered as non-neutral grounding. This grounding method is mostly for between low to medium voltage systems. Their composition and modes of installation may also differ from one region to the other.

Solid Grounding: This is a means of connecting the neutral point of a system directly to the ground with no impedance using a conductor that has the capacity to send over voltage and fault current to the earth without delay. This system has the ability to effectively hold the neutral at earth potential during a fault. It can effectively mitigate against over-voltage. [2].

b) Neutral Point Grounding Systems

i) Voltage Transformer Grounding: Unlike the star configured windings, a system with delta configuration in both windings has no neutral point connection. As such, the system of voltage transformer grounding is applied in grounding delta configured side of such windings. This is mostly found in power or distribution transformers.

This method of grounding by voltage transformer method is, mostly for cost consideration, applied on high voltage systems, ranging from 20kV and above, and in most cases, on step-up power transformers. Although these grounding methods could also be used for lower voltages, it is however, seen to be costly for such application and is usually and most often avoided. This system also has an advantage in that, since the system is of a highly rated voltage, applying many of the other grounded types might result in earth arcing as a result of the huge amount of fault currents. A step-down transformer grounding would help to reduce the voltage and then solid or resistance ground the neutral point of the star grounded voltage transformer, thereby limiting fault current values as well as arcs [2, 3].

Neutral Point Grounding

Connection of the neutral part that is the current-carrying neutral part of the conductor of a three-phase AC system to ground (general mass of the earth) by low resistance earthing lead or conductor less than 0.1ohms is referred to as neutral grounding system. The neutral points are taken from the star connected part of the generators, stator winding of an electric motor, and transformer winding [5] This earthing system is different from equipment earthing. Figure 2 gives an illustration of the neutral grounding system.

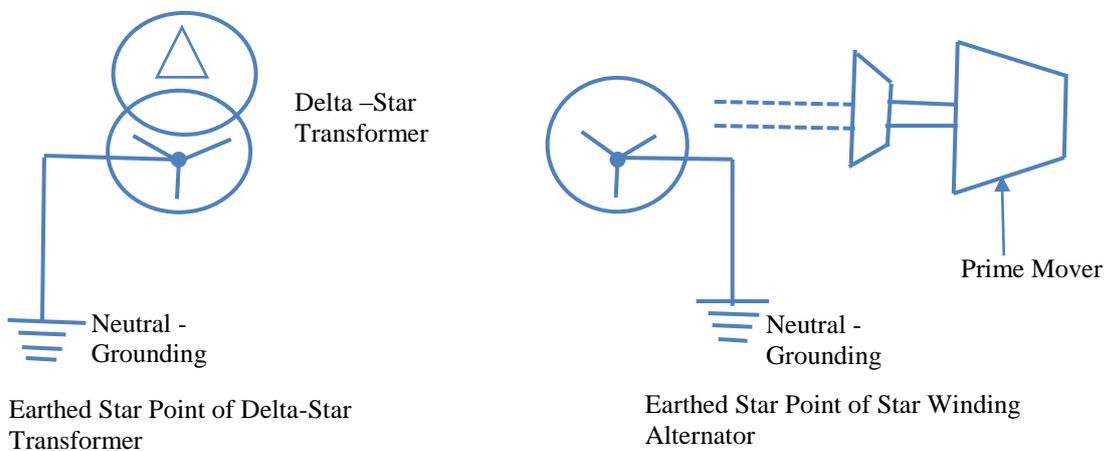


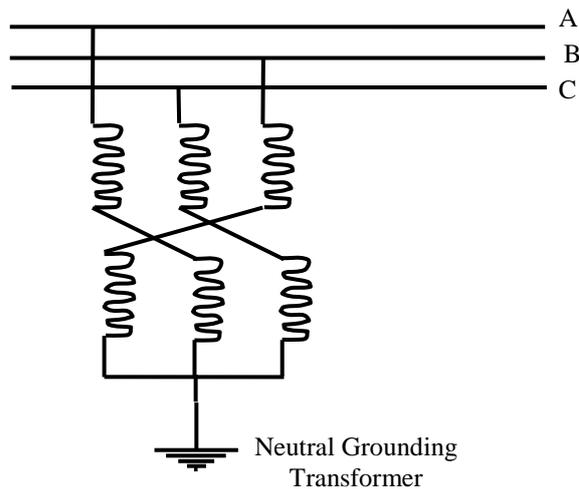
Figure 2: Neutral Point Grounding System Illustration

Earthing the transformer neutral at the sending end will greatly reduce the third harmonic current flow problem in power system operation. In a situation where the neutral point is not available, a special earthing transformer of zig-zag connection or a separate Star-Delta transformer is provided. This is very necessary at each system voltage level.

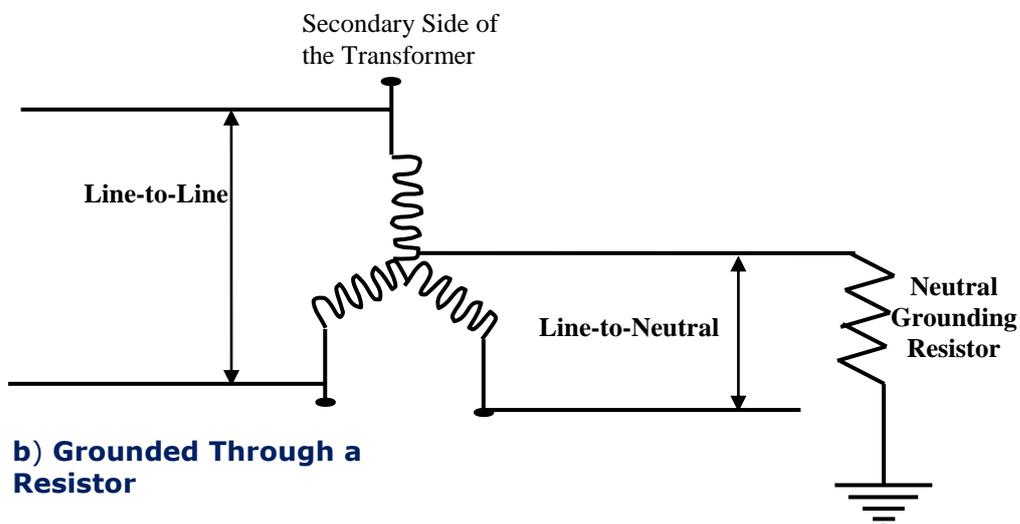
ii) Neutral Grounded Transformer

In a neutral grounding system, the neutral point of a star configured winding of the system or transformer is connected to the ground. The potential of neutral connection concerning

earth is greatly determined by the neutral grounding mode applied to a power system design. This is due to that some major aspects of the system's behavior and operation, like short circuit handling, stability, and response to protection control is, in one way or the other, tied to the condition of the neutral. Two of the numerous means of grounding a three-phase system are illustrated in Figure 3 (a & b).



a) Directly Connected



b) Grounded Through a Resistor

Figure 3: Neutral Grounding Transformer

iii) Zig-Zag Transformer: This type of grounding takes its name from the way in which the winding of the transformer is made. Such a transformer has no secondary winding. It has the sole purpose of a grounding system of very high voltages that are above 33 kV. The zig-zag transformer has the advantage of sharing the fault current equally among the three conductors, hence limiting the magnitude of fault current on any particular part. When carefully designed and implemented, it is possible to combine the installation of this grounding type with circuit breakers. In so doing, it is necessary to ensure that the breaker

rating does not surpass that of the transformer. These breakers are there to serve to defend and protect the grounding transformer against fault currents that is greater than the rating of the transformer [2].

iv) Resistance Grounded: In this, the grounding is implemented with a resistor. This class is frequently subdivided into low and high-resistance categories. The resistance value is chosen in consideration of the voltage level. This is because if the value is too low, the system may behave like a solid grounded system and if too high would behave like an ungrounded system.

It is worth noting that a grounding resistor may contain a considerable value of inherent inductance. An example is a cast-iron grid resistor which though may have a power factor of 98% or less, resulting in a reactance of about 20% of the resistance at system frequency [6]. Figure 4 represent the resistance grounded equivalent diagram.

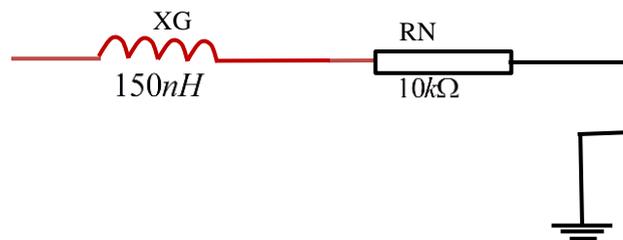


Figure 4: Resistance Grounded Equivalent diagram

v) Reactance grounded: Here Inductance is inserted between the neutral and ground. When a single-phase to earth occurs, the fault current generated is usually equal in magnitude but 180° out of phase with the capacitive current flowing on the other two normal conductors. As such, they would almost cancel each other in the fault. This system is called an arc-suppression coil or Peterson coil when the value of inductance is so adjusted that the two opposing currents exactly cancel each other. This system has the ability to completely eliminate possible damage caused by arcing ground using a self-extinguishing capability [6]. Figure 5 represents the reactance grounding equivalent diagram.

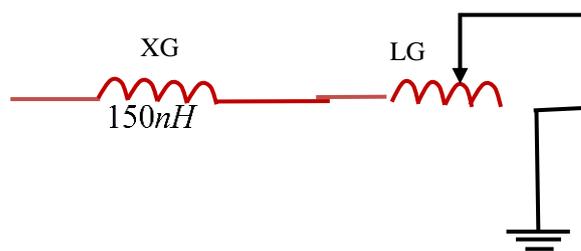


Figure 5: Reactance Grounding Equivalent Diagram

vi) Capacitance grounded

In this method, grounding is achieved through an impedance arrangement using capacitance as the principal element. Capacitance is usually not inserted directly in a connection to ground for the purpose of system grounding. However, capacitance may be used in grounding connection as a voltage surge front-of-wave sloping purposes. Besides, neutrals of shunt capacitor banks would have been connected solidly to ground an ungrounded systems. Figure 6 represent the capacitance grounding equivalent diagram. There is a need to carefully analyze Capacitance grounding before implementation, to avoid a situation where resonance or increased fault current will occur.

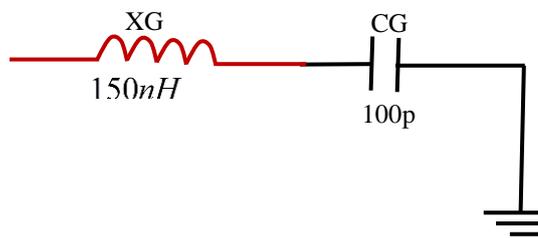


Figure 6: Capacitance Grounding Equivalent Diagram

vii) Ungrounded (isolated neutral): This system has no pre-meditated mode of connection to the ground. However, its conductors do have capacitance between one another and the ground. The respective capacitive currents are displaced from one another by 120° and lead their respective line voltages by 90° . This system is stable during normal operating conditions but very hazardous to both the installation and personnel during fault conditions, this is because the capacitive fault current is of less magnitude than the requirement for operating the protective system.

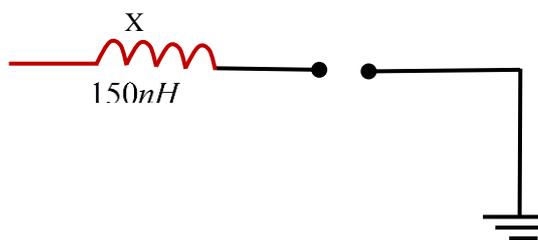


Figure 7: Un-grounded Equivalent Diagram

viii) Ground Fault Neutralizer: This system is also called Peterson's Coil, it is used as a means of mitigating against arcing within the grounding conductors using the inductor's back EMF. They are often used with a parallel capacitor in order to regulate high-frequency harmonics in the system. Electronics devices like the Silicon controlled Rectifier, SCR, used in HVDC lines are generally responsible for introducing Harmonics into the transmission

lines, and other causes are driven with variable frequency and disturbance from radio signals.

Given a simple power system, typical distribution system, or power-plant auxiliary system; a situation where a single transformer is being used as both the power source and system-neutral grounding point, the means of grounding of such transformer neutral defines the performance characteristics of the neutral grounding system. A good example is that of a system supplied by a single transformer having its neutral grounded through the resistance method [6]. The line to ground protection solution used presently in transmission lines of medium voltages ranging between 6kV to 35kV is a subject of debate and non-agreement in the industry due to the non-availability of a universally accepted mode of design and or application of the neutral grounding systems though produced using the same principle, but they most often differ widely in their technical design [6].

However, for the more complex systems, including the typical high voltage (HV) or extra-high voltage (EHV) transmission lines, there are a lot of other apparatus, which though can stand alone, becomes part of this larger system. Transformers, capacitor banks, reactors, etc. these apparatus may have their individual separate grounded neutrals within the parent system. In such a multiply-grounded system, the class of grounding of the system is determined by the aggregate effect of all the individually grounding points. If a similar means of grounding is applied in most of the major transformer neutrals, then the system may relatively be described as being of one class.

In general, for a system where there are multiple grounding points of different types of apparatus and different means of apparatus used for the neutral grounding, the class of such grounding can only be determined by the zero-sequence to positive-sequence symmetrical component ratios, as viewed from a selected location within that system [7, 8].

c) System Grounding Motives

Grounding is carried out among other reasons, for these two main primary concerns:

(i) Protection and Safety. (ii) Reference Voltage.

Other reasons as have been mentioned by different writers and researchers are anchored on the two mentioned above.

Figure 8 shows different types of grounding symbols. A signal ground symbol is used as an indication for voltage referencing, whereas the chassis ground symbol is applied as a requirement to reduce the effect of electrostatic voltages on the metal parts of equipment. On the other hand, also, earth ground is applied for draining fault currents. Among these

three, the chassis and the earth grounds serve to provide the needed protection of appliances and the safety of humans. They allow for immediate draining of charges from the chassis to the ground.



Figure 8: Ground Symbols

Power system groundings could be either chassis or earth ground and in majority of cases both. The provision of a low impedance route for fault currents to dispense into the ground is the major essence of grounding in any power system installation. The choice of the best solution to apply would, among other things depend on the economy of implementation. One of the major determinants of the coast path to adapt is the location's soil type. There is a need, therefore that we always design our grounding to match the most effective solution. As stated by the American National Electrical Safety Code as a definition for effective grounding: "An effectively grounded system is intentionally connected to earth through a ground connection or connections of sufficiently low impedance and having sufficient current-carrying capacity to limit the buildup of voltages to levels below that which may result in undue hazard to persons or connected equipment" [3]. Secondly, the Green Book (IEEE Standard 142) states that: "An effective grounding is achieved when: $3X_1 > X_0$ (1) $R_0 < X$, Where, R_0 is zero sequence resistance, X_0 is zero sequence reactance and X_1 is positive sequence reactance". Grounding system design for a system as a unit would defer for design made for individual equipment that made up the system.

3. Applications

a) Neutral Grounding: This is the act of connecting the neutral point of a three-phase system to the ground. It could be done directly using a low resistance conductor or through other modes amongst the ones first enumerated. For any of the type applied, an earth pit or pits containing some metallic rods/rod is formed to lower the resistance of the soil resistance around the installation. This in effect enables the easy and fast dissipation of fault current and transient over-voltages to the ground, hence protect the system installations from damage or even un-necessary stress. Some among the numerous advantages of neutral grounding are

- i) It forces the voltages of healthy lines to remain constant even during a single-phase fault.

- ii) It offers the opportunity to install and use automatic protective devices that operate and isolate systems when a fault occurs.
- ii) It removes unwanted voltage by eliminating the possibility of an arcing ground.
- iii) Lightning induced over-voltage dissipated to the earth with great ease.
- iv) The Safety of personnel and equipment is better assured.

b) Earth Pit Installation with high Resistance grounding for a 33/0.415KV transformer:

We have observed through practical experience that the arrangement of the earthing rods inside an earth pit will to a very great extent determine the result of the resistance test. The major essence of creating the earth pit is to ensure a low impedance path, into the ground, for fault current or lightning flashes. It is necessary to ensure that the distances between the adjoining earth rods are made to be greater than or equal to the length of individual rods. Placing the rods at closer distances below the recommended distance would cause the adjoining effects of the rods to cancel one another and hence increase the overall resistance of the installation.

Figure 9 shows a 2.5 by 2-meter earth pit with the earthing rods fixed at distances in between that are less than the rods' length. The resistance test for this scenario was obtained as 12 ohms. An improved pit dug just beside this one also could not change the result. To correct this high resistance results, fewer rods were laid at distances greater than their lengths without allowing the connecting conductors to intercept each other. And with this, a result of 0.5 ohms obtained. Hence it has been established that the effectiveness of a grounding installation is determined, not by the mode chosen, but also to a large extent on the placement of the earth rods. With this method we were able to achieve a reading that was far below the least recommended limit of 5 ohms as stipulated by the regulating body; thus given a much better output result.



Figure 9: 2.5m by 2m earth Pit

C. Equipment Grounding: Figure 10 shows a grounded perimeter fence support metal pole. The earthing provides a path for charges and fault currents through the conductor to the ground (Pit). It is a means of ensuring that personnel accessing the substation do not get shocked when they touch metal objects in the substation. In Figure 11 is the grounded part of the transformer. The grounding conductor is tied to another conductor that is coming from the arrestors and both were sent to the pit through a copper conductor. This grounding path provides an easy path for fault current caused by lightning and protects the system equipment from over current and arcing.



Figure 10: A grounded 300KVA of 11by 0.415KV Substation

Figure 10: A grounded metal pole used for fence support

4 RESULTS

Different kinds of literatures, mostly research papers, relating to the effectiveness of neutral grounding in power system applications have been read and analyzed. Conclusions and results from such literature had also been studied and compared. Different types of neutral grounding had been studied and compared both from literature and from practical field experiences on the bases of implementation and operational differences. Efforts were made to distinguish and bring to the fore the advantages of a grounded neutral over the ungrounded system.

The effective method of installing an earth pit for a neutral grounding has been shown.

Table 1: Comparison of different grounded systems

Methods	Ungrounded	Solid	Resistance
Effect of transient Over Voltages	Bad	Good	Good

Effect of line –to- earth fault.	Bad	Excellent	Good
Arcing damage Reduction	Bad	fair	Good
Probability of Personnel safety	Poor	Excellent	Excellent
Operational Reliability	Stable only without fault	Better	Best
Economy of maintenance and over-head-cost	Worst	Poor	Good
Sustaining Operation during a Single Line-to-Ground fault situation.	Possible for a very short time	Not possible	Not possible
Ease of Locating ground faults on the installation.	Difficult	Easy	Easier
Coordination within the System	Not possible	Good	Better
Ability to reduce the number of Faults	Worst	Better	Better
Relative ease of upgrading the grounded system	Difficult	Easy	Easier
Sustaining different voltage levels on the Same system	Not applicable	achievable	Not applicable

Table 2: Ungrounded Vs Grounded Systems

	Behavior/ Capacity	Ungrounded System	Grounded System
1	Direct Connection to the earth	Do not exist	Exists
2	Statue on normal operating condition	Normal and assumed transposed	Normal and transposed
3	The magnitude of fault Current	Incapable of operating protective devices	Capable of operating the protective devices
4	Effect of arcing ground	Exist and damaging	Not applicable
5	Magnitude of voltages on the healthy lines during a single line to ground fault	Between 4 -to- 6 times due to arcing ground	Constant (Normal line -to- earth value)
6	Ability to operate a protective during a fault	Cannot Capacitive current not enough to operate protective devices	Can Operate protective devices
7	Provision of Personnel safety	Poor	Excellent
8	Operation and Maintenance cost	High	Low
9	Ease of Discharging over-voltage	Poor	Excellent

Neutral grounding is a form of protection that is of a very serious necessity in power system installation and applications. However care should be taken in choosing the type on neutral grounding method to implement such that it will be in synch with the devices and operational needs of the equipment it is meant to protect. A deviation may turn out to be counterproductive and inimical to the system which it is meant to protect. Table 1 shows the grounding system comparison and where they are best suitable, while Table 2 shows the comparison between ungrounded and grounded systems. From the results in table two, it is obvious that the effectiveness of neutral grounding on power system installation are

numerous. This in effect explains as to why the ungrounded system is seldom implemented in today's installations.

5. CONCLUSION

This paper has been able to highlight the different types of neutral grounding, their mode of application, and the distinction between neural grounded and ungrounded power system installation. It has been able to show that neutral grounding of power system installations is an effective and an important aspect of protecting both equipment and personnel. Table two above summarized in simple terms the superiority of the grounded against the ungrounded systems and shows why the ungrounded is no more implemented on today's installations. We have also shown that the installation of an efficient grounding does not come from the number of electrodes used or the size of the earth pit but on proper placement, spacing, and interconnection of such rods.

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