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Power transmission lines electromagnetic pollution with consideration of soil resistivity

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Abstract

The alternating current (AC) total interference of power lines may pose a threat to personnel and equipment in its vicinity. The main objective of this work is to determine the electromagnetic distribution and induced voltages on human body, equipment, and houses due to the AC total interference for different soil resistivities. The electromagnetic field and induced voltages may cause health problems to the human body and put it at risk. Two main approaches were used to compute the electromagnetic and induced voltages, namely the field approach, which is based on electromagnetic field distribution, and the circuit approach, which uses the circuit grounding analysis to compute the conductive interference and then uses the circuit based models to compute the inductive interference. Human body, steel houses and 10-km-long transmission line were modelled. The soil resistivity was varied, and the induced voltages obtained from both approaches were compared. Soil resistivity and soil structure are important parameters that affect the AC interference level. The results show that the touch voltage increases when the distance between electromagnetic source and human body increases. For high soil resistivity, the danger of the touch voltage becomes more prominent compared to that for low soil resistivity. Power system voltage level and soil resistivity are two key factors influencing the induced voltage level.

Keywords: *AC interference, electromagnetic pollution, human body, soil resistivity, transmission line*

1. Introduction

Due to the increase of population, some people build their homes, warehouse and workplace nearby an electromagnetic source, such as an electrical transmission line, as shown in Figure 1. Human body is commonly exposed to electromagnetic field radiation caused by overhead transmission lines (TL). The electromagnetic fields emitted by electrical installation using alternating current at 50-60 Hertz might have long-term effects on health [1]. Working or living near electromagnetic sources may cause undesirable electromagnetic interference between the TL and human body even within houses. The electromagnetic interference may lead to the consequence of unsafe level of the touch voltage that exists between a human body and any nearby metal [2]. A touch voltage higher than the safe level may be dangerous to human or can be harmful to equipment. The consequence of interferences between the TL and its surrounding area is now increasing in significance due to the environmental concerns which have been enforced on various companies. These are mainly aimed to reduce the influence posed by the interference on wildlife, nature and mankind [3, 4].

When a high current flows in the TL, as well as in the TL towers due to a power system fault, switching operations, or lightning, high voltages may be induced in human body and along any nearby metal structure. The induced or touch voltages are as a result of some form of energy transfer from the TL system to human body through several paths. The paths which exist as a result of various respective couplings in the commonly shared right of way (ROW) are known as conductive, inductive, and capacitive paths [5, 6]. The instantaneous or simultaneous resultant effect of the conductive, inductive, and capacitive couplings is commonly referred to as "the AC total interference" [7-10].

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Two independent approaches are available to carry out an AC total interference study such that in the TL and human body interaction, which are the circuit-based approach and the electromagnetic field approach. Within last several decades, the AC total interference related studies were extended to include several effects and major concerns. Many studies were carried out to determine the effects of several key parameters, such as soil resistivity, soil structure, fault current, and TL tower footing resistance, on the TL-human body inductive interference [11, 12]. Several methods to correctly compute the effects of those parameters on the TL-human body inductive interference were also proposed. The finite-element method (FEM) (field approach) was presented by several authors [13-16].

An important aspect of the TL-human body interference study is on the effects of the surrounding soil. The effect of soil structure on the conductive and inductive interferences is described by many previously published work. Despite of the existence of many published works, such as those described in [17, 18], the effects of soil structure are still being studied. The importance of considering an accurate soil structure, when computing the TL-human body interference level, and when designing a mitigation system against high induced voltage for the pipeline, is described in [19-25]. This work aims to determine the AC total interference between an overhead high voltage transmission line and human body, specifically, when touching nearby metal structure for various soil resistivities.

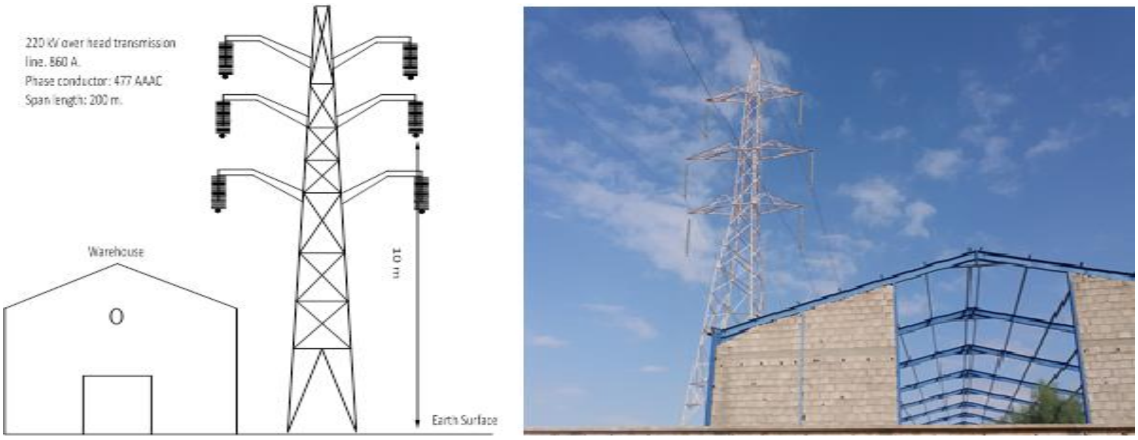

Figure 1. Installation of human dwellings near an electromagnetic source such as a transmission line

2. Research Method

Two simulation approaches used to compute the touch voltages on human body were utilised. These are the field approach, which is based on the electromagnetic field theory, and the circuit method, which is based on the circuit analysis. The results between the two methods were compared and validated. The touch voltage on human-body due to AC total interference between a transmission line with a fault current flowing and a human-body is important for determining the severity of the touch voltage on the human-body, and hence the safety to service personnel and related equipment. To select a suitable approach for each part of the research, it is important to know the features and disadvantages of each approach.

In this paper, CDEGS was used when carrying out computations using the field theory approach. In this approach, the electromagnetic interference between the electrical components in the right-of-way must be considered without performing any approximation. CDEGS software, which utilizes Maxwell's equations, is one of the leading software based on field approach. This approach is capable to compute the AC total interference between any human body and transmission line system configuration as shown in Figure 2.

A circuit-based approach of the system under study is developed from the real right-of-way configuration system. The system consists of a transmission line and human body at a chosen location shown in Figure 3. Electrical components in the circuit-based model such as transmission line, mutual and shunt impedances are calculated based on constant line equations. The circuit could be enhanced by adding some other components such as transmission tower ground resistance and the grid impedance of the terminals [19]. The circuit-based method computes the inductive and the conductive interference separately. All the conductors inside or close to the right-of-way, soil characteristics, and fault currents should be modelled correctly in order to determine accurately circuit parameters such as mutual and series impedances resulting from the inductive coupling. The circuit-based model offers an option to combine the electromagnetic field produced by both inductive as well as conductive couplings. Thus, the circuit-based model is capable to produce the touch voltage on human-body obtained by AC total interference. Hence, it can be said that, modelling and studying the AC total interference by utilizing circuit-based approach is more complicated than in the case of field approach. The circuit-based model is used to simplify and to automate the modelling of complex right-of-way configuration. Furthermore, it can create various observation points at different locations of the corridor for various quantities such as human body voltage, earth surface voltage, step-voltages, and tower potentials.

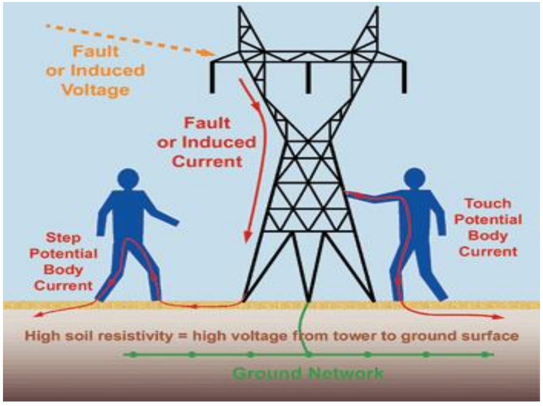

Figure 2. Interference between any human body and transmission line system configuration [11]

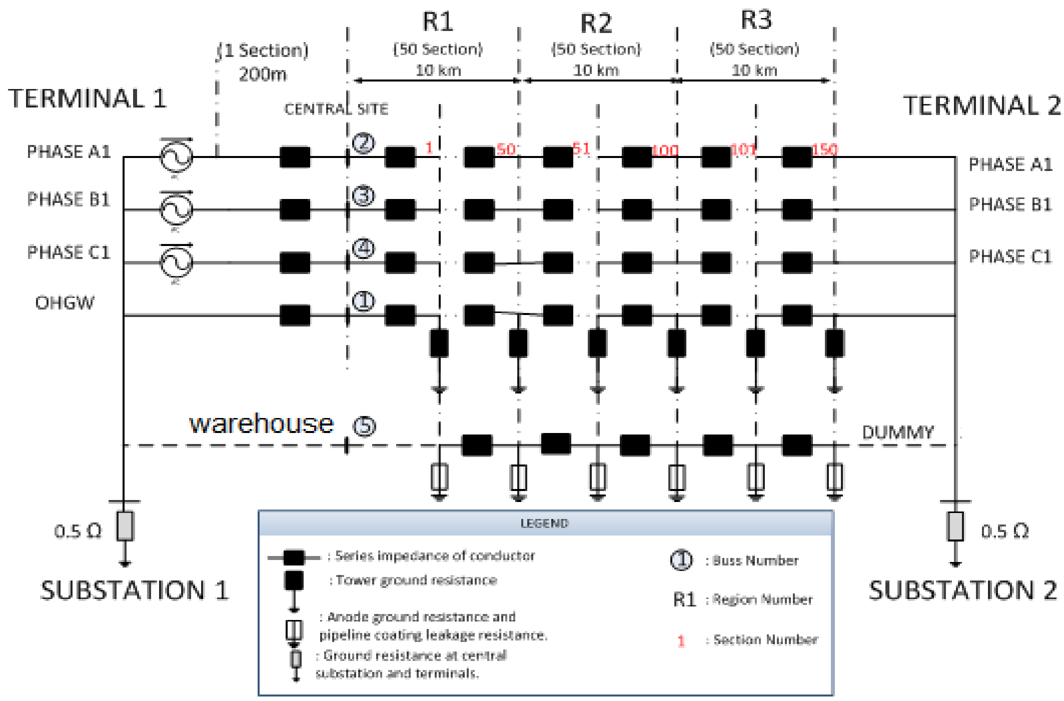

Figure 3. The circuit-based equivalent circuit [5]

Overhead transmission line (OHTL) and Human-body (HB) in vicinity were used as the baseline model as shown in Figure 4. The baseline model has the following specifications. The height of the phase conductors was fixed at 10 m above the ground. The human-body was standing directly on the ground and touching metal structure of warehouse adjacent to the TL. The relative resistivity of the metal structure was 12 (with respect to annealed copper), while its relative permeability was 250 (with respect to free space). The soil was assumed to be uniform, with resistivity of 100 Ω-m. A 860 A steady state current was set to flow in the 400 kV transmission line phase conductor from one terminal to another. The section length was equal to span length which was 100 m.

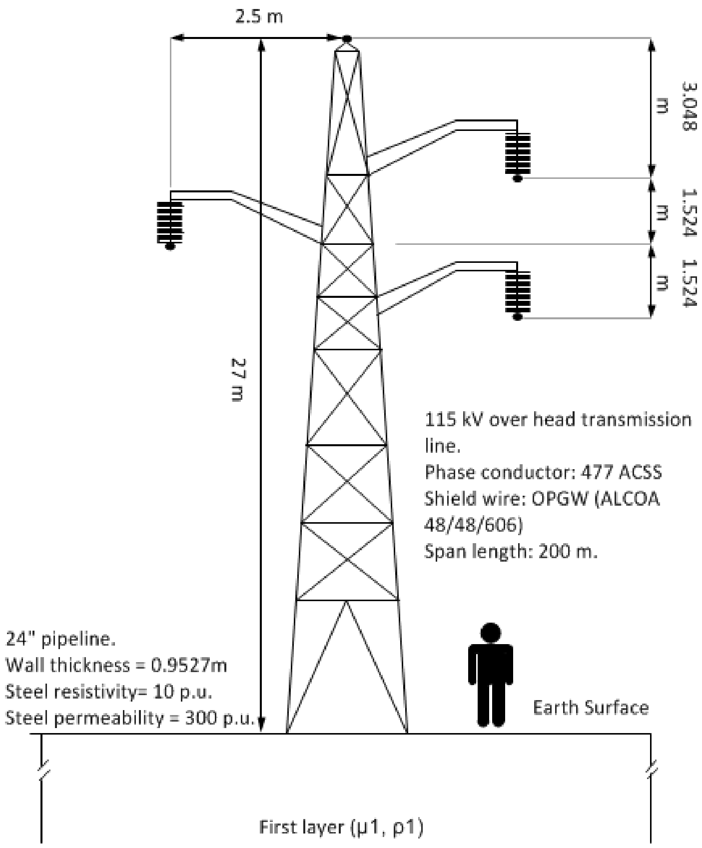

Figure 4. Cross section of human body and transmission line right-of-way

3. Results and Analysis

A fault current of 5 kA drawn from each terminal was used. The separation distance was varied at distances of 5, 10, 20, 30, 40, 50, 60, 80, and 100 m. Figure 5 shows the maximum touch voltages on the human body in relation to variation of TL-human body distance. In the figure, two types of induced voltages were depicted. It can be seen, the induced voltage decreases when the human body moves away from the TL. The highest induced voltage is given by the touch voltage, followed by the ground potential rise (GPR). The maximum value of touch voltage when both inductive and conductive couplings were considered is 2180 V. This high voltage magnitude could kill human operators and animals. Therefore, a proper mitigation system must be used for small TL-human body separation. The induced voltage decreases with the separation distance. This is because, generally, the smaller the separation distance, the larger will be the inductive and conductive interferences and hence the induced voltage. The more dominant effect is on the inductive interference. It is noted that the effects of separation distance are uniform for the two types of induced voltage. Also, the separation distance affects the inductive interference more than the conductive interference.

The effect of soil resistivity due to the interaction of steady-state electromagnetic fields and human body is universally known, that is an increase in the soil resistivity will result in an increase in the induced voltage. This result is also true for the fault condition when only the inductive coupling is considered. In this paper, not only the inductive coupling was determined, but the conductive coupling is also taken into consideration. Figure 6 shows the variation of the maximum induced voltage on the human body with the soil resistivity. The separation distance was kept constant at 50 m. As can be seen, the earth surface ground potential rise (GPR) increases when the soil resistivity increases. This is because the GPR are dependent on the conductive coupling, which in turn is dependent on the current injected to the ground. On the other hand, the touch voltage decreases when the soil resistivity increases. When the soil resistivity increases, the effective tower grounding resistance will also increase, thus making the shield wire attractive as a fault current return path. Therefore, a greater proportion of the fault current flows back towards the sources through the shield wires, and is out of phase with the current in the faulted phase. Hence, this reduces the net touch voltage in the human body. It is noted that the effects of soil resistivity are not uniform for all types of induced voltage. Also, the soil resistivity affects the conductive interference more than the inductive one (as can be seen in the higher rate of changes for earth surface GPR in Figure 6).

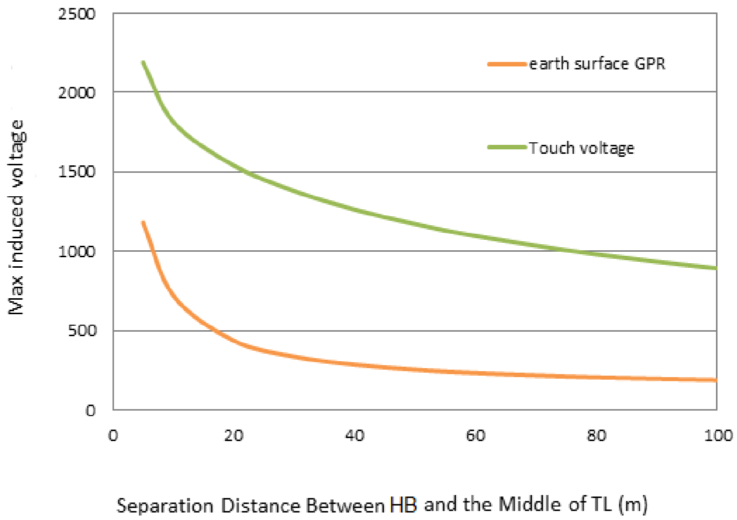

Figure 5. Induced voltages on human body in relation to TL-human body separation distance

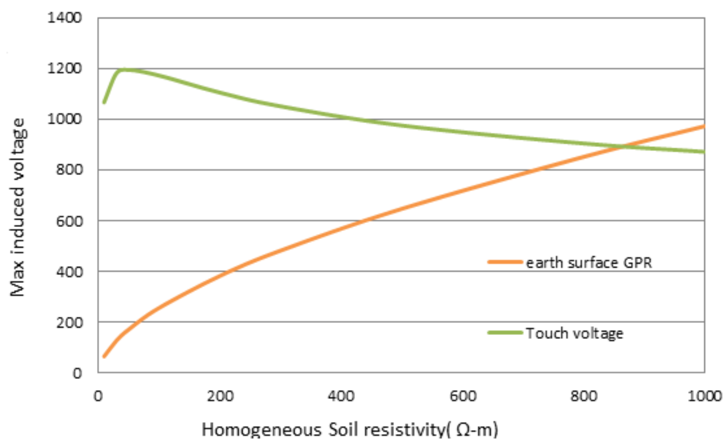

Figure 6. Variations in the induced voltage on human body with respect to modification of soil resistivity, under local fault condition

4. Conclusion

In locations where the human body is exposed to electromagnetic radiation from transmission lines, a relatively higher voltage than normally allowed, or an overvoltage, may be induced in the human body due to the AC total interference. This overvoltage may also cause damage to equipment such as meters and gauges. Furthermore, it may also pose a threat to human safety, such as to service personnel when touching nearby metallic structures. Therefore, it is important to determine the induced voltage and to limit the overvoltage that may jeopardize equipment or human safety as suggested by many standards.

The most important induced voltages is the touch voltage. An excessively high touch voltage poses threat to human and equipment safety. This study accurately modelled, simulated and computed the effects of several parameters on the simultaneous conductive and inductive couplings between the TL and the human body in the form of AC total interference. The study shows that the touch voltage is mainly influenced by the inductive interference. The TL-human body inductive interference increases with the fault current, but decreases with the TL-human body separation distance, and with soil resistivity. Nevertheless, the conductive interference is also significant especially when the soil resistivity is low, when the fault current is high, and when the separation distance between the TL and human body is small.

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