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Experimental measurement, analysis and prediction of electric and magnetic fields in open type air substations

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ABSTRACT

In this paper, the electric and magnetic flux density values in open type air substations are analyzed. For this reason, an extensive measurement survey was conducted to identify potential large sources of electric and magnetic fields within seven 132/11 kV open type air substations always having them compared with the International Commission Non Ionizing Radiation Protection (ICNIRP) safety guidelines published in 1998. The maximum electric and magnetic flux density values obtained in the open air circuitry units are found to be 7696 and 7306.5 V m^{-1} and 45.89, 38.11, 35.30 μT, which are 1.30, 1.37, and 10.9, 11.3, 14.1 times below the safety guidelines of the ICNIRP. In one of the coil rooms, the magnetic flux density was found to be 6.26 times above the safety guidelines, constituting an immediate threat to working personnel of the substation. Furthermore, a simplistic theoretical methodology based on experimental measurements is proposed that establishes a linear correlation between the transformer current and the maximum magnetic flux density based on Biot–Savart law, provided that the distance from the source remains constant, to predict the magnetic flux density by extrapolation to the permitted and nominal currents and compare them to the safety guidelines of the ICNIRP.

1. Introduction

Electrical energy is generated, transmitted and distributed via generation, transmission and distribution networks. The transition of electricity from the transmission to the distribution network is achieved via substations. These substations reduce the operating voltage, and forward the increased current to the distribution network of the electric grid. There are three types of substations, the open, closed and underground type substations. The location and cost will ultimately determine what type of substation should be used. At areas where there is very limited space, such as in urban areas, closed type substations are preferred, where most of the equipment is kept in a building. Open type substations tend to occupy more space than closed type substations, and since they are cheaper to build, they are preferably used at the country side, where there is plenty of space available. In cases that substations must have minimum environmental impact, underground substations are preferred.

In open air type substations, the very high voltages and currents generate high electric and magnetic fields that may pose a threat to working personnel and general public. There is a general concern from the public for any possible health effects that these fields may cause due to the ever increasing cancer incidents in the Republic of Cyprus the last few years. This concern has also been shared worldwide for many years, thereby a series of phenomenological and epidemiological studies have been performed in an attempt to clarify whether electric and magnetic fields are harmful to human beings [1–5]. These studies have shown that the ionizing radiation at the very high frequency range is harmful [6–10].

For the low frequency radiation, which is also defined as non-ionizing radiation, excitation of the molecules occurs instead of ionization, inevitably reducing the possibility of alternation of the molecular structure of the human DNA. Nevertheless, it has not been proven beyond any doubt that this is the case, especially in the long run, even though numerous extensive studies have been performed throughout the years [11–15]. Due to the general concern of the consequences of electric and magnetic field exposure, most of the counties of the European Union have adopted the safety guidelines of the ICNIRP published in 1998 [16], which state the amount

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of electric and magnetic field exposure that the working personnel or the general public should be exposed to. The Republic of Cyprus has adopted these guidelines recently, and different electricity and communication supply authorities are obliged to conform to these guidelines.

Many researchers have conducted experimental and numerical measurements within open type air substations in an attempt to verify that the magnetic field values are below the ICNIRP guidelines which are 100 μT for the public, and 500 μT for the working personnel [17]. An extensive review of the work conducted in open air type substations is included in a recent paper by the authors [18].

In the theoretical approach, there are no solid theoretical models for calculating the fields in open type substations, thereby numerical methods are mostly performed, such that the field distributions are calculated. Such numerical methods are the Finite Element, Finite Volume and Finite Difference techniques which are used to solve the Maxwell's differential equations, such that the electric and magnetic fields are calculated.

Further to numerical methods, many people have used experimental techniques to measure and monitor the electric and magnetic fields that exist in open type air substations.

Extensive work has been conducted both numerically and experimentally to measure electric and magnetic field values in open air type substations. However, there is scant work performed on predicting the field values based on experimental measurements. Consequently, the authors of this paper utilize extensive experimental measurements of electric and magnetic flux density for seven open air type substations of the Electricity Authority of Cyprus (EAC) [19] to predict field values at the worst case scenario.

In this paper, firstly, a general description of the technical and structural features of a typical open air type substation, together with the methodology of the field measurements in these substations are discussed. Secondly, representative selective plots for the electric and magnetic flux density distributions obtained are presented, discussed, and compared to the safety guidelines of the ICNIRP. The worst case electric field exposures are extracted from the above extensive experimental electric fields and are expected to be similar to the operating ones, since the voltages of the substations do not change significantly. Finally, a proposed simplistic theoretical methodology based on Biot–Savart law is proposed that utilizes experimental field measurements to predict the worst case magnetic flux density exposure close to the transformers of open type air substations.

2. Structural, technical features and methodology of measurements

2.1. Structural features

An open type air substation consists of two main units, which are the open air circuitry equipment unit, and the control room unit, with the latter usually enclosed in a cement building. Due to the fact that the open air circuitry equipment unit is open to the surrounding environment, the electric field remains unshielded, which is not the case for closed type substations.

The architectural design of open type substations is environmentally unfriendly, since they can be seen by the general public from a distance away. This constitutes an extra reason for the public to be hesitant in accepting the building of new substations, and the presence of those that already exist. Furthermore, open air substations are build mostly in suburban areas, where people are less keen with technology and science, and are less willing to listen to epidemiological or phenomenological studies, indicating that there is no danger from electric and magnetic field exposure. Even though there is a fence at the perimeters of the substations and are well protected, there is always the possibility that an intruder will enter the substation, with the danger of getting electrocuted.

Table 1
List of equipments and their levels and symbols referring to Fig. 2 for the open type substation of Latsia.

Levels & symbols	
1	Lightning arresters
2	Voltage transformers
3	Air switch/earthing of current
4	Current transformers
5	Automatic switch
6	Air switch
P.T.	Power transformer
E.T.	Earth transformer
P.I.	Power insulator
M.K.	Control and cable box

2.1.1. Control room unit

Fig. 1 shows the architectural drawing of the control room of the Latsia open type substation. It is shown that the control room consists of a storage, a W.C., a control and relay, an 11 kV switchgear, a battery, a telecommunications, and a capacitor room. The control and relay room consists of three tap changer devices, one for each transformer T1, T2, T3 of the substation. The tap changers are power conditioning devices that use pre-selected transformer taps to compensate for varying line voltages for the transformers T1, T2, T3. A microprocessor control selects the correct tap, and makes a connection through high power electronic switching devices. Furthermore in the control and relay room, there exists three relay panels, one for each transformer, in case one wants to switch off their operation due to maintenance or electrical fault. Furthermore, in the control and relay room, there are three control panels to monitor the transformers' operation, by measuring their current, voltage and power factor.

In another small room next to the control and relay room, there is the battery room, where large DC, Uninterrupted Power Supplies (UPS) batteries exist. In the event of an electrical fault or maintenance operation, the vital control systems of the substation are powered with electricity from the UPS batteries, such that the substation is brought back to normal conditions. Furthermore, the UPS batteries supply power to operate the switchgear controls and associated devices for the substation, when a loss of power occurs. There is also an AC/DC converter which keeps the UPS batteries always charged.

The telecommunication's room consists of systems operating at 110 V, and it is used for remote control and monitoring of the substation, for phone calls outside the substation, and for intercommunication with other substations of the electricity network. The ventilation system that supplies fresh air into the control room of the substation consists of a hollow squared tube of cross sectional area of 20 cm × 20 cm in dimension. The capacitor room, also sometimes referred to as coil room consists of banks of capacitors and coils that are used for power factor correction, such that power losses are minimized. In the 11 kV switchgear room, there are panels including voltage and current meters, as well as safety switches from where one can switch on and off the many 11 kV lines that are fed from the Latsia substation. There is also a 400/230 V AC distribution board to channel electricity at the 230 V level for devices, and to be further converted to DC current for the telecommunication's room.

2.1.2. Open air circuitry equipment unit

The open air circuitry equipment unit of Latsia substation is shown in Fig. 2. Table 1 shows a list of equipment and their