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Magnetic Field Measurement & Simulation of A 230 kV Substation

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ABSTRACT

The possible effect of 60-Hz magnetic field exposure in occupational and residential environments raises the question of how electric and magnetic fields are created, and what effects they may have. Utilities in particular are interested in the sources and levels of magnetic fields associated with their transmission lines, feeders, substations and related equipment. Monitoring equipment for electric and magnetic fields have improved considerably in recent years. The use of this equipment for detection and measurement of electric fields and magnetic flux density has helped utilities to characterize exposure to these fields. In order to accurately determine which pieces of equipment within a substation are the main sources of high magnetic fields, detailed measurement must be taken. This paper presents the results of measurement and simulation of the magnetic fields on a typical 230 kV substation in Saudi Arabia. The substation area includes all transformers, circuit breakers, feeders and buses. Measurements of magnetic fields were taken using the FIELD STAR™ 1000 meters, developed by EPRI and manufactured by DEXSIL Corporation. Simulation of magnetic fields was done using SUBCALC Magnetic Field Modeling Program developed by EPRI Environment Division running under Microsoft Windows. The resulting magnetic field environment is presented in a variety of graphical formats including contour and three-dimensional maps.

KEYWORDS

Magnetic Fields, Measurement, Simulation, Substation.

INTRODUCTION

Questions about effects from exposure to power system alternating current electromagnetic fields are of continuing interest to Utilities, Regulators, Consumers and Power Equipment Suppliers. The possible effect of 60-Hz magnetic field exposure in occupational and residential environments raises the question of how electric and magnetic fields are created, and what effects they may have. There is uncertainty about the potential health hazards from these field exposures. Until there is more definitive information available on the health effect of EMF, it is not possible to determine if there is a safe or unsafe level of exposure [1-5]. Scientists do not agree on how to interpret the currently available information. There is agreement, however, that this is an important issue and that it should be resolved.

There is no doubt, however, that many people are concerned about the magnetic field effects of power frequency electric currents associated with AC transmission and distribution systems, appliances, tools, etc. while health studies are in progress, it appears desirable to conduct parallel technical studies related to the electromagnetic fields that can be found in occupational areas. Most interest in EMF research is focused on results of epidemiological studies, which report that cancer risks are increased in people who live or work around electric power facilities [5-6].

Utilities are aware that the public's concerns about this issue are widespread and sincere [6-13]. They recognize and take seriously their responsibilities to help resolve those concerns. Utilities in particular are interested in the sources and levels of magnetic fields associated with their transmission lines, feeders, substations and related equipment. The environmental effects of electric fields have been studied since the early 1970's, resulting from the Soviet reports in the 1966 about health problems experienced by men working in 400 kV and 500 kV switchyards, but the effects of magnetic fields gained publicity only during the last few years as a result of the several controversial epidemiological studies.

Monitoring equipment for electric and magnetic fields have improved considerably in recent years. The use of this equipment for detection and measurement of electric fields and magnetic flux density has helped utilities to characterize exposure to these fields. In order to accurately determine which pieces of equipment within a substation are the main sources of high magnetic fields, detailed measurement must be taken. Once the main field sources have been determined, recommendations can be made to reduce the field levels and substation design can be modified to make use of this information.

This paper presents the results of measurement and simulation of the magnetic fields on a typical 230 kV substation in Saudi Arabia. The substation area includes all transformers, circuit breakers, feeders and buses. Measurements were using the FIELD STAR™ 1000 meters, developed by EPRI and manufactured by DEXSIL Corporation. Simulation of magnetic fields was done using SUBCALC Magnetic Field Modeling Program developed by EPRI Environment Division running under Microsoft Windows.

SUBSTATIONS MAGNETIC FIELD CALCULATION

There are several assumptions [7-8] taken into consideration in calculating the magnetic fields in substations, which are summarized as follows:

a. Source currents are confined to measured values and current path (earth currents are neglected regardless of their origin).
b. The earth is non-magnetic
c. Field distortion is due to steel structure of substation.
d. The image current below ground is not accounted for, and
e. Induced currents on the counterpoise wires and the ground wires are ignored.

Low frequency magnetic fields are generated by electric currents according to Maxwell's equations [14-15]. Since currents in substation are usually confined to straight conductors (e.g. lines or buses), magnetic fields can be calculated by Biot-Savart law:

$$B = \frac{\mu_o}{4\pi}\int \frac{idl}{r^2}\hat{a}_r \qquad (1)$$

Where:
i: is the current flowing through the conductor
r: is the distance between an observation point and a source point.
$\hat{a}_r$: is a unit vector directed towards the observation point.

There are two significant models of sources in analysis of magnetic fields in substations namely, point source and long-conductor source. The current carrying conductors are modeled as point source if length (*l*) of conductors or conductor spacing (*d*) is much smaller than distance (*r*). The magnetic field for single, double, and triple conductors are given as:

For single: $$B = \frac{\mu_o I_o}{4\pi r^2} l \qquad (2)$$

For double: $$B = \frac{\mu_o I_o}{2\pi r^3} dl \qquad (3)$$

For triple: $$B = \frac{\mu_o I_o}{2\pi r^3} \sqrt{3}\, dl \qquad (4)$$

The current-carrying conductors are modeled as long conductor source if conductors are much larger than distance r, as well as conductor spacing d is much smaller than r. The magnetic field for single, double, and triple conductors is given as:

For single: $$B = \frac{\mu_o I_o}{2\pi r} \qquad (5)$$

For double: $$B = \frac{\mu_o I_o}{2\pi r} \sqrt{3}\, dl \qquad (6)$$

For triple: $$B = \frac{\mu_o I_o}{2\pi r^2} d \qquad (7)$$

The basic elements in substations are: buses, cables, transformers, circuit breakers, capacitor banks, etc. From the perspective of magnetic field, these elements can be grouped into two distinct categories: conductor-type elements (e.g. buses) and equipment-type elements that have additional metallic parts beside conductors, which might affect fields around theses elements.

The following information is necessary for the evaluation and presentation of substation magnetic field calculations, simulations and measurements [7-8,19,21]:

A) <u>Geometry</u>

(i) Substation layout plan, description of components.
(ii) Conductor, tower and substation geometry, including configuration, phasing, sag and clearance data,
(iii) Test traverse location, level and direction, and
(iv) Location of test points.

B) <u>Electrical Parameters</u>

(i) Line voltage, bus voltage,
(ii) Real and reactive line and transformer loads,
(iii) Waveshape, harmonic content (if available),
(iv) Location of electrical measurements, and
(v) Grounding conditions.

C) <u>Magnetic Filed Meters</u>

(i) Types of meters and probes, based on single-axis or multiple-axis principles,
(ii) Characteristics, and responses,
(iii) Calibration information and correction factors, and
(iv) Height of meter during measurements, positioning and orientation, of the meter.

D) <u>Micellaneous</u>

(i) Description of environment,
(ii) Time and duration of measurements,
(iii) Coordinate system, and
(iv) Correlation of magnetic field and load variation

MAGNETIC FIELD MEASUREMENT OF THE 230 KV SUBSTATION

The substation magnetic fields are somehow more complex and more difficult to measure than the magnetic fields near power lines or homes. The substations are complex concentration of magnetic field sources, which consist of many interconnecting points for transmission and distribution lines. The line currents passing through substations bus and equipment produce magnetic fields within the substations, which have much, the same attributes as magnetic fields beneath the lines themselves.

The close proximity of substation equipment and the grounding mat complicate the field attributes especially the spatial variability to some extent but do not inherently change the nature of the magnetic field. It is evident that the most prevalent sources of magnetic fields in substations are summarized as follows [10,18-19, 27-29]:

(a) High voltage and low voltage buses and lines, which include:
  (i) Low voltage side transformer buswork,
  (ii) Buswork segments within the racks which, due to loading, are forced to carry high currents,
  (iii) Pot-heads, and
  (iv) Underground cable entering / leaving the facility.

(b) Currents in connections to the ground mat from structural steel, fences, transformers and other metallic structures in the substation.

(c) Air core reactors.

(d) Capacitor banks.

In order to accurately determine which pieces of equipment within a substation are the main sources of magnetic fields, detailed measurement must be taken. Once the main field sources have been determined, recommendations can be made to reduce the field levels and substation design can be modified to make use of this information.

In this paper, a study of the magnetic fields was done on a 230 kV substation in Saudi Arabia. The substation is connected through four overhead double circuit transmission lines.

The current loading for a typical day of the four transmission lines is presented in Table 1. Measurements of magnetic fields were taken by dividing the substation into five meter by five meter grid and the magnetic fields were then measured at the grid points. All measurements were taken at one meter height above the ground [24] using the FIELD STAR™ 1000 meters, developed by EPRI and manufactured by DEXSIL Corporation.

Table 1. Typical Loading Condition of the Substation

Transmission line #	**Loading (MW)**
1	402.3
2	289.9
3	334.5
4	107.2

The FIELD STAR 1000 electric and magnetic field exposure meter is designed to measure, record data as function of time, distance, or position and analyze power frequency magnetic fields. Measurements are stored in the meter's memory and later transferred through a serial communications port to the Personal Computer for storage, display and analysis. The instrument can be held in any position and with an update rate of once per second, real-time data can be used to locate field sources.

The measured values of magnetic field inside the substation-measured area is presented in two different formats for the specified voltage, current and time conditions of the substations.

The 3D representation of the measured data is shown in Figure 1, and the contour representation for the same measurements is depicted in Figure 2.

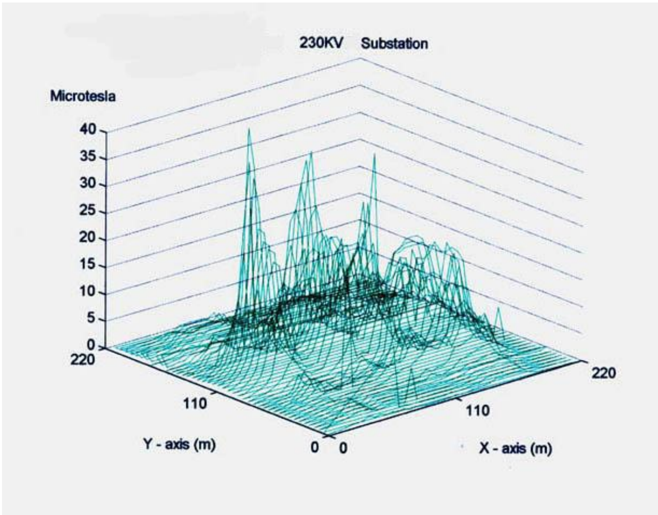

Fig. 1. 3D presentation of the measured magnetic field

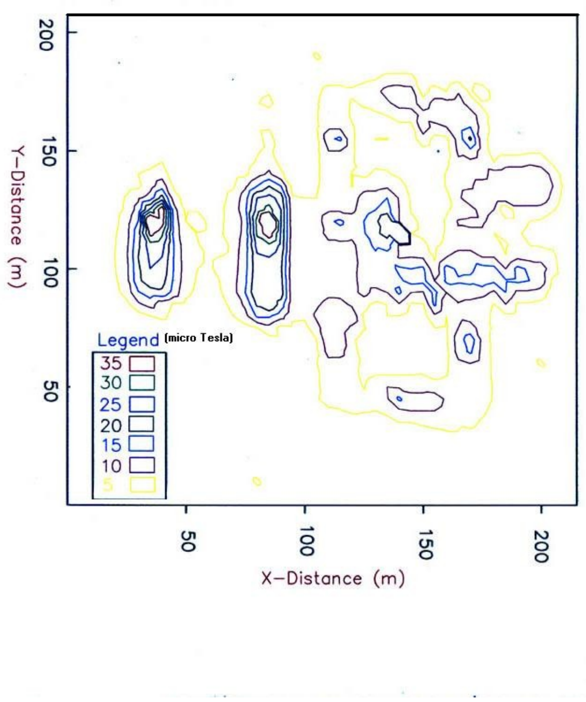

Fig. 2. Contour presentation of the measured magnetic field

MAGNETIC FIELD SIMULATION OF THE 230 KV SUBSTATION

Simulation studies can be used to determine the magnetic field distribution in and around the power facilities in substations [13,16-17,21-23,25]. They are useful for the following purposes:

a) It allows an environmental effects related evaluation of substation design.
b) It is a good complement to full scale studies for both measurement and analysis techniques.
c) It can be used as a design tool that can save money in the development stages of substations.
d) Simulation and modeling can be used to accumulate large amounts of data in a short line.
e) Ground level magnetic field strength or magnetic flux density mapping can be done.
f) Easy change of operating and geometric conditions.
g) Development of mitigation techniques, and
h) Systematic study of parameters the influence that magnetic field distribution.

The following assumptions were taken into consideration in calculating the magnetic fields in the substation:

a) Source currents are confined to the measured values and the current path (earth currents are neglected regardless of their origin).
b) The earth is non-magnetic.
c) Field distortion is due to steel structures of substations.
d) Induced currents on the counterpoise wires and the ground wires are ignored.

In this study, the SUBCALC program is used to model the magnetic fields in the 230 kV substation. SUBCALC Magnetic Field Modeling Program is developed by EPRI Environment Division and running under Microsoft Windows. This program models the power frequency magnetic fields from a user specified array of transmission, primary distribution lines, and substation conductors. The resulting magnetic field environment can be presented in a variety of graphical formats including contour and 3D maps. The program maintains a transmission line and distribution line database. The calculations within the model are based on the Biot-Savort Law governing magnetic fields.

The magnetic field output of the SUBCALC simulation program for the same measured substation and for the same loading conditions is also presented in two different formats. The 3D representation for the simulated output of the substation model is shown in Figure 3, and the contour representation of the same results of the program is shown in Figure 4.

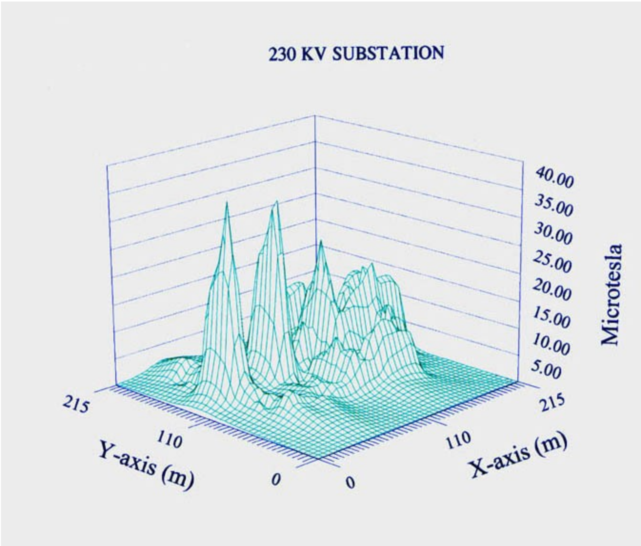

Fig. 3. 3D presentation of the simulated magnetic field

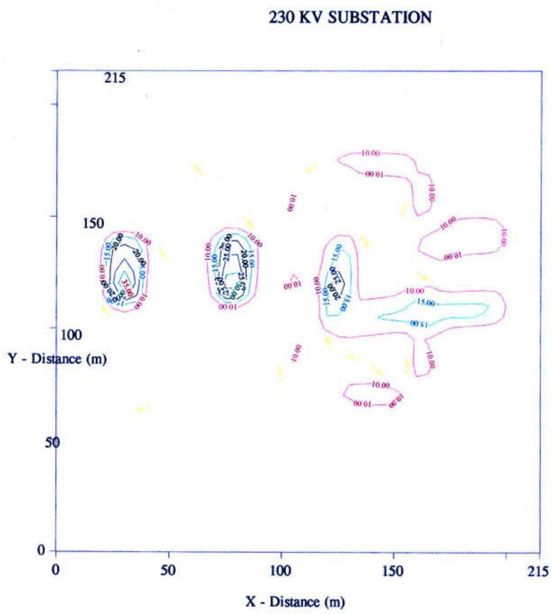

Fig. 4. Contour presentation of the simulated magnetic field

VERIFICATION OF THE MEASUREMENT RESULTS

The SUBCALC program and the measuring meter are used to provide closer look at the variation of the magnetic field density within some specified locations inside the substation and to present direct comparison between measured and calculated magnetic fields at that defined locations inside the substation. Figure 5 shows the field profiles inside the substation at Y=130 meter, while varying the X-axis. Figure 6 presents the profiles for another case inside the substation at X=75 meter and varying Y-axis.

It can be observed that the simulation agrees with the measurements in the sense that overall distributions of fields are similar. These results are reasonably lower than the limits presented by international guidelines [25-26].

CONCLUSIONS

This paper has presented the results of measurement and simulation of the magnetic fields on a typical 230 kV substation in Saudi Arabia. The substation area included all transformers, circuit breakers, feeders and buses. Measurements of magnetic fields were taken using the FIELD STAR™ 1000 meters, developed by EPRI and manufactured by DEXSIL Corporation. Simulation of magnetic fields was done using SUBCALC Magnetic Field Modeling Program developed by EPRI Environment Division running under Microsoft Windows. The resulting magnetic field environment has been presented in a variety of graphical formats including contour and three-dimensional maps. The attainable measured and modeling results were coordinated and showed almost full agreement. The results were reasonably lower than the limits presented by international guidelines.

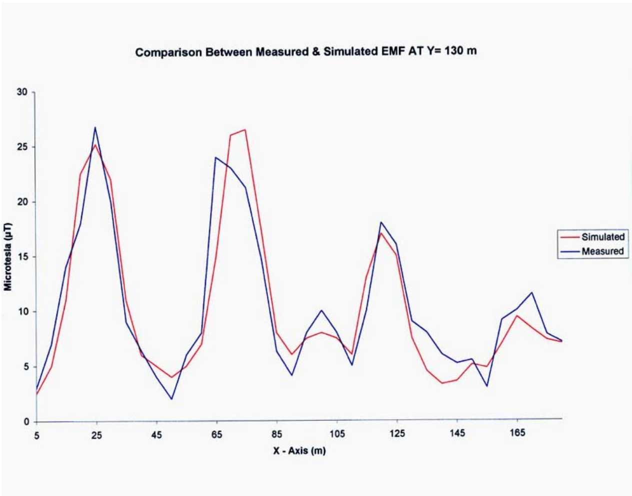

Fig. 5. Simulated and Measured Magnetic Field Profiles at Y=130 m.

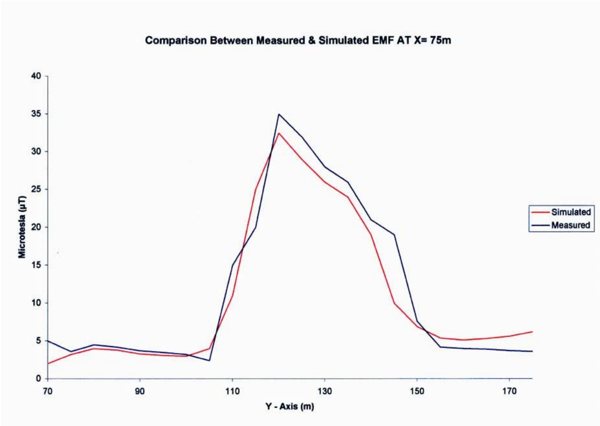

Fig. 6. Simulated and Measured Magnetic Field Profiles at X=75 m.

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