POWER FREQUENCY MAGNETIC FIELD MANAGEMENT IN POWER DISTRIBUTION SUBSTATION

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ABSTRACT

Levels of Electromagnetic Fields (EMFs) in our environment have increased steadily over the past 50 years.
There are many ways to mitigate the power frequency magnetic field (PFMF) either by design modification of electrical facilities and equipment, or by shielding using Conductive shielding (as Aluminum and Copper) or Ferromagnetic shielding (as : mu-metal).
In this paper the magnetic field management was applied using a developed SUBCALC program, also the magnetic field measurements were taken at distribution substation with and without shielding.
Different shielding materials are used in the measurements. The materials used were 3% silicon steel, primarily used for transformer core, mu-metal, and copper sheets. These materials were placed just adjacent to the transformer at the low voltage side and measurements were taken. The comparative result at each location is presented, and the comparison between the different materials is shown. A comparison was made between the experimental results and modeled one.

***Key words**: magnetic field management, magnetic field mitigation, shielding, modeling.*

INTRODUCTION

In Egypt, it is usual, especially in the neighborhood with dense populations, to situate distribution substation in the ground floor inside buildings. These locations are very close to the public and different workplaces. Power frequency magnetic field (PFMF) emitted will interact with the living organism and with the electronic equipment within the surrounding environment.
So, magnetic field management becomes a very important aspect. First, to minimize the impact of possible health effects of PFMF while maintaining power system reliability, safety and effectiveness. Secondly, when the PFMF is higher than **1** μT, it is known to produce interference with electronic beam devices such as TV, computer monitors, and industrial aspect.[1-2]

MAGNETIC FIELD MITIGATION

There is an increasing demand for effective and low-cost mitigation of extremely low frequency (ELF) magnetic fields. Due to these reasons, remarkable efforts have been devoted to research suitable techniques to achieve the desired reduction of magnetic fields generated by electrical systems. Several techniques have been applied in these sources to mitigate the magnetic field that can be classified in two groups:
"Intrinsic methods", when they act on the base factors affecting the field strength, such as phase arrangement, and "External shielding techniques", when special apparatus external to the system is used, such as grids of insulated conductors and shields made of ferromagnetic or conductive materials.[3-4]

Intrinsic methods

1- *Magnitude of phase current:* at power frequency, the magnetic field strength is proportional to the phase current magnitude. Line currents on substation buses, vary widely in both their magnitudes and phase angles, so utilities normally calculate magnetic field levels using estimated current magnitudes. Current unbalancing also affects magnetic field strength and slows the rate at which the magnetic field decreases at distances far from the conductor.

2- *Height of conductors above/below ground:* increasing the height of the current- carrying conductors will reduce the magnetic fields at or near ground level.

3- *Conductor configuration:* the magnetic field level in substation is the sum of the fields produced by the currents in all conductors and is dependent upon the distance between the observer and each current - carrying conductor. Placing the three conductors as close together as possible creates greater field cancellation and the magnetic field at or near ground level is reduced.

External shielding techniques

Field management can also be achieved through the use of material shielding. Material shielding of ac magnetic fields uses either conductive material or ferromagnetic material.

Conductive Materials (flux cancellation)

Conductive materials (e.g. copper and aluminum) act as a shield because induced eddy currents produce a magnetic field that opposes the main existing magnetic field**.**

Ferromagnetic Materials (flux-shunting)

Ferromagnetic materials such as iron or steel, shunts the magnetic flux. Iron and steel have high permeabilities, but some alloys such as mu-metal, which is a mix of nickel, iron, copper and chromium, have higher permeabilities. These alloys have higher permeabilities than just iron or steel but are more expensive.

MEASURMENT AND SIMULATION CASE STUDY

A typical indoor distribution substation for a residential area which houses a (delta/star) transformer rated at 1000kVA with 11kV circuit breakers and the 3phase, 4 wire 380/220 V distribution panel as shown in Fig.1. The Magnetic field measurements were carried out at this substation at height of one meter above ground level and the results are indicated in the measuring grid of (0.5m×0.5 m) ; the 3D representation is illustrated in Fig.2.The currents measured during the magnetic field measurement is of an average value of 200A, and the neutral current was 48.7 A. The measurements were made from 11 am to 1pm [5-6].

SUBCALC Magnetic Field Modelling Program was developed to model, simulate and calculate the magnetic field at any point on the grid. The program models the power frequency magnetic fields substation. The program is based on the Biot- Savart law in calculating and modelling the magnetic fields. In this research, the program is used to model the magnetic field in 11/0.4 kV distribution substation.[6] The magnetic field output of the simulation program for the same measured substations and for the same loading conditions is also presented in 3D format for the simulated output of the substation model as shown in Fig.2.

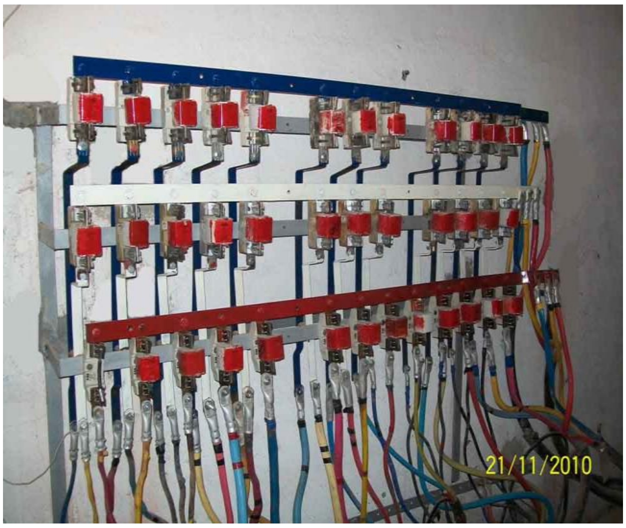

Fig.1. Low voltage panel

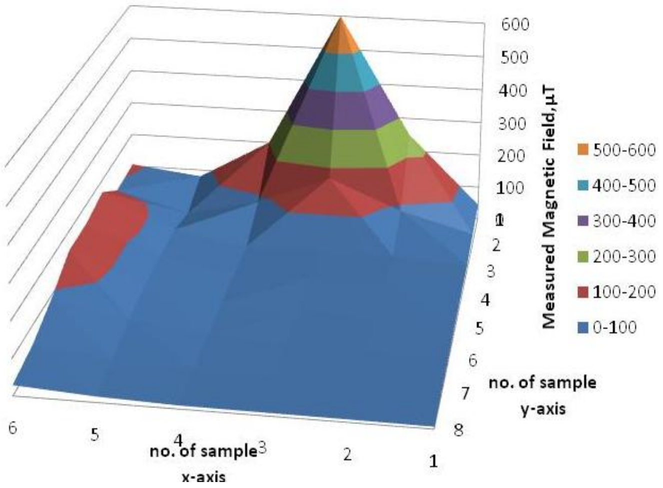

Fig.2. 3D representation for the magnetic field measurements

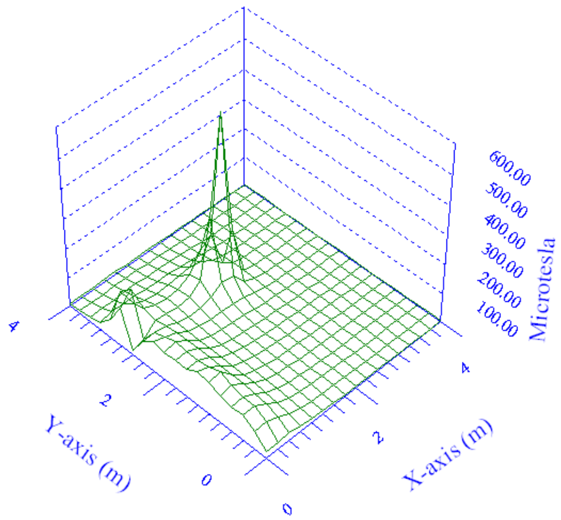

Fig.3. 3D format for the magnetic field simulation

COMPARING THE MEASUREMENTS RESULTS AND THE SIMULATION RESULTS

It can be observed that the simulation profile agrees with the measurements profile on the overall distribution of the magnetic field. This indicates the effectiveness of the developed program. This good agreement will encourage us to use the program in applying many modifications in the LV cables and the low voltage panel boards arrangements.

Management application

The developed SUBCALC program was used to find out the effect of the new arrangements in the distribution substation with the same current loads. The new arrangements were as follows:

1- Reduce the useless separation between the LV cable side
2- Re-arrange of the low voltage panel boards by making the LV busbars in the same horizontal level with lateral distance between phases of 5cm, instead of the vertical arrangement.

These new arrangements were applied and the simulated results represented in 3 D format is shown in Fig.4.

The maximum calculated magnetic field was 250µT, while before these modification the maximum values was about 600µT.[3]

This means that we could reduce the magnetic field emission without cost .

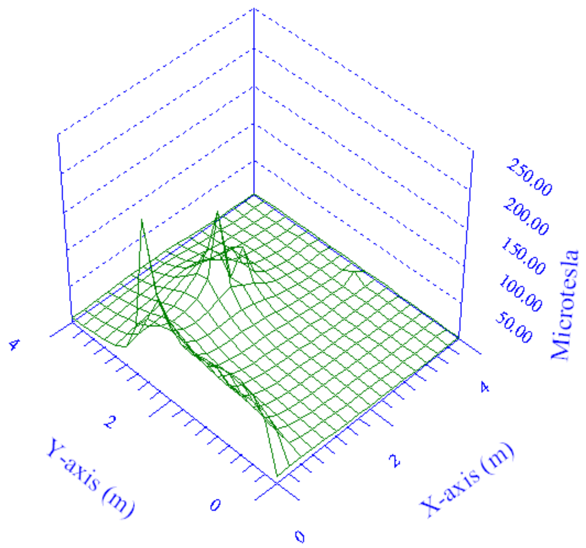

Fig.4. 3D format for the magnetic field simulation

External Shielding Experiments

The physical experiments were arranged to measure the magnetic field over the LV cables outage trench before shielding and after putting shielding materials over the trench. The materials which were used for shielding were sheets of electrolytic copper (with 1mm thickness, 0.5 m width, with conductivity $\sigma=58\times10^6$ S/m, and Relative Permeability $\mu_r=1$), Aluminum sheets (with 2mm thickness , 0.5 m width ,$\sigma= 38\times 10^6$ S/m, and $\mu_r=1$), low-loss silicon steel (with 0.5mm thickness ,0.5m width, and μ_r = 1000) and mu-metal(with 90µm , thickness 0.5m width, $\sigma= 2\times10^6$ S/m, $\mu_r = 10^5$). Magnetic field measurement results were taken along the z-axis at a height of 0.5 m over the shielding material. The measurements are shown in Fig.6

To discuss the shielding effectiveness we should calculate the shielding efficiency which depends on the ratio of the field measured at the point (x,y,z) for two different circumstances with shielding and without shielding. For power frequency magnetic field Shielding effectiveness the following equation can be used:[4]

$$SE = 20\log_{10}\frac{B_o}{B_{Shielding}} \qquad dB$$

Where:

B_o : is the field without shield,
$B_{shielding}$: is the field when the shield is present.

Fig.7. illustrates the shielding efficiency for the different used materials

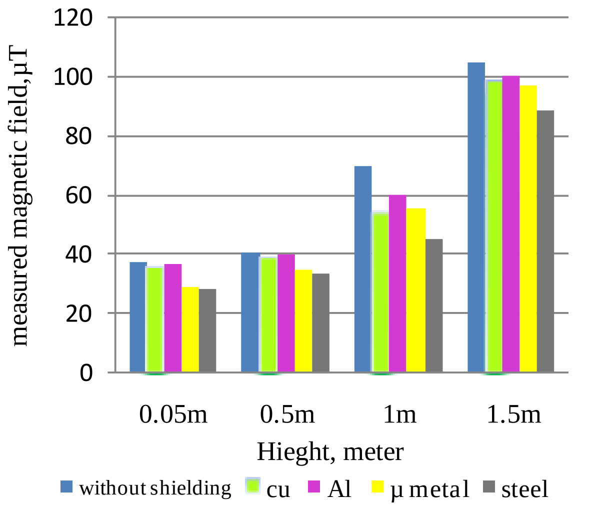

Fig.6. The measurements before and after shielding with different material

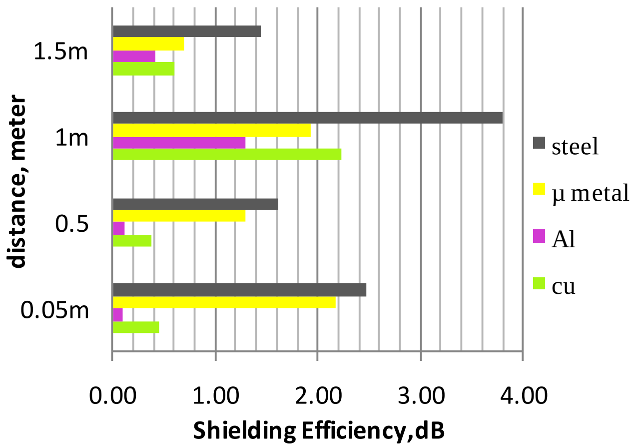

Fig.7. Shielding efficiency results

RESULTS AND DISCUSIONS

The magnetic field measured values were higher at distance 1.5m because in this position the magnetic meter was adjacent to the low voltage panel. The best shielding efficiency value was for the low-loss silicon steel which reaches 3.81dB, then for the mu-metal which reaches 2.17 dB taking into consideration that the mu-metal thickness was 90µm and the low-loss silicon steel thickness was 0.5mm.the shielding efficiency for Aluminum and copper were the lowest values. The reason may be because that the penetration depth (δ)at 50 Hz for copper is 9.44 mm and for Aluminum12.33 mm, the penetration depth in magnetic material as low-loss silicon steel or mu-metal are much smaller than that of aluminum or copper. Therefore, it is common to regard conductive flat shielding with thin non-magnetic materials at power frequencies as inherently inefficient (since any practical shield would have thickness < δ) [5-8]

CONCLUSION

- This paper used the developed SUBCALC simulation program to find out the results of the magnetic field managements by rearranging the distribution substation components. These applicable managements gave the best reduction values for the magnetic field exposure without additional cost.
- For the shielding experiment the obtained results show that the use of low-loss silicon steel give best shielding results, then the mu- metal material which is very thin compared to the rest of the used materials although it has higher cost. Their high permeability makes them attract the field lines to their interiors.
- The conductive materials (copper and aluminum) are not good shielding materials for power frequency magnetic flat shielding.
- It is recommended to apply the no cost or low cost solution before external shielding which expenses higher cost.

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