Assessment of Electromagnetic Field Distribution at Malbase Substation

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Abstract

This paper presents insights into the assessment of the electromagnetic field at the 400 kV Malbase substation, located in Pasakha. With the development and increase in the number of hydropower plants in Bhutan, the Malbase substation was constructed for the transmission and distribution of power within and outside of the country. With the increase in the generation of electricity, there is an increase in the radiation of electric and magnetic fields from the substation, which when exposed to any individuals working or living in the vicinity, can have negative health effects. This EMF radiation is measured using an EMF meter and simulated in EFC400 software, which is then compared with the reference levels for safe general public and occupational exposure, given in the guidelines of the International Commission for Non-Ionizing Radiation Protection (ICNIRP). The highest recorded electric and magnetic field during practical measurement is 1728 V/m and 29.3 µT and in the simulated output, the highest electric and magnetic field is 1704.66 V/m and 29.56 µT respectively, all recorded at the transformer zone. The simulated data of EMF is validated with the practically measured data. Even though the electric and magnetic field values are high, the values are still below the reference safe level, indicating that the substation EMF level is at a safe range.

Key Words: *Electromagnetic field,Eelectric and magnetic field measurements, Outdoor electric power substation, Safe public and occupational exposure, EFC400 software*

1. INTRODUCTION

The advent of modern technology and the wider use of electricity has introduced the world to the Electromagnetic field. It occurs in the natural world, and people have been exposed to it for the whole human evolution. The source of EMFs is the equipment that uses electricity and also the energized high-voltage power-transmission equipment which is often overlooked (Haus & Melcher, 1971)

As the electricity demand continues to rise, the exposure to this man-made electromagnetic field is also increasing. The transmission and distribution of electricity is performed by all electrical substations. It plays an important role in converting the electricity into different voltage levels. These substations consist of switching equipment, protection equipment, and transformers, which in the process of generation of electricity generate electric and magnetic fields.

Electric fields are produced due to the voltage difference whereas the magnetic field is produced due to the flow of current through a conductor (McCormick & Sanders, 2008). The increase in exposure to EMF has led to a growing concern among people regarding the potential health hazards. The high values of EMF can have a bad effect on the health of the workers, visitors, and even the people living in the vicinity (Safigianni & Kostopoulou, 2023). In the context of Bhutan, no studies have been taken into consideration to date. Hence, no safety measures regarding EMF exposure have been made. EMF is produced when the system voltage and load connected is high. The rationale for selecting Malbase substation is that, it deals with the interconnection of high-voltage transmission.

This research is necessary since EMF is an inherent consequence of electrical energy transmission and transformation, its influence on human health is inadequately explored.

2. SUBSTATION DESCRIPTION

The electromagnetic field measurements have been taken at an outdoor electric power substation, 400 kV, 43,555 m^2 in area, situated in Pasakha. The site of the Malbase Substation interconnects the 400/220 kV. The substation area is enclosed by the 4.5 m high concrete wall. There are eight transformers installed within the substation, consisting of four units with a rating of 66.67 MVA each and the other four units with a rating of 100 MVA.

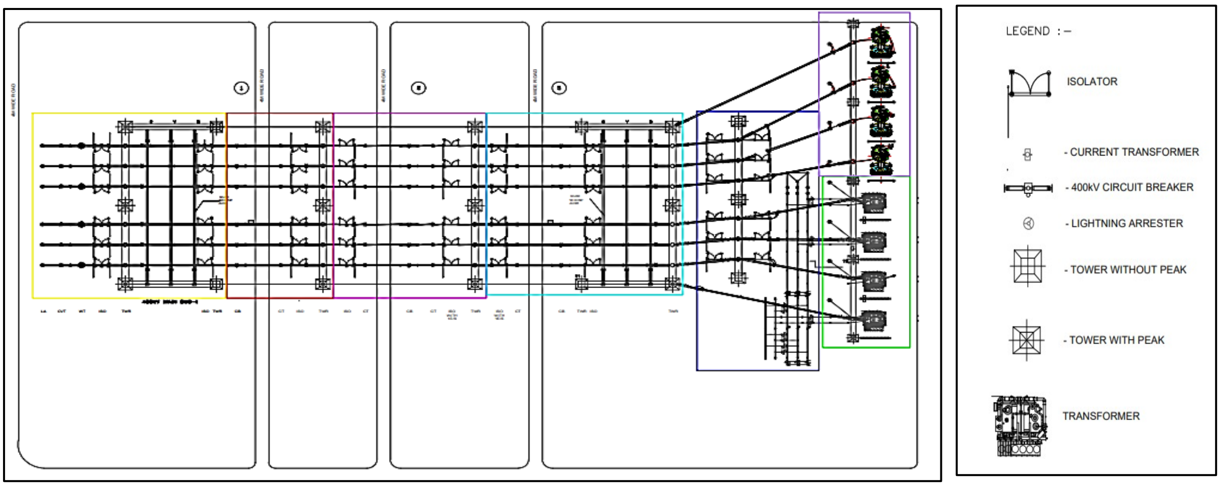

Fig.1: *Overview of 400 kV Substation Layout*

The other important components used in the substations are as follows;

i. 420 kV, and 245 kV SF6 Gas Circuit Breakers
ii. 420 kV, 220 kV, and 33 kV Isolators and Earthing Switches
iii. 420 kV, 245 kV and 33 kV Instrument Transformers (Current Transformers, Voltage Transformers)
iv. 390 kV, 216 kV, 54 kV, and 39 kV Lightning/Surge Arresters and 40 kV Surge Capacitors.

The substation is divided into seven different zones for easier measurement and coverage during the practical measurement. Fig.1 shows the 400 kV substation layout and the legend used for easy references.

3. SIMULATION OF EMF USING EFC-400 SOFTWARE

The simulation of EMF for the 400 kV distribution substation was done in EFC-400 software which supports 2D simulation and Isolines representation. Both electric and magnetic field simulation has to be done separately with electric field simulation taking longer time compared to magnetic field simulation. Computation of electric field and magnetic field is done using the law Charged method and Biot-Savart law respectively.

Fig.1 was imported as a background map in the EFC400 software where the components were placed. All the components are already available in the library manager.

Fig.2 shows the overall view of the substation. Starting from the left, it includes a lightning arrester, current transformer, isolators, tower, and bus bar, with the substation being surrounded by bushes to depict the presence of vegetation. At the far end of the substation lies the 66.67 MVA and 100 MVA transformers. The whole substation is interconnected with a twin moose Aluminum conductor steel-reinforced cable ACSR cable to provide the

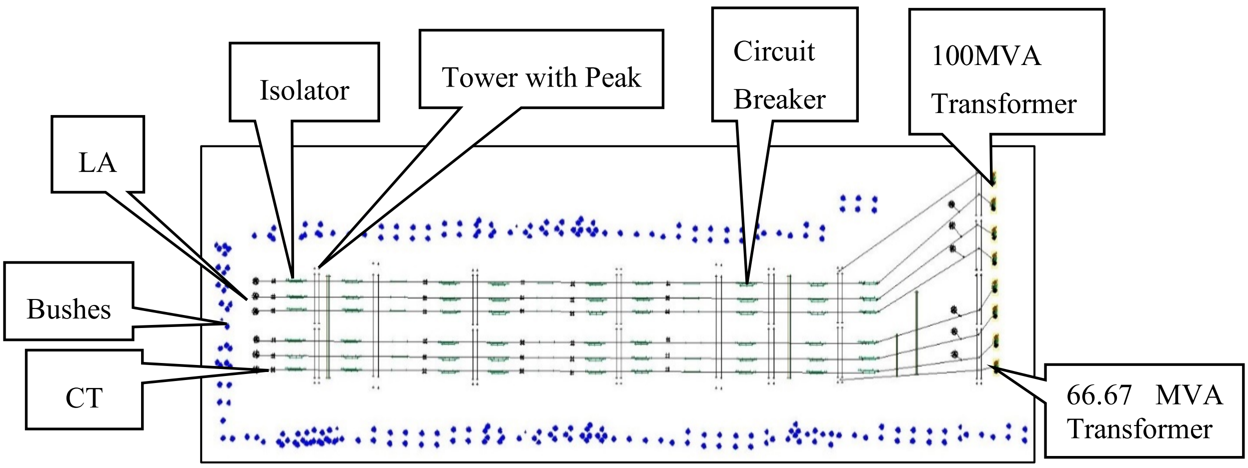

Fig.2: *Substation layout in EFC400 software*

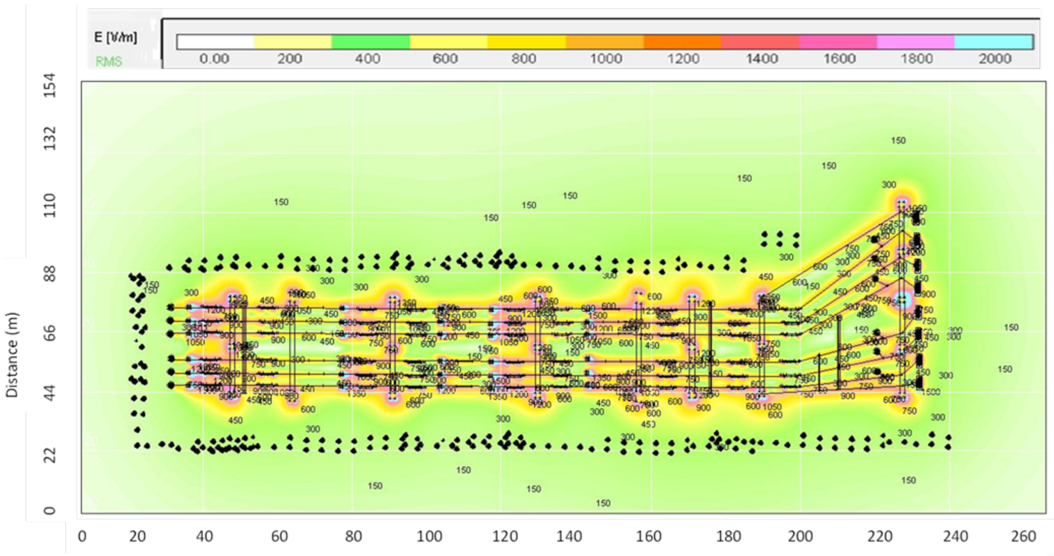

Fig.4: *2D Electric Field Simulated Output*

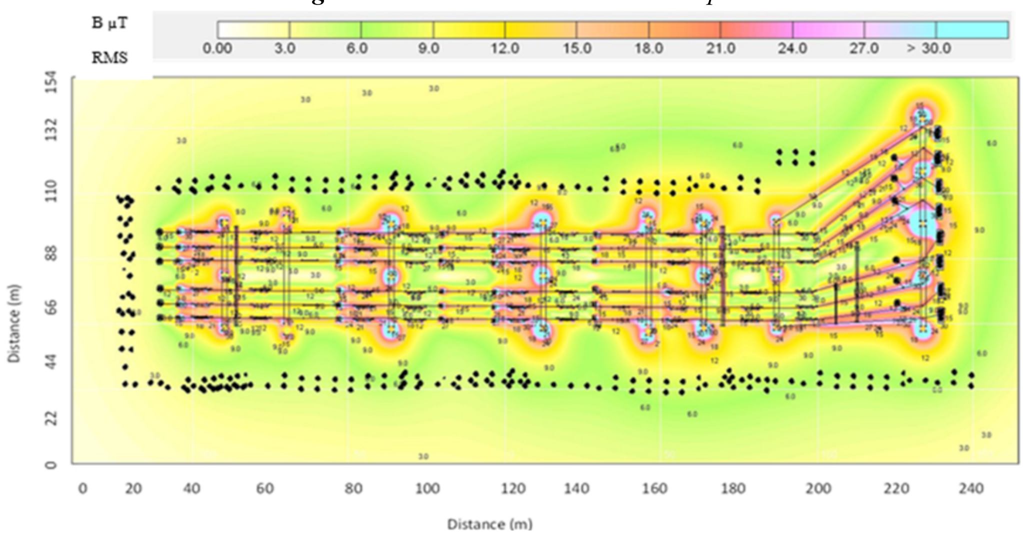

Fig.3: *2D Magnetic Field Simulated Output*

actual depiction of the actual substation.

To simplify the model, certain assumptions were made in the modeling process to ensure less error in the simulation. The environmental condition such as the temperature of the substation is considered to be constant at 32 °C. The practical measurement was performed at a temperature of 32 ̊C, to maintain the accuracy of the simulation with the practical measurement while the temperature is kept at 32 ̊C. The area of measurement of EMF is far from the walls of the substation due to which the substation is modeled with an open boundary. This allowed the fields to leave the conducting components without reflecting, which helped to better simulate the actual substation.

3.1. Simulation Execution

The simulation is performed in EFC400 software. It generates a 2D representation onto the XY plane. The total time taken for the simulation of an electric field was 58 hours on a computer and the total time taken for the simulation of the magnetic field was 44 hours on a computer. The *x* and *y* axis shows the distance in meters.

Fig.2 shows a details electric field map of the substation. The color gradient legend shows the intensity of the electric field in V/m from 0 V/m to 2000 V/m.

Fig.3 shows the 2D representation of the magnetic field. The strength of the magnetic field ranges from 0 µF to 30 µF.

4. PRACTICAL MEASUREMENTS

The electric and magnetic fields were measured at the 400 kV Malbase substation using the two EMF meter, which measures both the electric and magnetic field simultaneously while also providing the temperature. Measurement was done in zones for easier measurement of the EMF.

Table 1: *Technical Details of EMF Meter*

EMF Meter 1	EMF Meter 2
EF range: (1-1999) V/m	EF range: (1-1999) V/m
MF range: (0.01-99.99) µT	MF range: (0.01-99.99) µT
Testing bandwidth: (5-3500) MHz	Testing bandwidth: (5-3500) MHz
Operating temperature: (0-50) ˚C	Operating temperature: (0-50) ˚C
Power supply: 3*1.5 V AAA battery	Power supply: 3.7 V

Using the substation as a coordinate system with x and y axes, the point of measurement is placed at a distance of 5 m intervals, both horizontally and vertically, and the spot measurement method is applied.

A 5 m interval is maintained in the measurement process to ensure all the critical areas of the substation are covered. It ensured thorough and accurate coverage of the electric and magnetic field throughout the entire substation area.

The selected measured spot was measured at a heart height of 1.5 m. The measurement procedures were done by following the guidelines provided in IEEE Standard 644-1994 (Misakian, 1994).

From the seven zones, 672 spots were measured and were recorded in a colour co-ordinted Excel sheet. During the measurement period, the mean load was 34 MW. The recorded ambient temperature during the period of measurement was noted to be 30 ˚C to 35 ˚C. All measurements were carried out at a 50 Hz frequency.

5. ICNIRP GUIDELINES

ICNIRP stands for International Commission for Non-Ionizing Radiation Protection. It is a non-profit scientific organization based in Munich, Germany. It is a recognized association formed in collaboration with the World Health Organization (WHO) and the International Labor Organization (ILO). It seeks to protect people and the environment against the harmful effects of non-ionizing radiation (NIR).

To prevent harmful health effects from interacting with low-frequency fields, ICNIRP has framed certain guidelines that contain exposure limits. The exposure limits were derived considering the worst-case scenarios. The reference levels for general public and occupational exposure to 50 Hz electric and magnetic fields are, according to the ICNIRP guidelines as follows (ICNIRP, 2009):

Table 2: *ICNIRP Guidelines*

	Electric Field Strength	Magnetic field Strength
General public exposure	< 5 kV/m	< 100 µT
Occupational exposure	< 10 kV/m	< 500 µT

6. COMPARATIVE ANALYSIS

6.1. Measured and Simulated Electric Field

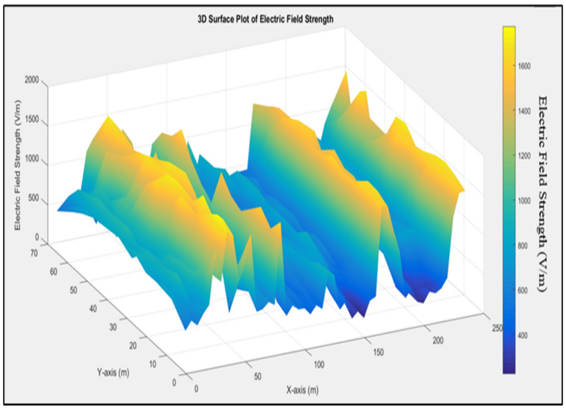

Fig.5: *3D Plot of the Measured Electric field*

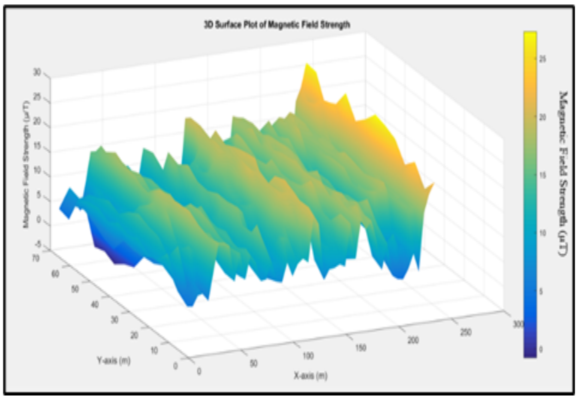

Fig.6: *3D Plot of the Simulated Magnetic field*

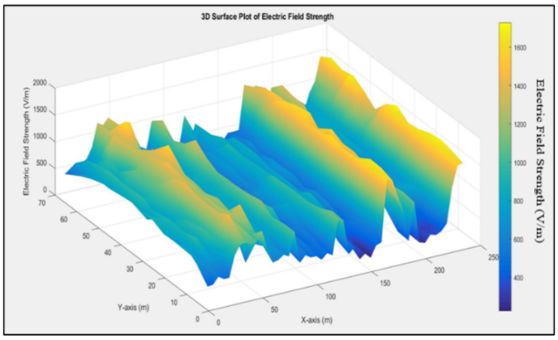

***Fig.**7: 3D Plot of the Simulated Electric field*

Figure 5 and **Error! Reference source not found.**ure 7 shows the 3D plot of the measured and simulated magnetic field. The graphs are generated from MATLAB software. The areas around the busbar, towers, and the transformers are the areas where the electric field values were the highest. The peak point or the darker yellow shade of the graph shows the high intensity of the field measured around the areas.

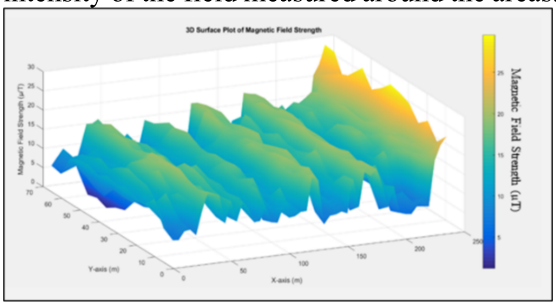

***Fig.8:** 3D Plot of the Measured Magnetic field*

6.2. Measured and Simulated Magnetic Field

Figure 8. and Figure 6 shows the 3D plot of the measured and simulated magnetic field respectively. It illustrates the intensity of the magnetic fields around the substation. It ranges from 0 to 30 µT. From both the measured and the simulated graph, it shows that the areas around the transformer, busbars, and the towers, show high intensity of magnetic field.

7. RESULTS

Figure 9 represents the difference between the measured and the simulated output of the electric field. There is not much variation between the two but the highest intensity of the field is around the transformer region, showing an Individual should not stay around these areas for a long time.

The error between the simulated and measured data is generated from MATLAB using the Root-mean-square error (RMSE) method. The error generated is 6.02 %, which shows that the accuracy of the simulated electric field is at a reasonable level.

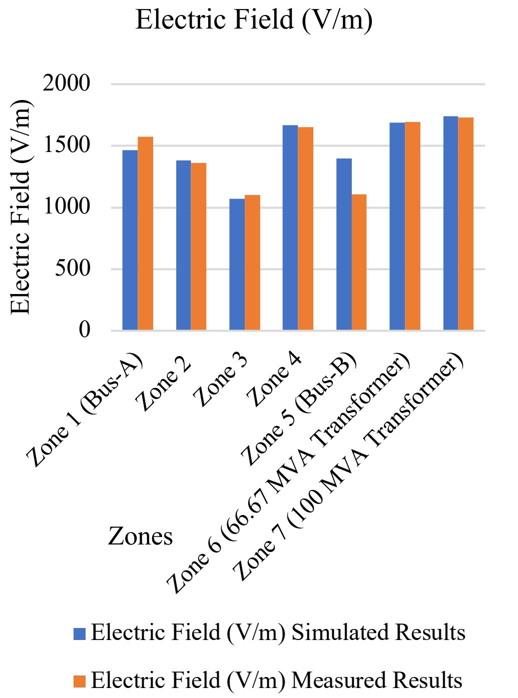

***Fig.9:** Measured and Simulated Bar Graph of Electric Field*

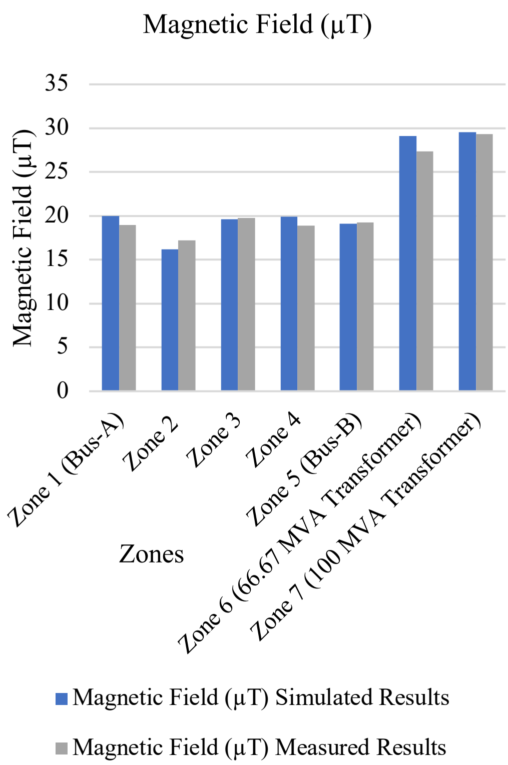

***Fig.10:** Measured and Simulated Bar Graph of Magnetic Field*

Figure 10 represents the difference between the measured and the simulated output of the magnetic field. The highest intensity of the magnetic field is noted around zones 6 and 7. There is less difference between the simulated and measured magnetic field values. The error generated is 4.79 %, which shows that the accuracy of the simulated electric field is at a reasonable level.

8. CONCLUSION

A computational approach is made for the simulation of electric and magnetic fields around the substation in EFC400 software, which provides data visualization of the field, according to the intensity of the field. The electric field ranges from 204.266 V/m to 1740 V/m and the magnetic field ranges from 3.672 µT to 29.56 µT for simulated output. For measured output, the electric field ranges from 258 V/m to 1728 V/m and the magnetic field ranges from 5.31 µT to 29.3 µT for simulated output using an EMF meter, practical measurement is performed, from where the highest recorded value is around the transformer region followed by bus bars and around towers. The electric and magnetic field gradually decreases as the distance is increased from the source. Even though the highest value for both electric and magnetic fields is recorded around the transformer, the value does not exceed the reference level for safe public and occupational exposure from ICNIRP guidelines, which serve as a globally recognized standard.

In conclusion, the measured and the simulated field values around the substation fall within the recognized safety guidelines, indicating that there is no danger to the public or working personnel, thus no cause for concern.

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