Measured magnetic field profiles at HV gas insulated substations (GIS), underground cables and generating stations

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Abstract: Electrical power industry has to face new design and operational changes from time to time. One such problem is the reported interaction between the living beings and the electric and magnetic fields produced by power lines and devices, which use electric power for their working. This is called as Biological effects of extremely low frequency (ELF) electric and magnetic fields. Epidemiological and laboratory studies have been under taken world wide to investigate this problem and suggest remedial measure like design changes and fixing the maximum permissible exposure levels for electric and magnetic fields. This study was aimed at obtaining information on maximum field strength (µT) as well as the magnetic field dosage (µT-day) to which an occupant is subjected to in a wide variety of places, where, magnetic field is continuously produced. The places considered were high voltage gas insulated substation, under ground cable and generating station. The data collected is compared with maximum permissible ELF magnetic fields proposed by the IRPA and WHO and were found to be within the limits.

1. INTRODUCTION

Electric power is a major source of energy to human beings. It is generated at pithead or remote hydro stations and transmitted to major load centers by high voltage transmission lines of different voltage levels, depending on the quantum of power to be transmitted.
This could be a HV line of rated voltage of 220 kV or an EHV line of 400 or 800 kV or an UHV line of rated voltage ranging between 1000 – 1200 kV. At the load centers, the power is distributed to consumers by lines of rated voltage ranging between 11 kV to 132 kV, the voltage level again determined by the magnitude of the power to be supplied. Major industries are supplied at these voltages directly. In big cities, shopping and office complexes are also supplied at 11 kV. For domestic consumption, the voltage is reduced to 440 Volts. In the domestic load centre, variety of equipment and gadgets use electric power for the working.

The electric power is made of voltage and current. All along the generation to domestic load, the voltage and current are present with different magnitudes. A common factor is the frequency of the supply voltage, which could vary between 47.5 Hz to 52.5 Hz, the nominal value being 50 Hz in our power system. In the vicinity of the conductors of these transmission and distribution lines, and around the electrical equipment and gadgets which use electrical energy for their working, electromagnetic non-ionizing radiation is present in the form of electric field (due to voltage) and magnetic field (due to current). The frequency of these fields being low and equal to the power supply frequency, they are called Extremely Low Frequency (ELF) electric and magnetic fields or power line caused fields. The International Radiation Protection Agency (IRPA) has issued an interim guideline [1] on the limit of exposure to the power line electric and magnetic fields. Table 1 shows these limits. A joint CIGRE / WHO statement [2] for public puts the permissible level of electric & magnetic fields at 20 kV/m and 640 µT respectively. In recent times, attempts are being made to characterize the magnetic field exposure in different environment, including the vicinity of power transmission and distribution lines, residential houses, shopping and office complexes, industries etc. [3-10] This kind of data collection helps in comparing the magnitudes at different location with the permissible field levels as per the IRPA guidelines, and also provides data for designing laboratory exposure studies.

Central Power Research Institute (CPRI), Hyderabad was also contemplating laboratory magnetic field exposure studies on animal and plant systems. Hence, it became necessary to collect data on the magnetic field dosages to which people are exposed in various environments mentioned earlier. In order to have representative data from all the major sources of ELF magnetic fields, following locations were chosen for the data collection in the present investigation.

Table 1: IRPA Limits of Exposure to 50/60 Hz Electric and Magnetic Fields[1]

Exposure Characteristics	Electric field Strength, kV/m (rms)	Magnetic flux density, µT
Occupational:		
Whole working	10	500
day short term	10 to 30	5000
General public :		
Up to 24 hrs. daily	5.0	100
Few hours per day	10.0	1000

2. OBJECTIVES AND SCOPE OF THE PRESENT WORK

In order to investigate the reported possible bad effects of magnetic fields (like increased risk of cancer, leukemia, change in blood composition, growth, behavior, immune system and neural functions), the foremost requirement would be the assessment of the magnetic field dosage to which a living being is subjected to in various electrical system environments. Thus an exhaustive data bank has to be created for use in the laboratory exposure studies. Unlike the electric field, which depends on the voltage and remains approximately constant for a given system, the magnetic field closely follows the load pattern and hence is statistical in nature. It is important to represent this statistical variation also in the laboratory exposure studies. Hence this study was taken up as a pre-requisite to the long-term laboratory exposure studies.

This study is aimed at measuring the field pattern in typical Gas Insulated substations, under ground cables and Generating station. This data will be essential to undertake laboratory exposure studies under magnetic fields, which is also envisaged by the Bio-monitoring laboratory of CPRI, Hyderabad.

3. METHODOLOGY OF MAGNETIC FIELD CHARACTERIZATION

In this study, the measurements were performed for Gas insulated substations, under ground cables and Generating stations. Two types of magnetic field measuring devices were used, one type for the conventional spot measurement and another type for the long duration recording for statistical analysis of the data. Two different ranges were chosen for the spot measurement meter to suit measurements at both low field and high field locations. Spot and dosimeter measurements were carried out after obtaining due permission from their owners. Physical layouts of the place of measurement were collected and the spot measurement values were recorded on them. Among the population in the location, if the number is more than three, one volunteer each from those performing similar duty were requested to wear the dosimeter. This helped in obtaining the exposure dosage of different category personnel in the same location.
The loads of lines, during spot measurements and dosimeter recordings in Gas Insulated substations, Under ground cables and Generating stations were recorded from the control room and time load variation curves were drawn for the duration of the measurement. The following considerations were also made during the measurement.

As per the international practice, measurement was always done at approximately 1m height from the ground level for both spot measurement and dosimeter recordings. For dosimeters, the sampling rate was selected as 10 seconds per point and the measurements were done for a total duration of 60 hours continuously.

Whenever necessary, the spot measurements were first made before the dosimeter recordings. Depending on the nature of work of different persons in a given place, two to three persons were requested to wear the meters simultaneously. For transmission line related fields, two types of buildings i.e. house, which is nearer to the line, and house, which is away from the lines were selected for placing the meters.

4. DETAILS OF MAGNETIC FIELD MEASURING DEVICES

4.1 Spot meters: This is a non-recording three-axis digital survey meter, designed to measure power frequency magnetic fields. It measures the x, y, and z magnetic field components and calculates a resultant field value within their on-board computer for display on the LCD.
The meters are extremely simple to use, with its size and weight makes it suitable to magnetic field survey measurements. These meters require 9V battery of Alkaline or Lithium type. Figure 1 (a) and Figure 1 (b) show the EMDEX and DEXIL meters respectively. The maximum-field range of EMDEX meter is 100 µT and that of the DEXIL meter is 300 µT. DEXIL meter was used for spot measurement in heavy industries only.

Figure 1 (a): EMDEX make Spot Meter

4.2 Dosimeter: This is a programmable data-acquisition meter, which measures the x, y, and z vector components of the magnetic field through its internal sensors. Measurements are stored in the memory of the meter and later transferred through a serial communication port to an IBM- compatible personnel computer for storage, display and analysis by the EMCALC software. While using, the sampling rate of the meter could be adjusted as per the requirement different sampling rates are available. They are 4, 10, 30, 60,120, 300, 600 and 1200 seconds per measurement.

This means that, if the sampling rate is 1200 seconds per measurement, it can acquire data for about 300 days continuously. If sampling rate is 4 seconds per measurement it can acquire data for 24 hours. The maximum field strength meter can record 100 µT. The meter requires 9 V battery of Alkaline or Lithium type for its operation.

Figure 1 (b): EMDEX make Dosimeter Meter

5. MEASUREMENT OF MAGNETIC FIELDS IN DIFERENT LOCATIONS

5.1 HV Gas insulated Substation 220/110kV
5.2 Under ground Cable at 11 kV
5.3 Generating station 210 MW at 15.75 kV

5.1.1 HV Gas Insulated Substations (GIS):

GIS is a fast emerging technology in countering the requirement of space for establishing substations, in India GIS are being set-up at almost all voltages rating from 33 kV to 400 kV, as the substation is compact, the operational personnel of the substations very much close to the current carrying conductors than over head substations. Though the conductor is enclosed in SF_6 medium in metallic containers, which shields the magnetic field, the proximity makes exposure level to personnel in the substation be higher than the overhead substation. These measurements were done at 220/110kV GIS building, outdoor switch yard, and master control room.

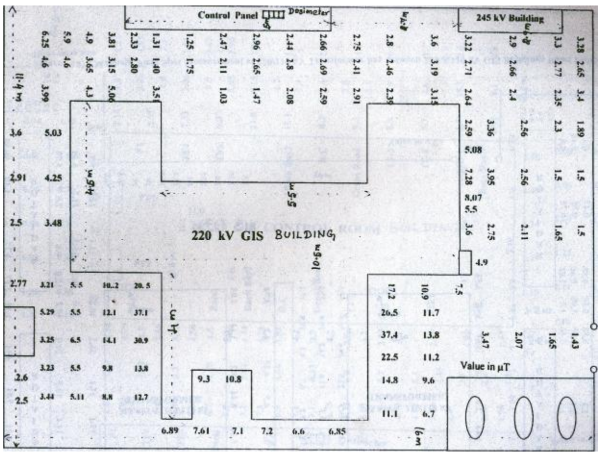

Figure 2: 220 kV GIS building with spot measurement meter

5.1.2 Results of the Magnetic field measurement at 220/110 kV GIS:

The approximate layout of this substation is given in Figure 2 gives the overall GIS interconnections. Spot measurements were done in both the GIS buildings, master control room and in outdoor switch yard. During this measurement the meter was kept at a height of 1m from the ground. The spot measurement results are given Figure 2 and at the time of measurement most of the outgoing feeders were fully loaded. Figure 3 Indicates the Histogram of magnetic fields measurement. Table 2 summarizes the maximum and minimum magnetic field measured by spot measurement method.

Table 2: Spot meter measurement results at 220/110kV GIS

Location	Magnetic field (µT)	
	Max	**Min**
In side 110 kV GIS room	19.5	0.6
220/110kV Transformer bay	56.8	0.4
In side 220 kV GIS room	37.4	1.03
Around 110/22 kV, 8 MVA transformer	109	1.1
110kV switch yard	35.7	2.5
Master control room	5.88	0.6

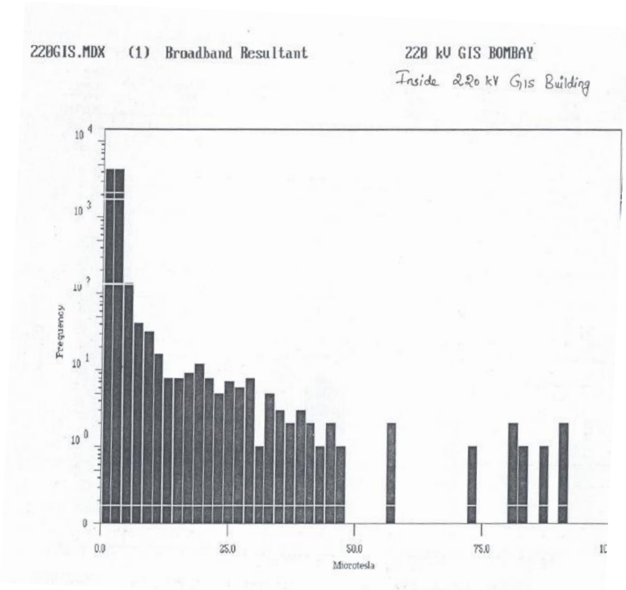

Figure 3: Histogram of magnetic fields measurement in 220 kV GIS building

As it was not possible to find volunteers to put on the dosimeter, one meter was kept at 110kV GIS building and another was at 220kV GIS building. Table 3 gives the summary of the results.

Table 3: Dosimeter measurement results in 220/110kV GIS

Bin range(µT)		No. of Occurr-ences	Magnit-ude (µT)		L_X (µT)	Exposure In24 h (µT-day)
Min	Max		*	**		
Location of the measurement: 220 kV GIS building						
0	20	10117			L_5= 8.5	
20	40	49				
40	60	35	99.28 (2)	5.73	L_{50}= 5.75	137.57
60	80	2			L_{95}= 2.0	
80	100	6				
Location of the measurement: 110 kV GIS building						
0	20	8792			L_5= 6.0	
20	40	98				
40	60	8	99.28 (4)	2.74	L_{50}= 2.6	570.06
60	80	1				
80	100	5			L_{95}= -	
100	106	4				

* (Highest) Number in the bracket indicates how many times the highest value occurred
** (Average) Number in the bracket indicates standard deviation

5.1.3 Observations on the measured Results:

It is observed that the very high value of exposure of 137.57 µT-day measured in 220/110kV GIS has no consequence as inside the building no personnel would be present continuously. The building housing GIS is not generally accessible to the workers under normal circumstances.

5.2. Underground cables

The general practice to use 11kV cables for supplying urban consumers by power utilities. Hence the probability of exposure to magnetic field produced by under ground cables to general public is high.

5.2.1 Computation of magnetic field produced by under ground power cable: In this computation, numerical method is used to calculate the magnetic field above ground generated by a three phase cable buried in side the ground fourier series expansion is used to calculate field both interior and exterior to the cable by considering electromagnetic properties of the dielectric surrounding the conductors and that of the earth. The three different phase currents in the cable are modelled by electric line currents at the centres of their respective conductors. The total magnetic field is calculated by applying the principle of superposition to the magnetic fields generated by each phase conductor.

The cross sectional view of an underground cable without steel pipe enclose is shown in figure 3 the Z- directed magnetic vector potential A_z for this configuration is calculated by solving Helmoltz equation of A_z in two different regions, namely in the dielectric surrounding the conductor and earth surrounding the dielectric.

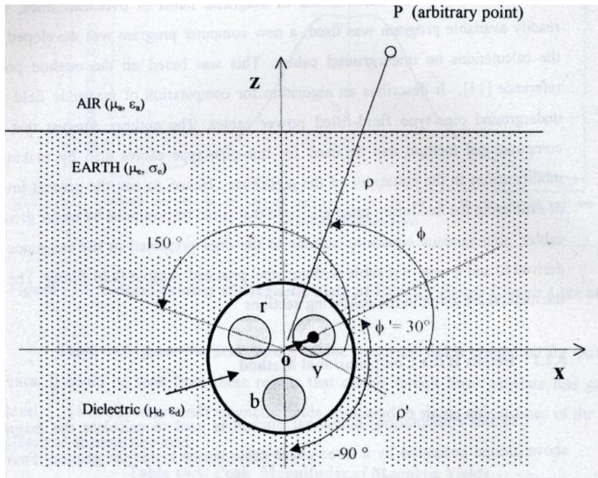

Figure 3 Cross section of an under ground cable and various angles physical parameters

A 3 phase XLPE underground 11 kV cable installation was supplying fairly balanced load of about 0.5 MVA (24 A). The cable was buried at 0.7 metres. Magnetic field lateral profile was measured using the spot meter at 1 m above the ground for a lateral distance of 4.5 m on either side of the cable. This case was simulated using the computer program. Figure 4 shows both measured and computed fields. The correlation between the measured and computed fields is fairly good considering the resolution of the meter used which was only 0.01 µT

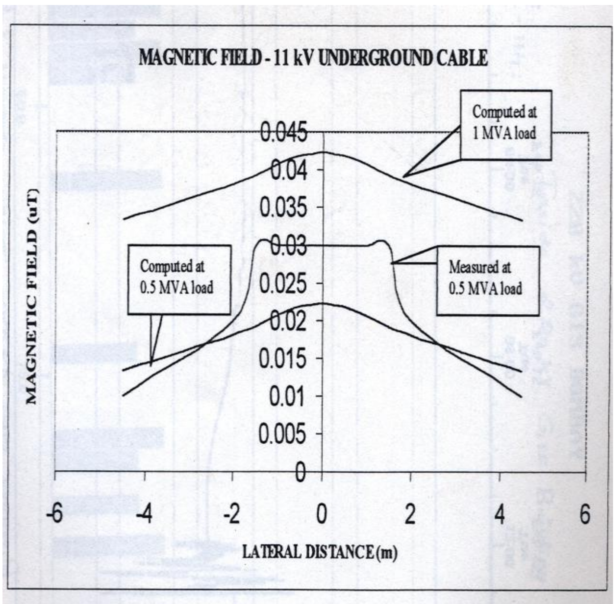

Figure 4 Lateral Magnetic fields of 11kV under ground cables

This is attributed to the closeness of the phase conductor by in the cable which helps in the cancellation of the field produced by one conductor by other. As the magnitudes of the magnetic fields (hence the exposure) due to the under ground cables are low. Further case studies were not taken up.

5.3. Generating stations

5.3.1 Measurement in Generating Station

A generating station offers variety of magnetic field environment. It starts from generator hall where power is generated by a turbo generator at a relatively low voltage, say 210 MW at 15.75 kV at full Load current of 7.7 kA and its associated monitoring and control room. The output of generator is brought to the ground floor by means of bus duct around which very high magnetic field would be present. The out put of the transformer is 220 kV connected at main bus of switching station. Hence the personnel concerned with the generating station including those in generator control room are subjected magnetic field produced by the generator and those who are concerned with the transmission of power are subjected to magnetic field produced in the switchyard. Apart from this, personnel also present in the area of auxiliary motors and cable gallery, where a large number of power supply (400V & 11kV) cables and control cables are run. This is similar to magnetic field exposure in an industrial environment. The measurements were done in different locations of generating station are :

i. 210 MW turbo Generator hall
ii. Generator unit control room
iii. Generator output bus duct & Generator Transformer
iv. Auxiliary motor and 6.6 kV & 400 V panel
v. Cable gallery

5.3.1.1 Results of measurement in 210 MW turbo generator hall

During the measurement, the generator was supplying the full load current of 7.7 kA at 15.75 kV and offering worst case magnetic field intensity around it. Figure 5 shows the approximate layout of the generator hall around one of the generators. Spot measurement results are marked on the layout. Measurements were avoided close to the body of the generator. The maximum and measured values are 63 µT and 0.3 µT.

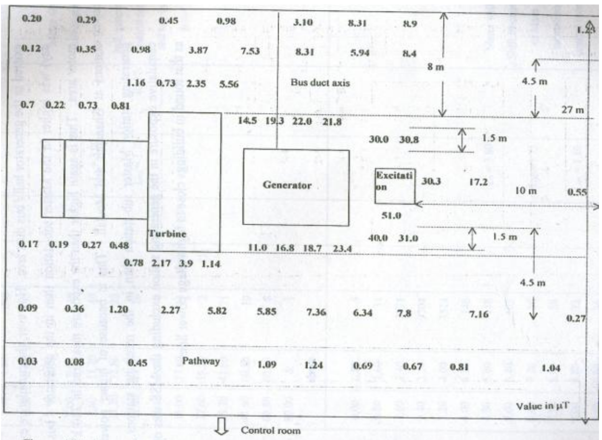

Figure 5 Layout of area around 210 MW generator and results of spot measurement

5.3.1.2 Results of measurement in generator control room

The operators will be going to take some meter readings and to reset the relays. The maximum and minimum field strength where the operators are always present are 4.98 µT and 0.02 µT respectively.

5.3.1.3 Generator output bus duct & Generator Transformer

The bus duct drops vertically from the generator floor by about 4 m upwards and finally going towards generator transformer. Many operational personnel work beneath this duct. Operational personnel occasionally go to this place for inspection of turbine, which is towards the left of the neutral bus duct.

The magnetic field was measured using the spot meter in the following locations:

i. Vertical portion of the R-phase bus duct and 1/2m away : 26.00 µT
ii. Vertical portion of the R-phase bus duct and 1/2m away : 11.5 µT
iii. Horizontal portion of the R-phase bus duct and 1/2m away : 130.00 µT
iv. Horizontal portion of the R-phase bus duct and 1m away : 75.00 µT
v. Horizontal portion of the R-phase bus duct and 2m away : 43.00 µT
vi. Horizontal portion of the R-phase bus duct and 7m away : 4.60 µT

5.3.1.4 Auxiliary motor and 6.6 kV & 400 V panel

One 6.6 kV 4 MW feed water pump was chosen as a representative auxiliary motor for measurement. The field strength appears to be appreciable touching a high value of 105 µT at a distance of about 0.5 m from the motor and close to the 6.6 kV cable and the measurement at 400 V supply panel is varying between 0.5 µT to 26.6 µT.

5.3.1.5 Cable gallery

In a generating station, bunches of power cables will be run in cable galleries. They are at basement of the building. Two such galleries were chosen. Since the corridors are very long to carryout detailed spot measurement. A slow walk along the path way between two adjacent racks was undertaken to note down highest and lowest magnitudes. At the 6.6 kV gallery the maximum and minimum measured fields were 16.2 µT and 14.2 µT respectively, where as at control cable gallery the respective fields were 0.85 µT and 0.06 µT.

5.3.2 Results of Dosimeter Measurement

Two dosimeters were handed over to the generating station personnel. The first was given to a technician, who works in generator hall, generator control room and close to the bus duct. The second was with the shift engineer who supervises the work in these areas. Table 4 gives the summary of the results.

Table 4: Meter with technician in generator hall, generator control room

Bin range(µT)		No. of Occurr-ences	Magnit-ude (µT)		L_X (µT)	Exposure In24 h (µT-day)
Min	**Max**		*	**		
0.0	2.0	16673	130.02 (2)	0.70	L_5= 2.00 L_{50}= 0.69 L_{95}= -.-	16.75
2.0	4.0	460				
4.0	6.0	82				
6.0	8.0	43				
8.0	10.0	38				
10.0	12.0	60				
12.0	14.0	33				
14.0	16.0	15				
16.0	18.0	40				
18.0	20.0	19				
20.0	22.0	13				
22.0	24.0	30				
32.0	50.0	41				
50.0	80.0	13				
80.0	100	4				
100	above	2				

* (Highest) Number in the bracket indicates how many times the highest value occurred
** (Average) Number in the bracket indicates standard deviation

6. CONCLUSIONS

i. The very high value of exposure of 137.57 µT–day measured in 220/110 kV GIS has no consequence as inside the GIS building, no personnel would be present continuously. The building of the GIS is not generally accessible to the workers under normal circumstances.

ii. Measurement of lateral profile of an 11 kV under ground cable corroborated the results of the computation which had predicted low magnetic field levels above cables buried in ground.

iii. Measurement in the generating station shows that the highest field intensity existed in the generator hall / bus duct area. Measured results that the average fields in the work place where workers are present round the clock is high. The operator who is present at constant location throughout the shift is exposed to more fields compared to a shift engineer who does not have a fixed place. The exposure of 301.7 µT– day measured for the operator is highest exposure measured. The shift engineer is exposed to the highest magnetic field of 103.14 µT– day, but his average field and µT–day were far less than that measured for the operator

iv. Exposure of the magnetic fields are lesser than the permissible limits of International Radiation Protection Agency (IRPA), CIGRE and WHO.

7. ACKNOWLEDGMENTS

Authors wish to thank the management of CPRI for giving permission to publish this paper.

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