Report on
Study of influence of environmental parameters on Electric and Magnetic field in POWERGRID lines

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Table of Contents

1. Executive Summary

A power transmission line during its operation emits electric and magnetic field. The strength of the electric and magnetic field depends on their operating voltage and current flowing (line loading) through the line. Equipment operating at high voltage produces comparatively stronger electric fields than the equipment operating at low voltage. Similarly, highly loaded lines produce stronger magnetic field than lightly loaded lines. The electric and magnetic field strength at any point is inversely proportional to square of the distance from the source.

Electric and magnetic fields generated by HV/EHV substation equipment and transmission lines in their vicinity are likely to have hazardous effects on human beings, plants, and animals when their exposure levels exceed specified limits. Human beings or animals coming in direct contact with electrically isolated objects lying below the HV/EHV equipment or transmission line would experience shocks, which at times may be fatal. Therefore, it is necessary to keep these field levels in the vicinity of HV/EHV equipment & lines within limits.

The level of field values under the transmission line, plays a very crucial role in the reliable operation of such a high voltage transmission system. Therefore, there is a need to validate the designed field values with the actual measurements, so that necessary action may be taken in order to keep these field values within the prescribed safety limits.

The electric and magnetic field measurements were carried out under selected 132kV, 400kV and 765kV transmission lines of POWERGRID in summer, winter and monsoon seasons to study the impact of environmental factors (Temperature and Humidity) on the field values. The electric and magnetic field measurements were planned to be carried out under selected transmission lines spans in all the seasons, however, measurement in some lines could not be carried out due to rain/storm/presence of crops etc. The list of transmission lines and maximum value of Electric field and Magnetic field obtained during measurement are given in table 1.1.

Sl. No.	Region	Voltage level (kV)	Name of Line	Max. E.F. (kV/m)	Max. M.F.(uT) (Loading)
1	NR-1	765	Koteshwar-Meerut S/C	8.6	1.22 (64 MW)
2	SR-2	400	Thiruvalam-Kalivanthapattu D/C	2.8	3.90 (430 MW)
3	SR-2	765	Dharmapuri-Tumkur S/C	4.6	4.24 (71 MW)
4	NR-1	400	Kaithal-Baghpat D/C	6.6	2.82 (265 MW)
5	NR-2	220	Salal-Jammu II S/C	1.6	4.26 (146 MW)
6	NR-3	765	Varanasi Fatehpur S/C	7.9	5.08 (651 MW)
7	WR-2	400	Mundra-Jetpur D/C	3.6	3.81 (349 MW)
8	SR-1	765	Raichur-Kurnool-1 S/C	6.7	1.20 (94 MW)
9	NR-2	765	Moga-Bhiwani S/C	8	4.68 (594 MW)
10	Odisha	400	Baripada-Pandiabili-Duburi D/C	8.4	3.13 (165 MW)
11	NR-3	400	Singrauli-Fatehpur D/C	3.0	3.16 (276 MW)
12	ER-1	400	Sitamarhi Darbhanga D/C	3.0	0.31 (26 MW)
13	NER	400	Silchar-PK Bari D/C	2.1	1.57 (70 MW)
14	NER	132	Khleriat-Badarpur S/C	0.5	1.34 (40 MW)
15	WR-1	765	Aurangabad Padghe D/C	6.9	5.69 (1284 MW)
16	WR-1	765	Pune Solapur S/C	6.7	8.71 (1285 MW)

17	NR-1	765	Agra Jhatikara S/C	5.5	4.40 (804 MW)
18	NR-1	400	Gurgaon-Manesar D/C	6.6	1.03 (85 MW)
19	NR-1	400	Manesar Neemrana D/C	4.9	2.84 (212 MW)
20	NR-1	765	Aligarh-Jhatikara S/C	5.8	2.92 (464 MW)
21	NR-1	400	Gurgaon-Sohna M/C	3.7	0.24 (27 MW)
22	ER-2	220	Rangpo-New Melli D/C	1.7	2.70 (39 MW)
23	ER-2	400	Binaguri-New Purnea D/C	1.8	0.50 (95MW)

Table1.1: Details of transmission lines and maximum value of Electric field and Magnetic field

All the measurements were carried out at 1m height from the ground as per IEEE 644-1994 guidelines and also, at 1.8m from the ground (i.e. at normal human height) to study the effective field intensity levels on human beings. Guidelines of CEA Urban RoW and ICNIRP are generally being followed for limiting the exposure of electric and magnetic field from transmission lines. The limits for electric field are 5kV/m for general exposure at the edge of RoW and 10kV/m for exposure within the Right of Way. The limits for magnetic field are 200uT for general exposure at the edge of RoW and 1000uT for exposure within the Right of Way. The field values were compared with the limits prescribed by International Commission on Non-Ionizing Radiation (ICNIRP) and Institute of Electrical and Electronics Engineers (IEEE) guidelines. It was found that the EMF values are affected due to environmental factors like temperature and humidity, however they were found to be within the acceptable limits in all the seasons. The measurement results are assessed and co-relation between EMF values w.r.t. to different season is derived and discussed in detail in the report.

2. International Standards and Guidelines

The possibility of human exposure to electric & magnetic field is increasing with the use of HV, EHVAC & UHVAC voltage level for power transmission, which has raised concerns on their possible health effects. General guidelines for electric and magnetic field exposure have been established for occupational and public exposure by national and international organizations. These guidelines are intended to limit electric and magnetic field exposure that can results in shocks or might cause health effects.

In 1974, the "International Radiation Protection Association" (IRPA) formed a working group on non-ionizing radiation (NIR), to examine the problems arising in the field of protection against the various types of NIR. At the IRPA congress in Paris in 1977, this working group became the "International Non-Ionizing Radiation Committee" (INIRC). In cooperation with the Environmental Health division of the World Health Organization (WHO), the IRPA/INIRC developed a number of health criteria documents on NIR as part of WHO's environmental health criteria programme, sponsored by the United Nations Environment Programme (UNEP).

At the 8th international congress of the IRPA, a new, independent scientific organization "International Commission on Non-Ionizing Radiation Protection" (ICNIRP) was established as a successor to the IRPA/INIRC. The functions of the commission are to investigate the hazards that may be associated with the different forms of NIR, develop international guidelines on NIR exposure limits, and deal with all aspects of NIR protection.

The International Committee on Electromagnetic Safety (ICES) is a committee under the sponsorship of the Institution of Electrical and Electronic Engineers, a USA-based organization (it is also known as IEEE Standards Coordinating Committee 28). It develops different standards for different frequency ranges which are published as IEEE standards. IEEE C95.6 covers 0 to 3 kHz and therefore includes power frequencies. Guidelines of CEA Urban RoW and ICNIRP are generally being followed for limiting the exposure of electric and magnetic field from transmission lines. The limits for electric field are 5kV/m for general exposure at the edge of RoW and 10kV/m for exposure within the Right of Way. The limits for magnetic field are 200uT for general exposure at the edge of RoW and 1000uT for exposure within the Right of Way.

The occupational and public exposure limits recommended by ICNIRP & IEEE guidelines are mentioned in table 2.1 below:

Sr. No.	Organization	Type of Exposure	E-field (kV/m)	B-field(μT)
1.	ICNIRP	Occupational	10	1000
		General public	5	200
2.	IEEE	Occupational	20	2710
		General public	5	904

Table 2.1: Reference levels for electric and magnetic field exposure

Note:

a) Within power line right of way, the guideline is 10kV/m
b) Sources: ICNIRP, 2010 & IEEE, 2002, CEA Urban RoW guidelines
c) Occupational Exposure: All exposure to EMF experienced by individuals in the course of performing their work
d) Public Exposure: All exposure to EMF experienced by members of the general public.

3. Field Measurement Methodology

Electric field is generated by electric charges. The electric field at any point represents the force exerted on the electric charge due to one another. The strength of an electric field depends on the voltage associated with these charges. The electric field is present around the equipment/conductor due to its operating voltage. High voltage equipment & lines produce comparatively stronger electric fields than low voltage equipment & lines. The field reduces if the equipment is grounded/external conductive objects are present nearby. The magnitude of the AC electric field is expressed in terms of Volts per metre or kV per metre (kV/m).

Just as an electric field is always linked with the presence of charges, a magnetic field always appears when an electric current flows. A static magnetic field is formed in the case of direct current, whereas time-varying electric and magnetic fields are produced by alternating current power transmission systems. Magnetic fields pass through most common materials without being significantly affected and it is very difficult to shield objects from Magnetic field. The magnetic field/flux density is measured in units of micro/milli Tesla (uT/mT) or milli Gauss (mG). The magnetic field strength at point varies inversely proportional to square of distance from the source. The field generated by the lines is of same frequency as that of operating voltage of line. The factors which primary influence the electric and magnetic field strength beneath an overhead transmission line are given below:

a. Actual (rather than the nominal) voltage on the line for electric field
b. The rms value of the actual (rather than the nominal) current flowing through the line for magnetic field
c. Height of the conductors above ground (which is influenced considerably by the ambient temperature and heating caused by the current passing through the conductor)
d. Geometric configuration of phase and ground conductor on the towers, and in the case of two circuits in proximity, the relative phase sequencing
e. Proximity of the grounded metallic structure of the tower
f. Proximity of other tall objects (trees, fences, etc.)
g. Distance of point of measurement of field from the conductor
h. Height above ground at the point of measurement
i. Atmospheric conditions (Temperature, humidity, wind speed etc.)

3.1 Measurement Procedure

All the measurements were carried out at 1 meter height from the ground level as per IEEE standard 644-1994 guidelines and also, at 1.8 meter from the ground (i.e. at normal human height) to study the effective field intensity levels on human beings. Distance between the sensor and operator was ensured to be more than 2.5m.

a) Longitudinal Profile

The longitudinal profile of electric and magnetic field strengths were measured along the line at 1 m & 1.8m above the ground level. The longitudinal profile measurements were carried out at generally 10 no. of points (refer Figure 3.1.1) under all the three phases of the single circuit line and both circuits of double circuit line starting from the one tower to the adjacent tower.

b) Lateral Profile

The lateral profile of electric field strengths along a span were measured at 1 m &1.8 m above the ground level in a direction normal to the line at maximum sag point. The lateral profile measurements were made between two outer phase of single and double circuit line and up to a lateral distance of corresponding RoW from the outer phase of transmission line or to a distance of insignificant field at generally 8 no. of points (refer Figure 3.1.1) spread across the RoW.

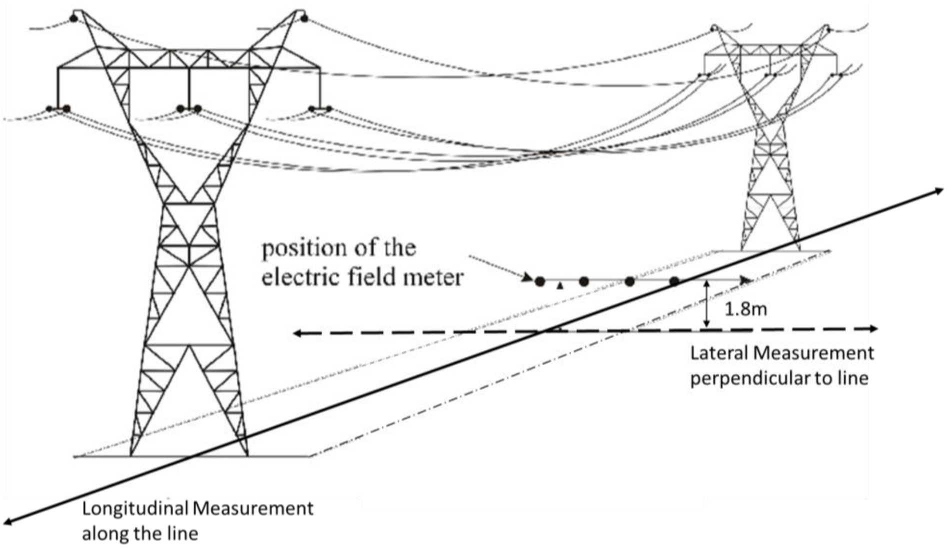


Figure 3.1.1: Lateral and Longitudinal measurements

3.2 Instrument used

a) Electric field meter

The Instrument used for the measurement (figure 3.2.1) is a free body type suitable for survey type measurements, which has been designed, developed, fabricated and calibrated as per IEEE 644-1994 with parallel plate arrangement. The meter measures the power frequency induced charge between two hemispherical electrodes of an isolated conductive body in an Electric field. The incident field on the meter electrodes is directly proportional to kV/m. It is portable and does not require a known ground reference. The incident charge Q across the electrodes is directly proportional to the voltage gradient. That is, Q = C V, where C is capacitance of the medium. The Electric field meter has a measurement uncertainty of ±10%.

b) Magnetic field meter

The Instrument used for the measurement is a 3-axis free body type which has been developed by Kamtron. The meter is capable of measuring environmental magnetic fields, fields in the vicinity of electrical power equipment and compliance testing of household appliances. The instrument has memory function, for storing upto 99 data points in the memory. The magnetic field waveforms can be observed by connecting the instrument to an oscilloscope. The free body Magnetic Field Meter view is shown in figure 3.2.2.

Figure 3.2.1: Electric field meter

Figure 3.2.2: Magnetic field meter

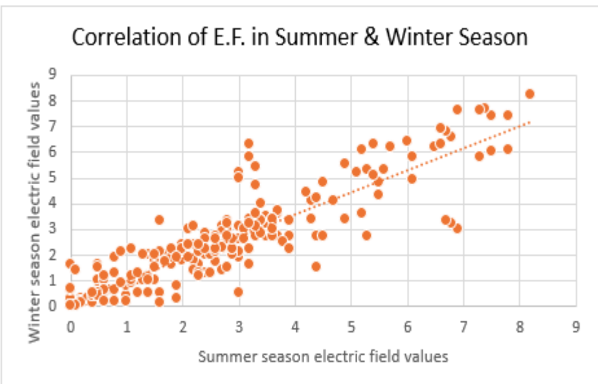
4. Assessment of Measurement results

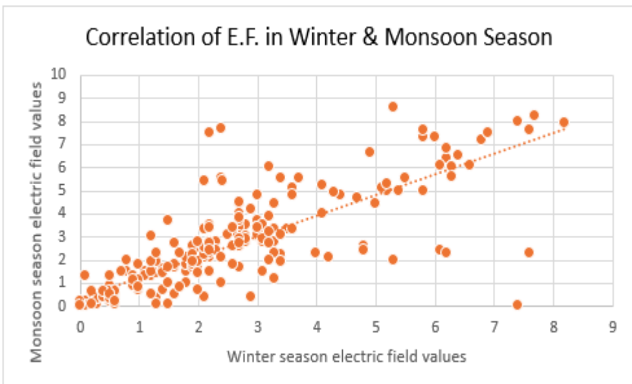
The results discussed in the report are based on the measurements carried out under actual site conditions and system load conditions prevailing at the time of measurement. The electric and magnetic field measurements were carried out under selected 132kV, 400kV and 765kV transmission lines of POWERGRID in summer, winter and monsoon seasons to study the impact of environmental factors on the field values however, measurement at some of the points couldn't be performed in certain seasons due to presence of crops/rain/water-logging. The measurement was performed at 1-meter height from the ground level as per IEEE: 644-1994 guidelines and also, at 1.8 meter from the ground (i.e. at normal human height) to study the effective field intensity levels on human beings.

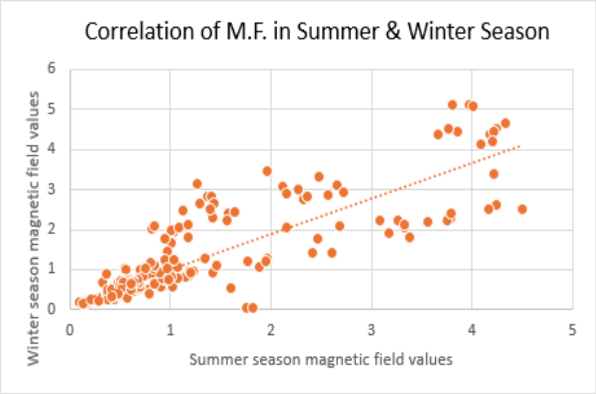
It is observed that the longitudinal profile of electric and magnetic fields reaches maximum value at the maximum sag point and they reduce from the maximum sag point towards the towers. The lateral profile of electric field reaches maximum under each of the three phases and reduces as we move away from the phase conductors in direction transverse to the line. Also, the electric field under the middle phase is generally less than the electric field under the outer phases. The lateral profile of magnetic field reaches maximum value under the middle phase and then reduces as we move further away from the middle phase in direction transverse to the line. Also, the magnetic field under the middle phase is generally more than the magnetic field under the outer phases.

The presence of tree/bush at ground potential has a significant effect in electric field distribution in its vicinity. The effect of bush/tree is clearly visible in few of the cases above where the electric field value reduces drastically below the bush/tree. In general, the presence of tree/bush shifts the effective ground plane near to the top of vegetation resulting in increase in electric field on the tip of bush and simultaneously shielding the area below the bush. The effect of wet land can also be seen in few of the cases where the electric field increased significantly. However, the presence of the bush/tree/wet lands doesn't have any significant effect on the magnetic field distribution.

For correlation study, only those points were considered where measurements were carried in all three seasons. The Electric and Magnetic field values for these points were sorted as per temperature and humidity to analyze whether the field values are following any specific trend w.r.t. temperature and humidity. No general trend was observed between field values and environmental parameters; however, the field values of all seasons were found to be highly co-related. The co-relation between field values of different seasons are shown in figure below:







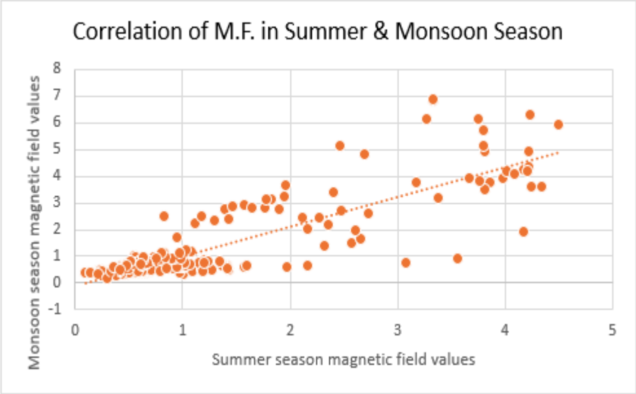


Fig 4.1: Correlation profile of Electric and Magnetic field values of all 3 seasons

The electric and magnetic fields obtained under all the transmission lines in all the seasons were found to be normal and well within the acceptable limits w.r.t to the occupational as well as public exposure limits of IEEE and ICNIRP guidelines.

5. Glossary

Electric field strength: The force (E) on a stationary unit positive charge at a positive charge at a point in an electric field; measured in volt per meter (V m-1).

Magnetic field strength: An axial vector quantity, H, which, together with magnetic flux density, specifies a magnetic field at any point in space, and is expressed in ampere per meter (Am-1).

Non-ionizing radiation (NIR): Includes all radiations and fields of the electromagnetic spectrum that do not normally have sufficient energy to produce ionization in matter; characterized by energy per photon less than about 12eV, wavelengths greater than 100nm, and frequencies lower than 3x1015 Hz.

Occupational exposure: All exposure to EMF experienced by individuals in the course of performing their work.

Public exposure: All exposure to EMF experienced by members of the general public, excluding occupational exposure and exposure during medical procedures.

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