Assessment of extremely low frequency electric and magnetic field of 400kV transmission lines and substations in Oman

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Abstract. The present study is centered on the investigation of longitudinal and lateral profiles of Extremely low-frequency Electromagnetic field experiments conducted at three distinct locations in Oman. The investigation encompasses findings obtained from 400kV transmission lines and substations. The analysis of electric and magnetic fields emitted by transmission lines was conducted using an EHP-50F E&H field analyzer sensor set and an environmental meter. The measurements were conducted at 400kV transmission lines or to a distance of the insignificant field at the high-voltage substation, various components such as power transformers, CT (current transformers), PT (potential transformers), circuit breakers, reactors, earth switches, transport couplers, lightning arrestors, and other. This research in Oman marks the initial exploration of various factors pertaining to the Oman Electricity Transmission Company (OETC) and its technical standards, which are founded on optimal practices. These factors encompass the interphase spacing, the spacing between conductors within a bundle of twin conductors, the configuration of phases on a tower, the cross-sectional area of conductors, and similar considerations. The proposed study aims to support the Sultanate of Oman's objective of establishing a high-quality smart transmission grid by 2030. This system will facilitate the efficient, reliable, and secure transfer and distribution of power, while also offering economic benefits. This research aims to cater to the needs of students and engineers by offering a highly practical approach that utilizes appropriate equipment. This article presents a systematic approach to the implementation of a smart transmission grid, incorporating the aforementioned attributes.

Keywords: Electromagnetic field, Human exposure, Measurements, OETC.

1. Introduction

Oman, formally known as the Sultanate of Oman, is a sovereign state situated in the southwestern region of Asia. The Arabian Peninsula's southern coast

is traversed by a waterway that serves as the entrance to the Persian Gulf. The current population residing in this area is estimated to be 5,470,512. The Oman Electricity Transmission Company SAOG (OETC) plays a crucial role in the Oman Electricity Sector by being responsible for the ownership and operation of the primary transmission network, as well as the transmission network in Dhofar. These networks facilitate the transmission of electricity from generating stations to distribution load **centers** across all governorates of the Sultanate. The concept involves **utilizing** the 400kV system as the primary infrastructure, the 220kV system for transmission purposes, and the 132kV system for subtransmission functions. The transmission voltages often employed in the primary electrical grid are typically 132 kilovolts or greater [1]. The design criteria for 400kV double circuit overhead transmission lines with 479 mm2 Aluminium Alloy Quad-Yew Conductors (AAAC) on lattice steel towers are addressed in the specification OETC-AMP-O-AMT-M-003. The OETC-AMP-O-AMT-M-044 standard encompasses a total of 27 sections, which comprehensively outline the design specifications for a 400 kV Substation. These sections encompass a wide range of aspects, including General Requirements, Transformers, Shunt Reactors, HV **switchgear**, MV Switchgear, Protection and Control, SCADA**,** and telecommunication, as well as various other auxiliary assets housed within the substation.[2] The initial segment of Oman's 400 kV transmission system was constructed by the Oman Electricity Transmission Company (OETC) with the purpose of linking the sizable GIS power plant located in Sur, which has a capacity of 2000 MW, to the Main Interconnected Transmission System (MITS) in the northern region of Oman. One of the 400 **kilovolts** (kV), 250 **kilometers** (155 miles) double-circuit overhead transmission lines **were utilized** for the purpose of providing electrical energy to the 400 kV New Izki Grid Substation. Furthermore, the OETC has successfully implemented the construction of 100 **kilometers** (equivalent to 62 miles) of 400kV double-circuit overhead transmission lines. These lines have been established between Sur PS and Jahloot, Ibri and the New Izki Grid Substation (spanning a distance of 264 kilometres or 164 miles), as well as Sohar Free Zone and the Sohar Interconnection Substation (covering a distance of 34 kilometres or 21 miles). In addition, a 400kV double-circuit overhead line spanning 100 km (62 miles) between the New Izki Grid Substation and Misfah was successfully implemented in the year 2020. In this study, we conducted a novel investigation in Oman to assess the electric and magnetic fields along 400kV transmission lines and substations of three regional areas of sohar, Izki and Ibri. The objective of this study is to examine the longitudinal and lateral electric and magnetic fields in proximity to the 400 kV transmission lines. Our research employed advanced technology, specifically the EHP-50F field analyzer sensor and Environmental metre, to measure these fields in both longitudinal and lateral directions. The sensor analyzer utilized in our investigation is the EHP-50F, a probe designed to capture and analyze electric and magnetic fields of low frequencies. The device operates within a frequency range of 1 Hz to 400 kHz, providing a technical solution suitable for field inquiry with great dynamic range and **high-frequency** capabilities. The device incorporates a calibrated very efficient integrated spectrum analyzer capable of simultaneous measurement in three dimen-

sions, namely X, Y, and Z. The **utilization** of a compatible computer-based EHP-50 TS software in conjunction with the EHP-50F is recommended for the purpose of recording and **analyzing** online data obtained from the sensor installed at the gearbox line. Moreover, the implementation of a disconnected mode of operation enables the uninterrupted collection of data for a duration of 36 hours. In 2012, a research conducted by a scholar from Oman determined that the electric and magnetic fields generated by transmission lines in the power system of Oman adhere to the allowed exposure levels outlined by the International Commission for Non-Ionizing Radiation Protection (ICNIRP) . The researcher, however, hypothesised that forthcoming escalations in electricity consumption would result in elevated levels of electromagnetic fields in Oman [3]. Furthermore, according to the IEEE C95.1-2019 standard, there exists a lack of substantial data to establish that prolonged exposures below the specified level outlined in the IEEE C95.1-2019 standard have adverse effects[4]. The findings of our research will carry substantial ramifications for the electrical sector, in accordance with the goals of Oman 2030's vision for a sophisticated smart transmission infrastructure. Electricity may be transmitted and distributed with greater reliability, safety, and sustainability if this infrastructure is built and put into use. Along with the previously mentioned benefits (lower electricity rates and quicker power restoration after disruptions), reduced peak demand is another positive outcome. Taking into consideration the backdrop, this research presents empirical data on the magnitudes of electric and magnetic fields at three distinct geographic locations within the Sultanate of Oman. Table I displays the recommended openness reference values for the general public in the vicinity of transmission lines and occupational employees [4-5]

Table 1. ICNIRP Limits Occupational and General Public [4-5]

Exposure Characteristics	Electricfield kV/m(rms)	Magnetic flux density in µT (rms)
Occupational	10	1000
General public	5	200

2. Experimental Methodology

2.1 Equipment Utilized

The longitudinal and lateral measurements of electric and magnetic field profiles have been conducted in the vicinity of 400 kV power lines at Sohar port substation to Sehm Al Makeram substation, as well as along the New Izki to Qabel line and between Ibri Independent power plant (IPP) and Ibri City. The field measurement sensor device used in this study was the EHP-50F E&H Field Analyzer sensor. This sensor was housed in a small cubic box with a pedestal and positioned at a height of 1 metre above the ground. The EHP-50F TS software was installed on a Windows PC, which was positioned at the measurement location using a 10-meter fibre optic

cable. This setup aimed to ensure the acquisition of highly accurate readings without any modifications to the results. Subsequently, the PC stored the collected data locally, as depicted in Figures 1 and 2, correspondingly.

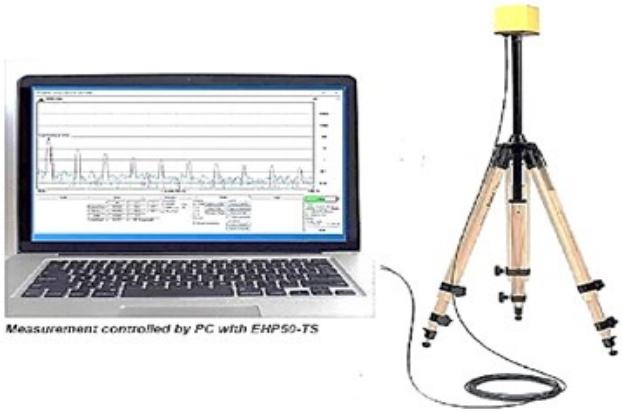

Fig. 1. EHP-50F E&H Field Analyser sensor unit 1Hz-400 kHz,Standalone /PC Us

Fig. 2. EHP-50F sensor

The EHP-50F sensor has excellent frequency coverage thanks to its use of FFT analysis, which spans subranges from 1 Hz to 400 kHz. The smaller the frequency range, the greater the objective and the slower the resolution transfer speed, resulting in faster estimation execution. In addition, relative humidity, air temperature altitude, wind pressure, wind speed, etc. were recorded by an environmental meter during the measurement of ELF-EMF [5], as shown in Figure 3.

Fig. 3. Environmental meter

2.2 Methodology

The selection of the starting point for the longitudinal measurements of the electric and magnetic fields was made at the highest sag point, situated precisely between the two towers. In order to obtain precise measurements, it is necessary to position the EHP-50F field analyzer at an elevation of one metre above the ground. It is recommended to perform this task periodically, commencing at one extremity of the towers and proceeding sequentially to the other. Electric and magnetic field measurements were conducted in a perpendicular manner on both sides of the double circuit transmission lines, starting at the centre of the maximum sag point and extending up to a lateral distance of fifty metres. These measurements were done at regular intervals, following the guidelines outlined in IEEE Std 644-1994. The environmental metre was used to measure the current temperature and relative humidity. [6]

2.3 Measurements of three different sites in Oman

The longitudinal and lateral profiles of electric and magnetic fields have been measured in three regional locations of the Sultanate of Oman, namely Sohar, Izki, and Ibri. These localities are in close proximity to 400kV transmission lines. The field measurement sensor device was positioned at a height of 1 meter above the ground using an EHP-50F E&H Field Analyzer sensor. The PC was connected to a ten-meter fiber optic cable using the Windows-based EHP-50F TS software. The PC was strategically positioned near the measurement site to minimize any distortion caused by human presence.

2.3.1 Site measurements at 400 kV transmission lines

Line 1: A 400 kV twin conductor delta structured, double circuit line connecting Sohar port to Sehm Al Makeram.

Line 2: A 400kV twin conductor delta structured, double circuit line connecting New Izki of Al Dakhaliya region to Qabel of North Sharqiya

Line 3 : A 400 kV twin conductor delta structured, double circuit line connecting Ibri Ipp to the Ibri city.

Electric and magnetic field strength measurements were taken in both lateral and longitudinal profiles, and the results are displayed in Table 2.

Table 2. Displays information of circuit 1 of Lines 1,2,3

Line	Voltage kV (MW)		Load	
	Lowest	Highest	Lowest	High-est
1	398.85	403.28	68	72
2	396.55	398.63	59	62
3	396.85	398.19	45.15	46.25

The measuring towers employed in line 1 were positioned at a precise distance of 5km from the Sohar Port IPP substation, extending towards the sehm al Mekarem. The area situated between towers 9 and 10 exhibited a level topography, characterized by a smooth ground surface adorned with a layer of fine sand. During the time of investigation, the recorded temperature and relative humidity were 29 degrees Celsius and 40.8%, respectively. Figure 4 illustrates the positioning of the Line 1 tower, the line profile, as well as its configuration consisting of a twin conductor with two circuits.

Fig. 4. 440 kV Twin conductor double circuit of Line 1

The measuring towers utilized in the second line were strategically placed at a certain distance of 3 kilometers from the New Izki substation, stretching in the direc-

tion of the Qabel. The region located between towers 4 and 5 is distinguished by its rocky sandy terrain. During the period of investigation, the recorded temperature and relative humidity were measured at 30.3 degrees Celsius and 20.7%, respectively. Figure 5 depicts the spatial arrangement of the Line 2 tower, the profile of the line, and its specific configuration comprising a twin conductor with two circuits.

Fig. 5. 440 kV Twin conductor double circuit of Line 2

The line 3 measurement towers were strategically positioned 1 kilometer away from the Ibri substation, in the direction of the city of Ibri. The terrain between towers 1 and 2 is characterized by its sandiness. The recorded temperature and relative humidity during the investigation period were 31 degrees Celsius and 31.7%, respectively. Figure 3 depicts the spatial arrangement of Line 3's structure, the line's profile, and its specific configuration, which consists of a twin conductor with two circuits.

Fig. 6. 440 kV Twin conductor double circuit of Line 3

3 Results

The utilization of twin bundle conductors in all 3 lines serves the objective of achieving a reduced Geometric Mean Radius (GMR), thereby resulting in a decrease in the inductive reactance of the twin bundle conductor. This reduction in reactance subsequently leads to a decrease in losses and an increase in the efficiency of the transmission system. Figures 6, 7, 8, and 9 depict the longitudinal and lateral profiles of the electric and magnetic fields for Line 1 (Sohar Independent Power Plant to Sehm Al Mekarem), Line 2 (New Izki to Qabel), and Line 3 (Ibri Independent Power Plant to Ibri city), respectively. In order to enhance the discernment of regions inside transmission lines that generate the most potent electric and magnetic fields, three lines are depicted, accompanied by Gaussian field distribution graphs that are color-coded. The measured values of the longitudinal and lateral components of the electric field in lines 1, 2, and 3 do not fall significantly within the limits set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). This can be attributed to the following factors. One potential issue that may arise is the interference caused by nearby 132 kV and 220 kV power lines. The occurrence of sagging is seen to be higher as a result of increasing temperatures and an increase in the percentage of relative humidity. The presence of twin bundle conductors in circuit 2 also leads to interference with circuit 1 measurements.

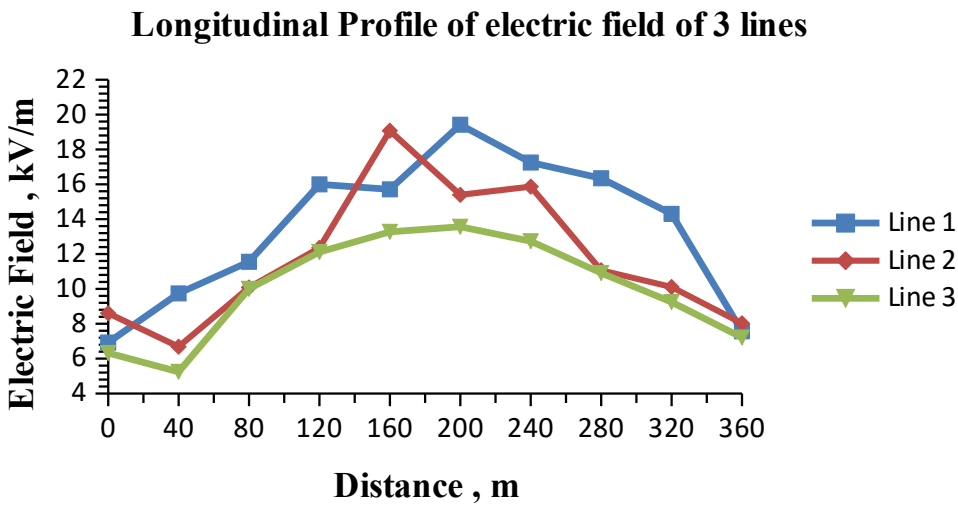

Fig. 7. Longitudinal profile of the electric field of all 3 lines

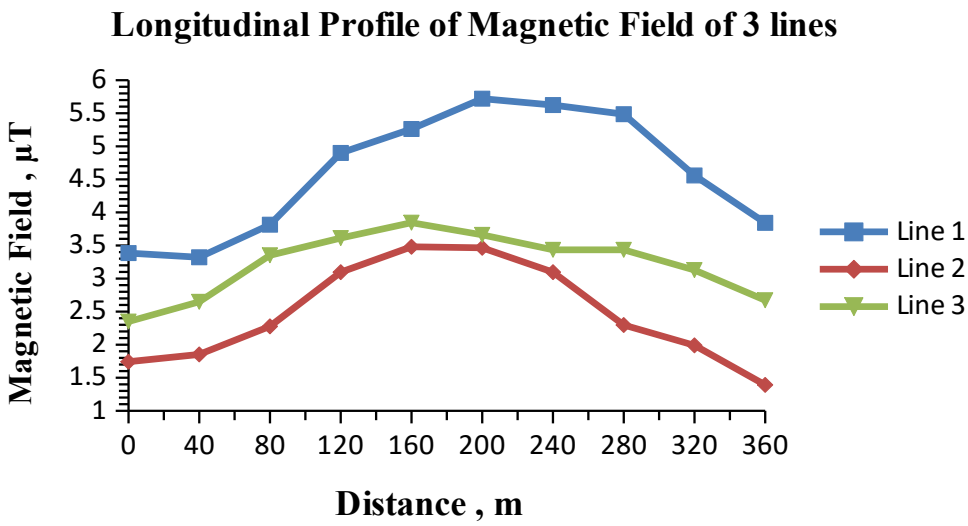

Fig. 8. Longitudinal profile of the Magnetic field of all 3 lines

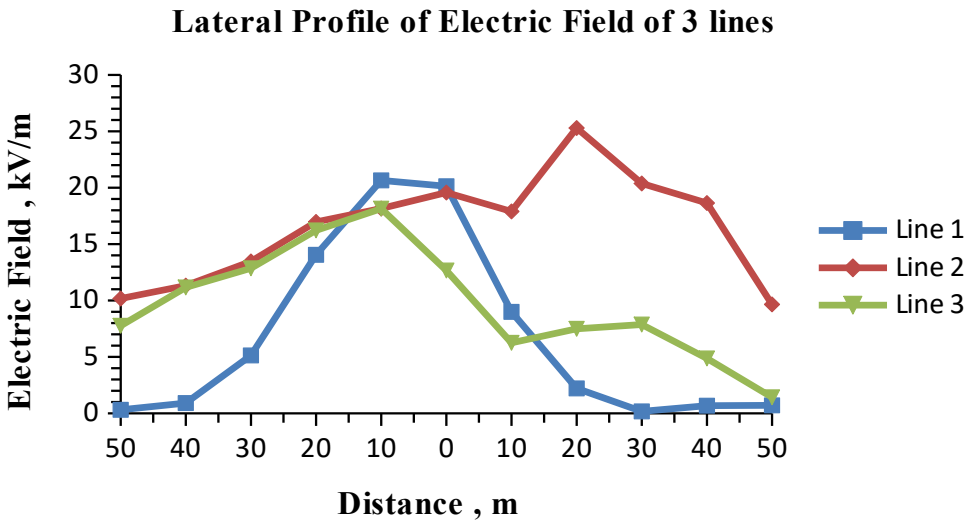

Fig. 9. Lateral profile of the Electric field of all 3 lines

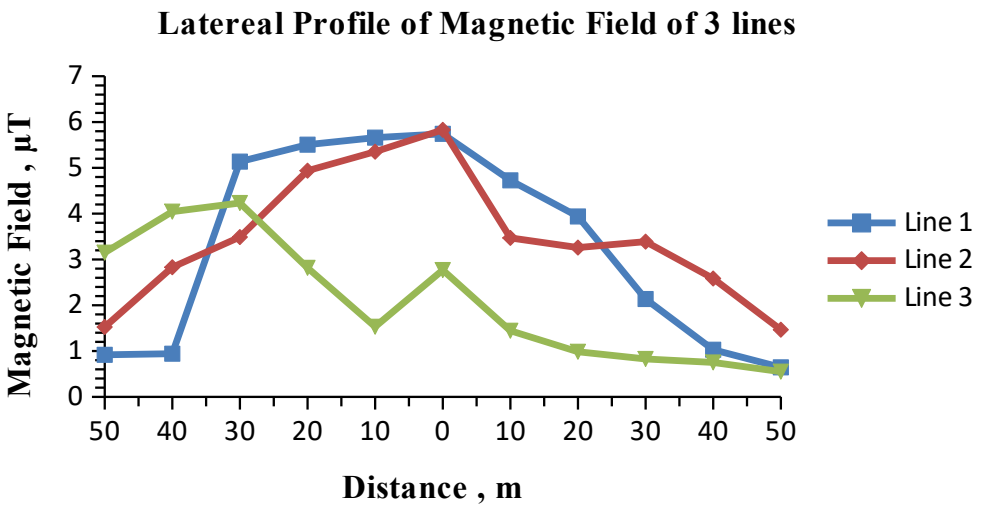

Fig. 10. Lateral profile of the Magnetic field of all 3 lines

Ibri 400kV Substations

The Substation equipment, including Current transformers, potential transformers, circuit breakers, Reactors, Earth switchers, Bus couplers and lightning arrestors, play a crucial role in ensuring the efficient operation of the transmission system. These switch gears are essential for preventing severe breakdowns caused by short circuits, lightning strikes and other disruptions. The implementation of a supervisory control and data acquisition system (SCADA) enables intelligent management of these equipments. In Oman, the grid-connected substations are interconnected with the load centres in order to implement intelligent control through the utilisation of SCADA technology [10].

The measurements of the electric and magnetic fields were conducted at a height of 1 metre above the ground and at a distance of 1 metre from the substation equipment that is linked to the Ibri Independent Power Project (IPP). The findings of these measurements are presented in Table 3. Measurements of temperature and humidity were recorded, with the temperature reading at 25.2 degrees Celsius and the relative humidity at 46.2%. The Bus section and P.T. are equipped with a GIS Bus duct, which effectively minimizes the release of electric and magnetic fields, as indicated in the aforementioned table 3. Conversely, the Earthing switch, Lightning arrestor, and Reactor are situated in an outdoor switchyard, as depicted in the figures 11and 12, and are exposed to typical atmospheric conditions without any protective coverings. The electric field values surpass the established ICNIRP standard limit of 10 kV/m. The magnetic fields fall under the ICNIRP limits of 100 **μT**. By connecting the HV and LV terminals of the 500 MVA power transformer with high voltage XLPE cables, a zero field is created.

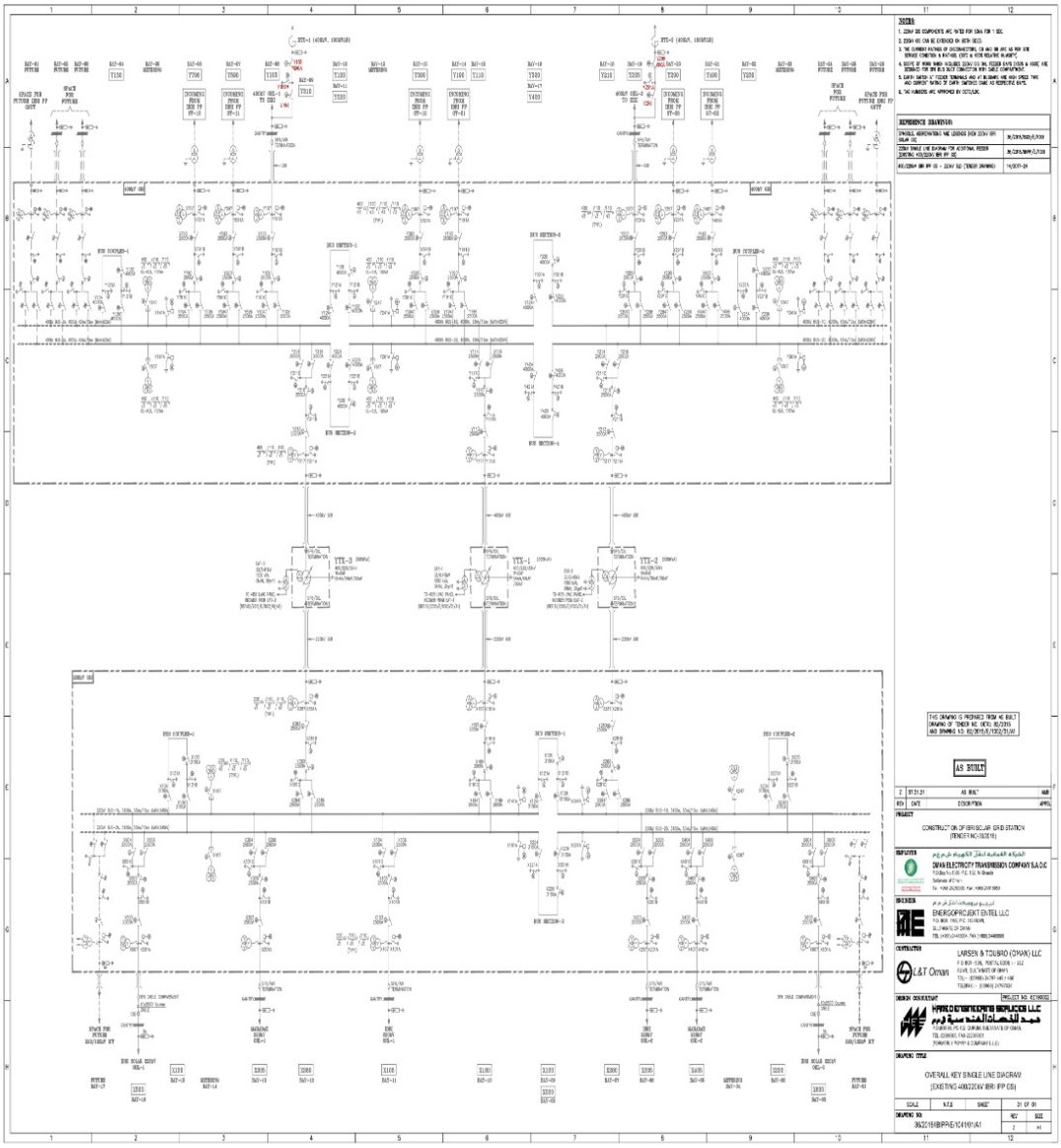

Fig 11. SLD of 400 kVSS to displays information about circuits 1 and 2's lowest and great-est loads and voltage l at IBRI SS

Fig. 12. 400kV Switchyard

Fig. 13. 400kV Reactor

Table 3. Electromagnetic fields around the periphery of the equipment

Sl.No	Equipment name	ID number of the equipment	Electric field strength,kV/m R-phase	Magnetic field strength,µT R-phase
1	500MVA,400/220 kV power Transformer (outdoor yard)	HV side	0.0005	0.1315
		LV side	0.0007	1.1915
2	Lightning Arrester (Outdoor Yard)	Siemens	21.149	3.3706
3	Capacitor voltage transformer (outdoor yard)	CVT1	13.933	3.1387
4	Current transformer (Indoor)		9.7979	11.811
5	Potential Transformer (Indoor)		0.0013	4.3516
6	Earthing switch (Indoor)	EBM5245C Toshiba	19.572	2.587
7	Bus coupler	EBM 63412C	7.2734	17.773
8	Bus section	EBM 63413C	0.0011 1.1223	
9.	100 MVAR Reactor		7.3790	10.884

4. Conclusions

Through the implementation of maintenance measures, our research investigated the technical configuration that can effectively prevent sagging caused by rising temperatures and relative humidity. The following measurements were drawn as follows

1. Minimum spacing between the phase and earth is 3.5 meters
2. A distance of 450 millimeters is recommended between the bundle's subconductors.
3. Delta configuration and AAAC YEW
4. The conductor with a cross-section of 479 sqm in the design of the phase in the tower,

This has led us to the conclusion that the technical standards set by the Oman Electricity Transmission Company (OETC) are exemplary, but the conductor must be restrung to prevent sagging, as observed in the study. Nonetheless, it is essential to recognize that interference from neighboring 220 kV and 132 kV electricity lines is a potential concern that could arise. To mitigate this interference, it is recommended to estimate the spacing or span length between each transmission tower based on the intended height of the transmission conductors (wires) at the span's midpoint above the ground. For transmission lines with voltage classifications of 132kV, 220kV, and 400kV, the required distance between towers is typically between 450 and 550 meters. Additionally, the existence of twin bundle conductors in Circuit 2 also contributes to the interference in Circuit 1.

Consequently, the voltage levels are upheld within established thresholds, specifically below 400 kV, while the load on lines 1, 2, and 3 remains below 80% of their respective rated capacities. Therefore, the magnetic fields in all three regional lines are significantly lower than the ICNIRP standard.

The electric and magnetic fields measured in close proximity to outdoor switchyard equipment, such as lightning arrestors, grounding switches, and reactors, are found to exceed occupational limits. This is attributed to the exposure of this equipment to the normal atmosphere without any form of shielding. Furthermore, with indoor equipment, both field levels are within the requirement due to the presence of GIS Bus ducting. Therefore, the implementation of shielding measures is necessary in a 400 kV substation.

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