Analysis of Transmission Line Arrester for Transmission Line Surge Protection

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Abstract: Tropical countries located in the equatorial belt are having high atmospheric humidity and heat. These atmospheric conditions lead to the development of cumulonimbus clouds during the wet season. Thunder clouds are typical clouds whichproduce lightning events. Lightning strikes in overhead transmission lines (OHTL) are the major reasons for unscheduled interruptions and tripping in the power system. Due to lightning strikes extensive damage to electric equipment of KSEB (Kerala State Electricity Board) are reported and estimated about more than 60% of the tripping in KSEB's EHT Transmission power system has been caused by lightning. In order to mitigate this problem KSEB has taken numerous measures to ensure the reliability and stability of the power system. Several methods have been introduced to keep the failure rate low and to avoid the disturbance to the OHTL system. These methods include improving the tower footing resistance, reinstalling the damaged earth wires, and installation of Transmission Line arrester (TLA). Due to economical consideration, installation of TLA in every conductor of OHTL is not viable. This paper presents an analysis of OHTL performance and determination of optimum quantity of TLA required in a 220kV typical transmission line with installation procedure.

(Key words: Back Flash Over, Lightning Protection, Line Performance, Transmission Line Arrester)

1 Introduction:

Transmission network, the backbone of any power system which is used to transfer the bulk power from the generating stations to the substations and load centers. Over the years the intra state transmission infrastructure in Kerala has grown substantially with the addition of more EHT substations and OHTL. In the 220kV and 110kV network of Kerala Power system, the need of uninterrupted power supply is acute necessary. An abstract of the transmission system of the KSEBL, the state power utility owned by the Government of Kerala, India is given in the table-1 below. There are 2900K.M of 220kV lines and 4800K.M of 110kV lines in the system network of KSEBL and proper maintenance of the lines are critical for maintaining the system reliability.

Sl No	Voltage	No of Substations	Line length in Circuit kms
1	400 kV	1	-
2	220 kV	22	2910.98
3	110 kV	162	4803.28
4	66 kV	70	2100.64
5	33 kV	158	2082.69

Table-1 Abstract of Transmission System of KSEB

Source: KSEB Web Site

Overhead transmission lines are the most prone to lightning strokes. Lightning induced voltages reaching the tower and causing the line insulator to flash over results in major interruption. Due to the lightning, discharge current flowing through the tower due to back flash over results in potential difference across the line insulator due to high tower footing resistance. A very nominal interruption will result in a heavy revenue loss. At present, the measures for lightning protection of transmission line itself essentially depend on the stringing of the overhead ground wire on the tower top, its operation and maintenance work are mainly depending on the required level of tower foot resistance. Like trees and other tall objects, transmission towers are likely to intercept lightning strikes.

With routine preventive maintenance and periodical inspections, most of the probable causes of interruptions are being arrested. However, owing to the unpredicted lightning strikes, the long transmission lines are prone to get affected as these circuits are passing through many lightning sensitive geographies. As a remedial solution, the use of TLAs are being engaged in various lightning prone locations.

2 Literature Survey:

2.1 Transmission Line Arrester: TLA is a voltage surge arrester equipment connected in parallel with transmission line insulator. The main purpose of connecting the TLA is to prevent the back flash which happens during a lightning strike. To reduce the impact of back flash (BF), the arrester conducts the lightning current from the down ground to the phase conductor. The basic purpose of installing TLA is to secure the transmission line from interruption caused due to the flash over of insulators as a result of lightning induced surges. In case, if the line which is not having such preventive equipment is directly impacted with a lightning strike, the surge current will travel through the conductor and results in a back flash since the insulator fails to withstand the surge voltage. Further this will result in a power frequency arc finally resulting in an unwanted interruption.

It is evident that on making the transmission line equipped with an arrester, the insulator flash over can be omitted thereby eliminating even the momentary outages even. It can also be stated that by providing such arrester in each phase of every tower, even with a direct strike of lightning on the shield or phase, an insulator failure can be completely avoided. Moreover, with the provision of transmission line arresters in each phase in every tower, the criticality of ground will get reduced.

Thus, by providing TLA s in each phase of every tower, the transmission line can be considered as a lightning proof system. A sectionalized installation is also a remedial measure in which the TLAs have to be installed in areas such as hill tops dry soil surfaces etc. which are highly sensitive to lightning strokes. The positioning of arrestors shall be decided by considering the tower foot resistance and the ground flash density (flashes/ km^2 /year).

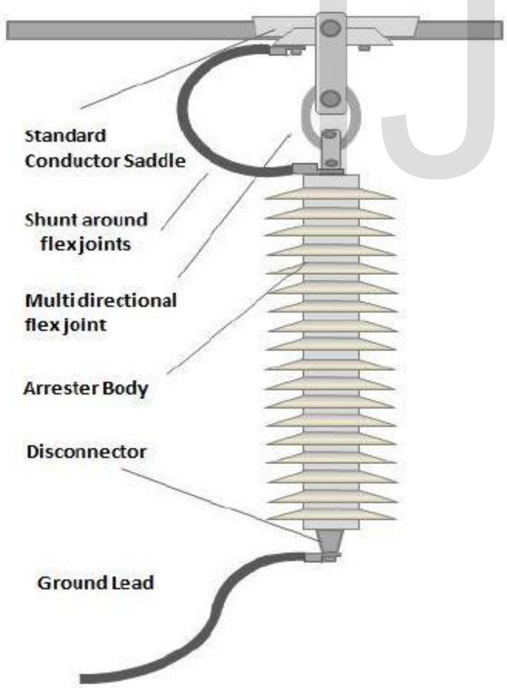

Fig 1 Components of TLA

Source: National Electrical Manufactures Association

Fig 2. GA of TLA in a typical transmission line

Source: National Electrical Manufactures Association

The above figure (2) shows the transmission line arrester (TLA) connected in line and the general arrangement of details of the same. The salient components of a transmission line arrester are described in the figure (1). The standard conductor saddle clamp is the component used to connect the conductor and insulator. The multi directional flex joint eliminates mechanical stress on arrester caused due to the motion of conductor. This also aids the longevity of the arrester. The surges are being conducted through the arrester body. There are two different types of transmission line arresters. One is non gaped lightning arrester NGLA and externally gapped lightning arrester EGLA. A comparison chart of NGLA v/s EGLA is shown in table (2). NGLA for transmission lines are normally named as TLA which are directly suspended from the line conductor close to an insulator. The earth connection is connected to the tower steel member.

Electrical Stresses	Typical requirement of TLA	Requirements to be considered	
		EGLA	NGLA
System Voltage	Long-term life of ZnO elements	X	✓
Lightning Over Voltages	Suitable residual voltage of ZnO elements	✓	✓
	Energy absorption capabilities of ZnO elements	✓	✓
	Voltage withstand capability of the arrester	✓	✓
	Suitable gap flashover characteristics against insulator withstand voltage	✓	X
Switching Over Voltage	Energy absorption capability of ZnO elements	X	✓
	Voltage withstand capability of the gap	✓	X
Temporary Over Voltage	Energy absorption capability of ZnO elements	X	✓
	Voltage withstand capability of the vessel under pollution condition	X	✓
	Follow-current interruption under polluted condition	✓	X
	Isolation from the line at TLA failure	X	✓

Table 2 – Comparison chart of EGLA v/s NGLA

The disconnector at the bottom most portion of the arrester is a very important functional agent. When the arrester fails, the same will become a dead short circuit to the earth which is not at all a desirable characteristic. Under such circumstances, the disconnector acts to isolate the arrestor from ground. With the ground lead, the connection to the earth is established. The length of this lead is also critical since the clearance with the other phases has to be validated.

2.2 TLA selection and Application:

The TLA is gapless silicone polymer housed equipment with metal oxide varistor. The metal oxide varistor (MOV) elements are stacked in modules and these modules are arranged in series so as to obtain the voltage grading. During normal operating conditions, that is, when the terminal voltage of arrester is not beyond the operating voltage, the arrester offers a very high resistance, and the line operates as in normal condition. When a lightning overvoltage occurs, the arrester starts conducting the current keeping its terminal voltage below the protective level, without causing a short circuit. When the surge has mitigated below the arrester operating voltage, the conducted current also returns to its initial, negligible level.

Following are the important parameters to be considered for the correct TLA selection.

1. Continuous operating voltage of the TLA with respect to the highest system operating voltage
2. Rated voltage of the TLA with respect to the temporary over voltages expected in the system
3. Discharge class
4. Short circuit rating of surge TLA with respect to the expected fault current
5. Residual voltage of TLA for lightning. This is to be finalized considering critical flash over voltage of insulator to be protected.

3 Objectives:

1) To examine the performance of TLA in KSEBL transmission line network.
2) To study the requirement and feasibility of TLA in the EHT transmission line.
3) To find out the improvement of Transmission Line performance after installing the TLA in the KSEBL network.
4) To examine the methodology adopted for the installation of TLA in the network of KSEBL.

4 Research Design:

Secondary data collected from KSEBL, Transmission Division, Madakkathara, Thrissur, Kerala, India from 01.05.2017 to 31.12.2019 will be used for analysing the comparison between the performance of 220kV Lower Periyar-Madakkathara (2LPMD) 1&2 feeders before installing the TLA and after installing the TLA.

5 Research methodology:

5.1 Description of overhead line of 220kV Lower Periyar-Madakkathara (2LPMD 1&2):

2LPMD 1 &2 OHTL system located between 400kV Madakkathara substation and 220kV Lower Periyar Switchyard is under KSEBL.It comprises of 309 Towers of double circuit line those are mostly located in hilly terrain area. This line is commissioned on 20.01.2000, and the phase conductor used is ACSR KUNDAH with a circuit length of 102.1km. The technical parameters required for simulation study in 2LPMD feeder is listed in Annexure-1.

5.1.1 Geographical profile:

The entire towers located are plotted on Google map image of the OHTL end to end as shown in fig. (3). The towers are given names by T followed by continuous numbers.

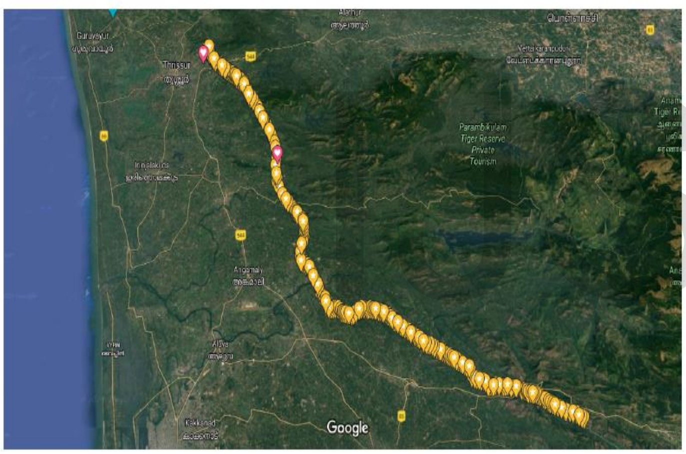

Fig. 3 Google map image of 2 LPMD 1 and 2

5.1.2 Tripping records:

From the data collected from the Line Maintenance Sub Division, Madakkathara, the office which is responsible for the maintenance of above line the TLA has been installed in 2LPMD 1 &2 in September 2018 in the topmost conductor at different locations as listed in table (5).According to the interruption register available at 400kV Substation Madakkathara main control room the total tripping recorded from 01.05.2017 to 31.08.2018 that is before installation of TLA is recorded in Table (3) below. For the easiness of comparison, the tripping details of 16 months before the installation of TLA is taken and it is 19 numbers of tripping.

Tripping history of 2LPMDI &2LPMD 2 Feeders 01.05.2017 to 31.08.2018 (16 months)				
No	Date	Time	Circuit	Remarks
1	02.05.2017	19:44	L2	Distance Protection Trip
2	24.05.2017	15:53	L2	Distance Protection Trip
3	13.08.2017	05:38	L1	Distance Protection Trip
4	28.08.2017	04:07	L2	Distance Protection Trip
5	07.09.2017	16:09	L1	Distance Protection Trip
6	13.09.2017	12:23	L1	Distance Protection Trip
7	23.12.2017	19:01	L2	Distance Protection Trip
8	21.03.2018	06:28	L1	Distance Protection Trip
9	26.03.2018	21:26	L1	Distance Protection Trip
10	01.04.2018	12:26	L2	Distance Protection Trip
11	07.04.2020	17:00	L2	Distance Protection Trip
12	13.04.2018	16:55	L2	Distance Protection Trip
13	13.04.2018	23:27	L1	Distance Protection Trip
14	25.04.2018	15:43	L2	Distance Protection Trip
15	05.05.2018	17:42	L1	Distance Protection Trip
16	05.05.2018	17:42	L2	Distance Protection Trip
17	09.05.2018	22:26	L2	Distance Protection Trip
18	13.05.2018	18:21	L2	Distance Protection Trip
19	24.06.2018	21:37	L2	Distance Protection Trip

Table-3 Tripping History of LPMD1&2 before installing the TLA

Source-KSEB interruption register at Madakkathara

Similarly, the Table (4) below shows the tripping data after installation of TLA for another 16 months (01.09.2018 to 31.12.2019) which is 8numbers of trippings.

Tripping history of 2LPMDI &2LPMD 2 Feeders 01.09.2018 to 31.12.2019 (16 Months)				
No	Date	Time	Circuit	Remarks
1	20.09.2018	14:00	L1	Distance Protection Trip
2	30.09.2018	16:49	L1	Distance Protection Trip
3	30.09.2018	16:49	L2	Distance

				Protection Trip
4	27.10.2018	12:24	L2	Distance Protection Trip
5	15.01.2019	05:18	L2	Distance Protection Trip
6	31.07.2019	10:39	L1	Distance Protection Trip
7	09.10.2019	15:41	L2	Distance Protection Trip
8	02.12.2019	03:37	L2	Distance Protection Trip

Table-4 Tripping History of LPMD1&2 after installing the TLA

Source: KSEB interruption registers at Madakkathara.

Table (5) below indicates the readings taken from the counter of TLA's placed in the 2LPMD 1&2 feeders as on 31.12.2019.

Location No	Counter reading in LPMD -1	Counter reading in LPMD -2
47	6	burnt out
91	0	0
191	0	0
272	1	burnt out

Table-5 Counter Readings of LPMD1&2 after installing the TLA as on 31.12.2019

Source: KSEBL Line Maintenance Sub Division, Madakkathara

5.1.3 Methodology

A lightning performance tripping rate to be calculated to ascertain whether transmission line requires improvement in terms of performance. Lightning performance is a measure of lightning related flashover for an OHTL. The major flashover occurs in an OHTL are Back Flash Over (BF) and Shielding Flashover (SF). When the lightning strikes the ground wire or the tower, Back flashover can occur. When lightning strikes the phase conductors and exceeds the voltage of the insulation strength shield flashover occurs. For this study the lightning performance tripping can be calculated as follows

LP= 100T/ (S x l)

Where LP-lightening performance, T-no. of tripping, S-Period of service years, l-Length of line in kms

LP for LPMD before the installation of TLA = 100X19/ (1.333X102.1) =13.96 Approx. 14

(Where, 1.333 is the period taken against 16 months of operation)

If LP is less than 1.82 trips per hundred km per year the lightning study is not necessary. And if it goes beyond 1.82 the study is required. From the calculation the tripping rate for the 220kVLPMD 1&2 line is 14trips per hundred kms per year and study is required.

5.2 Methodology used in KSEBL

Presently, the positioning of such TLA is being carried out in such a way that there is no any particular scientific tool or simulator to authenticate the positioning of such transmission line arresters. The recurring of lightning affected transmission towers is identified and then installing the transmission line arresters in the top most conductor is the practice which is being executed in the system. Such a primitive methodology is not sufficient to tackle this issue.

Moreover, the procurement system also has to be updated for better mobilization. Strictly speaking, even while planning a transmission line, a sufficient study using a simulation software has to be conducted in placing the arrester in transmission line. The location as well as in which conductor it has to be installed, how much interval of towers is required for a complete protection etc is to be identified. Without such techniques, an error free system cannot be designed. In view of the cost wise interpretation, the installation of transmission line arresters will be cost effective when the cost implications against the revenue loss during interruption are calculated.

5.3 Proposed methodology to be considered in KSEBL:

A proposed Methodology flow chart is shown in Fig (4).

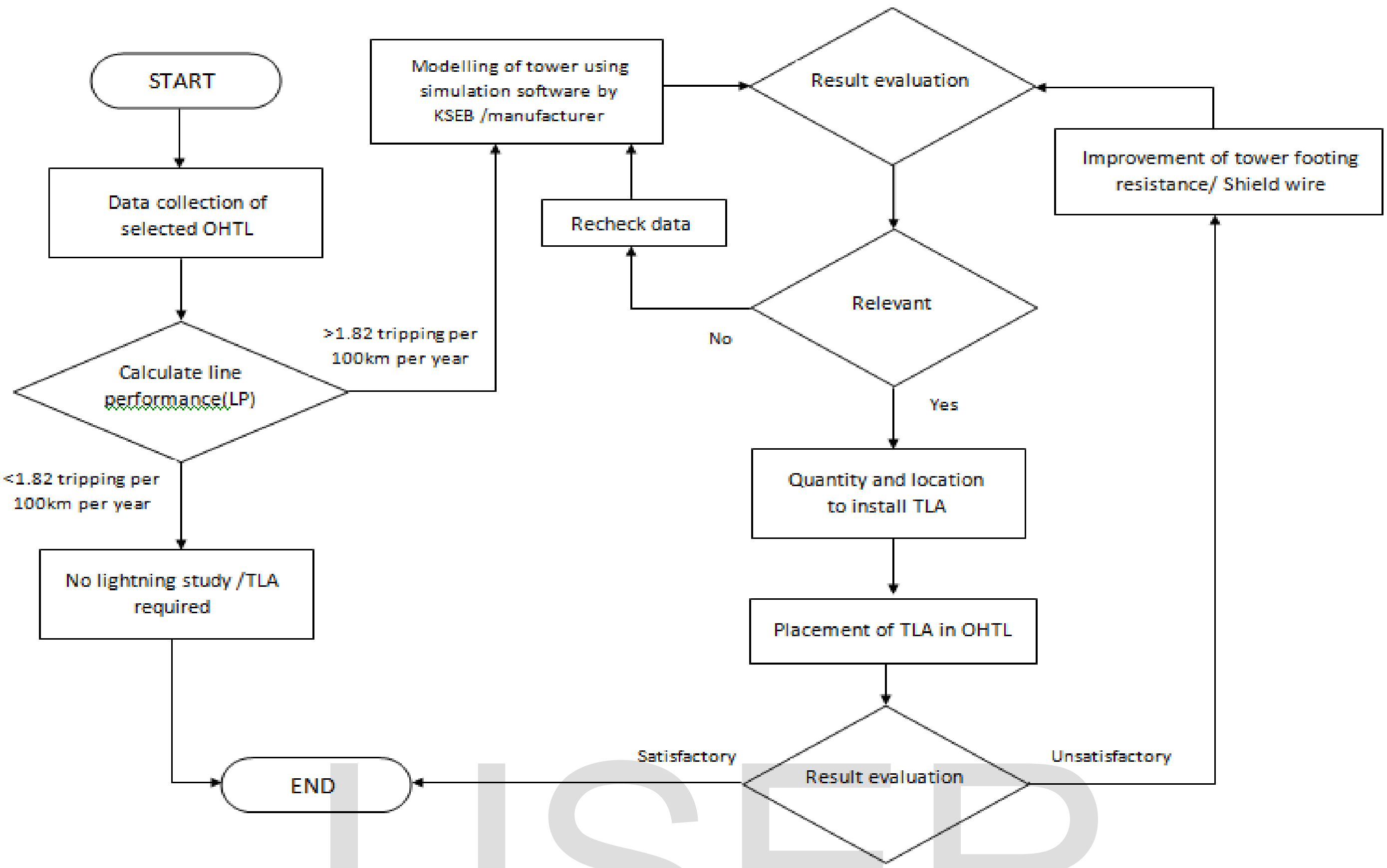

Fig (4) - proposed Methodology flow chart

Locate the TLA as close as possible to the insulator to be protected keeping sufficient clearance in the event of TLA overloading and disconnector operation. The number of TLA required in a transmission line depends basically on the tower geometry and configuration as well as earthing transient impedance behavior.

A. Transmission towers with horizontal conductor configuration -TLA to be installed on both two outside phase conductors.

B. Transmission towers with vertical conductor configuration-Conductors arranged above each other, the resultant transient voltage across the insulator string sets is usually higher at the bottom string which presents a lower distance to the soil and lowest coupling with the shield wire. Therefore, transmission line with vertical configuration and lower footing resistance, only one TLA is necessary to install the bottom conductor. In case of higher footing resistance, it must be necessary to install two or sometimes three TLAs. The topmost and the middle insulators are normally protected by shield wires. Bottom most insulators are more vulnerable for flash over for which TLAs are required.

6 Results andDiscussion:

1. While comparing the Table (3) and Table (4) above it is evident that the number tripping is reduced from 19 to 8 (58%) before and after installing the 16 months from the month of installation of TLA

2. From Table (5) it is evident that total 7 numbers of lightning were recorded in the counter provided in 2LPMD 1 feeder during the above period. The two TLA's provided in 2LPMD 2 feeders is burned out and therefore not recorded.

3. At present, all the TLA provided in 2LPMD 1 & 2 are installed in the topmost conductor which is scientifically not true according to the proposed methodology discussed above.

4. The location of the TLA has to be finalized before procuring TLAs for an OHTL based on

the proposed methodology flow chart shown in fig (4).

5. The tower footing resistance has to be measured and ensured that the same is beyond the limit before installing the TLA in middle and topmost conductor

6. For new transmission lines, the proposed location of TLAs to be ascertained as part of the transmission line design.

7. As part of this study, the team has contacted the TLA manufacturers in India for getting a simulation study on 2LPMD 1 & 2 feeders and it is learnt that even the suppliers of KSEB and other power utilities are not conducting any simulation study before installing the TLA in transmission line. This is not the case in foreign countries. Simulation software such as T Flash is used by the utilities before procuring and installing the TLAs in transmission lines.

7 Research Gap:

[1] A simulation study is not conducted as part of this analysis due to the cost impact of available software.

[2] A financial analysis is not conducted against the gain of revenue after the installation of TLA.

8 Conclusion

A healthy transmission network is an absolute necessity for the development and sustainability of a nation. Utmost care and importance shall be bestowed for this purpose by continuous monitoring and updating by eradicating all the unnecessary hurdles that resulted in an interruption of the transmission line. Lightning induced interruptions are totally unpredictable and results in huge delay for the restoration work. At the same time, through detailed engineering and study and utilization of available remedial measures, even these unscheduled interruptions can be totally eliminated. The study revealed that installation of TLA is such a technique through which this unwanted situation can be easily eliminated. Through proper simulation and early planning, the exact locations for installing these TLAs can be identified and the outcome will be that the interruptions can be minimized. It is evident from the available records that the feeder considered for this study has got such a result that 58% of the interruptions werereduced only because of the installation of these TLAs in line. Though procurement of TLA is being carried out in KSEBL, a proper methodology in installation such as conducting a software simulation has to be mandatorily carried out either through an owned simulator or through a simulation study conducted by the supplier in case to case before procurement of TLA for a respective OHTL. In transmission network, the installation of TLA is a vital requirement since majority of tower locations are very hard to access in case for a restoration work due to lightning or surges. Moreover, once the installation is carried out, a routine monitoring and maintenance shall be conducted to make it healthy throughout.

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Annexure-1

Transmission Line data in order to select the correct number of TLA's for a given System by simulation Study

[1] Company name: Kerala State electricity Board

[2] Transmission Line Name: 220kV Lower Periyar – Madakkathara Double circuit.

[3] Line location: Central Kerala, India

[4] ( ) New Line (√) existing Line ( ) Single circuit ( ) Double Circuit

[5] Transmission Line Length (km): 102.1km

[6] Maximum system operating voltage (Phase – to - phase): 245 kV

[7] Neutral configuration: (√) Solid Earthed ( ) Earthed by impedance ( ) isolated

[8] Phase- to- earth fault factor:<1.4 (less than 1.4 for earthed systems)

[9] Phase to earth short circuit current (KArms): 20 Duration of fault (seconds): 1

[10] Type of arresters installed on the substation: ( ) silicon Carbide (SiC) (√) zinc oxide arresters (ZnO)

[11] Arresters rated Voltage (kV): 198kV Arresters MCOV (kV) only for ZnO: 168

[12] Low frequency resistance range values for the structures (Ohms): Foot resistance 10Ω including structure

[13] Low frequency resistance range value considering earthing improvements (Ohms):5Ω

[14] Average spans between towers (Meters): Tension - 500m, Suspension-300m

[15] Distance between earthing points (meters): all towers earthed Avg.330m

[16] Soil resistivity (Ohms –meters)/Dielectric constant: 600

[17] Type of land- Please consider the line percentage: (√) Plain (√) uneven land (√) Mountainous

[18] Natural shielding (trees, tall structures, metallic structures etc): ( ) Yes (√) No

[19] Phase conductor characteristics and diameters (mm): ACSR kundha (Al-400mm^2; Covered dia 26.8mm2)

[20] Average conductor sag (m): 1.5m

[21] Does the line present shield wire? (√) Yes ( ) No

[22] Shield wire numbers and cable diameter (mm):1 no.7/3.15mm GI wire

[23] Shield wire average sag (m): 0.5m

[24] Insulator strings characteristics: Type, Manufacturer and number of discs in the insulator strings (consider One for polymeric insulators): L1 & L2 – 374 polymer type; balance porcelain

[25] Are the insulators directly connected to the earthing system: ( )Yes (√) No?

[26] If not, please inform the type of structure and the distance between the insulator and the earthing point: Insulator is suspended in the cross arm of the tower which is connected to earthing point

[27] Ground Flash Densities (discharges/ (km^2.year) or keraunic level: ……… ( ) GFD ( ) KL- Not known

[28] Current average Non schedule outages in the line (discharges/100km.year): 14

[29] Average Non schedule outages wanted for the line (discharges/100km.year) :<2

[30] Critical flash over voltage of insulated string:

For suspension – 90kN- positive peak – 135kV

For Tension – 120kN- Negative peak – 130kV Non polymer

For suspension – 90kN- positive peak – 140kV

For Tension – 120kN- Negative peak – 135kV polymer

All the above types of insulated string-1100kV

[31] Earthing characteristics for the structures: Type of earthing configuration:

( )Electrodes ( ) Counterpoise (√) Electrodes plus Counterpoises

[32] For the earthing configuration based on electrodes please inform: - Number of electrodes, type and earthing configuration, distance between the electrodes: 6m diagonally

[33] Geometric characteristics of the electrodes (diameter - mm and length - meters): 5.5m length 50x6mm GI

[34] Conductor cable diameter used to connect the electrodes and deep of the cables :7/3.15mm GI wire 3m depth; counterpoise-1.5m

[35] Soil resistivity (ohm. meter) for the regions crossed by the line evaluated-600ohm-m

[36] For earthing configuration based on Counterpoises please inform: Number of Counterpoises and its disposal (radial, horizontal, etc ...): horizontal

[37] -length of each Counterpoise (per cable leg) and distance among Counterpoises (earthing Geometric configuration): 5.5m

[38] -Conductors characteristics used as Counterpoise, in special the cable diameter: 50x6mm GI strip

[39] -Cable deep in the soil (usually around 0, 5 meters) :1.5m.

[40] In case of natural shielding ((trees, metallic structures. etc ...) please inform the structure height as well as its distance from the line: NA.

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