66/11 kV DISTRIBUTION SUBSTATION DESIGN

Mr. Vishnu Suthar[1], Mr. Kamlesh Dhaduk[2], Prof. Ajay Patel[3]
[1,2] *Final Year Students, B.E. Electrical at B.V.M. Engg. College, Vallabh Vidyanagar, Gujarat*
[3] *Assistant professor, Elect. Engg. Dept. at B.V.M. Engg. College, Vallabh Vidyanagar, India*

ABSTRACT

Over the decades power demand increases drastically. The electric power is produced at the power generating stations which are located at quite away from consumers. It is delivered to consumer through a large network of transmission and distribution lines. At many places in line of the power system, it may desirable and necessary to change some characteristic of electric supply. This is accomplished by suitable assembly of apparatus called Substation. Some of the characteristic of electric supply include voltage level, power factor, frequency, AC to DC etc. The modern sub-station is a complex structure as it requires items of equipment and allied services before it can serve the purpose. To design such modern complex structure with considering all design standards is a great challenge.

INDEX TERMS - *Clearances, Equipment's Ratings, SLD (Single Line Diagram), Plan Layout, Section Elevation Layout, Earthing Grid, Earthing Grid Design, DSLP (Direct Stroke Lightning Protection), DSLP Design, OPGW Cable, Distribution Substation and Substation Design*

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1. INTRODUCTION

The sub-stations are important part of power system. The continuity of supply depends to a considerable extent upon the successful operation of sub-stations. It is, therefore, essential to exercise utmost care while designing and building a sub-station.

The following are the important points must be kept in view while laying out a sub-station:

a) It should be located at the proper site. As far as possible, it should be located at the centre of gravity of load.

b) It should provide safe and reliable arrangement. For safety consideration must be given to the maintenance of regulation clearances, facilities for carrying out repairs and maintenance, abnormal occurrences such as possibility of explosion of fire etc. for reliability consideration must be given for good design and construction, the provision of suitable protective gear etc.

c) It should be easily operated and maintained.

d) It should involve minimum capital cost.

A description of the design stages, basic design considerations, understanding of the system inputs to design and identifying their sources and establishing main design parameters such as capacity of substation, power frequency and essential supplies, environmental parameters, bus bar schemes - signal bus or double bus, clearances & space planning in substation, substation layout, selection of switchgear, short circuit & insulation ratings of equipment's, earthing grid, lightning protection etc.

Bus bar is the important components in the sub-station. There are several bus bar arrangements that can be used in a sub-station. The choice of a particular arrangement depends upon various factors such as system voltage, position of sub-station, degree of reliability, flexibility & cost etc.

The commonly used bus bar schemes at Sub Stations:

a. Single bus bar scheme

b. Single bus bar with sectionalize scheme

c. Main and Transfer bus bar scheme

d. Double bus bar scheme

e. Double Main and Transfer bus bar scheme

f. One and a half breaker scheme

2. DESIGN OF 66/11KV, 20MVA SUB-STATION

Before the ratings of various items of equipments in a substation are chosen and their locations in the substation decided it is necessary to draw a Single Line Diagram, also called Key Diagram.

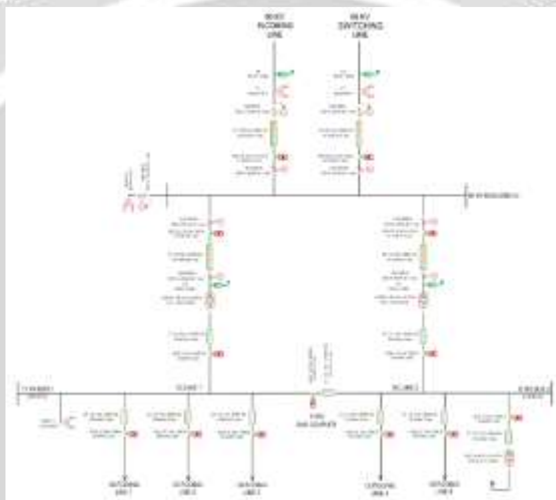


Fig: 1 Single Line Diagram

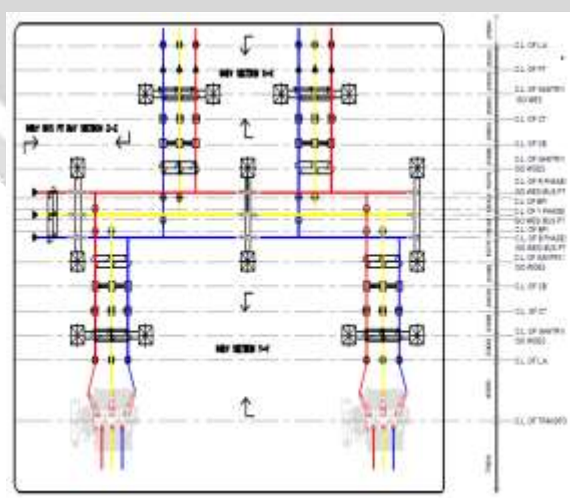


Fig: 2 Plan Layout

The total power supply capacity of substation is decided from load survey of that area with consideration of future expansion.

Here single bus-bar arrangement with sectionalisation scheme is shown in SLD. All drawings are prepared in AutoCAD software. After key diagram prepared, layout drawings are prepared to show the actual position of each equipments includes PLAN & SECTION layout.

These layout would reveal

a) Physical position of each equipments.
b) Distance between various equipments.
c) Phase segregation distance.
d) Phase to ground segregation distance (Horizontal).
e) Phase to ground clearance (Vertical).

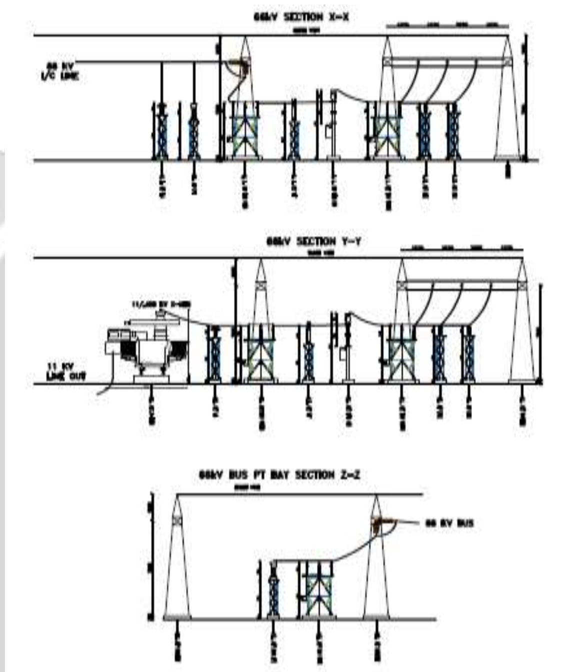


Fig: 3 Sectional Layout

Distinction should be made between electrical clearances which are necessary to ensure satisfactory performance in service and safety clearances which are required for safety of personnel in inspection, operation and maintenance work. The electrical clearances and safety clearances are recommended in IS: 3072-1975 and BS: 162-1961 respectively.

For 66/11 kV substation, following minimum electrical & safety clearances are required.

Nominal System voltage (kV)	Highest System Voltage	Phase and earth (mm)	Between Phases (mm)	Safety Clearance (mm)	Ground Clearance (mm)
11	12.1	178	230	2600	3700
66	72.5	1970	1830	3660	6400

The design of substation cannot be finalized without all Equipment's rating selection and design calculations are performed and has to be postponed till the orders of various items have been placed and equipments dimensions have been obtained from the suppliers.

General Technical Specification of Equipments	
Sr. No.	**Description**
1	Type
2	Service
3	Reference Standard
4	System Details
4.1	Rated Voltage
4.2	Nos. of phases
4.3	Frequency
4.4	System Neutral Earthing
5	Insulation Level
5.1	HV terminal & earth kVp
5.2	Lightning Impulse withstand Voltage (1.2/50 µs kVp)
5.3	Rated current KA rms
5.4	Number of secondary winding
6	Temperature rise
6.1	Design Ambient Temperature
6.2	Maximum temperature rise
7	Short-time Withstand Current
7.1	Rated 1 or 3-second Current KA rms
7.2	Rated dynamic Current KA peak
8	Auxiliary System
8.1	Motor
8.2	Control & Interlock
9	Mounting
10	Terminal Connector type
11	Partial discharge level in pC
12	Creepage distance mm (based on 31mm/kV)
13	Basic impulse level (B.I.L.) kV peak

3. EARTHING SCHEME DESIGN

The present day earthing system in a substation takes the form of a grid or mat comprising a number of square or rectangular meshes of earthing conductor buried horizontally and connected to several electrodes driven at interval as shown in figure.

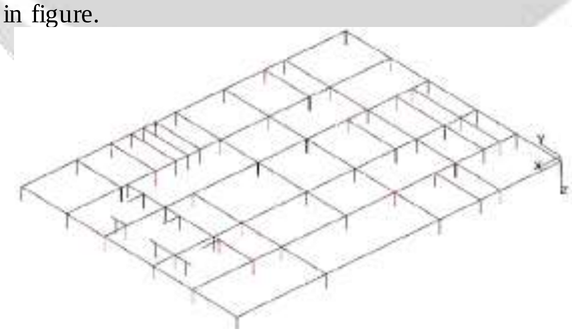


Fig: 4 Model of Earthing Grid

The object of earthing system is to provide as nearly as possible a surface, under and around a station, which shall be at a uniform potential and as nearly zero or absolute earth potential as possible with a view to ensure that:

a) All parts of apparatus (other than live parts) connected to the earthing system (through earthing conductors) shall be at ground potential,
b) Operators and attenders shall be at ground potential at all times.
c) It should provide low impedance path to fault current for reliable & prompt operation of protective devices during ground fault.

Most affected parameters for design of earthing grids are:

a) Magnitude and duration of fault current.
b) Soil and surface resistivity at the substation site (Soil structure and soil model).
c) Property and cross-section of material used for earth mat conductor.
d) Earthing mat geometry (area covered by Earth mat).
e) Permissible touch and step potentials.

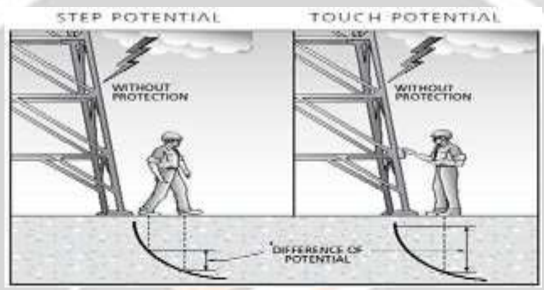
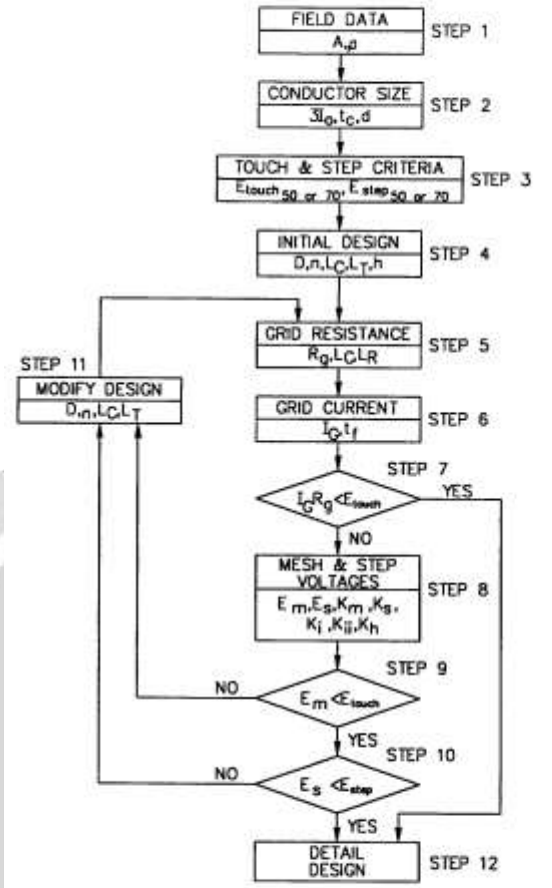


Fig: 5 Step & Touch potential

The different methodologies adopted for grounding grid design but we adopt universal method as per IEEE-80 discussed in this section.



The flowchart and sample calculation for earthing is described above & below in which all the required parameters are shown related earthing mat design of 66/11 kV sub-station.

Design Input Data		
Description	Notation	Unit
Symmetrical fault current in substation	I_g	A
Duration of Shock for determining allowable body current	t_s	Sec.
Duration of fault current for sizing ground conductor	t_c	Sec.
Surface layer resistivity	ρ_s	Ω-m
Surface layer thickness	hs	M
Grid reference Depth	h_0	M
Soil resistivity	P	Ω-m
Depth of ground Grid conductors	H	M
Length of Grid conductor in X direction	L_x	M
Length of Grid conductor in Y direction	L_y	M
No. of Grid conductor in X direction	N_X	Nos.

No. of Grid conductor in Y direction	N_Y	Nos.
Spacing between parallel conductors	D	M
Length of Ground rod at each location	L_r	M
Number of rods placed in area	n_R	Nos.
Decrement factor for determining IG	D_f	------
Equivalent earthing mat area	*A*	m2
Total length of Buried Conductor=(LX X NY)+(LY X NX)+(Lr X Nr)	L	M
Total length of ground rods	L_R	M
Equivalent impedance Zeq	Z_{eq}	Ω
Total length of conductor in horizontal grid	L_c	M
Peripheral length of grid	L_P	M
RMS Current	I	Ka
Maximum Allowable Temperature	T_m	°C
Ambient Temperature	T_a	°C
Reference Temperature for material constants	T_r	°C
Thermal coefficient of resistivity at 0°C	α_0	1/°C
Thermal coefficient of resistivity at reference temperature Tr	α_r	1/°C
Resistivity of the ground conductor at reference temperature Tr	ρ_r	μΩ.cm
1/α0 or (1/αr) –Tr	K_0	°C
Duration of Current	t_c	sec.
Thermal capacity per unit volume	TCAP	J/(cm^3.°C)

Earthing grid conductor Area,

$$Amm^2 = \frac{I}{\sqrt{\left(\frac{TCAP \times 10^{-4}}{t_c \alpha_r \rho_r}\right)\ln\left(\frac{K_0 + T_m}{K_0 + T_a}\right)}}$$

Cs Surface layer derating factor,

$$C_s = 1 - \frac{0.09\left(1 - \frac{\rho}{\rho_s}\right)}{2hs + 0.09}$$

$$E_{touch50} = (1000 + 1.5C_s \times \rho_s)\frac{0.116}{\sqrt{t_s}}$$

This is tolerable touch voltage of grid considering 50 kg person.

$$E_{step50} = (1000 + 6C_s \times \rho_s)\frac{0.116}{\sqrt{t_s}}$$

This is tolerable step voltage of grid considering 50 kg people.

Grid Resistance

$$R_g = \rho\left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{20/A}}\right)\right]$$

Typically, the site engineer specify a resistance of grid. The earth resistance shall be as low as possible and shall not exceed the after following limits:

- Power Stations - 0.5 Ω.
- EHT Substations - 1.0 Ω.
- 66/11 kV Stations - 2.0 Ω.

If the soil resistivity is 800 ohm-meter or above it would have been difficult to obtain the desired low resistance of 1 to 2 ohm for the grid substation with the earthing strip alone. In such cases it becomes necessary to increase the area of earthing grid. Mere increase in the quantity of earthing strip may not help much to reduce the resistance of the earthing system and the use of deep driven rods may be inevitable.

Ground Potential rise (GPR) = (Maximum grid current Ig * Grid resistance Rg)

Now compare GPR < E touch tolerable voltage
If yes then DESIGN IS SAFE.

If GPR > E touch
Then Find (Estimated E mesh and E Step)

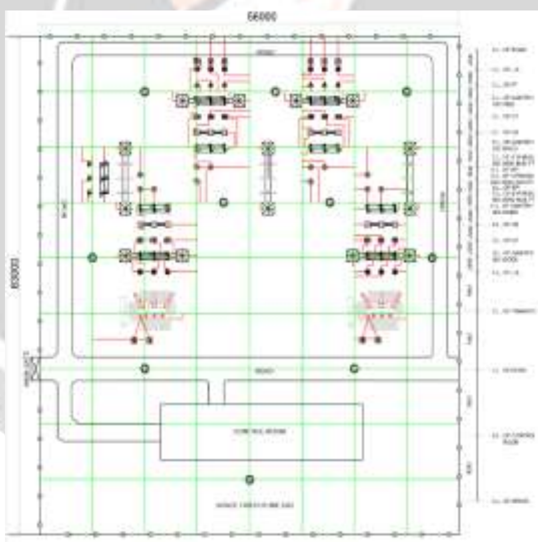


Fig: 6 Earthing Grid Design

Estimated Mesh voltage,

$$E_m = \frac{\rho \cdot I_G \cdot K_m \cdot K_i}{L_C + \left[1.55 + 1.22 \cdot \left(\frac{L_r}{\sqrt{L_x^2 + L_y^2}}\right)\right] \cdot L_R}$$

Estimated Step voltage,

$$E_s = \frac{\rho \cdot I_G \cdot K_s \cdot K_i}{0.75 \cdot L_C + 0.85 \cdot L_R}$$

Compare E mesh estimated < E touch tolerable,
If yes then Compare E step estimated < E step tolerable, if yes then DESIGN IS SAFE.

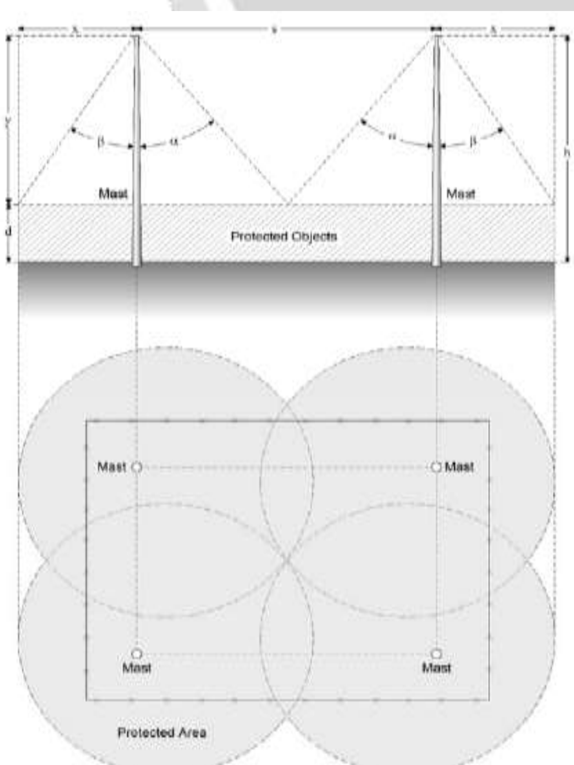
Otherwise, modify by increasing or decreasing spacing of conductor, Length of conductors or by increasing or decreasing number of rods and Calculate design parameter again.

4. DSLP (DIRECT STROKE LIGHTNING PROTECTION) DESIGN

Direct strokes from lightning can damage substation equipment and bus work. To protect equipment, substation engineers can install direct stroke lightning shielding. Here earth shield wire and lightning mast are used in substation to protect equipment from direct stroke of lightning. In plan layout of Direct Stroke Lightning Protection, the whole area of sub-station should be covered by shield wire and masts. In sectional layout of DSLP of substation, actual view of how all equipments are protected from lightning stroke. For preparation of DSLP layout of substation, many design methods are used from among all, we are using FIXED ANGLE method for DSLP design. In this method we have assumed value of shielding angle as well as protection angle 45^o.

Sample Calculation for DSLP design:

Height of the equipment to be protected	d
Radius of Protection x	(h-d)*tan(Beta)
Radius of Protection	X
Height of the LM above equipment to be protected	Y



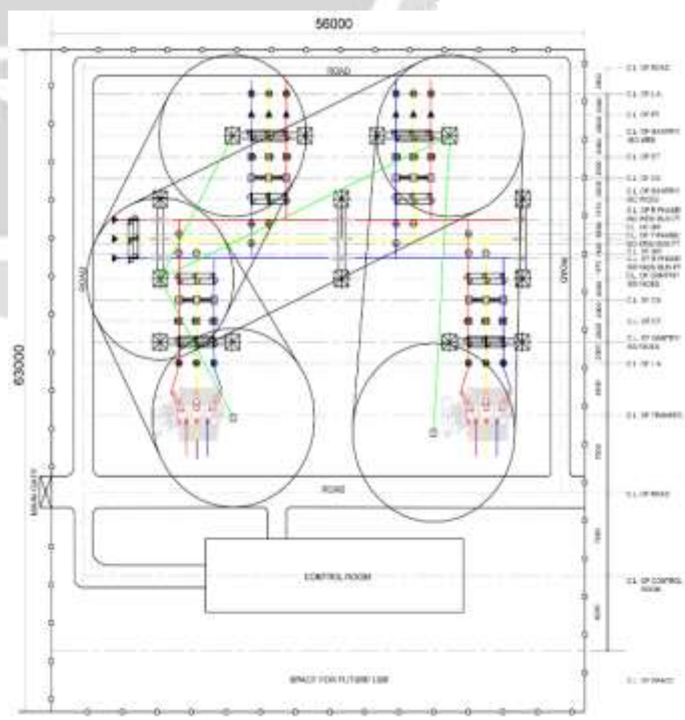


Fig: 8 DSLP plan layout

Fig: 7 Fixed angles for shielding mast

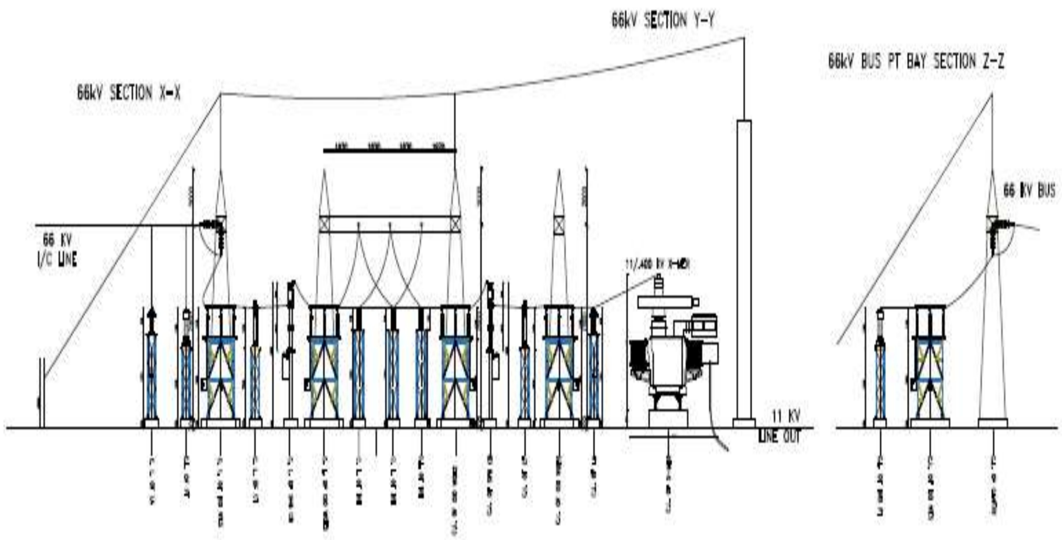


Fig: 9 DSLP sectional layout

5. OPGW TECHNOLOGY

Use of OPGW (optical ground wire) instead of CVT & wave trap communication circuit. From the construction point of view, OPGW is made of fiber cable putted in steel tubes as shown in above figure. This tubes are covered by aluminium alloy wires which actually worked as a ground wire for lightning strokes. An OPGW Cable is a special type of Ground Wire in which Optical Fibers are also embedded along with ground wire during manufacturing process to provide a high capacity data channel for communication purposes. Thus it helps in providing dual functions of Earth Wire and Optical Fibers which can be used for high bandwidth data transmission.

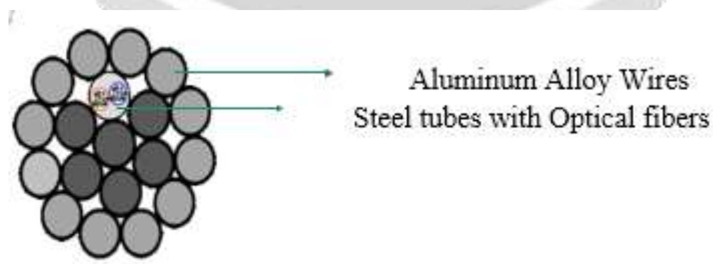


Fig: 10 OPGW Cable

- OPGW provides a relatively low cost solution to provide Communication and Data backbone trunks.
- As the Power Transmission Company has right of way for its towers it need not acquire land to lay down the fiber optic cable.
- No digging, trenching, filling etc. is required as the cable is laid high in the air and not underground. This is especially advantageous in hilly, marshy, rocky terrain. .

- The cable is well protected by a bundle of strong steel or aluminium conductors.

6. CONCLUSION

Power Networks will continue to grow and expand, so that Substation design is evolving to meet new requirements. The use of grounding grid with specific spacing and lightning rode with shielding wire will reduce both accidents as well as cost of substation without affecting safety of personnel working and protection against lightning strokes in substations respectively. Therefore, the goal of low installation & erection cost, future load expansible capacity, safe operation and easily maintenance, greater reliability with optimum design can be achieved and substation performance can be improved.

7. REFERENCES

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