A Survey on Power Transmission Towers Configurations in Haryana State

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ABSTRACT:Modern civilization depends heavily on the consumption of electrical energy for industrial, commercial, agricultural, domestic and social purposes. Electrical power is generated in large thermal and other generating system to distant distribution network& consumers via the transmission system. The modern electrical power system is in the form of a large interconnected 3 phase AC network. The generating station, transmission and distribution system are interconnected to form a 3 phase AC system operating synchronously at the common frequency of 50 Hz. The total network covers vast geographical areas of the States and Nation. The basic function of a transmission system is to transfer electrical power from one location to another location or form one network to another network. A transmission system includes terminal substation, transmission lines and intermediate substation, associated controls, protection, auxiliaries etc. The transmission lines are also the main constituents of the power system to transfer the power from one location to another. Thus, in order to understand the features and role of transmission lines set up by State Electricity Boards, study of various configurations of power transmission towers installed at various sites of Haryana State covering all levels of power transmission has been carried out in this paper.

***Keywords**: Configuration, Geographical, Intermediate, Substation, Terminal, Transmission.*

I. INTRODUCTION

Modern civilization depends heavily on the consumption of electrical energy for industrial, commercial, agricultural, domestic and social purposes. Electrical power is generated in large thermal& other generating system to distant distribution network via the transmission system in the form of a large interconnected 3 phase AC network operating synchronously at the common single frequency of 50 Hz. A transmission system includes terminal substation, transmission lines and intermediate substation, associated controls, protection, auxiliaries etc.& it is necessary for (1) bulk power transfer from large group of generating station to the main transmission network, (2) for the main transmission network (3) for system interconnection and, (4) for transfer of power from the main transmission network to the distribution substation. Important considerations are taken care in transmission system which includes power transfer and distance.

Trends in Transmission Voltage: The network of transmission and distribution lines is formed by three phase alternating current system. For longer distance lines and higher power transfer, higher transmission voltages are necessary for an electrical system in order to reduce the electrical losses of the system for their better efficiency. The choice of transmission voltage depends on power and distance of transfer. The 3 phase AC system has a tendency to operate naturally in synchronization and the operation and control should be very easy.For long lines and for higher power transfer, higher transmission voltages are necessary, (220kV¸400kV, 750kV AC). AC voltage above 220kV are called extra high voltage AC (EHV AC), which is in form of long transmission lines & the long AC transmission links need at least two parallel three phase transmission circuits to ensure reliability and stability during a fault on any one phase of the three phase lines.

SPECIAL FEATURES AND TECHNICAL CONSIDERATION:

(i) The most important features of EHV AC transmission line is power transmission ability, based on transient stability limit

$$P_{ac}= |V_1||V_2|\sin \delta$$

(ii) The line design is based on limit of corona radio interference, TV interference, electrical field at ground level

(iii) For EHV AC lines, the voltage stress at conductor surface should kept below critical voltage for achieving thus the use of bundle conductors is preferred.

(iv) EHV AC lines transmit bulk power. Outage of this cause stability problems in the network. Hence alternative transmission paths should be planned along with the protection system design by the use of different configurations of transmission towers.

II. ENGINEERING ASPECT OF EHV AC TRANSMISSION SYSTEMS AND TRANSMISSION PLANNING

An EHV AC Transmission system has two or more, long three phase AC transmission lines and associated terminal substations, intermediate substations, control system etc. Some of the engineering aspects of EHV AC lines (400kV and above) are distinctly different than those of HV AC lines (upto220kV).**[1]**

The engineering aspects have a decisive influence on the Generation planning, Transmission planning and Distribution planning. Transmission planning deals with short term, mid-term and long term plans regarding new transmission lines, interconnection and substations. Transmission planning should match with the generation planning and distribution planning.

Electrical, Mechanical Design Aspects:

Electrical Design Aspects: Electrical design of AC overhead transmission line system involve the following aspects:-

1. Power transfer ability.

2. Transient stability limit and dynamic performance studies.

3. Choice of rated voltage for new transmission lines.

4. Voltage control and Reactive Power Compensation, voltage regulation.

5. Power transfer controllability for tie-lines and AC lines.

6. Choice of conductor, corona ring.

7. Corona, radio Interference (RI), Television interference (TI), Audible Noise (AN).

8. Biological effects of electromagnetic fields at working level on the ground, below maximum sag point, electromagnetic spectrum.

9. Insulation coordination and overvoltage studies, surge arrester protection.

10. Transmission Losses and efficiency

11. Design of Insulator, creep age distances, clearances, grading ring.

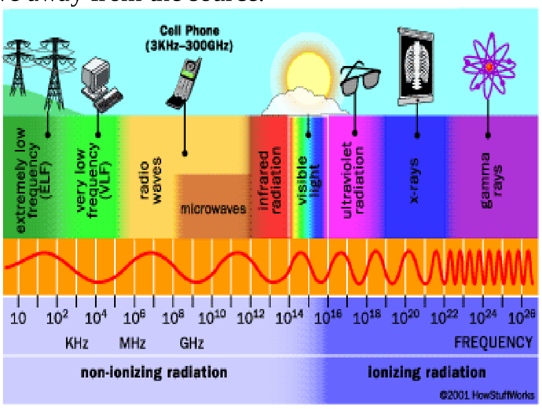
12. Lighting phenomena and overhead shielding wire.

13. Protective Relaying of transmission lines.

14. Safety.

ELECTROMAGNETIC SPECTRUM: [2]

Electric and magnetic fields or EMF are weak, invisible fields of energy that exist around anything that carries or uses electricity. The strength of these fields quickly decreases as you move away from the source.



Electromagnetic Management for Transmission Lines [3]: Due to HV, EHV and UHV overhead lines, production of EMF is more prominent. The installations and distribution of EHV transmission line produce the highest electric field near the ground surface. In the age of electrification, the evaluation of EHV, people are used to stay around ELF field sources, which may further lead to responsible for biological effects of human as well as living beings. Electric and magnetic field management of overhead transmission lines required in different factors of line design and techniques for configurations of transmission towers for reduction of EMF have low value. Electric field is reducing to extremely low values using ground grids of densely spaced wires and also it is possible to significantly reduce the magnetic field of lines with voltage upto 115kV or by using loops cancellation method. These structures were found with the transmission towers with EHV-AC lines during the study.

Mechanical and Structural Design: The transmission line design involves civil, mechanical and structural design aspects:-

1. Structure design. Choice of configuration of Towers, Insulators and conductors.

2. Mechanical loading calculations.

3. Conductor configuration and hardware.

4. Insulators.

5. Line hardware, Corona ring.

6. Design of overhead shielding.

7. Foundation, anchoring, guys.

8. Safety.

III. CONFIGURATION OF TOWERS FOR TRANSMISSION LINES

Tower (also called structure) is a lattice structure that supports insulators, overhead transmission lines conductors and overhead wire. Structures are also used for supporting flexible bus bar/insulators, equivalent insulators, rigid bus bar insulators, lightning masts and overhead shielding wire mesh in substations.

Towers and structures are three dimensional fabricated lattice structures made up by bolting/riveting/welding the structural members of Galvanised Steel (or of Aluminium Alloy in USA). The tower needs a single or multiple foundations.The lines installed on the various transmission towers can either be single circuit or a double circuit.

Single circuit AC towers:-Single circuit AC towers supports three bundled conductors. These towers preferred for HV AC due to higher reliability.

Double circuit AC towers:- These towers supports six or more bundled conductors. These towers used for 220kV and more voltage levels.

Single circuit design	Double-circuit design
It is subjected to less wind pressure of conductors and structures, so it requires less weight of steel tower member & lesser foundation.	It is subjected to more wind pressure structure due to more height and is of heavier members.
Less danger at the time of repair	There is always danger from the other circuit
The design is not reliable as regards the continuity of supply	The design is quite reliable as regards continuation of the supply.
Greater spacing of the conductors is required to reduce the electromagnetic induction and proximity effects	Lesser conductor spacing is required due to bundled conductors
Higher reactance as the spacing between conductors is high.	Low reactance, as spacing is low due to bundling..

Types & configurations of Self Supporting & Flexible Towers: Structural configuration of towers for three phase ac circuit has following principle categories:-

1. RIGID SELF SUPPORTING TOWERS
2. SEMI-FLEXIBLE TOWERS
3. FLEXIBLE TOWERS (GUYED TOWERS)

RIGID SELF SUPPORTING TOWERS	SEMI-FLEXIBLE TOWERS	FLEXIBLE (GUYED) TOWERS
• Single Circuit • Double Circuit	• Single Circuit	• Single Circuit

Table 1: Configuration of Tower according to circuit design

According to the IEC, the standard voltage levels in 3-phase A.C. power system are**[4]**:-

Description	HV	EHC AC	UHV AC
Rated Voltage (Nominal) kV	132, 220	345, 400, 500	750, 1000, 1150
Highest Voltage, kV	145, 245	362, 420, 525	765, 1050, 1200

Table 2: EHV AC Lines for different powers

The table 3 summaries the different lengths alongwith the requirement of the conductors for single circuit and double circuit designs according the power requirement**[5]**.

Length, Km	Power, MW	Number of 3Ph. AC lines n	At rated voltage , kV	No. of line conductors 3n
250	1000	2*2	400	12
500	1000	2*2	400	12
800	1000	3*2	400	18
1000	1000	4*2	400	24
1000	1000	2*2	750	12
1000	2500	4*2	400	24
1000	2500	2*2	750	12
1000	3000	2*2	750	12

Table 3: EHV AC Lines for different powers and lengths

The EHV-AC lines require a double circuit line for each transmission path.

IV. VARIOUS CONFIGURATIONS OF TRANSMISSION TOWERS

1. <u>NARROW BASE SINGLE CIRCUIT:-</u>

Fig. 1: Site of Single Circuit design at Bhatinda- Dabwali Road

This site is on Bhatinda- Dabwali Road having single circuit lines of voltage level of 66 kV.

2.(a) NARROW BASE DOUBLE CIRCUIT:-

Fig. 2: Site of Single Circuit Narrow Circuit at Bhatinda-Dabwali Road

This site is on Bhatinda- Dabwali Road having single circuit narrow line of voltage level of 66 kV.

2.(b) BROAD BASE DOUBLE-CIRCUIT:-

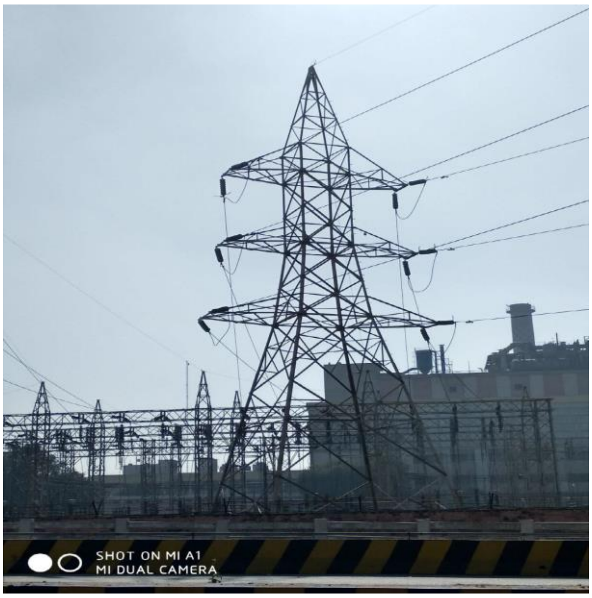


Fig. 3: Site of Single Circuit Broad Base Circuit at Bhatinda- Dabwali Road

VOLTAGE LEVEL:- 132KV

INSULATOR CONFIGURATION: STRAIN STRING

SITE:- BHATINDA-DABWALI ROAD

2.(c) BROAD BASE DOUBLE CIRCUIT:-

Fig. 4: Site of Single Circuit Broad Base Double Circuit at Dabwali (Haryana)

VOLTAGE TYPE:-132KV

INSULATOR TYPE:-SUSPENSION STRING

SITE:-DABWALI(HARYANA)

3. BROAD BASE SINGLE CIRCUIT:-

Fig. 4: Site of Broad Base Single Circuit at Hisar (Haryana)

VOLTAGE LEVEL:-400KV

CONDUCTORS:- MULTIPLE

FROM:- HSR-BSI (001)

SITE:- HISAR(HARYANA)

4. BROAD BASE DOUBLE CIRCUIT (MULTIPLE CONDUCTOR):-

Fig. 5: Site of Broad Base Double Circuit (Multiple Conductors) at Sampla (Rohtak)

VOLTAGE LEVEL:-400KV

INSULATORS:-V-STRING FOR SUSPENSION

FROM:-BGR-SNP(BHARDLI-SONIPAT)

SITE:-SAMPLA(ROHTAK)

5. BROAD BASE DOUBLE CIRCUIT(MULTIPLE CONDUCTOR):-

Fig. 6: Site of Broad Base Double Circuit (Multiple Conductor) at Sampla (Rohtak)

VOLTAGE LEVEL:- 220KV

INSULATOR:- INCLINED & HORIZONTAL STRAIN STRING

FROM:- BWN-BWI(0083)

SITE:- SAMPLA(ROHTAK)

6. BROAD BASE DOUBLE CIRCUIT (THREE PHASE):-

Fig. 7: Site of Broad Base Double Circuit (Three Phase) at Mayer (Hisar)

VOLTAGE LEVEL:-400KV

INSULATOR:-INCLINED STRAIN STRING

FROM:-HSR-BN II

SITE:-MAYAR(HISAR)

7. BROAD BASE SINGLE CIRCUIT (MULTIPLE CONDUCTORS):-

Fig. 8: Site of Broad Base Single Circuit (Multiple Conductors) at Mayer (Hisar)

VOLTAGE LEVEL:-400KV

INSULATOR:-INCLINED STRAIN STRING

FROM:-HSR-BN I

SITE:-MAYAR(HISAR)

8. CHAINNET STRUCTURE DOUBLE CIRCUIT:-

Fig. 9: Team working on the site analysing the data of various configurations of Transmission towers

Fig. 9 & 10: Site of Chainnet Structure Double Circuit at Sampla (Rohtak) with vertical and horizontal configurations respectively.

VOLTAGE LEVEL: - 132KV

SPECIAL CONFIGURATION:- COMBINATION OF VERTICAL AND HORIZONTAL

SITE: - SAMPLA(ROHTAK)

9. BROAD BASE SINGLE CIRCUIT (3 PHASE):-

Fig. 11: Site of Broad Base Single Circuit at Suratgarh Road

VOLTAGE LEVEL:- 400KV

SPECIAL CONFIGURATION OF INSULATOR

FROM STG TO RTG-II

SITE:-SURATGARH-GANGANAGAR ROAD

10. BROAD BASE DOUBLE CIRCUIT (MULTIPLE CONDUCTOR):-

VOLTAGE LEVEL:-400KV

SPECIAL CONFIGURATION OF STRING INSULATOR

SITE:- SURATGARH- GANGANAGAR ROAD

Fig. 12: Site of Broad Base Double Circuit at Suratgarh Road

11. BROAD BASE DOUBLE CIRCUIT:-

Fig. 13: Site of Broad Base Double Circuit at Nuhiyanwali, Sirsa (Haryana)

VOLTAGE LEVEL:- 132KV

HORIZONTAL STRAIN STRING INSULATOR

FROM NUIYAWALI TO CHORMAR

SITE:- NUIYAWALI,SIRSA(HARYANA)

12. BROAD BASE SINGLE CIRCUIT(MULTIPLE CONDUCTOR):-

VOLTAGE LEVEL:-400KV

SPECIAL CONFIGURATION OF STRING INSULATOR

SITE:- ROHTAK

Fig. 13: Site of Broad Base Single Circuit (Multiple Conductors) at Rohtak

13. BROAD BASE DOUBLE CIRCUIT(MULTIPLE CONDUCTOR):-

Fig. 14: Site of Broad Base Double Circuit (Multiple Conductors) at Suratgarh Road

VOLTAGE LEVEL:- 400KV

VERTICAL STRING INSULATOR

SITE:- SURATGARH, GANGANAGAR(RAJ.)

V. OVERHEAD LINE CONDUCTORS AND FITTINGS OF EHV-AC TOWERS

Bundled conductors are essentials required for EHV AC lines (400kV and above) & also for flexible bus bars in EHV AC for eliminating corona. Each phase of an EHV AC line consists of a bundled conductors with two or more identical, parallel sub-conductors & the spacers for supporting the bundled configuration along the length of conductor. Sub-conductors are in parallel and phase current is divided almost equally in the sub conductors. Sub-conductors are positioned in required configuration of the bundle by mean of spacers located at an interval of about 60mtr.along the length of conductor. The spacer supporting the sub conductors are with insulating bushes which permit axial movement of conductor & prohibit circulating currents within the sub conductors via the spacers.

Term	Description	Effects
Bundled Conductors	Assembly of two of more sub conductors per phase/pole.	Higher radius of bundle gives lower surface stresses & lesser corona.
Sub-conductors	Stranded ACSR with several layers of strands. Steel wires are galvanised.	High strength, low R, low loss.
Spacers	Sub-conductors are held apart in correct bundled shape by spacers fixed at regular interval of approximately 60mtr.	Spacers allow axial movement of sub-conductors.

The choice of number of sub-conductors N in the bundle is related with rated voltage of transmission line & limiting surface voltage stress against critical surface stress for corona inception.

CONFIGURATIONS OF BUNDLED CONDUCTORS:-

The various configurations alongwith the name assigned by the Power Grid of India for the bundled conductors is as per table 4**[6]**.

No. of Sub-conductors	Name	Configurations	Application
2 Sub conductors	Twin bundle	Horizontal or vertical	400kv AC
3 Sub conductors	Tri bundle	Triangular	500kv AC
4 Sub conductors	Quadri bundle	Square	750kv AC
6 Sub conductors	Multiple bundle	Ring	1000kv AC
8 Sub conductors	Multiple bundle	Ring	1200kv AC

Table 4: Configurations of Bundled Conductors

The above configurations are as shown below as observed during carrying out the study.

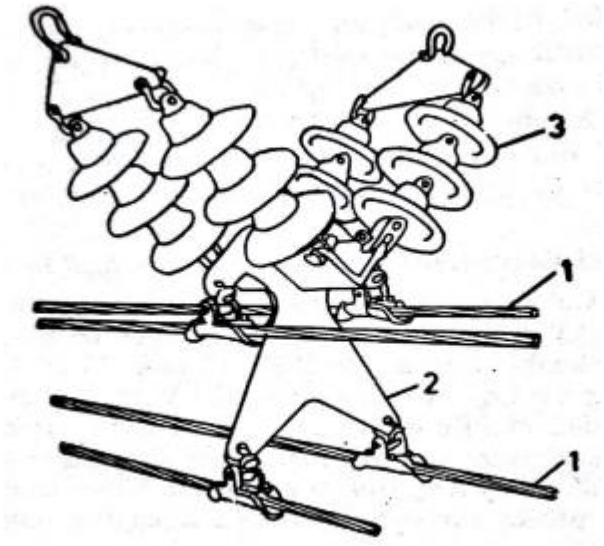


Fig. 15: Configuration of Quadruple Bundled conductors for 400kV Line

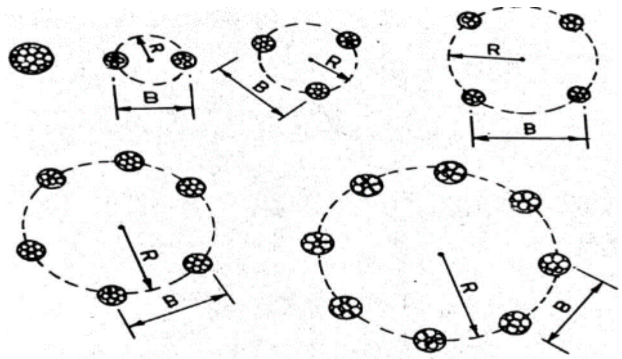


Fig. 16: Bundled conductors with 1, 2, 3,4,6 and 8 sub-conductors

SPACERS: As already mentioned that the sub-conductors of bundled conductors are held in position by mean of spacers at regular interval of about 60mtr.. These sub-conductors experience unequal wind forces, electromagnetic forces and oscillations. The functional requirements of spacers are:

- To hold sub-conductor in desired configuration long there length

- To prevent mechanical clashing, twisting, touching of sub-conductors

- To prevent circuiting currents through the spacers

- Corona free construction

- To permit axial movement of sub-conductor

- To permit pitch and yaw movement of sub-conductor at spacer clamp

- Should not damage sub-conductors

- Long service life

The resistance of the spacer between sub-conductor should be above 1MΩm which is achieved by synthetic rubber bushes during transmission lines laying.

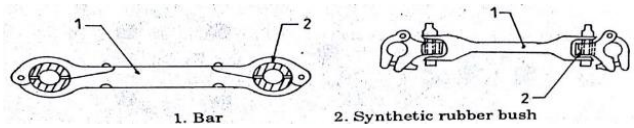


Fig. 17: Spacers for Twin Conductors Bundle

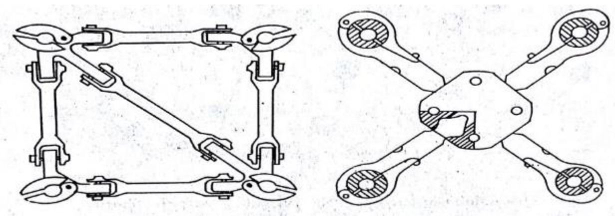


Fig. 18: Spacers for Quadruple Conductors Bundle

VI. LINE INSULATORS

In order to prevent the flow of current to the earth from support the transmission lines or distribution lines are well secured to supporting towers or poles with the help of insulators. Thus the insulators play an important part in the successful operation of lines. The chief requirements for the insulators for EHV-AC lines are:

(i) They must be mechanically strong

(ii) Their dielectric strength must be very high

(iii) They must provide very high insulation resistance to the leakage current

(iv) They must be free from the internal impurities or flaws

(v) They should not be porous

(vi) They must be impervious to the entrance of gases or liquid into the materials

(vii) They should not be affected with change in temp.

(viii) They must have high ratio of puncture strength of flash over voltage.

The main cause of failure of insulators is due to the flash over or punctures. The flashover may occur between the line conductor & the earth such that the pin of insulator & due to production of extreme heat produced by the arc the insulator. According to the material of manufacturing of insulators for EHV-AC lines, they are either made of Porcelain, Glass or Steatite Insulators. According to the requirements for voltage level on EHV-AC lines, the insulators are classified as Pin type, Suspension type, Strain, Stay, Shackle or Spool and String insulators**[7]**.

Pin type insulator is one of the earliest designs used for supporting lines conductors, since then many changes have been made in its design, but its appearance has not changed.For lower voltages,generally one piece type of insulators.Pin type insulators are used for transmission/distribution of electric power at a voltage level upto 33kV. As the line voltage increases the pin insulator to be used is become heavy & complicated in its construction, also its cost increases. Further the replacement of the damaged insulator will cost more. So, suspension type insulators are used in place of pin insulator for higher voltage. The suspension type insulator are designed by the use of discs & each disc is designed for low voltage, say 11kV. If the working voltage is 66kV, then six discs in series will be provided on the string. The suspension arrangement provides greater flexibility to the line. It is generally used with steel towers.

When there is a dead end of the line, or there is a corner or sharp curve, the line is subjected to greater tension. In order to relieve the line of excessive tension, strain insulators are used. If the pull on the string of the suspension insulators is high such as in case of long spans across the river, under these circumstances 2,3& 4 strings of insulator are used in series.

Fig. 19: Strain Insulator captured for Transmission Tower of 220kV

The string/ suspension insulator support the flexible ACSR or AAAC conductors.The string consist of several identical cap & pin units in series with & fittings on cross arm sides & conductor side alongwith the corona rings fitted for obtaining improved corona inception level, pollution performance & protection of insulators during flashovers. Special high strength assemblies are required for dead end, river crossings, transpositions, stormy areas.

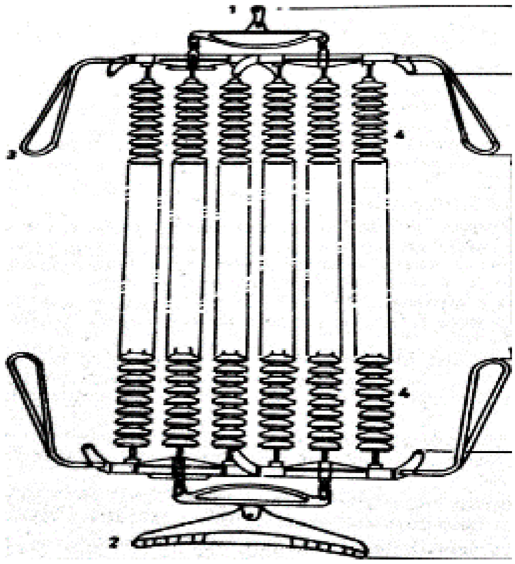


Fig. 20: String Insulators for EHV-AC Lines

The string insulators are further classified into the categories depending upon the various configurations and features**[8].**

Configuration	Remarks
Vertical strings for suspensions	i. Least effective against contamination of insulator surface as dust easily deposits on upper surfaces ii. Do not wash well during rains as the upper insulator units protect lower units against rain drops iii. Used in dry, clean area
V-strings for suspension	i. Least swinging ii. Self cleaning more effective iii. Each shade is exposed to rain drops iv. For given air gap, creep age length is increased v. Preferred for polluted atmosphere vi. Preferred for EHV, UHV, HVDC.
Horizontal strain or inclined strain string	i. Most effectively washed ii. Used for most polluted areas iii. Requires costlier heavy, strain type towers iv. Used for stringing the bus bars between two gantries
Special configuration	i. Combinations of vertical & horizontal, vertical & v shape.

	ii. Used to obtain extra long clearances.

Table 5: Various configuration of String Insulators

REFERANCESTAKEN FOR STRING INSLATORS FORMED BY ASSEMBLY OF DISC INSULATOR UNITS BY STATE ELECTRICITY BOARDS [9]:

Nominal system voltage (kV)	No. of units in the String		Minimum falling load	
	Suspension string	Tension string	Suspension string (kg)	Tension string (kg)
132	9-10	9-10	7000	11500
220	13-16	13-16	7000	12500
375	15-19	15-19	9000	16500
400	23-25	15-19	11500	16500

Table 6: Reference data for String Insulators for its application and features

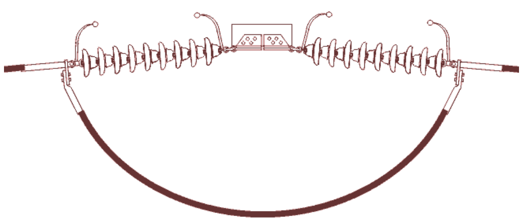
Choice of Insulator Units in a string: The number of insulator unit in a string is depending upon the choice of creep age distance per unit. The atmospheric pollution in the region through which the transmission line is passing & configuration of the string (vertical/ horizontal /V-shaped) **[10].**

Class of contamination	220kV		400kV		765kV	
	Standard	Anti-fog	Standard	Anti-fog	Standard	Anti-fog
A	12	9	21	16	35	26
B	12	9	21	16	35	26
C	15	12	26	20	44	35
D	19	15	32	26	59	44

Table 7: No. of units in a string insulator

Configurations of Insulator Strings for EHV-AC Transmission Lines:-

i. Strain-type with configuration: Due to higher transmission voltages, cascaded insulator units are used at insulator string.

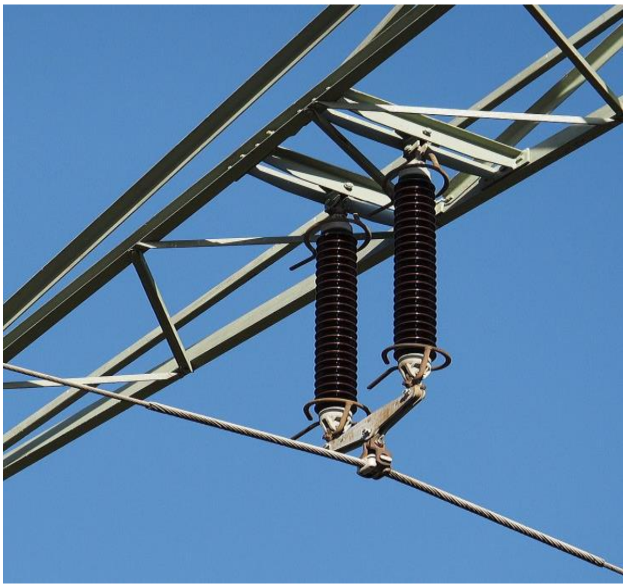


STRAIN INSULATOR

Fig. 21: Cascaded Strain Insulator

The jumper connection J is preferred from swinging by additional vertical string insulator.

ii. Suspension type with I configuration:-Suspension chains are used either in I formation or V formation. V-string formation has better self cleaning property during rains than the I formation.



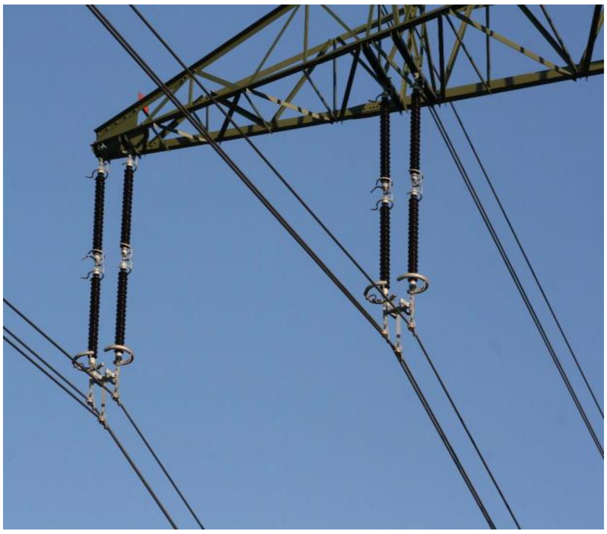


Fig. 22: I-Configuration Strain Insulators on Transmission Tower

iii. Suspension type with V-configuration:-The dust particles get charged and align along insulation surface along the direction of electric field. The alignment of these particles is maximum near conductor clamps due to high field strength. This gives process of surface leakage currents, surface tracking, corona. This problem is solved by use of string insulators in V-configuration.

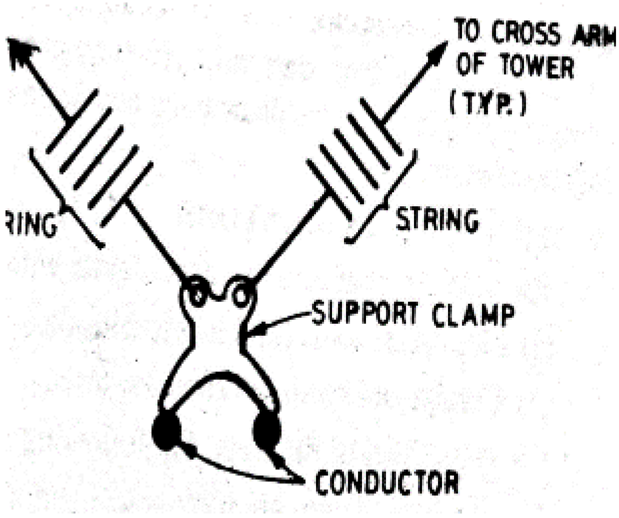


Fig. 23: String Insulator with V configuration

iv. Horizontal string configuration:-This is another type of configuration of string insulators placed on the transmission tower for EHV-AC transmission system as shown.

Fig. 24: Horizontal String Insulator Configuration

V. Special configuration :- (For extra high voltages)

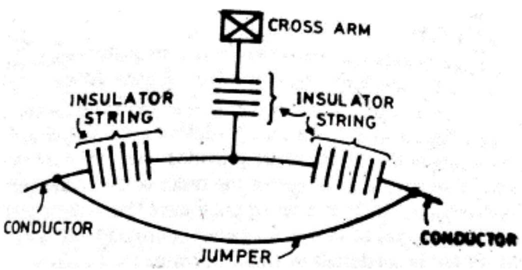


Fig. 25: Special Configuration of String Insulators

VII. CONCLUSION

From the above discussions and visit of various sites of towers in Haryana State, it has been observed that for effective power transmission of power in the State, various arrangement of transmission towers with different voltage levelshas been made alongwith the suitable fixtures and fittings by the Haryana State Electricity Board. It is further summarized that these configurations of towers situated at the various sites in the Haryana State are covering all parts of State providing 24 x 7 electricity supply available from different sources. Various effects such as corona, skin effect and proximity effect are taken care and minimised by suitable arrangements of configurations of conductors lying on the various transmission towers. Transmission towers are the backbone of the power network for effective transfer and valuable utilization of generated power. However, from the study, it has been observed that more work can also be carried out in this field such as sag calculations, tower configurations, insulator design, and many more, so that the new change can be made in the configurations for effective power transfer.

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