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Design & Analysis of EHV Transmission Lines

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***Abstract*: -- Modern Power, Transmission system is utilizing ultrahigh voltages. The distance of transmission and Bulk powers have increased to such an extent that Ultra High Voltages becomes the necessity. The problems encountered with these lines are voltage regulation, efficiency, losses, etc., This paper discusses the efficient design of Extra High Voltage transmission lines & also covers the theoretical analysis of various problems combined with practical applications.**

***Keywords* — EHV Transmission Lines, Design, Power Loss, Bundle Conductors.**

I. INTRODUCTION

The electricity demand is increased day by day due to rapid development in industrial and other sector across the country. The average power demand of the nation is 218 GW at present which will be increased to 323 GW approximately in year 2022. To satisfy the needed demand it is very much essential to increase the power generation capacity. But due to so many restrictions like fuel availability, environmental issues and others it is not possible to generate the power near to the load centers. The growth of non-conventional energy sources are also scattered across the country. So it is needed to transmit the bulk amount of power from the place of generation to the load centers which demands new transmission lines.

The erection of new transmission line is very much complex and costly task. It is very much difficult to acquire the land (ROW) for the transmission lines. The solution to this problem is the use of Extra and Ultra High Voltage levels for the transmission lines which allows the bulk power transfer with minimum number of transmission circuits [1,2]. There are many advantages of EHV/UHV transmission systems like

- Reduction in the current.
- Reduction in the losses.
- Reduction in volume of conductor material required.
- Decrease in voltage drop & improvement of voltage regulation.
- Increase in Transmission Efficiency.
- Increased power handling capacity.
- The no. of circuits & the land requirement reduce as transmission voltage increases.
- The total line cost per MW per km decreases considerably with the increase in line voltage.

However, there are some important issues with design of the EHV/UHV transmission lines.

- Minimization of Right of Way.
- Protection of flora & fauna, wild life.
- Creation of long distance high capacity transmission corridors to enable minimum cost per MW transfer.
- Minimal Impact on Environment.
- Strengthening of National Grid

The recent development in transmission line design and operation provide a number of advantages mentioned below which improve the power system operation and control.

- Regulation of power flow
- Flexibility in line loading
- Improvement of operational efficiency:
- Hotline maintenance
- Emergency restoration system
- Up gradation of HVDC terminal
- High capacity 400/765 kV multi-circuit/bundle conductor lines
- Condition based monitoring
- Live line insulator washing

II. DESIGN OF TRANSMISSION SYSTEMS

2.1 Conductor

The conductors used for the overhead transmission lines are Aluminum Conductor Steel Reinforce (ACSR). Aluminum is preferred over the copper though it has less conductivity due to following merits [3]:

- Lower cost
- Light weight
- Lower voltage gradient
- Reduction in corona effect
- High tensile strength

For overhead transmission lines following types of conductors are used for various voltage levels:

Table 1. Types of Conductors for Transmission Line

Voltage Level (kV)	Type of Conductor
132	Panther, ACSR 30/7
220	Zebra, ACSR: 54/7
400	Twin Moose, ACSR: 54/7

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The bundle conductors are used to reduce the corona effect and subsequent losses and related problems. It also decreases the proximity effect. In a bundle conductor more than one conductor per phase is used. Each conductor is known as sub-conductor in the bundle. Along with bundle conductor, transposition is also needed to further improve the performance of the transmission line [4].

2.2 Inductance and Capacitance Calculations

The double circuit line consists of three conductors in each circuit. The three conductors correspond to three phases, a, b, c and a′, b′, and c′. Conductors a and a′ are electrically parallel and constitute one phase. Similarly conductor's b, b′ and c, c′ form other phases.

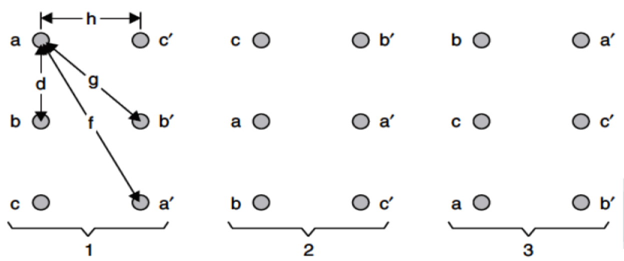

Fig. 1: Conductor Configuration

Here conductors are not symmetrically placed, to calculate inductance conductors should be transposed. The GMD of the conductors in phase 'a' with the conductors in other two phases in position 1,

The GMD in section 2 and 3 is

$$GMD_2 = (d*d*g*g)^{\frac{1}{4}} = (d)^{\frac{1}{2}}*(g)^{\frac{1}{2}} \qquad (2)$$

$$GMD_3 = (d*2d*h*g)^{\frac{1}{4}} = (2)^{\frac{1}{4}}*(d)^{\frac{1}{2}}*(g)^{\frac{1}{4}}*(\mathrm{h})^{\frac{1}{4}} \qquad (3)$$

The equivalent GMD of the system is given from Equations (1), (2) and (3).

$$GMD = (2)^{\frac{1}{6}}*(d)^{\frac{1}{2}}*(g)^{\frac{1}{3}}*(\mathrm{h})^{\frac{1}{6}} \qquad (4)$$

Self GMD of phase aa' conductor in position 1,

$$GMR_1 = Self\ \mathrm{GMD}_1 = (\mathrm{r'f})^{\frac{1}{2}} \qquad (5)$$

Self GMD in section 2 and 3 are,

$$GMR_2 = (\mathrm{r'h})^{\frac{1}{2}} \qquad (6)$$

$$GMR_3 = (\mathrm{r'f})^{\frac{1}{2}} \qquad (7)$$

The equivalent GMR is

$$GMR = \mathrm{r'}^{\frac{1}{2}} * \mathrm{f}^{\frac{1}{3}} * \mathrm{h}^{\frac{1}{2}} \qquad (8)$$

Inductance per phase is given by

$$L = 2\times10^{-7} * \ln\left(\frac{GMD}{GMR}\right) \text{ H/phase/km}$$

$$= 2\times10^{-7} * \ln\left((2)^{\frac{1}{6}}\left(\frac{d}{r'}\right)^{\frac{1}{2}}\left(\frac{g}{f}\right)^{\frac{1}{3}}\right) \qquad (9)$$

Capacitance per phase is given by

$$C = \frac{0.242}{\log\left(\frac{GMD}{GMR}\right)} \ \mu\text{F/phase/km} \qquad (10)$$

III. DESIGN CALCULATIONS

Table 2 provides the parameters of the 400 kV, 240 km long transmission line.

Table 2. Design of 400 kV Transmission Line

Description	Unit	Values
Voltage Level	kV	400
Power Factor		0.85
Ampacity of line[Single conductor per bundle]	Amp	343
AC Resistance at 64° C temp while transferring 344 amp	Ohm	0.06654453
% Load	%	100
Total length of Line	km	240
Transposed Length	km	122
Inter conductor spacing	m	0.45
Diameter of the conductor	mm	31.77
No. of Sub-conductor		2
No. of Circuit		1
Frequency	Hz	50
Barometric Pressure	cm	75.99
Temperature	ºC	64
Sending End Power for Twin Conductor & Double Circuit Arrangement	MVA	924
Sending End Power for Twin	MVA	784

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Conductor & Double Circuit Arrangement		
Sending End Power for Twin Conductor & Single Circuit Arrangement	MVA	462
Sending End Power for Twin Conductor & Single Circuit Arrangement	MVA	392
Horizontal distance between Conductor a & c'	m	14.6
Horizontal distance between Conductor b & b'	m	16.6
Horizontal distance between Conductor c & a'	m	18.6
Vertical distance between phases	m	8.2

For above discussed parameters of the line, following is the suggested configuration.

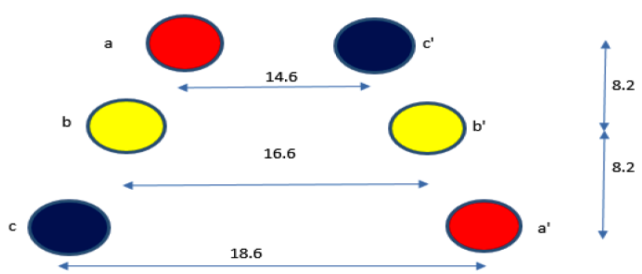

Fig. 2: Suggested Configuration

Here vertical & horizontal distances are specified as per datasheet given by client.
a,a' represents R phase
b,b' represents Y phase
c,c' represents B phase

3.1 Inductance of the line

Inductive reactance,

$$X_L = 2\pi fL = 38.92\ \Omega$$

Where L = 0.000516557 H/phase/km

3.2 Capacitance of the line

Capacitive reactance,

$$X_C = \frac{1}{2\pi fC} = 1144.931663\ \Omega$$

Where C = 0.022799796 µF/phase/km

3.3 Impedance and Admittance of the line [5]

Impedance Z = 7.9853 + 38.9277i
Admittance Y = 0.00087i
Characteristic Impedance ZC = 212.5643-21.5056i
Propagation Constant (γ) = YZ = -0.03411+0.0069i

3.4 ABCD Parameters

$$V_S = AV_R + BI_R$$

$$I_S = CV_R + DI_R$$

Considering long transmission line the various parameters can be defined in a following way:
A = cosh (γl) = 0.9830+0.00346i
B = Zc*sinh (γl) = 7.8950+38.7167i
C = (1/*Zc*)*sinh (γl) = -1.01182+0.00086i
D = cosh (γl) = 0.9830+0.00346i

3.5 Sending and Receiving End Voltage & Current

VS = 230940.1077 V
IS = 566.4739-351.0690i A
VR = 208901.1299-18433.7644i V
IR = 558.2884-543.6940i A

3.6 Sending and Receiving End Power

Sending end power (PS) = 3*VS*IS*cos (ΦS)
Receiving end power (PR) = 3*VR*IR*cos (ΦR)
Here,
PS = 392.4646 MW
PR = 379.9482 MW

The designed transmission line can be simulated for various operating conditions to test the performance. Based on the results of the simulation, the modifications can be done to achieve the optimal design of the line as per the client's requirements.

IV. CONCLUSION

From above design and analysis it can be concluded that the EHV/UHV transmission line can be designed as per the need of the client. The performance of the line can be tested to modify the parameters for the optimal design so that the best performance can be achieved.

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