

Improving Power Transfer Capability of EHV AC Double circuit Transmission line by Enhancing Surge Impedance Loading level

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Abstract:- Increase in the power demand requires the development of EHV (Extra high voltage) AC double circuit and high power carrying capacity transmission lines. Generally the power generating stations are far away from the distribution network, to connect the power surplus region to power deficit region long EHV AC double circuit transmission lines are required. But the power transfer capacity of long EHV AC transmission line are limited by their SIL (Surge Impedance Loading) limit which is much below the thermal limit of conductor due to large inductive reactance of the line. SIL depends on various factors and geometrical arrangement of double circuit transmission lines such as bundle spacing, diameter of conductor, no. of subconductors per phase and spacing between conductors. In this paper an attempt is made to present various techniques implemented on EHV AC double circuit transmission lines to improve SIL level and its effect on corona loss is shown with the help of mathematical programming in Matlab software. Also different double circuit configurations and its comparison are presented.

Keywords:- Surge Impedance Loading (SIL), Bundle spacing, Corona loss, Expanded Hexa, Delta configuration

I. INTRODUCTION

According to most updated statistics of India, the western region is surplus in power among all other regions, whereas the southern region is a most power deficit region. Gujarat being a part of western region whose installed capacity has increased by 68.8% compared to 31.34% increase in its load demand in last 5 years [1]. So Gujarat has enough surplus power to be fed to our neighbouring power deficit regions. To evacuate large amount of power from power surplus region to power deficit region requires long EHV (Extra high voltage) AC transmission lines. However the long EHV AC transmission lines are limited by SIL (Surge Impedance Loading) / Stability limits due to large inductance of the lines [2, 3].

The loading on a transmission line above SIL level, line consumes reactive power and if it exceeds some level it leads to voltage instability [4, 5] in the system. Voltage stability is obtained by keeping specified voltage magnitude within set operating limits under steady state condition. So to maintain the system stability and improve the power transfer capacity of transmission lines surge impedance loading level needs to be increased. The increase in the SIL level of existing as well as new transmission lines can be achieved by effective conductor configuration. In this paper various techniques to increase SIL level of double circuit EHV AC transmission line are explained which would enhance power capacity of transmission to maximum level.

II. SIL AND CORONA DEFINITION

SIL is the MW loading of the line where natural reactive power balance occurs i.e. reactive power produced by a line is equal to reactive power consumed by a line. Corona is the ionisation of insulating material at the surface of conductor or the complete disruption of dielectric strength of insulating materials at the surface of power conductor is treated as corona in transmission line.

For calculation of SIL,

$SIL = \frac{V^2}{Z_c}$, where Z_c is surge impedance and is given by $Z_c = \sqrt{\frac{L}{C}}$ and inductance L is given by $L = L_s - L_m$

$L_s =$ self inductance of line = $2 \times \frac{\mu_0}{4\pi} \ln \frac{2h}{r}$ H/m

$L_m =$ mutual inductance of the line = $2 \times \frac{\mu_0}{4\pi} \ln \frac{D}{r}$ H/m

Where GMD is geometric mean distance between conductors and GMR is the geometric mean radius of conductor.

For calculation of corona, the foul weather condition is considered. The formula used to calculate corona is Project EHV, USA by Anderson, Baretzky and McCarthy formula.

$$P_c = P_{fw} + 0.3606 k.V \cdot \ln(1+10\rho) \quad , \text{ Where}$$

P_c = Foul weather corona loss

P_{fw} = total fair weather corona loss

= 1 to 5 kw/km for 500 kV and 3 to 20kw/km for 700kV, for calculation of 400kV line P_{fw} is taken as 5 kw/km.

$K = 7.04 \cdot V$ for 400kV (based on Rheinau results) V = conductor voltage in kV, ρ - ph r.m.s

E = surface voltage gradient on the underside of the conductor, kV/cm, peak

ρ = rain rate in mm/hr, taken as 5mm/hr r = radius of conductor in cm

N = No. of sub conductors in bundle of each phase

Voltage gradient has been calculated using standard mangoldt's formula.

III. TECHNIQUES TO INCREASE SURGE IMPEDANCE LOADING LEVEL CONSIDERING

Corona Loss

For 400kV Double circuit transmission [6,7] line following methods are discussed with their result tables and graphs showing its effect on SIL level and foul weather Corona loss has been presented. The parameters used to obtain the results have been shown in the graph itself.

A. Bundle Spacing (B)

Bundle spacing is the spacing between subconductors, as the B increases Bundle radius R increases [9] and $GMReq$ of bundled conductor increases, which leads to reduction in self inductance of the line and we can have reduction in line inductance and increase in SIL level as the B increases. However the corona loss would slightly increase with increase in bundle spacing but comparative to that there is large increment in SIL level is obtained. The Table I and Fig. 1 show the effect of change in bundle spacing on SIL and corona loss (P_c).

Table I: Bundle Spacing (B) in cm v/s SIL and Corona

B (cm)	L(mH/km)	C(nF/km)	SIL(MW)	Pc(kw/3phase km)
35	0.389	29.05	1382.65	11.55
40	0.379	29.84	1419.48	11.76
45	0.37	30.56	1453.63	12.04
50	0.362	31.24	1485.0	12.37
55	0.355	31.88	1515.77	13.13
60	0.349	32.48	1544.39	13.55

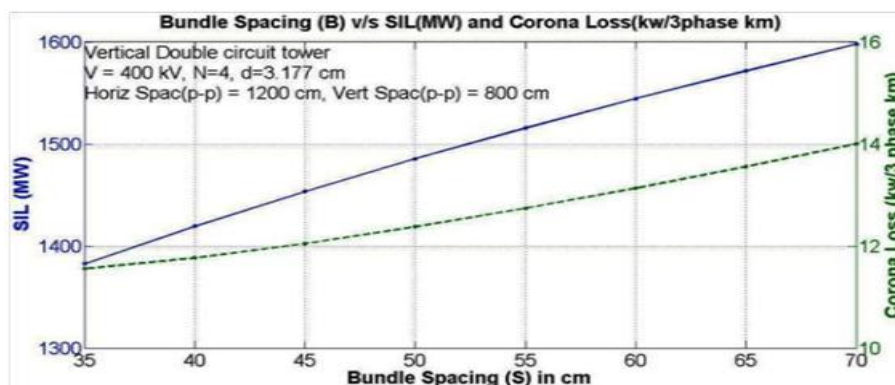


Fig. 1: Bundle Spacing (B) v/s SIL and Corona

B. Diameter of Conductor (d)

The diameter of the conductor is the size of conductor, with the increase in diameter of conductor the GMReq [10] of the conductor increases and self inductance of the line reduces, hence there is reduction in inductance of the line and there is increase in SIL level can be achieved. Also reduction in the corona loss is obtained with increase in diameter of conductor. The Table II and Fig. 2 show the effect of change in diameter of conductor on SIL and corona loss (Pc).

Table II: Diameter of Conductor (d) in cm v/s SIL and Corona

d (cm)	L (mH/km)	C (nF/km)	SIL (MW)	Pc(kw/3phase km)
2	0.381	29.62	1409.2	11.55
2.5	0.376	30.06	1430.2	11.76
3	0.371	30.44	1447.9	12.04
3.5	0.367	30.76	1463.2	12.37
4	0.364	31.05	1476.8	13.13
4.5	0.361	31.31	1488.9	13.55

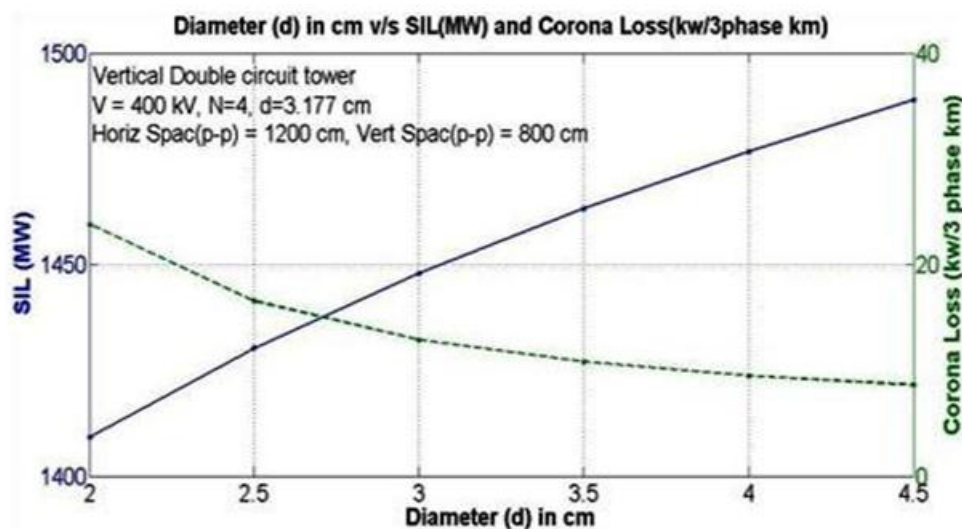


Fig. 2: Diameter of conductor (d) v/s SIL and Corona

C. No. of Subconductors per phase (N)

Increase in No. of subconductors of bundle increases GMReq of the conductor which would reduce self inductance of the line and inductance of the line, therefore there will be increment in SIL level is obtained. There is a large increment in SIL level is seen, so large improvement in power transfer capacity can be achieved. Corona loss would also reduce drastically with increase in No. of subconductors per phase. However, increase in No. of subconductors per phase loading on existing transmission tower increases, so to reduce the weight shift from twin ACSR moose conductor to quad ACSR zebra conductor having reduced diameter and weight, but still the overall weight on tower increases, so it is possible to enhance the power capacity of transmission if the tower is designed to carry increase in weight to fulfil the requirement of future increase in power demand. The following Table III, IV and Fig. 3 shows the effect of change in No. of subconductors per phase on SIL and corona loss (Pc).

Table III: N v/s SIL and Corona

N	L (mH/km)	C (nF/km)	SIL (MW)	Pc (kw/3phase km)
2	0.469	24.38	1153.9	55.49
4	0.37	30.56	1453.63	12.04
6	0.319	35.32	1683.33	7.16
8	0.285	39.52	1885.39	5.95

Table IV: N v/s SIL and Corona (including weight and cost)

N	ACSR Conductor diameter (cm)	Weight (kg/km)	Approx. Cost of cond. (Rs./m)	SIL (MW)	Difference in MW	Pc (kw/3phase km)
2	Moose 3.177	2004	300	1153.9	0	55.49
4	Zebra 2.862	1621	260	1443.4	289.5	13.71

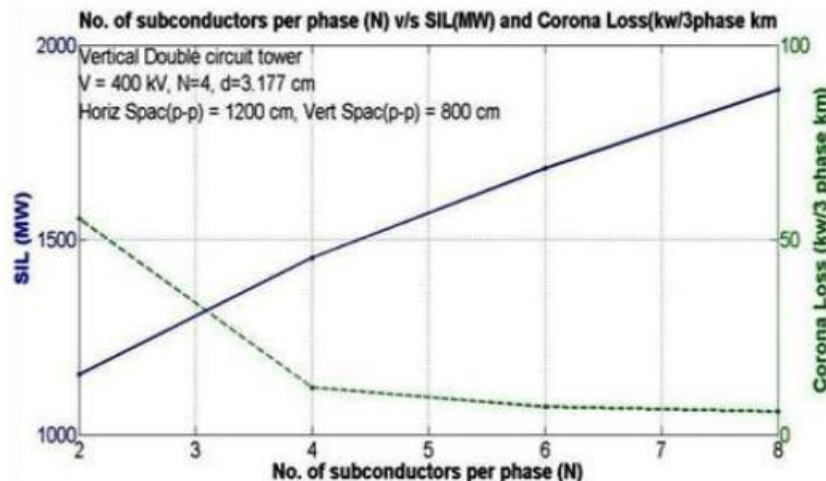


Fig. 3: No. of Subconductors per phase (N) v/s SIL and Corona

D. Horizontal Spacing (S)

The phase to phase spacing is a factor of GMD (Geometric Mean Distance), i.e. if the spacing between conductors is reduced GMD will decrease and there will be increase in mutual inductance of the line which leads to reduction in line inductance and increase in SIL level. However there is limit for the spacing between conductors due to sag of the conductors. This is due to the fact that more the sag more is the swing of the conductor and there are chances of Ph-Ph faults, but if we use V string insulators or conductor is replaced with HTLS (high temperature low sag conductors) eg. ACSS (Aluminium Conductor Steel Supported) either both the swinging of conductor is reduced and the spacing of conductors can be reduced. The Table V and Fig. 4 show the effect of change in spacing between the bundles on SIL and corona loss (Pc).

Table V: P-P Spacing v/s SIL and Corona

P-P spacing (m)	L (mH/km)	C (nF/km)	SIL (MW)	Pc (kw/3phase km)
10	0.366	30.90	1469.80	12.63
11	0.368	30.72	1461.32	12.31
12	0.37	30.56	1453.63	12.04
13	0.372	30.41	1446.69	11.83
14	0.374	30.28	1440.43	11.66
15	0.375	30.16	1434.81	11.51

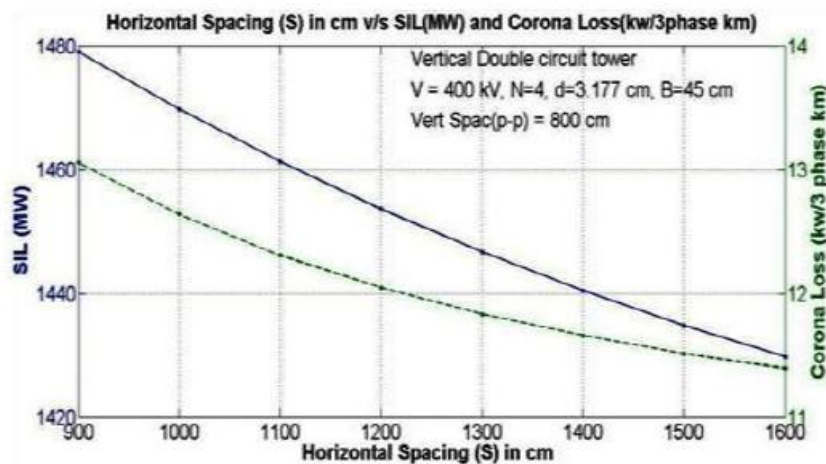


Fig. 4: Horizontal Spacing (S) v/s SIL and Corona

E. Vertical Spacing

The reduction in vertical spacing reduces GMD which leads to increases in the SIL level. But we cannot reduce this spacing much because we have to see the spacing of conductor from tower as well as the below crossarm. However we can reduce this spacing till the voltage gradient and corona loss is within limit. The Table VI and Fig. 5 show the effect of change in vertical spacing between the phases on SIL.

Table VI: Vertical Spacing v/s SIL and Corona

Vertical spacing (m)	L (mH/km)	C (nF/km)	SIL (MW)	Pc (kw/3phase km)
7	0.36	31.46	1496.14	13.06
7.5	0.365	30.99	1473.83	12.51
8	0.37	30.56	1453.63	12.04
8.5	0.375	30.17	1435.19	11.65
9	0.379	29.81	1418.23	11.30
9.5	0.384	29.48	1402.53	11.01

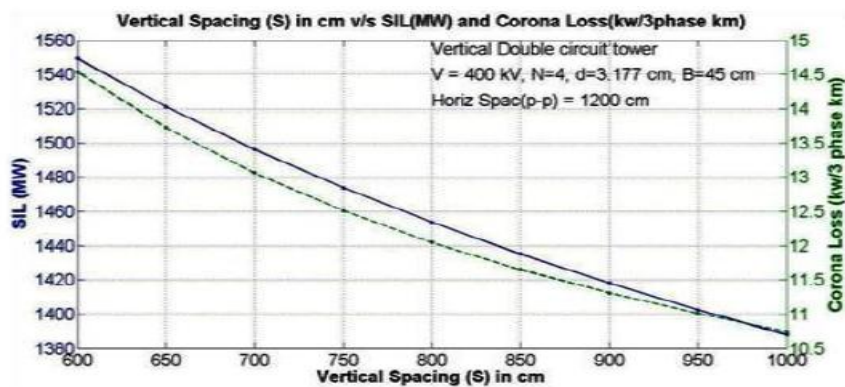


Fig. 5: Vertical Spacing v/s SIL and Corona

IV. DOUBLE CIRCUIT CONFIGURATIONS

The arrangement of conductors also affects the SIL level. The transmission line inductance can be reduced by proper geometrical configuration of conductors. For a 400kV Double circuit tower [9, 12] the configurations considered for analysis and comparison purpose are as shown in Fig. 6.

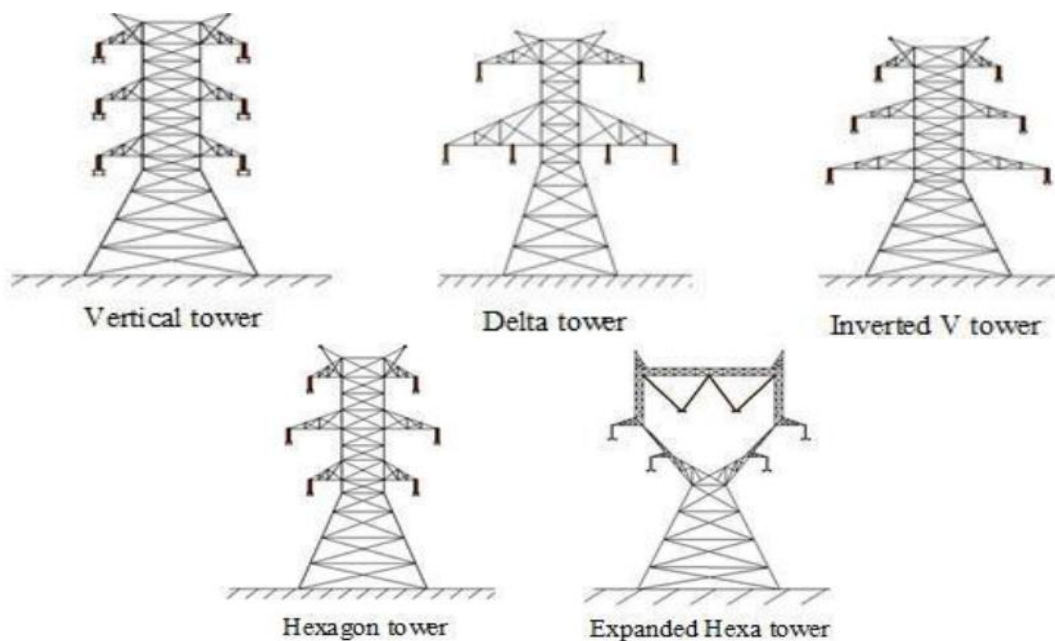


Fig. 6: Double circuit configurations

V. COMPARISON OF DOUBLE CIRCUIT CONFIGURATIONS

Comparing Delta, Expanded Hexa, Hexagon, Vertical and Inverted V tower configurations in terms of SIL level and fair weather corona loss for a specific given data $V = 400\text{kV}$, $N = 4$, $B = 45\text{ cm}$, $d = 3.177\text{ cm}$ (moose conductor), the spacing between conductors chosen is as follows for different configurations

- For vertical configuration $S = 1200\text{ cm}$ (horizontal p-p spacing), $S = 800\text{ cm}$ (Vertical p-p spacing)
- For delta configuration $D_{hb} = D_{hy1} = 600\text{ cm}$, $D_{hy} = D_{hr1} = 1400\text{ cm}$, $D_{hr} = D_{hb1} = 1000\text{ cm}$, $D_{vry} = D_{vbr} = D_{vy1b1} = D_{vr1b1} = 692.82\text{ cm}$, $D_{vyb} = D_{vr1y1} = 0\text{ cm}$, $D_{ry} = D_{yb} = D_{br} = D_{r1y1} = D_{y1b1} = D_{b1r1} = 800\text{ cm}$
- For Hexagon configuration $D_{hr} = D_{hb1} = D_{hb} = D_{hr1} = 600\text{ cm}$, $D_{hy} = D_{hy1} = 800\text{ cm}$, $D_{vry} = D_{vyb} = D_{vr1y1} = D_{vy1b1} = 800\text{ cm}$, $D_{vbr} = D_{vr1b1} = 1600\text{ cm}$
- For Inverted V Configuration $D_{hr} = D_{hb1} = 600\text{ cm}$, $D_{hb} = D_{hr1} = 800\text{ cm}$, $D_{hy} = D_{hy1} = 700\text{ cm}$, $D_{vry} = D_{vyb} = D_{vr1y1} = D_{vy1b1} = 800\text{ cm}$, $D_{vbr} = D_{vr1b1} = 1600\text{ cm}$
- For Expanded Hexa Configuration $D_{hr} = D_{hb1} = 350\text{ cm}$, $D_{hy} = D_{hy1} = 1250\text{ cm}$, $D_{hb} = D_{hr1} = 750\text{ cm}$, $D_{vry} = D_{vyb} = D_{vr1y1} = D_{vy1b1} = 500\text{ cm}$, $D_{vbr} = D_{vb1r1} = 1000\text{ cm}$

Where, D_{hr} = Horizontal distance of R phase from centre of tower, D_{vry} = Vertical distance between R and Y phase and S = Spacing.

Table VII: Comparison of various Double circuit Configurations

Double Circuit Configurations	L (mH/km)	C (nF/km)	Fair weather corona loss (kw/3phase km)	SIL (MW)
Delta	0.365	31.04	0.65	1476.2
Expanded Hexagon	0.368	30.72	0.69	1461.3
Hexagon	0.369	30.63	0.64	1456.9
Vertical	0.37	30.56	0.65	1453.6
Inverted V	0.374	30.25	0.64	1439.0

A. Advantages of using Delta configuration over Vertical

- There is an increase of approx. 23 MW in SIL for delta compared to Vertical.
- The advantage of using Delta configuration is reduction in no. of cross arm requirement. Also height of the tower can be reduced using Delta tower compared to vertical.
- There is no need for transposition of lines as the spacing between the lines is symmetrical, hence the voltage drop would be equal among the lines.

B. Advantages of using Expanded Hexa configuration over Vertical

- There is an increase of approx. 8 MW in SIL level compared to Vertical.
- The advantage of using Expanded Hexa configuration is that we can have reduction in no. of cross arm requirement compared to all above configuration except delta.
- The added advantage of using Expanded Hexa configuration is reduction in vertical spacing between conductors so we can reduce height of tower.

VI. CONCLUSION

The major power generation capacities in India is lying in Western part and most of power requirement is in southern part, so large amount of power transfer is required from power surplus region to power deficit region. To fulfill this bulk power transfer long EHV AC transmission lines are required. In case of long EHV AC lines the transmission capacity is limited to Surge Impedance Loading (SIL) level to maintain stability of system.

The power transfer capability of EHV AC lines can be improved by increasing the SIL level. The SIL level can be increased by reduction in transmission line inductance. This is possible by increase in Bundle spacing, increase in diameter of conductor, reduction in phase to phase spacing and converting twin moose tower to quad zebra tower. Increase in diameter of conductor and converting twin moose tower to quad zebra results in large increment in SIL level as well as large reduction in corona loss is obtained. Also by different geometrical arrangements of double circuit tower increment in SIL level has been achieved which has been analyzed and results are obtained. The delta and Expanded Hexa Configuration shows increment in SIL

compared to vertical tower, as well as it is possible to reduce height of tower. Hence it is possible to enhance the power transfer capability by above different techniques.

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