765kV Transmission Line for Capacity Enhancement

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***Abstract*-The growth of electricity with its generation, transmission and distribution mechanism has shown a multifold growth in the past few decades. The generation distribution have undergone paramount changes whereas transmission has not, thus in theexisting 400KV transmission system there are constraints to transfer growing electricity demands .This paper presents a novel aspect of 765kV transmission system for efficient transmission of power and makes a comparison with existing system.**

***Keywords:* Enhancement of transmission capacity, Loss minimization, Physical infrastructure reduction (RoW), Conductor Selection, Design aspect of 765kV line.**

I. INTRODUCTION

The basic function of transmission system is to transfer electrical power from one location to another. A transmission system include terminal substation, transmission line and intermediate substation associated control, protection, auxiliaries etc.

The Modern civilization depend heavily on the consumption of electrical energy for industrial, commercial, agricultural, domestic and social purpose. Electrical power generated in bulkat power stations is transferred from those stations to distant distribution network via transmission system.

The modern electrical power system having generating station, transmission system, and distribution system are interconnected through 3 phase AC system operating synchronously at a frequency of 50 Hz. The basic objectives of power system are[1]:

- To supply required amount of power to the consumers over different geographical area reliably.
- To provide better security of supply and avoid faults.
- To supply electrical energy at affordable cost.

Since transmission system form a very important part of network for fulfilling above mention task, nowadays, power systems are extensively interconnected requiring huge transfer of electric power. Considering that a typical transmission line with the existing voltage level of 400kV, can only carry a limited capacity of power, to fulfil increased power demand,it demands construction of new transmission lines at the same voltage capacity which occupies additional RoW and a complex control system.

In this context, this paper presents the possibility of deploying high voltage transmission system such as 765kV or 1200kV lines those requiring same or less RoW and maximising power transfer capacity.

II. NEED FOR VOLTAGE ENHANCEMENT OF TRANSMISSION LINES

The table below shows the installed capacity of Indian power scenario from which it is evident that despite having a generating capacity of 2, 50,256 MW, it is possible to transmit 1, 86,000 MW due to constraints of existing transmission network of 400 kV.

Sector	MW	Percentage
State Sector	93, 450.70	37.4
Central Sector	68, 393.30	27.3
Private Sector	88, 344.96	35.3
Total	2, 50, 256.96	100

Table1: Total Installed Capacity as on 31 July 2014 [2]

The future prospectus and industrial growth demands the enhancement of installed capacity to the extent of 7 lakh MW by 2027 [3] necessitating the power transfer capacity increase to the extent of 5 to 6 lakh MW.

The existing transmission mechanism at 400kV will not be capable of evacuating this power due to its own constraints and thus new technology of voltage enhanced transmission network need to be adopted.

III. CERATIN TECHNICAL REQUIREMENT FOR DESIGN OF TRANSMISSION NETWORK ARE AS FOLLOWS:

For capacity enhancement of transmission line different option available are:

A. Improvement of transmission system

1. Use of Higher Voltages

While selecting higher voltages different calculations are required as mentioned below:

a. No of conductor per phase(bundle)

In high power transmission, to reduce losses and limit the corona phenomenon, it is needed to increase the number of conductors per bundle, for which line current is calculated using Eq. (1).

$$I = \frac{S}{\sqrt{3}V} \quad 1$$

To balance the weight, the number of conductor bundles must be even (four or six).

b. Crossection of conductor

i. *Short circuit calculation* :

Conductor cross section is determined according to the rated current, and then based on the level of short circuit test. Eq. (2) and (3) assess the minimum cross-section required to withstand the heat generated due to the short circuit. [4]

$$S = \frac{I_{SC} * \sqrt{t}}{K} \quad 2$$

$$K = \sqrt{\frac{\omega.C.\Delta\theta}{0.24 * \rho}} \quad 3$$

Where:

S: Cross-section of conductor (mm)

I_{SC}: Standard SC current (A)

t: The persistence time of SCcurrent (s)

K: Constant coefficient related to the conductor material which is dependent on:

ω: Specific weight of the conductor (gr/cm^3)

C: Specific heat of conductor metal (Calorie/g-°c)

ΔΘ: The conductor temperature rise (°c)

ρ: Specific resistance of the conductor ($ohm\text{-}m/mm^2$).

ii. Crossection for fitting two parts together:

One of the problems occurred in fittings due to short circuit current is in welded joint corrosion,such as connecting two parts together or celebrating with a hole between the bolts and nuts. Considering the amount and time of current passing through lines, a cross section can be obtained using Eq. (2) and (3) for existing connections in the line, which are of steel and aluminium type such that short circuit current and in turn the generated heat do not deform them.

2. Bundle Conductor

Geometric mean radius (GMR) and Geometric mean distance (GMD) are calculated using:

a. Geometrical Mean Radius

$$GMR = (N*r*R^{N-1})^{1/N} \quad 4$$

Where: N-No. of conductor in a bundle

r- Radius of each sub-conductor

R- Radius of bundle

b. Geometrical Mean Distance[4]

$$GMD = \sqrt[3]{D_{12} * D_{13} * D_{23}} \quad 5$$

From this, inductive & capacitivereactance's can be calculated:

$$C = \frac{2 * \pi \varepsilon_0}{\ln(^{GMD}/_{GMR})} \quad F/m \quad 6$$

$$L = 2*10^{-7} \ln \frac{GMD}{e^{-1/4} * GMR} \quad H/m \quad 7$$

$$X_L = 2 * \pi * F * L \quad 8$$

$$X_C = \frac{1}{2 * \pi * F * C} \quad 9$$

3. Size up of system

For sizing up of the system various parameters are required to find out those are:

a. No of insulators in the string

To calculate the voltage distribution along the insulator string, the capacitance between insulators themselves and the tower should be determined. Although, capacitance of all insulators is not same, however, considering the short length of insulator string respect to the tower height and its uniformity, capacitance of whole insulators is same, C_1, and the capacitance between insulators and tower is C_2. Accordingly, by calculating α, voltage on to ends of insulator string is obtained [4],

$$\alpha = \left(\frac{C_2}{C_1}\right)^{0.5} \quad 10$$

$$V_{kg} = V_{ng} . \frac{\sin(\propto.K)}{\sin(\propto.n)} \quad 11$$

Where, C_1 and C_2 values are the capacitance between the metal part and earth, and insulator capacitance, respectively. Consequently, having the value of α, distributed voltage in two ends, no. of insulators is obtained.

In addition,

K-- Insulator numbers

n-- Total number of insulators

V_{ng--} phase voltage of transmission line

V_{kg} --K^{th} insulator voltage.

b. Voltage gradient calculation

Voltage gradient around the conductor and fittings can play an important role in the phenomenon of corona and the resulted losses. Voltage gradient for conductors in each phase is obtained using following eq. [4]

$$g_{max} = \frac{18\ C.V}{n.r}\left[1 + \frac{2(n-1)r.\sin(\frac{\pi}{n})}{GMR}\right] \quad 12$$

$$C = \frac{0.02413}{\log(\frac{GMD}{GMR})} \quad 13$$

` $$GMR = [r.n[\frac{B_s}{2.\sin 180/n}]^{n-1}]^{1/n} \quad 14$$

Where:

g_{max}: The maximum voltage gradient at the surface of conductors(kV/cm).
V: Line phase voltage(kV).
n: The number of bundled conductors per phase.
r: Radius of conductor(cm).
C: Line capacitance(F/km).
GMR: Geometric mean radius of the bundled conductors(cm).
B_s: Distance from the bundle conductors(cm).

c. Critical voltage

Critical voltage value is a function of the line physical features and environmental conditions which is calculated using following Eq. [4]

$$g_v = g_0.(1 + \frac{0.3}{\sqrt{\delta.r}}) \quad 15$$

$$\delta = \frac{298\ P}{T} \quad 16$$

$$V_c = g_v.m.\delta.r.\ln[GMD/r] \quad 17$$

Where:
g_v : Critical voltage gradient(kV/cm).
g_0 : The threshold breakdown voltage(kV/cm).
r : Radius of conductor(cm).
δ : Relative density.
P : Air pressure(At.)
T : Air temperature(°K)
m : Coefficient of conductor surface roughness.
GMD : Geometric mean distance between conductors(cm).

d. Amount of corona losses

The main disadvantage of corona phenomenon is the resulted losses which may be increased to ten times on rainy/snowy days. In typical EHV transmission line, the losses can be of a significant amount. Therefore, in designing transmission line the corona losses should be also calculated.

Amongst various methods, one method is presented byPik which is formulated according to Eq. (18) [4].

$$P_C = 0.00314.F.(\frac{V}{\log(GMD/r)}) \quad 18$$

Where:
P_C : Corona losses(kW/km)
V : Effective-phase voltage(kV)
GMD : Geometric mean distance between conductors(cm).
r : Radius of conductor(cm)
F: Constant coefficient and the critical voltage

Studies shows that, when corona losses are low, Peterson method has good accuracy [4].

$$P_C = \frac{0.545}{\delta}(V - V_C).\sqrt{r/GMD} \quad 19$$

In which;
P_C: Corona losses(kW/km)
V : Effective-phase voltage(kV)
Vc : A critical voltage(KV)
GMD : Geometric mean distance between conductors(cm).
r : Radius of conductor(cm)

e. Corona ring design

In corona ring design, three main parameters should be determined,[4]
1) Diameter profiles
2) Radius of the ring
3) Position of ring along the insulator strings.

f. Voltage regulation calculation

Voltage regulation is, the change of voltage, from zero to the rated divided to the nominal value which is expressed as:

$$\%VR = \frac{V_S - V_r}{V_r} * 100 \quad 20$$

Where:
VR: Line voltage regulation percentage
V_s : Sending end voltage(kV)
V_r : Receiving end voltage(kV)
V_r is the line rated voltage.
V_s is obtained in long transmission lines as follows:

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} * \begin{bmatrix} V_r \\ I_r \end{bmatrix} \quad 21$$

Where:
I_s : The sending end current(A)
I_r : The receiving end current(A).
Values of A, B, C and D are obtained

$$A = \cosh(\gamma l) \quad 22$$
$$B = Z_c \sinh(\gamma l) \quad 23$$
$$C = \frac{1}{Z_c}\sinh(\gamma l) \quad 24$$
$$D = \cosh(\gamma l) \quad 25$$

Here;

$$\gamma = \sqrt{zy} \quad 26$$
$$Z_c = \sqrt{\frac{z}{y}} \quad 27$$

Where:
y: Parallel Admittance of transmission line(Ψ/Km)
z: Series impedance of transmission line(Ω/Km).

B. Type of conductor

The conductor used in electric power transmission at 400kV/765kV in INDIA are:

- ACSR Moose/Bermis
- AAAC Conductor

Due to technological development different types of conductors are available which have advantages over others. Different High Tension Low Sag (HTLS) Conductors are [5]

1. AL59
2. TASCR(Thermal Alloy conductor steel Re-inforced)
3. ACSS(Aluminium Conductor Steel supported)
4. STACIR (Super thermal Aluminium Conductor INVAR Re-inforced)

5. ACCC (Aluminium Conductor Composite Core)
6. ACCR (Aluminium Conductor Composite Re-inforced)

These conductor have following important properties:

- High current carrying capacity.
- Low sag tension property.
- Easy and rapid installation,
- Long term reliability.
- Conductor cost is less.
- Low line loss.

IV. DESIGN ASPECT OF 765 kV LINE

For showing the effectiveness of the technical requirements and their benefits a typical 5000MVA power system has been considered which is to be transmitted over a distance of 800km assuming 50% of capacitor compensation, then the total reactance will be half of the positive sequence reactance, let's consider sending and receiving end voltages are equal, the phase shifting between two voltages is 30°.
Different parameters for 400 kV and 765 kV line can be calculated by using following formulae's:
Power handling capacity per circuit =

$$\left(\frac{E^2 * \sin\delta}{L * x} + \sim 10\%\ overlading\right)\text{MW}$$

Resistance of conductor used for 400kV = 0.031Ω/km [6]
Resistance of conductor used for 765kV = 0.0136Ω/km [6]

Total Current $I_t = \frac{S}{\sqrt{3}V}$kA

No. of circuits required = $\frac{\text{total power to be transferred}}{\text{power handling capacity per circuit}}$

Current per Circuit I = $\frac{\text{Total Current}}{\text{No.of Circuits}}$ kA

Power Loss per Circuit = 3* Resistance Per phase* $(I_t)^2$ MW

Total Power Loss = No. of Circuits * Power loss per Circuit

Power Loss per km = total power loss / Distance in km

By using above equations following parameters can be calculated:

Parameters Calculated	400kV	765kV
Power handling capacity	680MW	2980MW
No. of Circuit	8 Single Circuits 4 Double circuits	2 Single Circuits 1 Double Circuit
Total current	7.2169kA	3.7735kA
Current per circuit	0.91kA	1.89kA
Resistance for 800km	0.031*800 = 24.8Ω	0.0136*800 = 10.88Ω
Power Loss per circuit	$3*24.8*(0.91^2)$ = 61.61MW	$3*10.88*(1.89^2)$ = 116.59MW
Total loss	492.88MW	233.18MW (46.7%)
Loss/km	616.1KW	291.48KW

Table 2: Comparison of parameters for 400kV and 765kV

V. RESULTS & DISCUSSION

From the table 2 shown above following inferencescan be drawn:

1. The power handling capacity of single circuit 765 kV system is four times than a single circuit 400 kV system.
2. Total power loss in 765 kV system is only 46.7% as that of power loss on 400 kV system
3. Theno of circuit required to transfer the same amount of power are four times in 400 kV than 765 kV, increases RoW & spacing.

Following figure shows the difference between the Right of Way requirements for different lines.

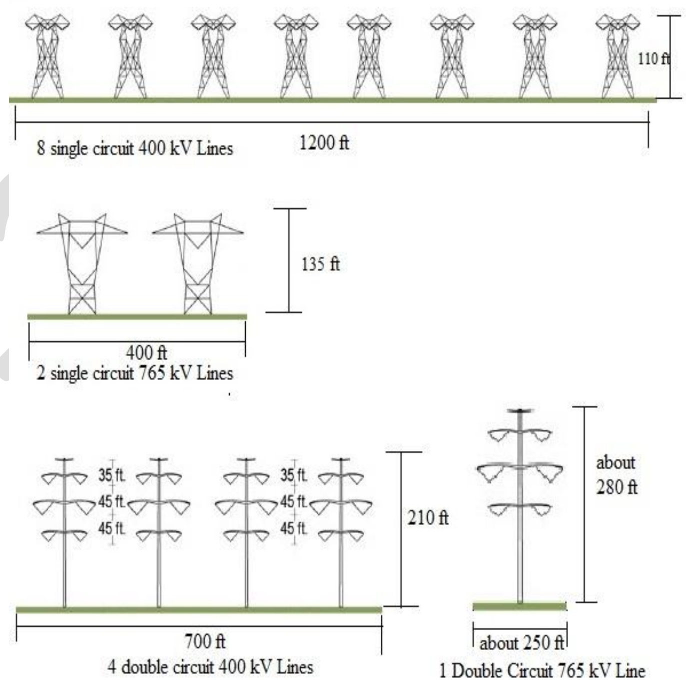

Fig1. : RoW comparison of 765kV and 400kV System.

VI. CONCLUSION

From the discussion made in the paper, it is evident that higher transmission capacities can be achieved by proper technical design of transmission system. Accordingly the results obtained from the design of 765kV lines shows that the power handling capacity increased from 3-4 times as compared to 400kV lines, whereas the losses can be reduced to the extent of 53.3%. Further the bulk power can be transferred with same or less area of land use by higher transmission network.

From which it is concluded that the increase in power demand can be fulfilled by enhancing transmission voltage to 765kV and above with proper technical design.

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