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Investigate Issues For HVAC Transmission Lines With And Without Compensation

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Abstract: Private participation in generating power is being encouraged in the country in order to meet high power requirement. As a result, many independent power producers (IPP) are establishing pit head thermal power stations. Many a times, the IPPs have to execute a contract with the state electricity board, under whose jurisdiction the location of the generating plant comes up lies, that a certain percentage of the installed capacity of the plant shall be supplied to the state grid and the balance power can be supplied to others. In such cases, there is a requirement for precisely controlled power flow over a transmission line between the IPP's generating station and the state grid substation at which the contracted power is to be delivered and provision for evacuating the balance power to nearby state grid substation. In a case where the installed capacity of the IPP is 500 MW, 300MW of power shall be supplied to the state grid whenever the generation is more than 300MW and full generated power if the generation is less than 300 MW. To achieve this control of power flow is essential. Hence it is required to select best conductor is required in order to reduce transmission losses and selection of percentage of compensation required to achieve control over the power flow in an AC transmission line. In this paper performance analysis is carried out in order to select best transmission line conductor amongst various conductors available and also percentage line compensation required to reduce reactive power flow and to control voltage and current in an AC transmission line.

***Index Terms* -** ACSR, Bersimis, conductor, twin, triple, quad moose conductor, line compensation etc

I INTRODUCTION

All transmission lines in a power system exhibit the electrical properties of resistance, inductance, capacitance and conductance. The inductance and capacitance are due to effects of magnetic and electric fields around the conductor. These parameters are essential for the development of the transmission line models used in power system analysis. The shunt conductance accounts for leakage currents flowing across insulators and ionized pathways in the air. The leakage currents are negligible compared to the current flowing in the transmission line and may be neglected. On long transmission lines, light loads are appreciably less than SIL results in a rise of voltage at the receiving end and heavy loads appreciably greater than SIL will produce dip in voltage. Shunt reactors are widely used to reduce high voltages under light load or open line conditions. Series compensation is used to improve voltage, increase power transfer, and the system stability. In this paper analysis is carried out in order to select best conductor amongst various conductors and also compensation required to reduce reactive power flow and to control voltage and current in AC transmission line.

1.1 Surge Impedance Loading: When the line is loaded by being terminated with impedance equal to its characteristic impedance, the receiving end current is given [3]

$$Ir = Vr/Zc$$

(1.1)

For a lossless line Z_c is purely resistive. The load corresponding to the surge impedance at rated voltage is known as the Surge Impedance Loading (SIL).

$$SIL = 3V_rI_r = 3 * V_r * \frac{Vr}{Zc}$$

(1.2)

$$V_r = V_{rated}/\sqrt{3}$$

(1.3)

SIL is a useful measure of transmission line capacity as it indicates a loading where the line's reactive requirements are small. For loads significantly above SIL, shunt capacitors may be needed to minimize voltage drop along the line, while for light loads significantly below SIL, shunt inductors may be needed. Generally the transmission line full load is much higher than SIL.

1.2 Thermal Loading: The power handling ability of a line is limited by the thermal loading limit and stability limit. The increase in the conductor temperature, due to the real power loss, stretches the conductor. This will increase the sag between transmission towers. At higher temperatures this may result in irreversible stretching. The thermal limit is specified by the current carrying capacity of the conductor and is available in the manufacturer's data. If the current carrying capacity is denoted by $I_{thermal}$, the thermal loading limit of a line is

$$S_{thermal} = 3 * V_{rated} * I_{thermal}$$

(1.4)

Where, V_{rated} is the rated voltage of the transmission line.

1.3 Power Transmission Capability: According to the power transfer equation, the theoretical max power transfer is obtained when $\delta = 90$. The practical load angle for the line alone is limited to no more than 30 to 45. This is because of the generator and transformer reactance, which, when added to the line, will result in larger δ for a given load. For planning and other purposes, it is very useful to express the power transfer formula in terms of SIL. For a loss less line 3Φ power is given by

$$\mathbf{P3\Phi} = \left(\frac{\mathbf{Vs(L-L)}}{\mathbf{Vrated}}\right) * \left(\frac{\mathbf{Vr(L-L)}}{\mathbf{Vrated}}\right) * \left(\frac{\mathbf{Vrated^2}}{\mathbf{Zc}}\right) * \left(\frac{\mathbf{sin\partial}}{\mathbf{sin\beta\iota}}\right)$$

(1.5)

Where, β= line phase constant= $2 * \pi * f * \sqrt{L * C}$.

$\boldsymbol{\partial}$= load angle.

V_s (L-L) = sending end line to line voltage.

V_r(L-L)= receiving end line to line voltage.

Z_c= surge impedance= $\sqrt{L/C}$.

L= Line inductance.

C= line Capacitance.

1.4 Line Compensation:

1.4.1 Shunt Reactors: Shunt reactors are applied to compensate for the undesirable voltage effects associated with line capacitance. The amount of reactor compensation required on a transmission line to maintain the receiving end voltage at a specified value can be obtained as follows

$$\mathbf{X_{lsh}} = \left(\frac{\mathbf{sin\beta l}}{\mathbf{1-cos\beta l}}\right) * \mathbf{Z_c}$$

(1.6)

The three phase shunt reactor rating is

$$Q = (kV)rated^2/X_{lsh} \qquad \text{Mvar}$$

(1.7)

Where, V_{rated} = rated transmission voltage in kV.

1.4.2 Series Capacitor Compensation: Series compensation is proposed at the receiving end of the line as it helps in boosting up the receiving end bus voltage to small extent and causes corresponding increases in the power transmitted. Series capacitors are connected in series with the line and are used to reduce the series reactance between the load and the supply point. This results in improved transient and steady state stability, more economical loading and min voltage dip on load buses. Series capacitors have the good characteristics that their reactive power production varies concurrently with the line loading. With the series capacitor the power transfer over the line for a lossless line is given by

$$P3\emptyset = \frac{abs(Vs(L-L))*abs(Vr(L-L)*sin\partial}{X-X_{cser}}$$
(1.8)

Where, X= line reactance.

X_{cser}= series capacitor reactance.

The ratio Xcser/X expressed as percentage is usually referred to as the percentage compensation. The percentage compensation is in the range of 25 to 70 percent. One major drawback with series capacitor compensation is that special protective devices are required to protect the capacitors and bypass the high current produced when a short circuit occurs [3].

II Simulation results

2.1 Line parameters:

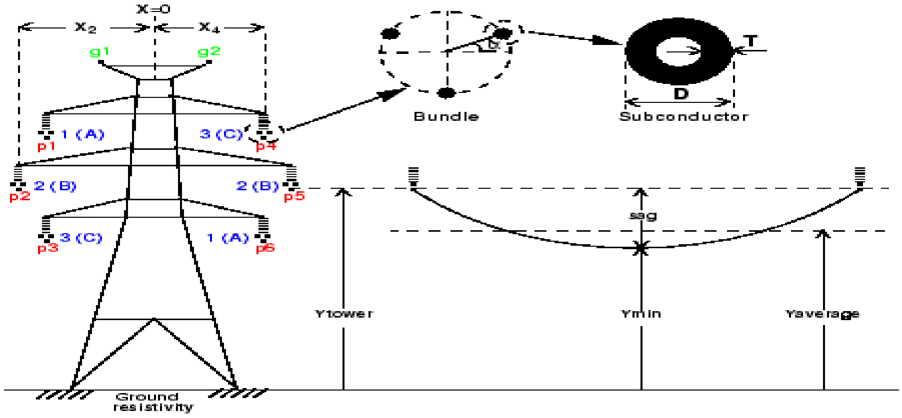

Fig 2.1 Configuration of a Three-Phase Double-Circuit Line

The line considered is a double circuit with standard vertical configuration, both circuits on the same tower. The same line configuration is used irrespective of the type of conductor for line loading performance comparison purpose. Table 1 shows the line resistance, inductive reactance per km of the line length.

Table 2.1 Line parameter for different conductors

SI NO	Conductor configuration	Resistance (Ω/km)	Inductive reactance (Ω/km)	Susceptance (micro-mho/km)
1	Twin moose ACSR	0.028713	0.31337	3.698
2	Twin moose AAAC	0.029490	0.31319	3.7
3	Quad moose ACSR	0.014655	0.25107	4.625
4	Quad moose AAAC	0.015048	0.25090	4.627
5	Triple moose ACSR	0.01934	0.2753	4.211
6	Quad Bersimis ACSR	0.011415	0.24960	4.6546

The Quad Bersimis ACSR configuration consists of four conductors in a bundle.

- It has the lowest resistance (0.011415 Ω/km) among all the configurations in the table.
- The inductive reactance of Quad Bersimis ACSR is 0.24960 Ω/km, and the susceptance is 4.6546 micro-mho/km.

2.2 Line Loading For Chosen Conductor Configuration: The power transfer capability of the line with different conductors and their bundle configuration is investigated. The different conductors and their bundle configuration considered are Twin moose ACSR & AAAC, Quad moose ACSR & AAAC, Triple moose ACSR and Quad Bersimis ACSR. Line lengths considered were 315 km representing X sending end and Y receiving end. The series compensation is proposed at the receiving end of the line as it helps in boosting up the receiving end bus voltage to a small extent and causes corresponding increase in power transmitted. The line is provided with minimum shunt compensation of 50 x 2 MVAr per circuit to control the line voltage during light load and line charging conditions and absorb excessive reactive power generated during total load throw off at Y receiving end.

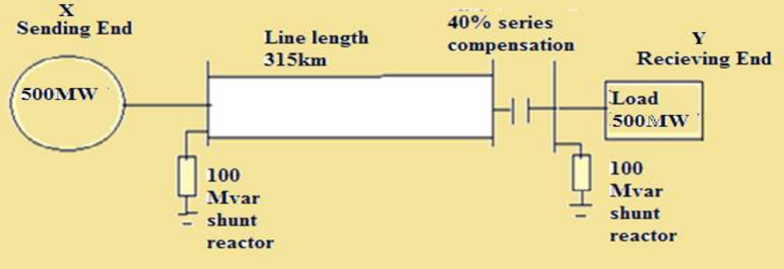

Fig 2.2 Line configuration

The line configuration is as shown in fig 2.2. The results of the computation of Thermal Loading, Surge impedance loading line real power flows, various bus voltages, and generator power factor and line real power losses with 30% and 40% series compensation at Receiving end using MATLAB Program are shown in table 2.2, 2.3 and 2.4. It could be observed from the result that even with the quad bundle configuration of Bersimis conductor for the 315km, 400kv double circuit line, it is not possible to receive 500MW at Y receiving end. It shall be noted that under normal circumstances, the power available at the sending end of the line is about 8% less of the rated generation capacity due to consumption by the auxiliary loads in the generating station itself. This makes the maximum power it could be received at Y receiving end to be 453MW.

Table2.2 Line Loading for Line configuration shown in fig 2.2

SI NO	Conductor	Thermal rating		Thermal loading	SIL Per circuit	Loading Limit Of 315km Line Per circuit	Loading Limit with 50% shunt compensation per circuit	Loading Limit with 50% shunt compensation and 40% series compensation per circuit
	Name	amp	temp	MW	MW	MW	MW	MW
1	Twin Moose ACSR	450	75	675	548	713	504	840
2	Twin Moose AAAC	450	85	962	548	713	504	840
3	Quad Moose ACSR	457	75	1350	686	892	630	1050
4	Quad Moose AAAC	457	85	1924	686	892	630	1050

Table 2.3 Line Loading for Line configuration shown in fig 2.2

SI No	Conductor	Line length	% Series Compensation At receiving end	Vs	Vr	Pr	Qr
	Name			(KV)	(KV)	(MW)	(MVAr)
1	Twin Moose ACSR	315	40	411.377	400	500	242
			30	411.383	400	500	242
2	Twin Moose AAAC	315	40	411.685	400	500	242
			30	411.691	400	500	242

3	Quad Moose ACSR	315	40	405.808	400	500	242
			30	405.813	400	500	242
4	Quad Moose AAAC	315	40	405.964	400	500	242
			30	405.968	400	500	242
5	Triple Moose ACSR	315	40	407.663	400	500	242
			30	407.668	400	500	242
6	Quad Bersimis ACSR	315	**40**	**404.529**	**400**	**500**	**242**
			30	404.533	400	500	242

Table 2.4 Line Loading for Line configuration shown in fig 3.2

Ps	Qs	PL	QL	PFs	PFr
(MW)	(MVAr)	(MW)	(MW)		
517.443	242.114	17.443	0.114	0.905753	0.9
517.443	242.133	17.443	0.133	0.90574	0.9
517.915	242.114	17.915	0.114	0.905901	0.9
517.915	242.133	17.915	0.133	0.905888	0.9
508.903	242.091	8.903	0.091	0.903028	0.9
508.903	242.107	8.903	0.107	0.903018	0.9
509.141	242.091	9.141	0.091	0.903106	0.9
509.141	242.106	9.141	0.106	0.903096	0.9
511.749	242.100	11.749	0.100	0.903948	0.9
511.749	242.117	11.749	0.117	0.903936	0.9
506.934	**242.091**	**6.934**	**0.091**	**0.902381**	**0.9**
506.934	242.106	6.934	0.106	0.90237	0.9

Comparing Conductor Types (Twin Moose ACSR vs. Twin Moose AAAC):

a. At 40% series compensation and a line length of 315 km, both Twin Moose ACSR and Twin Moose AAAC conductors have nearly identical receiving voltages (Vr) of 400 KV. However, Twin Moose ACSR exhibits a slightly higher active power (Pr) of 411.377 MW compared to Twin Moose AAAC with 411.685 MW. The reactive power (Qr) remains the same for both at 242 MVAr. Twin Moose AAAC shows a slightly higher sending voltage (Vs) of 411.685 KV compared to 411.377 KV of Twin Moose ACSR at 40% series compensation.

b. At 30% series compensation and the same line length, the values for Vs, Vr, Pr, and Qr are nearly identical for both conductors, with only slight differences in the fourth decimal place.

Comparing Conductor Types (Quad Moose ACSR vs. Quad Moose AAAC):

c. At 40% series compensation and a line length of 315 km, both Quad Moose ACSR and Quad Moose AAAC conductors have the same receiving voltage (Vr) of 400 KV, active power (Pr) of 405.808 MW, and reactive power (Qr) of 242 MVAr. However, Quad Moose AAAC shows a slightly higher sending voltage (Vs) of 405.964 KV compared to 405.808 KV of Quad Moose ACSR at 40% series compensation.

d. At 30% series compensation and the same line length, the values for Vs, Vr, Pr, and Qr are nearly identical for both conductors, with only slight differences in the fourth decimal place.

Comparing Conductor Types (Triple Moose ACSR vs. Quad Bersimis ACSR):

e. At 40% series compensation and a line length of 315 km, both Triple Moose ACSR and Quad Bersimis ACSR conductors have nearly identical receiving voltages (Vr) of around 242.1 KV and reactive powers (Qr) of 0.1 MVAr. However, Triple Moose ACSR exhibits a higher active power (Pr) of 407.663 MW compared to Quad Bersimis ACSR with 404.529 MW. The sending voltage (Vs) is also slightly higher for Triple Moose ACSR at 407.663 KV compared to Quad Bersimis ACSR at 404.529 KV.

f. At 30% series compensation and the same line length, the values for Vs, Vr, Pr, and Qr are nearly identical for both conductors, with only slight differences in the fourth decimal place.

These comparative statements highlight the performance differences between different conductor types under specific conditions of line length and series compensation. Engineers and planners can use this data to make informed decisions while selecting conductors for transmission lines, considering factors such as power flow, voltage levels, and power losses. Therefore, a transmission line equipped with a quad bundle Bersimis conductor and 40% compensation would exhibit superior adequacy for power transfer between X end and Y end compared to other conductors.

Hence a line with quad bundle Bersimis conductor and 40% compensation would be more than adequate between X end and Y end than other conductors.

2.3 Case Studies: Estimation of power loss at different line loadings for various line configurations is carry out in forthcoming sections.

2.3.1 Case study 1: The table 2.5 and fig 2.3 presents the electrical parameters and power flow values for a specific conductor configuration, namely the Quad Bersimis ACSR (Aluminum Conductor Steel Reinforced). The parameters provided include the source voltage (Vs) and receiving-end voltage (Vr), measured in kilovolts (KV). The power flow values include the sending-end active power (Ps), receiving-end active power (Pr), sending-end reactive power (Qs), receiving-end reactive power (Qr), sending-end apparent power loss (PL), and sending-end reactive power loss (QL).

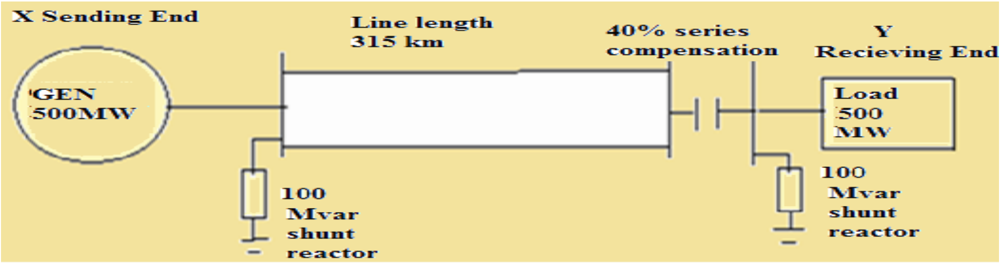

Fig 2.3 Line configuration for case study1

Table 2.5 Results of line configuration shown in fig 2.3

SI NO	Conductor	Vs	Vr	Ps	Pr	Qs	Qr	PL	QL
		(KV)	(KV)	(MW)	(MW)	(MVAr)	(MVAr)	(MW)	(MVAr)
1	Quad Bersimis ACSR	**404.529**	400	**506.934**	500	242.091	242	**6.934**	0.091

For the given conductor configuration, the source voltage is measured at 404.529 KV, and the receiving-end voltage is 400 KV. The sending-end active power is determined to be 506.934 MW, while the receiving-end active power is recorded as 500 MW. The sending-end reactive power is measured at 242.091 MVAr, and the receiving-end reactive power is observed to be 242 MVAr. The apparent power loss at the sending end is calculated as 6.934 MW, with a corresponding reactive power loss of 0.091 MVAr. It should be noted that under normal operating conditions, the power available at the sending end of the line is approximately 8% less than the rated generation capacity, attributed to the consumption by auxiliary loads in the generating station itself. From the results, it is evident that the maximum power that can be received at the receiving end, Y, is 453 MW (500 MW - PL - 8% of 500 MW). These values provide insights into the electrical behavior and power flow characteristics of the Quad Bersimis ACSR conductor configuration. They can be used to assess the performance and efficiency of the transmission system utilizing this specific conductor in terms of power losses and reactive power exchange.

2.3.2 Case study 2: Estimation of power loss for the given line configuration shown in fig 2.4.

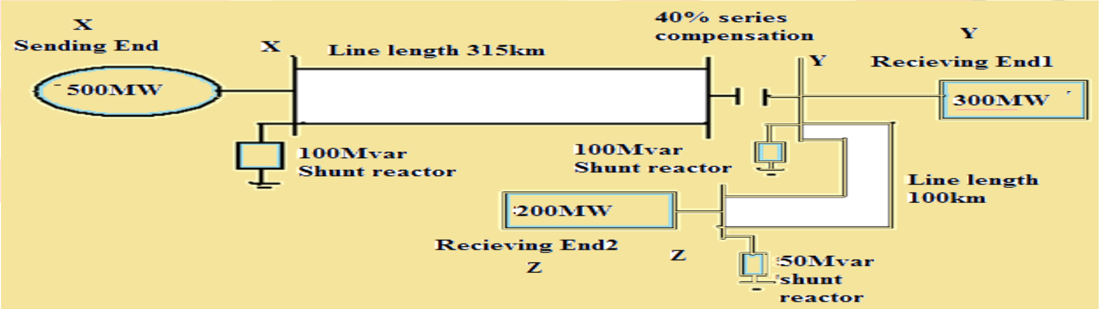

Fig 2.4 line configuration for case study 2

Table 2.6 Results of line configuration shown in fig 2.4

SI NO	Sending End(X) voltage	Receiving End1(Y) voltage	Receiving End2(Z) voltage	MW load at receiving End1(Y)	MW load at Receiving End2(Z)	PL(X-Y) 315km	PL(Y-Z) 100km	Total loss
	(PU)	(PU)	(PU)			(MW)	(MW)	(MW)
1	1.00	1.012	1.00	300	200	**6.934**	0.339	7.27

The table 2.6 provides a summary of the electrical parameters and power flow values for a transmission line. It includes the sending-end voltage (X), receiving-end voltage at End 1 (Y), and receiving-end voltage at End 2 (Z), all measured in per-unit (PU). The table also presents the MW load at End 1 and End 2, the apparent power losses for the X-Y section (PL), the Y-Z section (PL), and the total power loss. In this specific case, the sending-end voltage is 1.00 PU, while the receiving-end voltages at both End 1 and End 2 are 1.012 PU and 1.00 PU, respectively. The MW load at End 1 is recorded as 300 MW, while at End 2, it is 200 MW. The apparent power losses for the X-Y section and the Y-Z section are 6.934 MW and 0.339 MW, respectively. The transmission line experiences a total power loss of 7.27 MW. It is worth noting that, in typical operating conditions, the available power at the sending end of the line is approximately 8% lower than the rated generation capacity due to the consumption of auxiliary loads in the generating station itself. Consequently, the maximum power that can be received at the Y receiving end is 453 MW [500 MW with 8% power loss (500 MW)]. Out of the 453 MW, 300 MW is delivered to the Y end, while the remaining power is directed to the Z end. At the Z end, the maximum power that can be received is 152.66 MW [153 MW power loss (Y-Z) is incurred].

2.3.3 Case study 3:

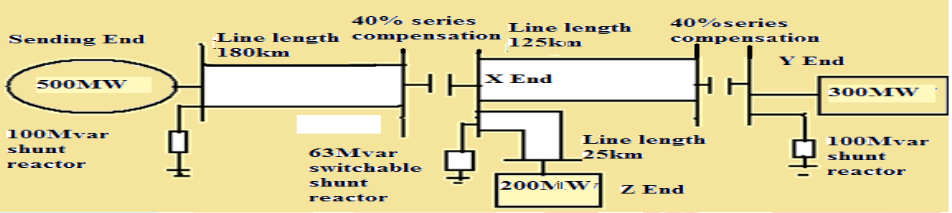

Fig 2.5 Line configuration for case study 3

Table 2.7 Results of line configuration shown in fig 5.5

Vs	Vx	Vy	Vz	Load at Z	Load at Y	PL(Sending End-X) 180km	PL(X-Z) 25km	PL(X-Y) 135km	Total Loss
(PU)	(PU)	(PU)	(PU)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)
1.00	1.01	1.00	1.00	200	300	3.963	0.086	1.042	5.091

In this case, the sending-end voltage is 1.00 per-unit (PU), while the voltages at intermediate point X, Y, and receiving-end point Z are 1.01 PU, 1.00 PU, and 1.00 PU, respectively. The load at point Z is 200 MW, and the load at point Y is 300 MW. The apparent power losses for the Sending End-X section, X-Z section, and X-Y section are recorded as 3.963 MW, 0.086 MW, and 1.042 MW, respectively. The total power loss in the transmission line is calculated as 5.091 MW. Under typical conditions, the power available at the sending end of the line is about 8% lower than the rated generation capacity, attributed to auxiliary load consumption at the generating station. Based on the results, the maximum power that can be received at the X receiving end is 456 MW [500 MW - power loss (Sending End-X) - 8% of 500 MW]. Out of this 456 MW, 300 MW is transmitted to the Y end, while the remaining power is directed to the Z receiving end. The maximum power that can be received at the Y end is 298.95 MW [300 MW - power loss (X-Y)], and at the Z end, it is 155.9 MW [156 MW - power loss (X-Z)].

III CONCLUSION

In this paper analysis is carried out to select best conductor which yields low loss and percentage compensation required to achieve control over the power flow in AC transmission line is carried out using MATLAB. Based on these comparisons, we can conclude that each table represents different conductor configurations and transmission line setups. Each table focuses on different aspects, such as voltage levels, power flow, and losses, providing insights into the behaviour and performance of the respective systems.. From the analysis it can be observed that a transmission line with quad bundle Bersimis conductor and 40% line compensation would be more adequate to achieve precise control over the power flow in AC transmission line.

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