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Optimum Compensation To Improve EHV Line performance

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Abstract— **Series compensation and shunt compensation are being used in EHV lines to improve their performance. While planning the compensation, it is necessary to select properly the degree of series and shunt compensation, the appropriate location or locations of the compensating equipment. The optimum selection of series and shunt compensation ha to be such that the total MVAR requirement is lower, the line voltage profile is well within the limits, the transmission efficiency is high and the system stability is improve. In this thesis a systematic method is developed to select the optimum series and shunt compensation to be employed in EHV lines for a given loading condition .Case studies are presented and a comparison of different compensation scheme is made.**

***Index Terms*—series compensation shunt compensation MATLAB**

I .INTRODUCTION

Series capacitors offer an effective and economic means of increasing power transmission capabilities of long extra high voltage lines problems concerning the effects of using series capacitors , their optimum location and the cost of these in proportion to their MVAR requirements have been studied. Ashok Kumar et al .[1] have suggested that the proper use of shunt reactors along with series capacitors would limit over voltages in addition to increasing power transmission. However, the method suggested therein involves a tedious semi graphical procedure. And the authors have not considered the voltage profile of the compensated line. Iliceto and Cinieri [2] have reported the choice of optimum series and shunt compensation schemes based on a semi graphical procedure from the points of view of improvement of system stability, total MVAR ,requirement, line voltage profile and power transmission efficiency. , Srikrishna and Srinivasan [3] have shown that twin capacitors at the terminals provide the most effective configuration for compensation and ease of maintenance, operation and control of capacitor banks. However, no systematic procedure is incorporated in the paper for the selection of series capacitors from the view points of transient stability, safe current and voltage profiles of

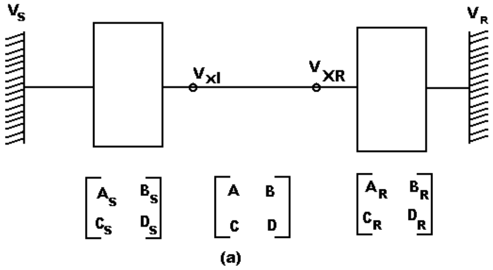
.

This paper presents a simple and elegant method to obviate the inherent complexities present in the compensation of a long line. The problem has been well disseminated with a view to designing the parameters of the compensating networks located at the terminals for optimum or desired power transfer under the relevant constraints for smooth operation of the transmission line. The technique is sufficiently general and well suited to any configuration and location of the compensating network.

It is well known that when optimum values of series capacitors located at either end or both ends are used to obtain for the maximum amount of received power transfer, an abnormal voltage rise occurs along the line. An attempt has therefore been made for the first time to evaluate compensating network elements under a constrained voltage at the capacitor terminal for maximum power transfer, using high degree equations in terms of the compensating elements with safe line current, Ferranti voltage and transient stability. Alternatively, non linear power and voltage constraints equations can be solved to yield the capacities of the compensating elements for a desired amount of received power with safe line current, Ferranti voltage and transient stability. It is noteworthy that previous authors [1,2] have suggested semi graphical methods for compensating an extra high voltage line involving cut- and-try-processes; whereas the present approach brings out a computer-aided design procedure selecting the elements of the compensating network.

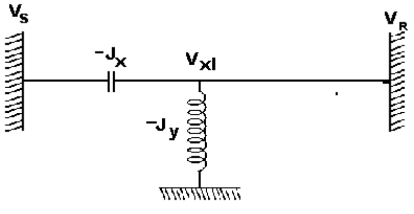
II. PRELIMINARY THEORY

Figures 1(a)-1(d) shows the single-line diagrams of a compensated line with a compensating network located at the terminals.

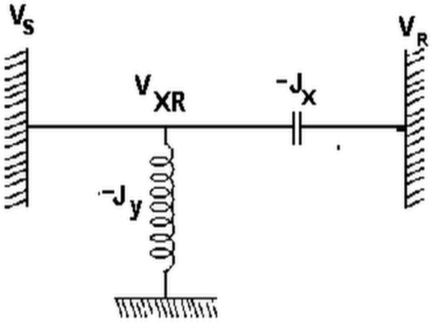


(a)

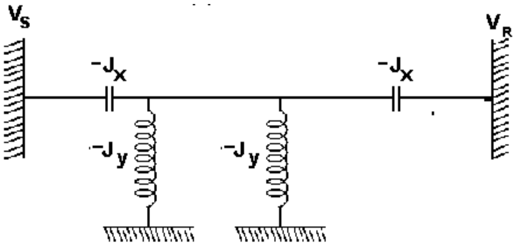
1(a)



(b)



(c)



(d)

The resultant line constants for the line shown in Fig 1 (a) are given by

$$\begin{bmatrix} A_0 & B_0 \\ C_0 & D_0 \end{bmatrix} = \begin{bmatrix} A_S & B_S \\ C_S & D_S \end{bmatrix} \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} A_R & B_R \\ C_R & D_R \end{bmatrix} \quad \text{------------} \quad (1)$$

The matrix operation is performed and the expressions for A_0, B_0, C_0, and D_0, corresponding to the configurations shown in Figs 1 (b)-1(d) are given in Appendix A. The equation for received power in terms of the uncompensated line constants and electrical transmission angle δ is given by

$$P_R = \frac{{V_R}^2}{{B_{01}}^2 + {B_{02}}^2}\left[(K\cos\delta - A_{01})B_{01} + (K\sin\delta - A_{02})B_{02}\right] \quad \text{-----} \quad (2)$$

With

$$w_1 = k\cos\delta \quad \text{------------------} \quad (3)$$

$$w_2 = k\sin\delta \quad \text{------------------} \quad (4)$$

$$P_R = \frac{{V_R}^2}{{B_{01}}^2 + {B_{02}}^2}\left[(w_1 - A_{01})B_{01} + (w_2 - A_{02})B_{02}\right] \quad \text{---------} \quad (5)$$

The receiving-end current I_R is given by

$$I_R = W_3 + W_4 \quad \text{---------------} \quad (6)$$

$$W_3 = \frac{V_R}{{B_{01}}^2 + {B_{02}}^2}\left[(w_1 - A_{01})B_{01} + (w_2 - A_{02})B_{02}\right] \quad \text{--------} \quad (7)$$

$$W_4 = \frac{V_R}{{B_{01}}^2 + {B_{02}}^2}\left[(w_2 - A_{02})B_{01} - (w_1 - A_{01})B_{02}\right] \quad \text{------} \quad (8)$$

For the configuration shown in fig 1(a),

$$V_{XR} = A_R + B_R \quad \text{----------------} \quad (9)$$

or

$$V_{XR} = V_1 + jV_2 \quad \text{-----------------} \quad (10)$$

$$\begin{aligned} &= A_{Rr}V_R + B_{Rr}W_3 - B_{Ri}W_4 \\ &+ (A_{Ri}V_R + B_{Rr}W_4 + B_{Ri}W_3) \end{aligned} \quad \text{-------} \quad (11)$$

If the capacitor terminal voltage is connected to the magnitude V, then $V_{XR} = V$ and we have

$$V_1^{\,2} + V_2^{\,2} - V^2 = 0 \quad \text{---------} \quad (12)$$

On substitution of V_1 and V_2 from eqn (11), eqn (12) is transformed to the following form

$$AX^8+BX^7+CX^6+DX^5+EX^4+FX^3+GX^2+HX+J=0 \quad \text{-----} \quad (13)$$

Where the coefficients of the equation are functions of Y and the line constants of the uncompensated line.

For the compensating network connected at the receiving end only, as shown in fig 1(c), eqn (12) reduces to

$$A'X^4 + B'X^3 + C'X^2 + D'X + E' = 0 \quad \text{---------------} \quad (14)$$

Where the coefficients are the functions of Y and the line constants of the uncompensated line. If it is desired to keep the voltage constrained at the sending–end capacitance point for the configuration of fig 1 (a), we has

$$I_S = C_0V_R + D_0I_R \quad \text{-----------------} \quad (15)$$

or

$I_S=C_0V_R+D_{O1}W_3-D_{O2}W_4+j*(C_{O2}V_R+D_{O2}W_3-D_{O1}W_4)$ --- (16)

$I_S=W_5+JW_6$ ------------------ (17)

$V_{XL}=D_SV_S-B_SI_S$ --------------- (18)

or

$V_{XL}=V_3+JV_4$ ------------------------- (19)

$=D_{Sr}W_1 - D_{Si}W_2 - B_{Sr}W_5+B_{Si}W_6 +j\ (D_{Si}W_1- D_{Sr}W_2-B_{Si}W_5-B_{Sr}W_6)$ ------------------------ (20)

With $V_{XL}= V$, eqn.(3.20) becomes

$V_3^2+V_4^2-V^2=0$ -------------- (21)

On simplification, eqn. (21) is transformed to an eighth-order polynomial equation of the form shown in eqn.(3.13). In this case when only the sending end terminals provided with the compensating network, eqn.(21) on substitution yields a fourth order polynomial equation of the form shown in eqn (14).

It is worth while noting that the degree of the voltage constraint equation is dependent upon the number of series capacitor banks or the number of shunt reactors per phase for a particular compensating scheme. The compensating schemes shown in figs. 1(b) and 1(c) each have one bank of series capacitors and one shunt reactor and the corresponding voltage constrain-t equation is of fourth degree expressed either in X with Y as parameter or vice-versa. Similarly, an eighth degree voltage constraint equation is obtained for the network of fig..1(d) when expressed I terms of X or Y.

III. METHODOLOGY OF SOLVING

3.1 Introduction.

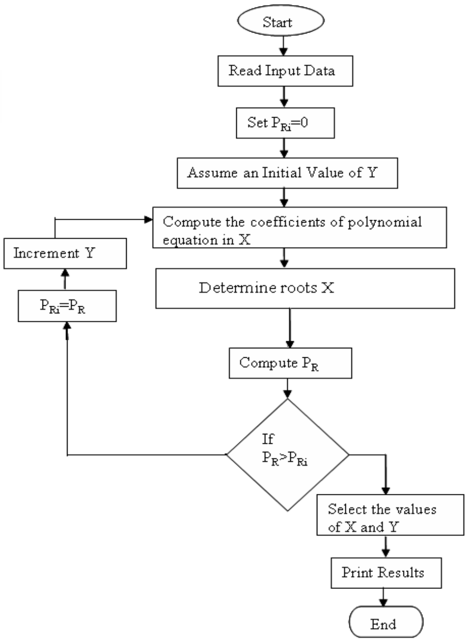
The voltage constraint equations derived earlier with compensating network connected at one or other end or both ends of transmission line are found to be polynomial equations of either fourth degree or eighth degree respectively.

3.2 Methodology Adopted.

The roots of the polynomial equation corresponding to a particular configuration of the compensating elements located at either end or both ends are found by using MATLAB program and the equation is solved by numerical techniques to determine the values of the compensating elements.

The power received is computed for each of the values of X and Y thus obtained and the values are finally selected by a search technique for maximum received power with the relevant constraints as mentioned earlier. A computer program is developed for the computation of maximum P_R for each type of configuration shown in Figs 1(b)—1(d). The flow chart is given in Fig 2.

Alternatively, for desired amount of received power under the constrained voltage at the capacitor terminal, the nonlinear power and voltage equations may be solved by any standard numerical method to determine X and Y



3.3 System under Study.

A theoretical system with the following data has been considered for the study and analysis of the impact of the compensating network on the system.

Line length : 1000km

Operating voltage : 500kV

Type of conductor: 1590 kcmil ASCR twin Conductor per phase with 46 cm Spacing

Phase spacing : 12 m

Z = (0.0084+j0.1305) p.u. /100 km

Y = (0+j0.0865) p.u. /100km

3.4 Assumption taken in carrying the Analysis.

Table - 1 Comparison of various parameters for different compensating schemes with $\delta = 30^o$

Parameter (p.u)	Compensating network Configurations		
	Capacitor at Sending End	Capacitor at Receiving End	Capacitor at Both Ends
K	1.05	1.05	1.05
V	1.05	1.05	1.05
X	0.198	0.212	0.491
Y	0.230	0.252	0.002
P_R	0.55119	0.56532	0.64395
Q_R	0.29278	0.13277	- 0.47372
Ps	0.57684	0.59214	0.74739
Qs	-0.14467	-0.29522	-0.60120
I_R	0.62412	0.58070	0.79942
I_S	0.56638	0.63014	1.23894
% Transmission Efficiency	95.55392	95.47130	86.16023

- Sending end receiving end voltages are held at 1.05 and 1.0 p.u. respectively.

The maximum electrical transmission angle is taken to be 30°

IV. RESULTS

The results are shown in Table 1 corresponding to the three types of configuration (fig 1(b), 1(c), and 1(d)) with no shunt reactor eliminates the capacitor location. It is found from the Table that the configuration with a capacitor at the receiving end only provides as suitable arrangement from the view point of maximum received power. But considering other aspects such as the MVAR rating of the capacitors, transmission efficiency and bidirectional power flow, the configuration with capacitors at both ends is found to be more effective.

Table 2 provides a comparison of X and Y, total MVAR ratings of the compensating network, transmission efficiency, various Sending-end and receiving-end quantities and Ferranti over voltage corresponding to optimum power for a different compensation schemes. Table 2 reveals that the addition of a shunt reactor to the configuration giving series capacitors at one or the other end increases the received power in comparison with the configuration having series capacitors only at either terminal .Furthermore, the addition of shunt reactors to the twin capacitors placed at the terminals shows no improvement in power transmission capability.

The simulation is carried by using a MATLAB program written for 6 different cases. The voltage constraint at the capacitor terminals held at 1.05p.u.for each type of configuration. In the case of capacitors at both ends, the voltage is held constant at one of the capacitor terminals and a check is made for the voltage at the other capacitor terminal.

CONCLUSIONS

This paper describes a voltage dependent method which provides a safe and reliable means of series compensation of extra high voltage lines with a compensating connected at one or other end or both ends. The method proposed in the analysis is a general one can be applies to cases where the compensating network is located at any point along the transmission..

Parameter (p.u)	Compensating network Configurations		
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Table - 2 Comparison of various parameters for different compensating schemes with $\delta = 30^o$

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