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# Effect of load characteristics on maximum power transfer limit for HV compensated transmission lines

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**Abstract**

In this paper a new method for calculating the maximum power transfer limit of high voltage compensated transmission lines is made. The effect of load characteristics as function of voltage and frequency is taken into account. Two schemes using series and shunt compensation are studied and numerical results for maximum power transfer limit, critical angular separation and critical voltage are given. These schemes are applied to the existing AC 500 kV transmission line connected between High-Dam and Cairo in Egypt.


*Keywords:* Load modeling; Compensation transmission line; Maximum power transfer limit

## 1. Introduction

Earlier, based on practical consideration and experience, St Clair [1], has derived loadability of uncompensated transmission lines and has expressed it in pu of the surge impedance loading (SIL) as a function of line length. Dunlop et al. [2], have presented the analytical basis for St Clair loadability curves and have extended their use into the EHV and UHV levels. They have shown that at higher voltages the loadability limits depend not only on the transmission line itself but also on the strengths of the terminal systems. They have stand that for EHV and UHV transmission lines, the only practical limitations to the line loadability are provided from considerations of line voltage drop and steady state stability as the thermal capabilities is significant only for very short lines.

The line loadability characteristic derived analytically by Dunlop et al. does not take into consideration the var reserves available in the system. Recently Kay et al. [3], have shown the importance of var reserve modeling in determining the line loadability limits. They have shown that the conventional steady state stability is applicable only to transmission lines with unlimited var supplies. With finite var supplies, the loadability limits is decided by voltage stability rather than by conventional steady state stability. They have not considered the effects of line resistance and line shunt susceptance and the distributed nature of the line model in determining the loadability. To over come the above disadvantage, Indulkar et al. [4,5], presented a modification of algorithm developed by Kay et al. This modification involves the determination of the line loadability limit taking into consideration the long line model of transmission line and the power factor of the load. They have shown that the loadability of lines with connected series capacitors and with finite var veserves depends on the voltage stability of the system. In addition to the use of series capacitors to improve the loadability, shunt reactors are required for voltage control [6–10].

In this paper the algorithm developed by Indulkar et al., is modified. The modification involves the determination of the line loadability limit, taking into consideration the long line model of the transmission line and load modeling as function of voltage and frequency. The effects of load characteristics on the maximum power transfer limit according to critical values of series and shunt compensation are calculated. Two different schemes using series and shunt compensation have been considered. These schemes are the same as these discussed in Ref. [11].

## 2. Proposed method

The proposed method to obtain the degrees of series and shunt compensation to achieve the maximum power

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**Nomenclature**

| | |
|---|---|
| $X_l$ | total series inductive reactance of the line |
| $B_c$ | total shunt capacitive susceptance of the line |
| $X_c$ | reactance of series capacitor |
| $b$ | susceptance of shunt reactor |
| $k_{se}$ | degree of series compensation |
| $k_{sh}$ | degree of shunt compensation |
| $A, B$ | generalized line constants after compensation |
| $V_r$ | receiving end voltage |
| $V_s$ | sending end voltage |
| $P_r, Q_r$ | active and reactive power loading of the line |
| PTC | power transfer capability |
| $P_r^o, Q_r^o$ | active and reactive power loading of the line at $V_r = 1.0$ pu |
| $m, n$ | constant of voltage characteristic of the load |
| $\alpha, \gamma$ | constant of frequency characteristic of the load |
| $K_a, T_a$ | exciter gain and time constant |
| $f$ | frequency |
| $J$ | Jacobean |
| $R$ | speed regulation in per unit |
| $k_1 - k_6$ | constant of the linearized model of synchronous machine |
| $V_t$ | terminal voltage |
| $T_e$ | electromagnetic torque |
| $T_{do}'$ | $d$-axis transient open circuit time constant |
| $E_{fd}$ | exciter field voltage |
| $\delta$ | torque angle |
| $E_q'$ | voltage proportional to direct axis flux linkages |
| $M, D$ | inertia constant and damping coefficient |
| $X_d, X_q$ | $d$-axis and $q$-axis reactance |

transfer limit $P_{r,crit.}$ of a transmission line is summarized as follows:

### 2.1. System equations

In this paper two schemes of compensation are considered: (scheme i and scheme ii) as shown in Fig. 1. Assuming the line is lossles, the active and reactive power flows at the end of transmission line with series and shunt compensation are given by:

$$P_r = \frac{V_s V_r}{B} \sin\delta \tag{1}$$

$$Q_r = \frac{V_s V_r}{B} \cos\delta - \frac{A V_r^2}{B} \tag{2}$$

where $A$ and $B$ are the generalized constants of the compensated transmission line.

### 2.2. Load model

The active and reactive load demand varies with voltage and frequency according the following functions

$$P_r = P_r^o V_r^m f^\alpha \tag{3}$$

$$Q_r = Q_r^o V_r^n f^\gamma \tag{4}$$

These functions are the same as these discussed in Ref. [17]. Also, the values $\alpha$ and $\gamma$ are given in this reference. $P_r^o$ and $Q_r^o$ are the nominal values of active and reactive power of load, respectively.

### 2.3. Mathematical development

Active and reactive power in Eqs. (1) and (2) must also satisfy the load active and reactive power of Eqs. (3) and (4). For a given value of the degrees of series and shunt compensation, the maximum power transfer is determined by considering a set of nonlinear equations as follows:

$$F_1 = P_r^o V_r^m f^\alpha - \frac{V_s V_r}{B} \sin\delta \tag{5}$$

$$F_2 = Q_r^o V_r^n f^\gamma - \frac{V_s V_r}{B} \cos\delta + \frac{A V_r^2}{B} \tag{6}$$

$$F_3 = A V_r + V_s \sin\delta \tan\phi - V_s \cos\delta \tag{7}$$

$$F_4 = V_s \cos\delta - A V_r - (f)^{(\gamma-\alpha)} V_r^{(n-m)} V_s \sin\delta \tan\phi \tag{8}$$

where $F_3$ and $F_4$ are derived in Appendix (A.1)

It is shown that Eqs. (5), (6) and (8) are function of $V_r, f$, $\delta$, $k_{se}$ and $k_{sh}$. Equations for calculating the relation between $f$ and $\delta$ are derived in Appendix (A.2) [13,14]. This relation is given by the following formula

$$f = -RH\delta \tag{9}$$

Rewriting Eqs. (5)–(8) according to Eq. (9), yields

$$F_1 = P_r^o V_r^m (-RH\delta)^\alpha - \frac{V_s V_r}{B} \sin\delta \tag{10}$$

$$F_2 = Q_r^o V_r^n (-RH\delta)^\gamma - \frac{V_s V_r}{B} \cos\delta + \frac{A V_r^2}{B} \tag{11}$$

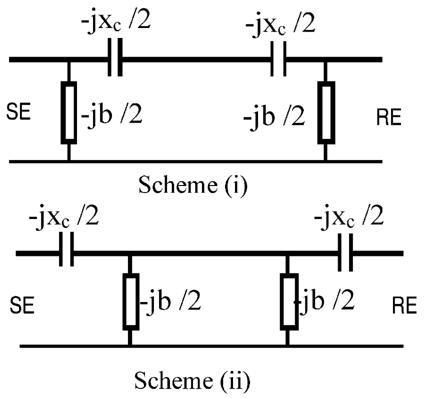


Fig. 1. Compensation schemes.