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LOAD END REAL & REACTIVE POWER OPERATING CONTOUR AND SHUNT CAPACITIVE SUPPORT AT VOLTAGE STABILITY LIMIT OF MULTIPHASE (6-phase & 12-phase) POWER TRANSMISSION YSTEMS

By

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Abstract:

Abstract:-Problems concerning power flow and stability, particularly the voltage stability are of vital importance at EHV and UHV level because of their sensitivity to real and reactive power changes. The problem has been studied to a considerable extent in case of three-phase systems; however the multi-phase (phase order more than three) systems have received little attention. The purpose of this paper is to investigate these aspects by extending the well established techniques of three-phase systems to multi-phase lines and construct performance characteristic curves related to power flow and voltage stability performance of such systems

Keywords:
Multi-phase, Power flow, Transmission lines, shunt capacitive support, voltage dependent load,Voltage stability.

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1. Introduction:

The problems regarding power flow and voltage stability are of particular interest to EHV threephase as well as multi-phase power systems because of their sensitivity to changes in real and reactive powers. In this connection, a proper analysis is essential to observe the behaviour of the system when real and reactive power changes take place in a given system. Voltage stability is obtained by keeping specified voltage magnitude within the set of operating limits under steady state conditions. When the voltage stability limit is crossed, it is not possible to bring back the receiving end voltage at its nominal value even with any variation in reactive power. The problem has been studied to a considerable extent in case of three-phase systems [1-10]. However, the multi-phase system has received little attention [11-12] and needs similar study. This paper attempts to address the issue by describing the real and reactive power profiles of three EHV transmission alternatives (3, 6 and 12- phase). Further a new scheme of voltage stability analysis of multi-phase line is presented assuming voltage dependent loads and the minimum requirement of shunt capacitance at the load bus to have voltage stable state is obtained by extending the well developed techniques of three-phase systems to multi-phase lines.

2. Basic Circuit Model and SampleSystem:

The basic circuit model with lumped parameters adopted for the appropriate characteristics analysis of un-compensated EHV power transmission system is represented on single phase equivalent basis as shown in Fig. 1. Let EA and IA represent the voltage and current at sending end whereas EB and IB are the voltage and currents at receiving end side. YT and YSH in Fig.1 represent equivalent series and shunt admittance of an equivalent pi-model of the transmission line.

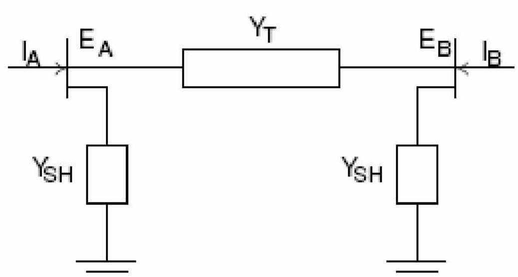

Figure (1): *Basic circuit model*

In order to construct and evaluate the appropriate characteristics curves, three transmission alternatives (3, 6 and 12-phase) with same number of conductors, same right of way and utilization of the same air space for power transmission are considered. Each system is energized at 462 kV line-to-ground (L-G) voltages and has the same thermal rating. The line-parameters are based on assumptions that complete transposition of conductors has been done. The Surge Impedance loading (SIL), series impedance (Z) in ohms/mile and shunt admittance (Y) of the transmission lines are specified in Table 1.

Table (1): *Test system specification & line parameters*

3-Phase line 462 kV (L-G)	6-Phase line 462 kV (L-G)	12-Phase line 462 kV (L-G)
SIL = 3275 MW Z=(0.0039+j0.2487) _ / km Y=j6.6487ſS/km	SIL = 4494 MW Z=0.0078+j0.2953) _ /km Y=j5.6003ſS/km	SIL = 5485 MW Z=(0.0162+j0.3542) _ /km Y=j4.6768ſS/km

2.1. Load End Real and Reactive PowerOperating Contour Maps:

The receiving end current ( ) *B I* in single line equivalent circuit model (Fig.1) of a multi-phase power transmission line can be written as,

$$I_B = (S_B / E_B) \tag{1}$$

S_B & E_B are receiving end complex power and voltage respectively. Also from Fig. 1, the system admittance matrix [6, 8] can be written as,

$$[\mathrm{Y}]=\begin{bmatrix} Y_{BB} & Y_{BA} \\ Y_{AB} & Y_{AA} \end{bmatrix}\begin{bmatrix} (Y_T + Y_{SH}) & (-Y_T) \\ (-Y_T) & (Y_T + Y_{SH}) \end{bmatrix} \tag{2}$$

Where, *T Y* and *SH Y* indicates, transfer and shunt admittances respectively. Using conventional expression [I] = [Y] [E] the system admittance matrix can be represented as:

$$\begin{bmatrix} I_A \\ I_B \end{bmatrix} = \begin{bmatrix} Y_{BB} & Y_{BA} \\ Y_{AB} & Y_{AA} \end{bmatrix} \begin{bmatrix} E_B \\ E_A \end{bmatrix} \quad (3)$$

Equation (4) can be written from (3) as,

$$I_B = Y_{BB}E_B + Y_{BA}E_A \quad (4)$$

Upon using (1) in (3) yields,

$$S^* = Y_{BB}E_B^2 + eY_{BB}E_B^* \quad (5)$$

Where, e = $Y_{BA}E_A / Y_{BB}$

On rearrangement, (5) can be written as,

$$|S_B| - |Y_{BB}^* E_B^2| = |eY_{BB}^* E_B| \quad (6)$$

The above equation is an equation of a circle with:

$$|Y_{BB}^* E_B^2| \text{ as centre and } |e^* Y_{BB}^* E_B|$$

as its radius.

Thus all state having constant amplitudes of:

$$e = Y_{BA}E_A / Y_{BB}$$

lie on the circles with these parameter on S-plane (Fig. 2). Each circle represents locus of $|S_B|,|$, the receiving end complex power, for any stable value of *B E* (receiving end Voltage) varying with in the range of 0.95 p.u. 1.05 p.u. Employing equation (1) and assuming sending end voltage EA to be constant at 1.0 p.u., the load end real and reactive power operating contour maps, for 3, 6 and 12-phase are constructed for 462 kV and 500 km transmission lines, on p.u. basis, are as shown in Fig.2. It is evident from the curves in Fig. 2 that the power handling capacity of multi-phase (employing more than 3-phase) transmission system is higher for specified sending end and receiving end voltages.

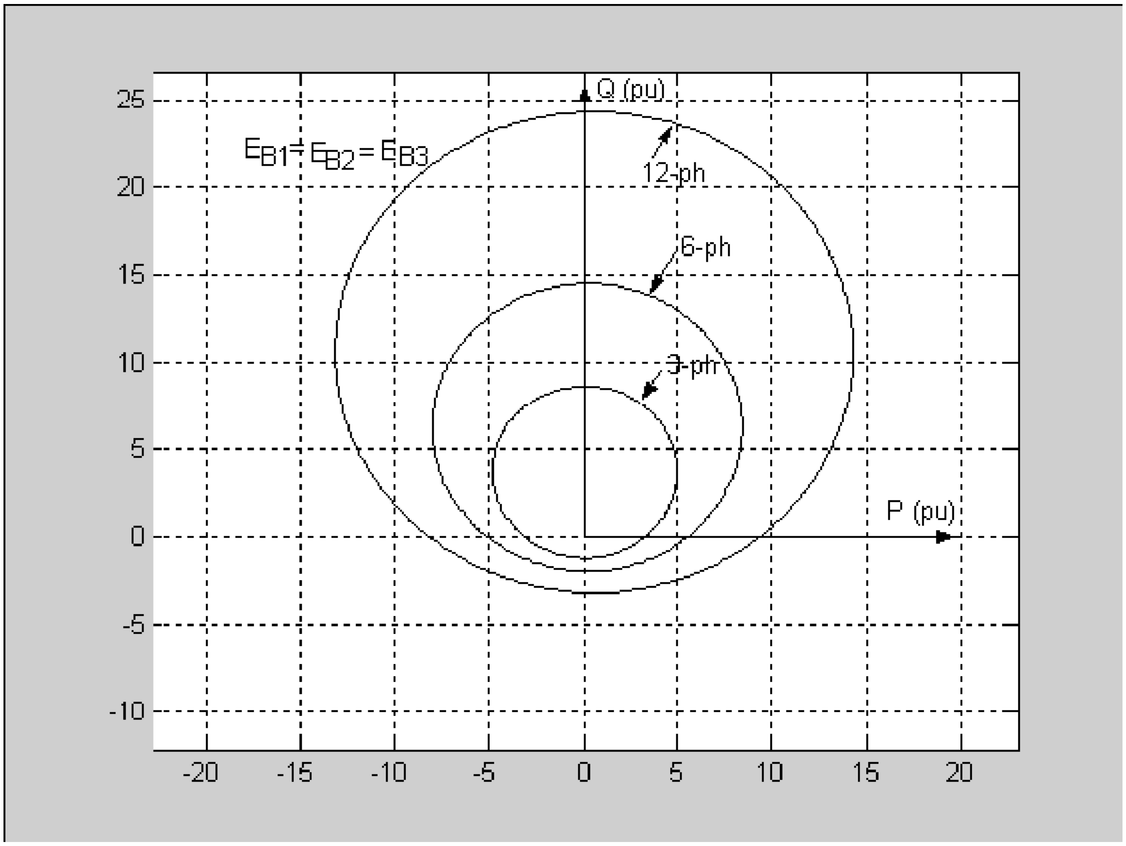

Figure (2): *Real & reactive power operating contours with same receiving end voltages (EB = 0.95 p. u.)*

Further more, Figs. 3 (a-c) confirms enhancement of power handling capacity for 3, 6 and 12-phase transmission system with 5% increase of receiving end voltage EB1 = 0.95, EB2 = 0.99 and EB3 = 1.05 p.u. maintaining sending end voltage (A E) as it is i.e. EA = 1.0 p.u.

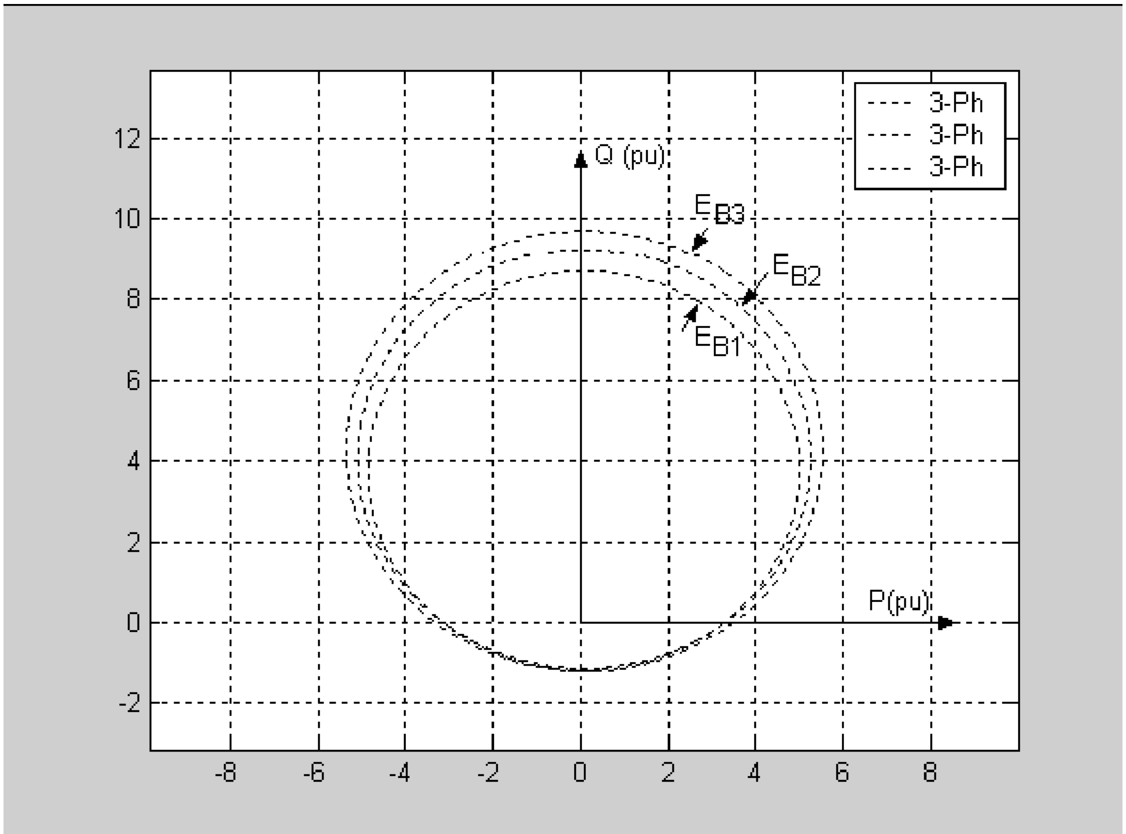

Figure (3a): *Real & reactive power contours of a 3-phase line with EB1 = 0.95, E 2 = 0.99 and EB3 = 1.05 p.u.*

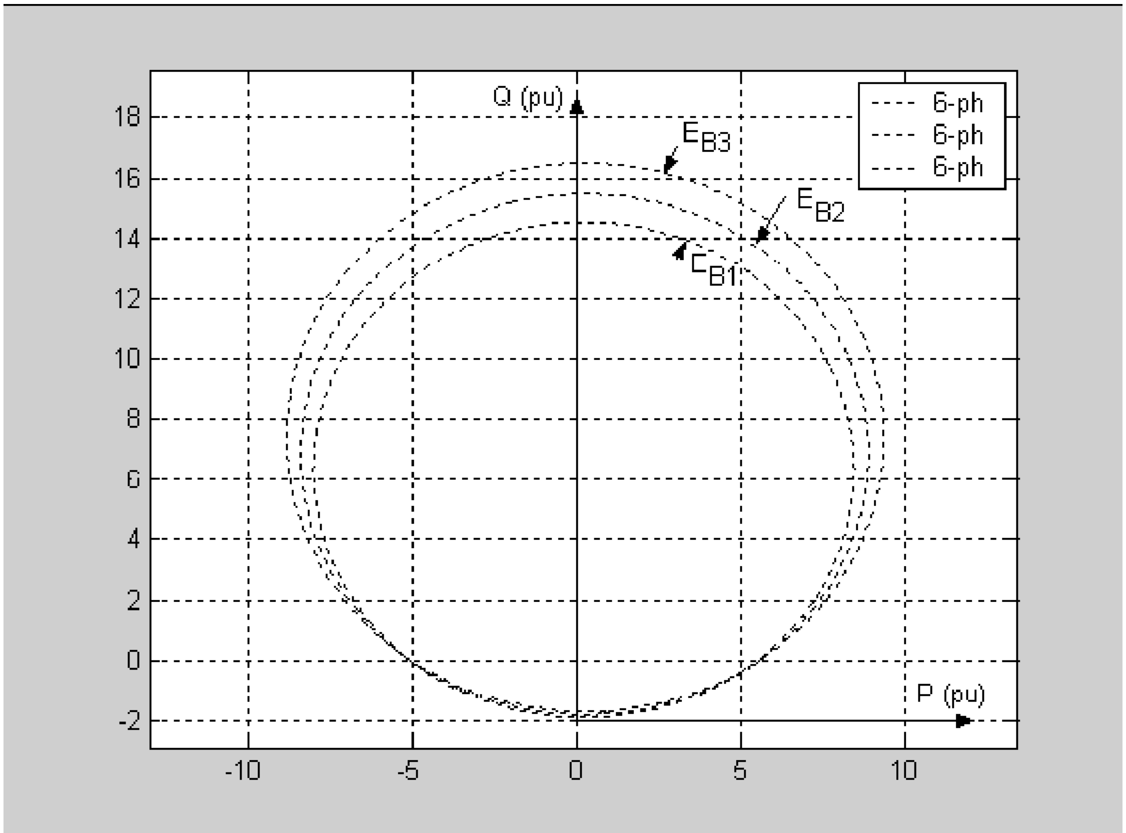

Figure (3b): *Real & reactive power contour maps of a 6-phase line with EB1 = 0.95, EB2 = 0.99 and EB3 = 1.05 p.u*

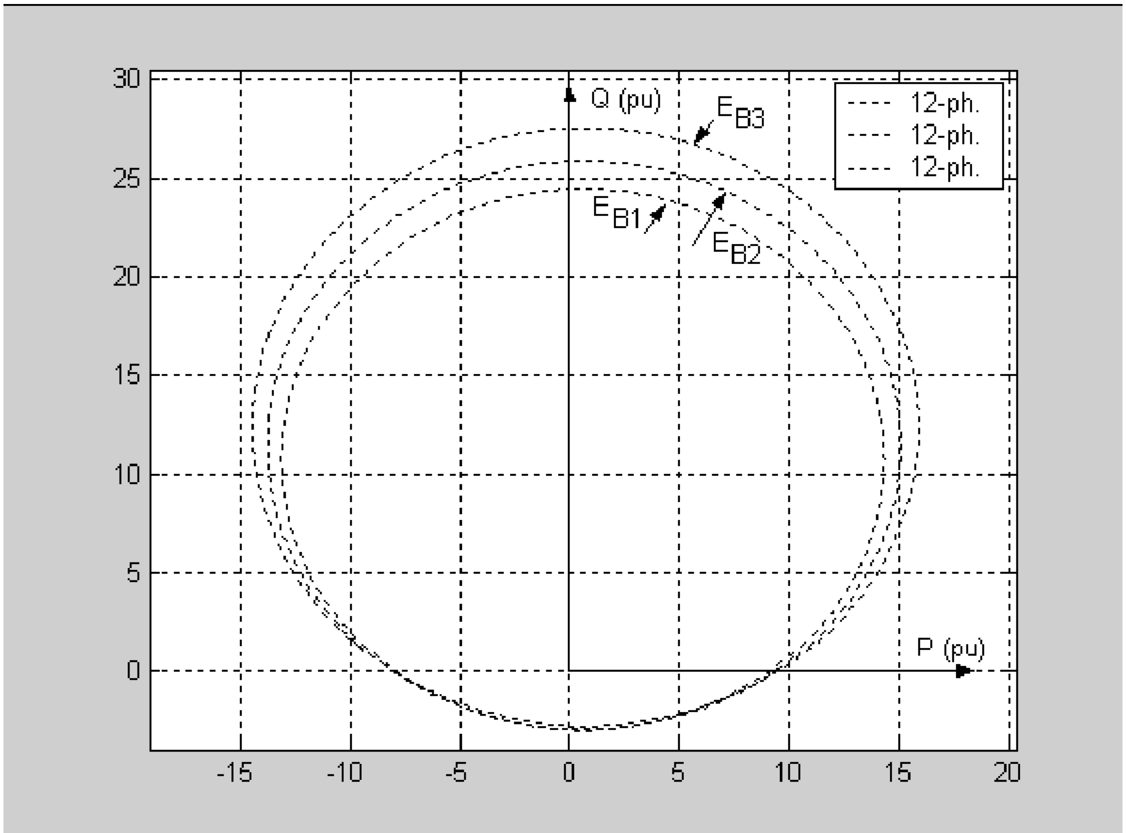

Figure (3c): *Real & reactive power contours of 12-phase line with EB1 = 0.95, EB2 = 0.99 and EB3 = 1.05 p.u.*

It is observed that reactive and real power handling capacity for 3-phase, 6-phase and 12-phase systems are increased by 11.85 %, 8.33 %, 7.71 % and 5 %, 4.385 %, 4.384 % respectively. As supplement, it can be seen from Figs. 3 (a-c) that increment in real and reactive power capacity for 3-phase, 6-phase and 12-phase takes place with an increase of 10 % in EB (within voltage stable zone) keeping EA constant at its previous value i.e. EA=1.0 p.u. It is observed that the corresponding percentage increase in real and reactive power capacity of 3-phase, 6-phase and 12-phase are found to be 10, 8.77, 8.73 and 17.41, 13.88 and 15.40 respectively. It is evident from the above contour maps that the reactive power transfer capacity increases with the increase of number of phases. Thus it can be inferred from the load end real and reactive power counter maps that the multi-phase transmission systems will be inherently more stable from voltage stability point of view than the traditional three phase transmission systems.

2.3. Shunt Capacitive Support at Voltage Stability Limit Using Characteristics of Voltage Dependence Load:

In a reactive power constrained line the magnitude of complex power at receiving end can be represented by

$$S_B = P_B Sec\phi \tag{7}$$

Considering the load characteristic [5-6] the receiving end power is given by

$P_B = P_0 E_B^m$ P_0

is the power at rated voltage B E and m is the load characteristic for voltage dependent loads. From (6), taking first derivative of B E with respect to BB U , the self admittance of receiving end bus, under any specified set of operating criteria is given by

$$\frac{dE_B}{dY_{BB}} = \frac{\left(|E_B||E_A||Y_{BA}| - |P_0||E_B^m|\sec\phi\right)}{\left[2|E_B| + |E_A|\left|\frac{Y_{BA}}{Y_{BB}}\right| - mP_0|E_B^{m-1}|\sec\phi\right]Y_{BB}^2}$$

$$= \frac{C-D}{\left[2|E_B| + |E_A|\left|\frac{Y_{BA}}{Y_{BB}}\right| - mP_0|V_B^{m-1}|\sec\phi\right]Y_{BB}^2} \tag{8}$$

Where, C represents the steady state stability limit and D the operating power, under normal operating conditions (C – D) being a positive quantity, (/) B BB dE dU will only be positive if denominator is greater than zero. As (/ U)®0 B BB dE d represents the voltage stability

limit [6], for a the voltage stable state, $\frac{dE_B}{dY_{BB}} > 0$

Thus from (8)

$$2|E_B| + |E_A(Y_{BA}/Y_{BB})| \geq< mP_0|E_B^{m-1}|Sec\phi \tag{9}$$

According as the system is at voltage stable state or system is at voltage stability limit, the same is under voltage instability. Therefore at voltage stability limits,

$$\left|Y_{BB}\right| = \frac{\left|E_S\right| . \left|Y_{BA}\right|}{mP_0\left|E_B^{m-1}\right|\sec\phi - 2\left|E_B\right|} \tag{10}$$

That is,

$$\left|Y_{SH}\right| = \frac{\left|E_A\right| . \left|Y_{BA}\right|}{mP_0\left|E_B^{m-1}\right|\sec\phi - 2\left|E_B\right|} - \left|Y_T\right| \tag{11}$$

$\left|Y_{BB}\right| = \left|\left(Y_T\,(line\ admi\tan ce) + Y_{SH}\,(shunt\ admi\tan ce)\right)\right|$

The equation (11) provides a relationship for the minimum of Y_{SH} at load end for getting a stable voltage state under set of specified operating conditions.

Fig. 4 (a) and (b) exhibits the magnitude of the minimum receiving end bus admittance at different per unit voltages for different power factors in case of multi-phase systems (3, 6 and 12-phase). The above cases are shown for m = 0.5 and m =1.0. It is observed that enhancement of shunt capacitive support is required to improve the receiving end voltage magnitude from the point of view of the stability of the system voltage in case of voltage dependent load (i. e. m < 1). It is further clarified that the requirement of shunts capacitive support rating for voltage dependent load is gradually reduced as the phase-order of the system is increased from 3 to 12.

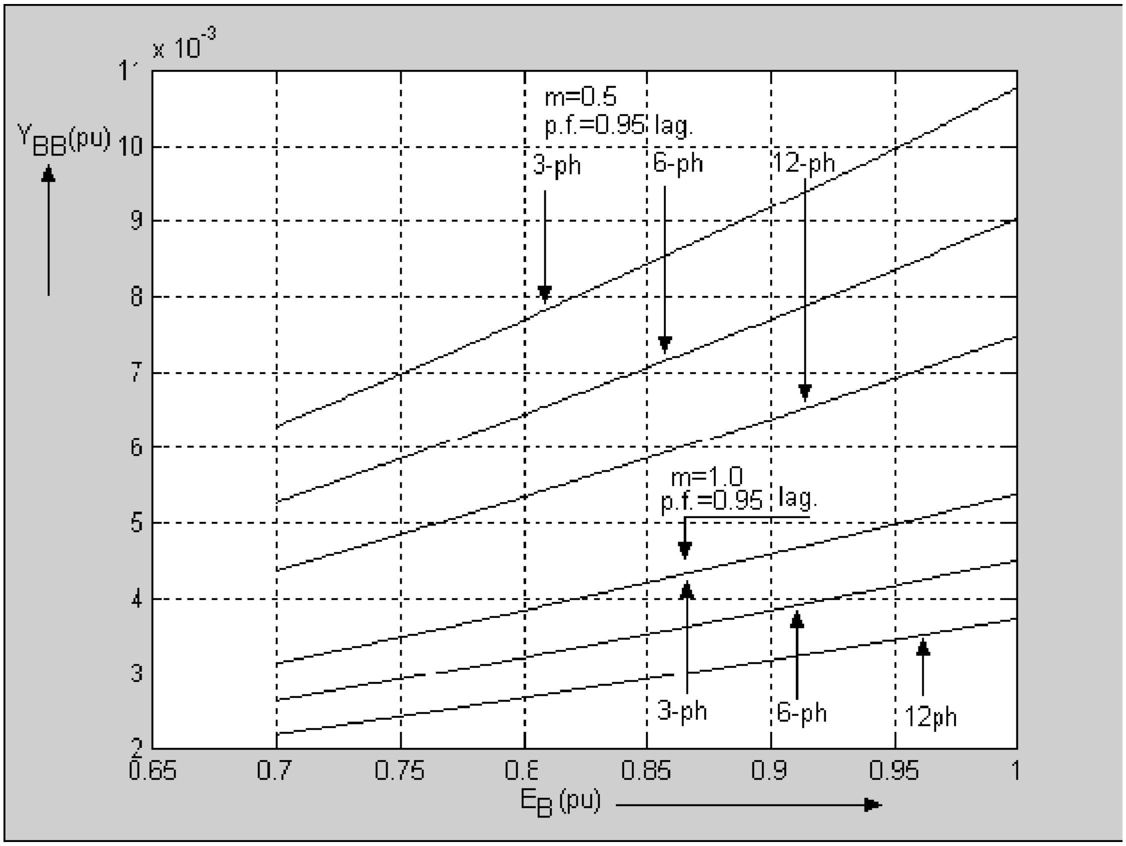

Figure (4a): *profile of minimum magnitude of load end bus admittance at different voltages with u.p.f. at voltage stable states.*

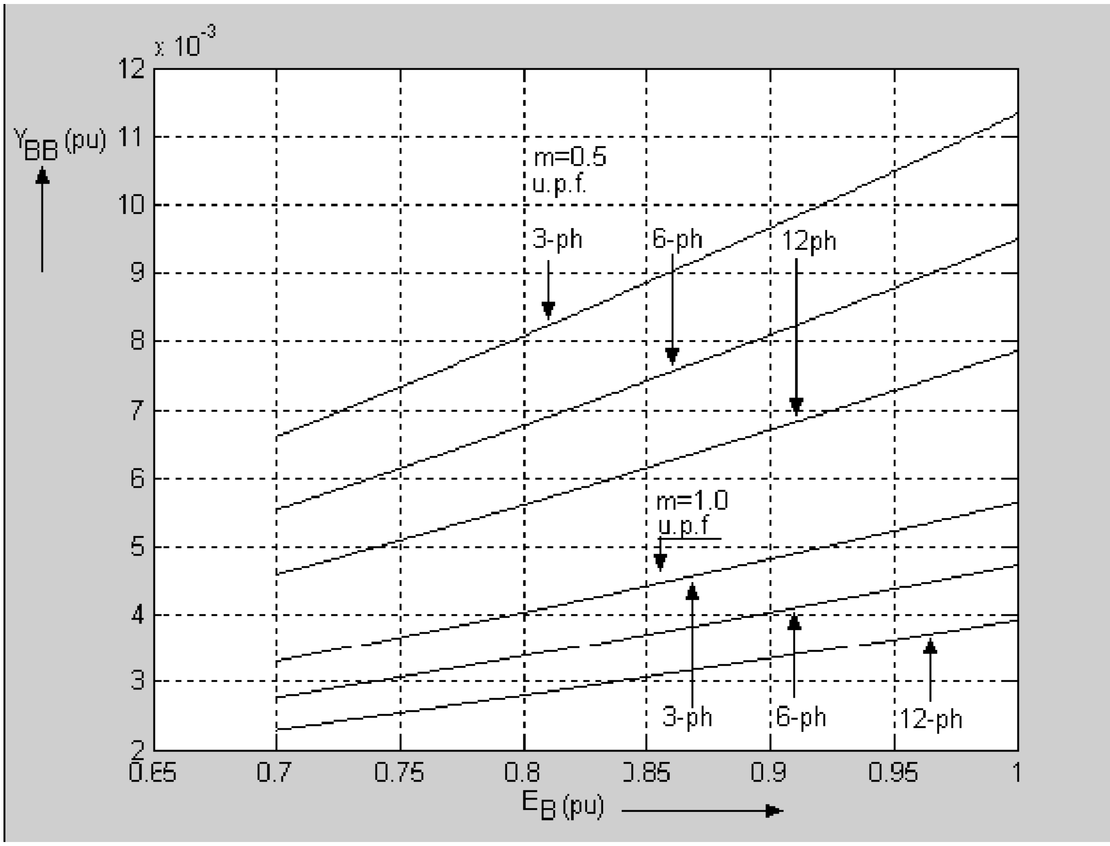

Figure (4b): *profile of minimum magnitude of load end bus admittance at different voltages with u.p.f. at voltage stable states.*

The same analysis has been carried for variation of length of transmission line and it has been given in Fog. 5 For analysis, in place of the variation of receiving end voltage, the length of transmission line is varied and the similar curves are drawn, then the same observations are noticed. Fig. 5 (a) and (b) represent the curves - shunt admittance $(Y_{SH} = Y'_{BB})$

Versus length (L) for different power factors (0.95 lagging & unity) at m = 0.5 and m = 1 in case various multi-phase transmission systems (3, 6 and 12 –phase). It can be concluded that with increase of number of phases the value of the shunt capacitive rating is reduced for voltage dependent load at voltage stability limit.

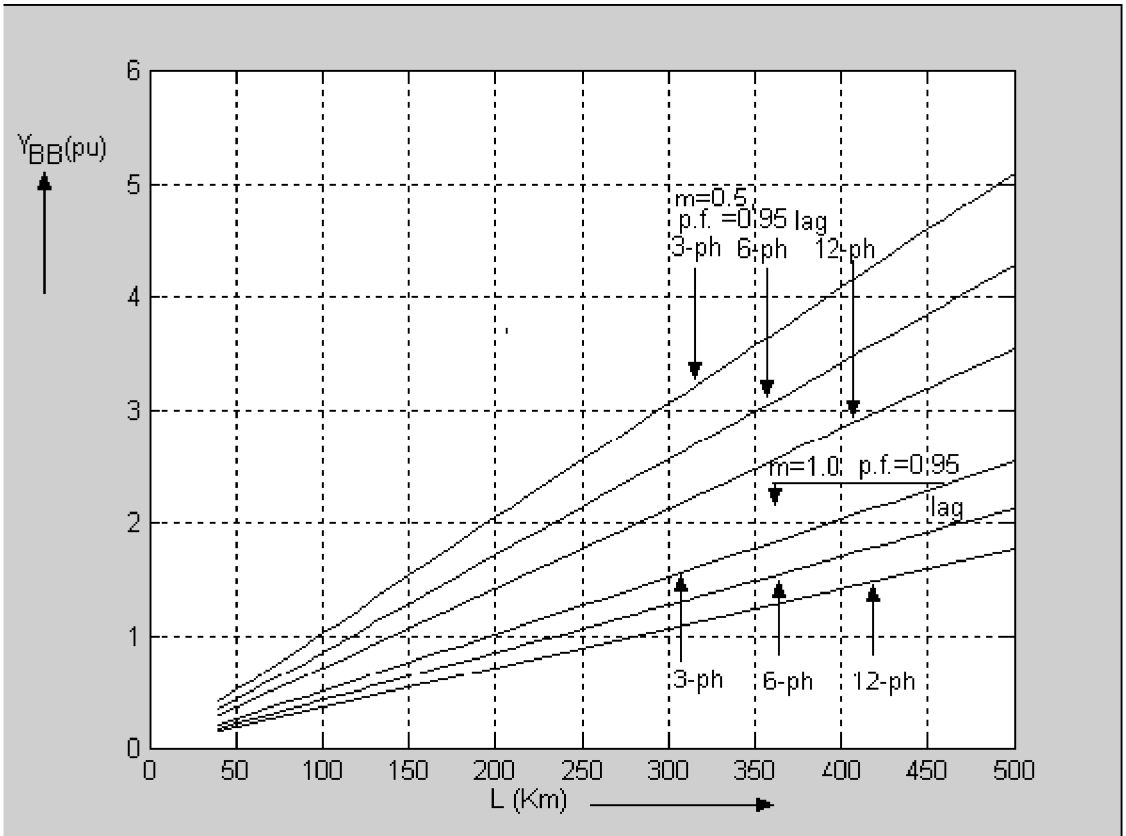

Figure (5a): *Profile of load end admittance for varying line length with p.f.0.95 lag at voltage stability limit.*

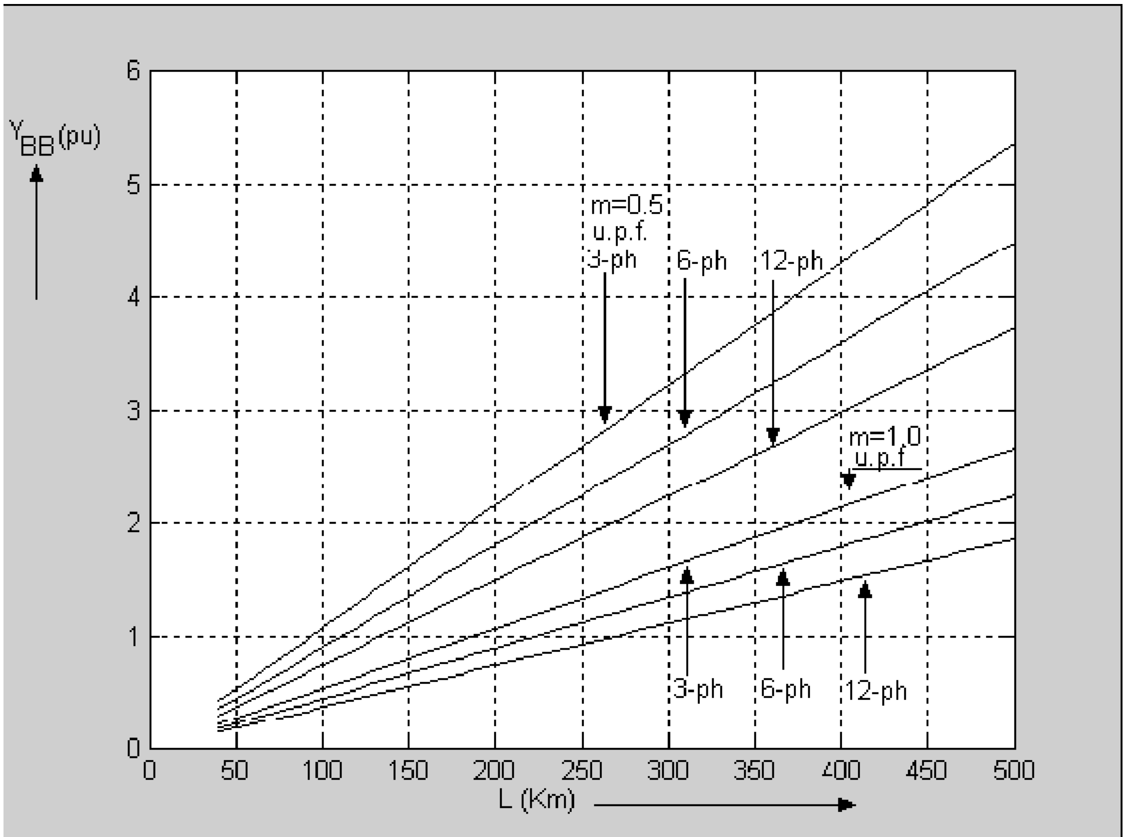

Figure (5b): *Profile of load end admittance for varying line length with u.p.f. at voltage stability limit.*

3. Conclusions:

In this paper the existing 3-phase concepts have been extended and employed to construct and analyze performance characteristics curves on power flow and voltage stability of the multiphase line. Based on the investigations of 6-phase and 12-phase transmission lines and their comparison with the conventional 3-phase system, following conclusion may be made.

The multi-phase lines (6-phase and 12-phase) show progressively increased power handling capacity, increased power at the load end, reduced rating of compensating devices, better voltage stability in case of voltage dependent load as the phase order is increased.

Theses aspects of multi-phase lines may be very attractive and beneficial to electric transmission utility. The present simulation has also revealed that the presence of voltage dependent loads play a important role in depressing the load bus voltage at voltage stability limits. However, the multiphase lines perform better than their lower phase order counterparts.

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