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Investigation of Multi Phase Power Transmission System With Thyristor Controlled Series Capacitor

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Abstract: Multi-phase transmission systems is considered potential alternative to conventional three-phase systems for bulk power transmission. Recent survey shows that the integration of flexible A.C. transmission system devices into conventional three-phase transmission system for enhancement and control of power flow is well established. This paper attempts to study: a FACTS device i.e. thyristor controlled series capacitor (TCSC), its model and effect on power flow and load ability of multi-phase transmission lines. Sample systems are used to study quantitative benefits of four-phase and twelve-phase lines.

Key Words: Power-transmission, Thyristor controlled series capacitor, Loadability, Multi-phase.

I. INTRODUCTION

This paper makes an attempt to study power flow and loadability of EHV transmission line equipped with TCSC. The multi-phase power transmission systems [1-6] have been investigated as potential alternative to increase transmission capacity with out increasing system voltages which have already reached.

Extremely high Voltage level i.e. UHV & EHV systems in constraints on land availability and several environmental problems have renewed the interests in techniques and technologies for power carrying capacity of existing ROW. It is noted that multi-phase power transmission systems (specially 4-phase & 12-phase) are beneficial and have better performance. [9]

The use of flexible A.C. transmission system controllers for power flow control and transmission capacity enhancement over an existing transmission corridor has rapidly met with favor with conventional three-phase system [5-9].

II. SYSTEM MODEL

Thsyristor controlled series capacitor (TCSC) is used in series with a transmission line. Generally, it is used to decrease the impedance of transmission line over a long distance. The circuit diagram of TCSC is given in figure-1. Thyristor T_1 and T_2 are fired in positive and negative half cycle of the line current respectively.

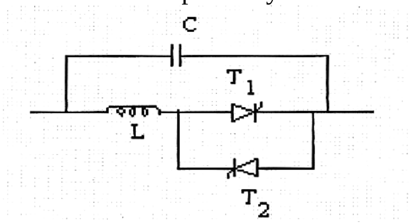

Fig. 1 TCSC Scheme

Depending on firing angle of TCSC thyristors it offers equivalent inductive or capacitive reactance TCSC as shown in Fig.1 has a fixed capacitor connected in parallel with series connected thyristor and inductor, known as TCR. The inductive reactance of a TCR at a firing angle ψ is given by-

$$X_{L(\psi)} = X_L \frac{\pi}{\pi - 2\psi - Sin\Psi} \quad (1)$$

$$X_{L(\psi)} = \frac{X_L(\Psi)X_c}{X_L(\psi) - X_c} \quad (2)$$

where Xc = $1/2\pi fC$, C is the capacitance of TCSC.

The design problem taken here is to design a TCSC, that means to determine the values of L (or X_L), C (or X_C) and the firing angle ψ of the thyristors T_1 & T_2 in order to obtain a desired values of compensation. Here $X_{TCSC}(\psi) = \alpha X_{TL,}$ α is the percentage value of compensation. Since at ψ =π / 2 , the TCSC yields maximum capacitance. It is to be insured that at ψ =π / 2, the TCSC gives minimum compensation α limit (say 9%) desired and achievable as;

$$X_{TCSC}(\frac{\pi}{2}) = a_{mim}\, X_{TL} \quad (3)$$

Where, X_{TL} is the inductive reactance of transmission line. The internal circuit resonance may be assumed to occur at ψ = ψ_R (say π / 6). Then, for $\psi_R = \pi/6,$

$$X_L = (\frac{2\pi}{3} - \frac{1}{2})\ \frac{X_C}{\pi} \quad (4)$$

Solving equations (3) and (4), the values of X_L or L and X_C or C can be obtained. Then the value of ψ for a given degree of compensation can be determined using the relation $X_{TCSC}(\psi) = \alpha X_{TL,}$ and equations (1) and (2) as done in [9].

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Table-1 Design parameter for different degree of compensations Ψ.

Deg. Of Compensation	3- Phase		4-Phase		12-Phase	
	Ψ (deg)	X_{TCSC} (Ψ)	Ψ (deg)	X_{TCSC}(Ψ)	Ψ (deg)	X_{TCSC}(Ψ)
25%	50.50	0.00995000	50.50	0.118151500	50.50	0.141500420
50%	40.50	0.1990020	40.50	0.2363010	40.50	0.28002440
75%	36.80	0.298510	36.80	0.354480	36.80	0.42449710

A series compensation of TCSC at the receiving end of a transmission line can be shown as given in figure-2 below:

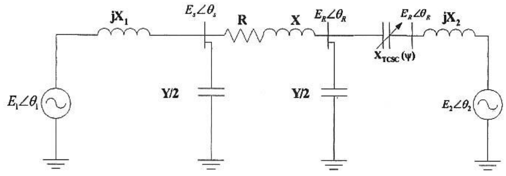

Fig. 2 Circuit model

$$E_R = \frac{2ZE_2 + jZ_3E_1}{Z_2 + Z_4} \qquad (5)$$

And E_s is given as

$E_s = (2ZE_1 - 2jE_R (X_1 - X_{TCSC}))/Z_1$ (6)

Where,

$Z = R + JX_{TL}$

$Z_1 = 2Z + j(X_1 - X_{TCSC(\psi)}))(2+YZ)$

$Z_2 = 2Z + jX2(2+YZ)$

$Z_3 = j4XZ_2 / Z_1$

$Z_4 = 4X_2 (X_1 - X_{TCSC(\psi)}))$ and

Ψ= firing angle of thyristors

This results in power flow equation given below:

$P_s = |E_s||E_R|\text{Cos}(\beta+\delta)/|B| + |A||E_S|^2 \text{Sin}(\beta-\alpha)/|B| = P_A$ (7)

Where,

δ: angle between E_S and E_R and

$A = (1+YZ/2) - (X_{TCSC(\Psi)}))Y(1+YZ/4)$

$B = Z - (X_{TCSC}(\Psi))\,(1 + \frac{YZ}{2})$

III. PERFORMANCE EVALUATION

In the circuit model, the transmission line may be represented by an equivalent π circuit with terminal systems as Thevenin equivalent as given in Fig. 2 [7,8]. The FACTS device model can be shown as TCSC in series with the line resistance and the line reactance. The Thevenin equivalent impedances can be obtained from short circuit voltages $|E_1|$and $|E_2|$ are specified as 1.0 and 8.5 p.u. respectively on the basis of a.c. load flow. The analysis for power flow and load ability on three different transmission alternatives (3-phase, 4-phase and 12-phase) for which system voltage is 460KV, L-G is performed. The specifications are given:

Table-2: Test system specification & line parameters

3-phase system 460k V (L-G)	4-Phase system 460 kv (L-G)	12-phase system 460 kv (L-G)
SIL = 3270 MW Z=0.0063+J0.398 Ω/mi Y= j10.630 µs	SIL = 4490 MW Z=0.0120+J0.4720 Ω/mi Y= j8.9600 µs	SIL = 5480 MW Z=0.020+J0.5660 Ω/mi Y= j7.480 µs

The power flow and loadability curves are plotted in following figures. The power flow for a transmission line of 200km length is computed for different degree of compensation. They are plotted and shown in Fig. 3 -6.

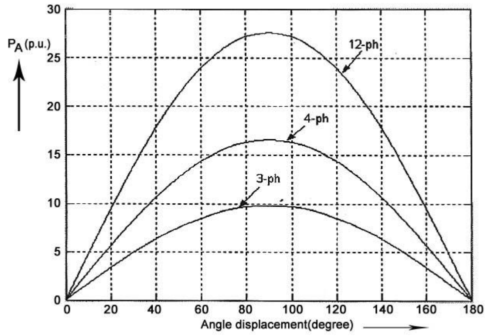

Fig. 3 power-angle curves for line length 200km. with no compensation

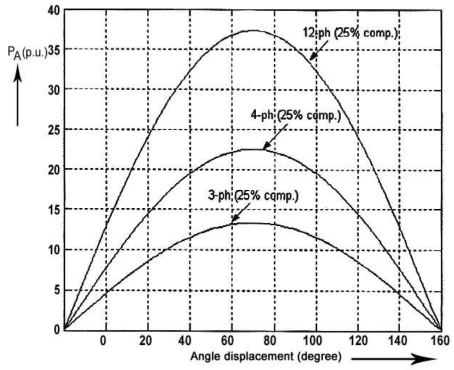

Fig. 4 power-angle curves for 200km. line with 25% compensation

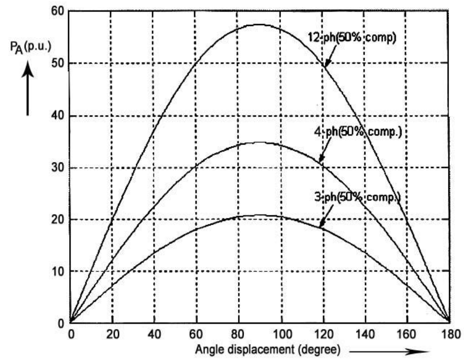

Fig. 5 power-angle curves for 200km. line with 50% compensation

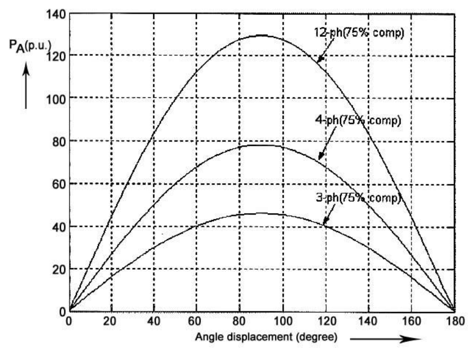

Fig. 6 power-angle curves for 200km. line with 75% compensation

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Similarly, the ratio P_A/SIL for uncompensated and various degree of compensation for 4% voltage drop and 25% stability margin criteria have been plotted against line length between 50 and 500 kms. and shown in Fig. 7-10. In these figures, the loadability characteristics are shown which describes the qualitative and quantitative benefits in each case clearly. It can be seen that the multi-phase power transmission with TCSC is an important candidate for use in power lines and it is found to be beneficial to the electric transmission utilities if compared with its 3-phase counterpart.

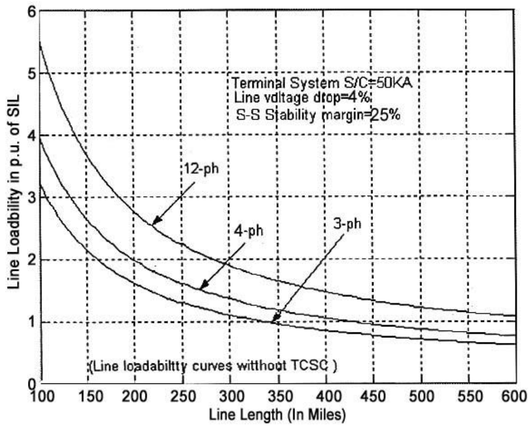

Fig. 7 Loadability curves for 460 kv without compensations.

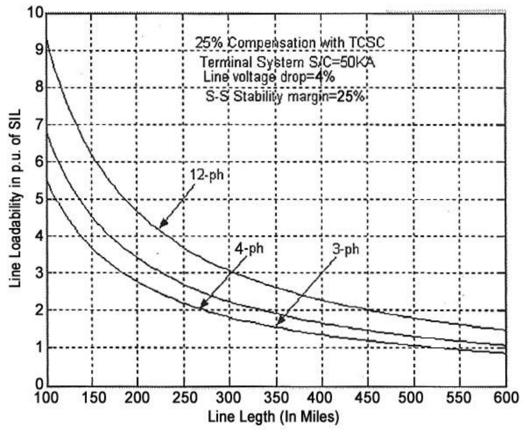

Fig. 8 Loadability curves for 460 kv lines with 25% compensations.

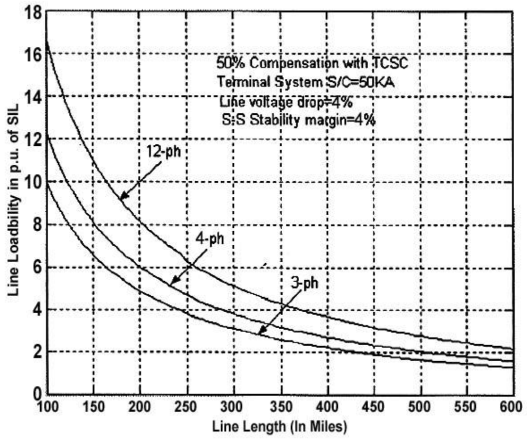

Fig. 9 Loadability curves for 460 kv lines with 50% compensations.

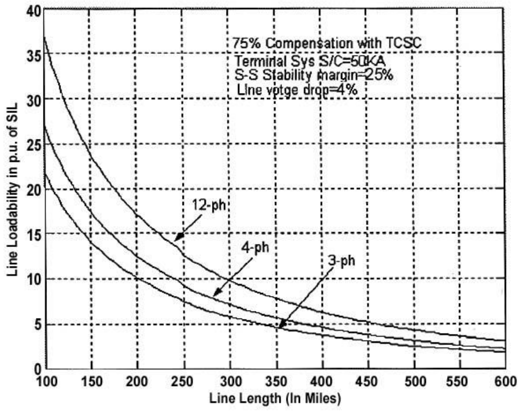

Fig. 10 Loadability curves for 460 kv lines with 75% compensations.

IV. CONCLUSIONS

A multi-phase power transmission with TCSC is found to be suitable to the transmission utilities. The performance of multi-phase lines in terms of power flow and loadability analysis is evaluated for three transmission alternatives. The power flow for different lines- uncompensated line and having different degree of compensation is also calculated and plotted. It is noted that a higher steady–state stability limit (P_{max}) is associated with multi-phase lines as compared to the 3- phase line. The loadability study for uncompensated line as well as compensated line with several degree of compensation has shown advantages in line loadability of multi-phase lines.

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