Stability Analysis of Thyristor Controlled Series Compensation Using Simulink

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Abstract: *The voltage and power level of the system changes when there is a change in the line impedance due to the faults in the line .The drop in the load voltage leads to an increased demand for the reactive power that ,if not met by the power system leads to a future decline of voltage at that location and in the neighboring regions, eventually resulting in voltage collapse. In this paper, FACTS (Flexible AC transmission systems) controller, Thyristor Controlled Series Compensator (TCSC), is incorporated in the system to maintain the reactive power (Q) so as to avoid the increase in reactive power demand. Smooth variation of reactive power is possible by controlling the firing angle of the thyristors. TCSC model is developed and tested in IEEE test system, and the outputs are given.*

Index Terms: *FACTS, Stability of system, TCSC, Thyristor controlled reactor*

1. INTRODUCTION

In recent years, power demand has been increased with a result of heavy load on the transmission system. This application of load on system, is the result of increasing number of loads and increased competition between the utilities itself. With the increased loads on the transmission , lack of proper planning and tendency of the electrical utilities to provide open access to generating companies and customers, have created a condition leading the system towards less security and reduced power quality. A partial but effective solution can be obtained by incorporating FACTS devices in the system[8]. Thyristor Controlled Series Compensation in the transmission line is useful in achieving enhance grid capacity and reliability. This is also a solution for capacity enhancement needs and upgrading the power capacity of the line. Series compensation will:

a. Increase power transmission capability
b. Improve system stability.
c. Reduce system losses.
d. Improve voltage profile of the lines.
e. Optimize power flow between parallel lines.

2. OPERATION OF TCSC

The basic operation of TCSC can be easily explained from circuit analysis [1]. It consists of a series compensating capacitor shunted by a Thyristor controlled reactor (TCR) as in Figure 1. TCR is a variable inductive reactor X_L controlled by firing angle α. Here variation of X_L with respect to α is given by:

$$X_L(\alpha) = X_L \frac{\pi}{\pi - 2\alpha - \sin 2\alpha}$$

The effective reactance of TCSC can be represented in terms of firing angle, α:

$$X_{TCSC}(\alpha) = -X_C + C_1(2(\pi-\alpha)+\sin(2(\pi-\alpha)) -$$
$$C_2\cos^2(\pi-\alpha)(\lambda\tan(\lambda(\pi-\alpha)) - \tan(\pi-\alpha))$$

Where,

$$X_{LC} = \frac{X_C X_L}{X_C - X_L}$$

$$C_1 = \frac{X_C + X_L}{\pi}; \quad C_2 = \frac{4X_{LC}^2}{X_L \pi}$$

$$\lambda = \sqrt{\frac{X_C}{X_L}}$$

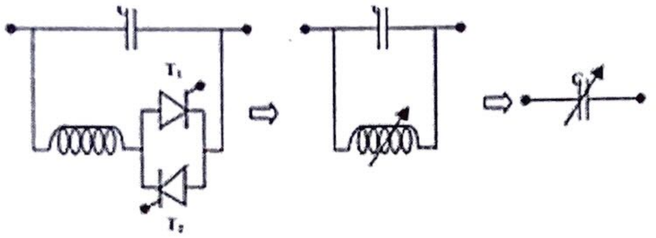

Fig. 1: Equivalent circuit of TCSC

2..1 IMPEDANCE CHARACTERISTIC

Impedance Characteristics of TCSC is plotted between effective resistance of TCSC and the firing angle, á [3]. The characteristics can be plotted as shown in figure (2) . From the characteristics it can be concluded that :

a. For 90 < á < áL_{LIM}-Inductive region.
b. áL_{LIM} < áC_{LIM} < áC_{LIM-} Capacitive region.
c. For áC_{LIM} < á < 180 –Resonance region.

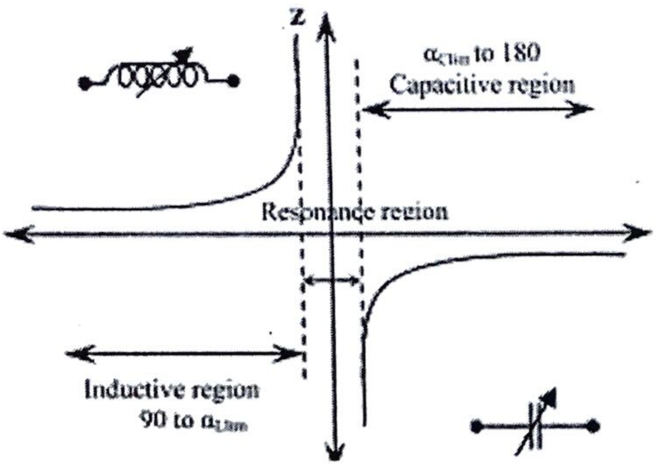

Fig. 2: Impedance characteristics of TCSC

The value of firing angle , á, is varied only up to the limit, the resonance condition between the inductor and capacitor has not reached .In any shunt network, the effective value of reactance follows the lesser reactance present in the branch .So by changing the firing angle, the effective reactance of the line can be changed or compensated [4].

3. SIMULINK MODEL OF THE TCSC

Fig. 3 shows the Simulink model of open loop TCSC device connected in series with the two area two machine transmission line system. For analyzing the Thyristor Current, Capacitor Current and Capacitor Voltage, firing angle pulse are given through pulse generator. To analysis about capacitive mode of TCSC apply the pulse in the region of vernier capacitive region (~160 to 180 degrees)[2]. Refer Appendix A1 and A2.

3.1. TCSC CONTROLLER DESIGN

The TCSC works on the value of firing angle. Circuit controlling the value of firing angle input to the TCSC is called the controller circuit [5]. Fig. 5 shows the design of the controller model for controlling the firing of the TCSC model shown in Fig. 4. In the model:

Vc-TCSC voltage magnitude, Vref-reference voltage, φ-controller reference angle, φ-voltage angle, τ_{d}- delayed voltage angle θ – line current angle,è-controller reference angle, α – actual firing angle .The controller model consists of a second order feedback filter , PI controller , PLL , series compensator and a transport delay model [9,10]. The PLL synchronizes thyristor firings with the line current phase angle. In this case the TCSC voltage feedback control is used where Vref. can be a function of other parameters at higher control levels[6]. This system can be considered as a sampled data system, because of thyristor firings at discrete time intervals , with the sampling frequency of 360Hz.The continuous model ,therefore ,includes a first order delay, given by time constant Td1 to accommodate the phase lag introduces by sampling the firing angle signal .The filter time constant is taken equal to 2ms.The voltage angle directly influences the thyristor firing angle ,as the thyristor firing angle is measured with respect to the voltage curve.

4. SIMULATION RESULTS AND ANALYSIS

A sudden inductive load is applied at the generator terminal bus bar at t = 0 sec and cleared after 0.4 sec. The original system is restored upon the fault clearance. The performance of TCSC controller is studied.

4.1 EFFECT ON ACTIVE AND REACTIVE POWERS

The active and reactive powers gets deviated from their steady state response upon the occurrence of the fault. Even if the fault has been cleared, the power responses are very far from their normal steady state response. With the TCSC incorporated in the system the results are very close to the ideal steady state

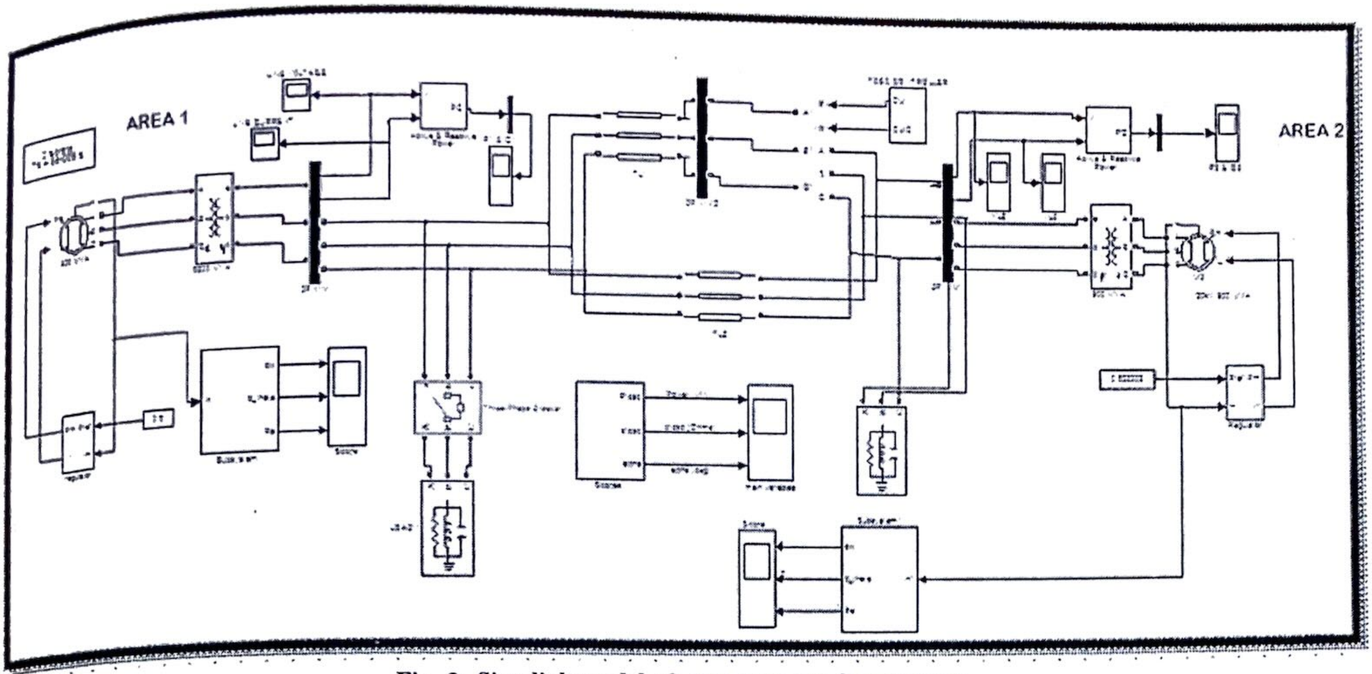

Fig. 3: Simulink model of two area two bus systems

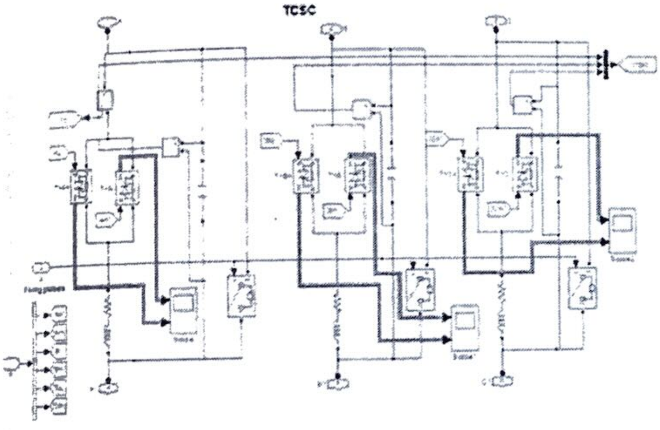

Fig. 4: Controller model and firing angle calculator

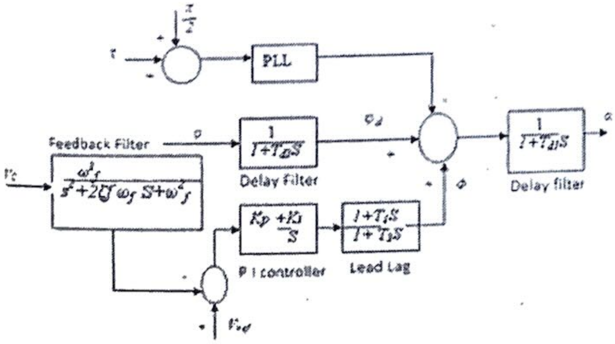

Fig. 5: Controller model and firing angle calculator

response[7]. The power oscillations are damped out within the specified time interval, to bring the SMIB to the condition as it was just before the occurance of the fault. In Fig. 6 both active and reactive power oscillations damping can be witnessed .

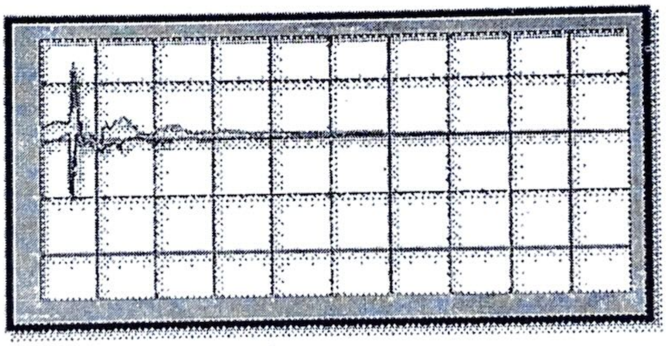

Fig. 6: Active and reactive power without TCSC

4.2. EFFECT ON LINE IMPEDANCE

The effect of TCSC on the impedance of the line and its effect on the terminal voltage can be seen from the result of the simulation ,as shown in the Fig. 7 and Fig. 8 respectively.

The variation of TCSC impedance (Xtcsc) with the circuit breaker operation is shown in Fig. 8.This figure illustrates that the TCSC impedance varies with the operation of the circuit breaker to compensate for the changed impedance of the line. This helps in damping the power oscillations which are introduced in the system due to sudden application of the load.

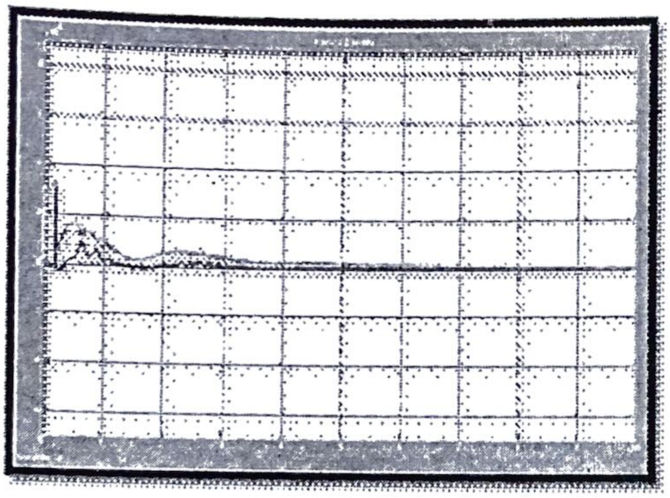

Fig. 7: Damped Active and Reactive Power Oscillations with TCSC

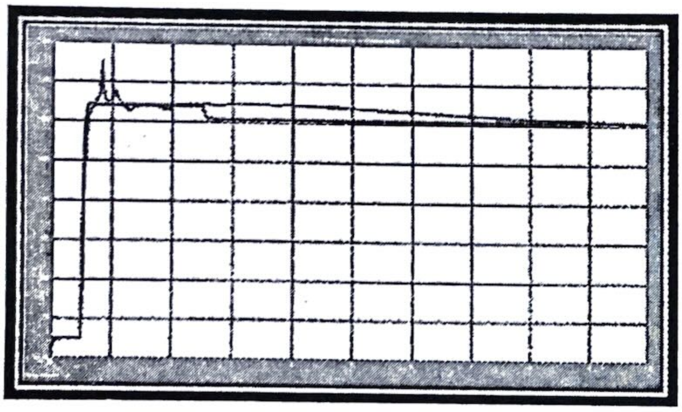

Fig. 8: The measured and reference impedance with TCSC

4.3. EFFECT ON SPEED, POWER ANGLE & POWER OUTPUT OF MACHINE

The simulation results for the speed , power angle and power output for the synchronous machine of area 1, without the TCSC, is shown in Fig.9. The circuit breaker is operated between 0 to 0.2 sec. These curves shows that after the circuit breaker operation, the speed, power angle and power output shows sudden oscillations which are settled to steady state in a time span of 5 secs due to the natural damping provided by the system. Here the settling time is 5 secs. The first peak after the circuit breaker operation is observed at 0.5 sec .

The simulation results for the speed , power angle and power output for the synchronous machine of area 1, with the TCSC, is shown in Fig.10. The circuit breaker is operated between 0 to 0.2 sec. These curves shows that after the circuit breaker operation, the speed, power angle and power output shows sudden oscillations which are settled to steady state in a time span of 3 secs due to the damping provided by the TCSC. Here the settling time is 3 secs. The first peak after the circuit breaker operation is observed at 0.3 sec.

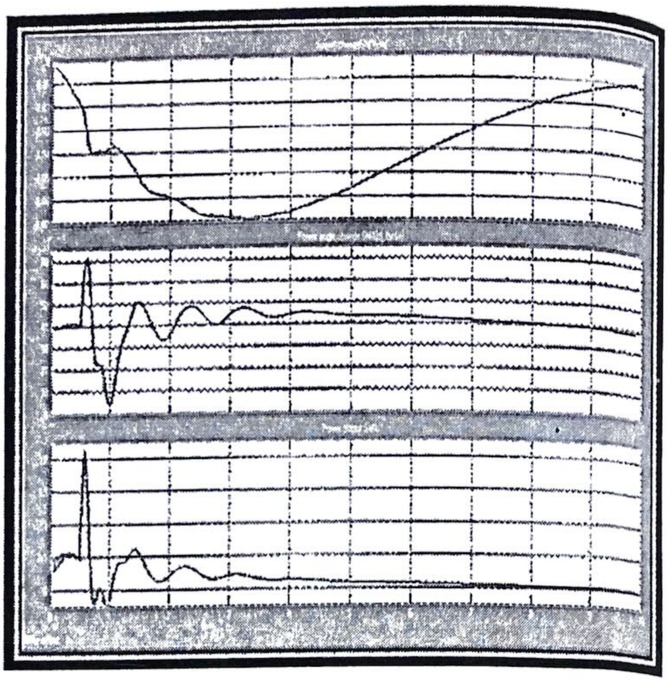

Fig. 9: Speed, Power angle and Power output without TCSC (fault at 0 to 0.2 sec)

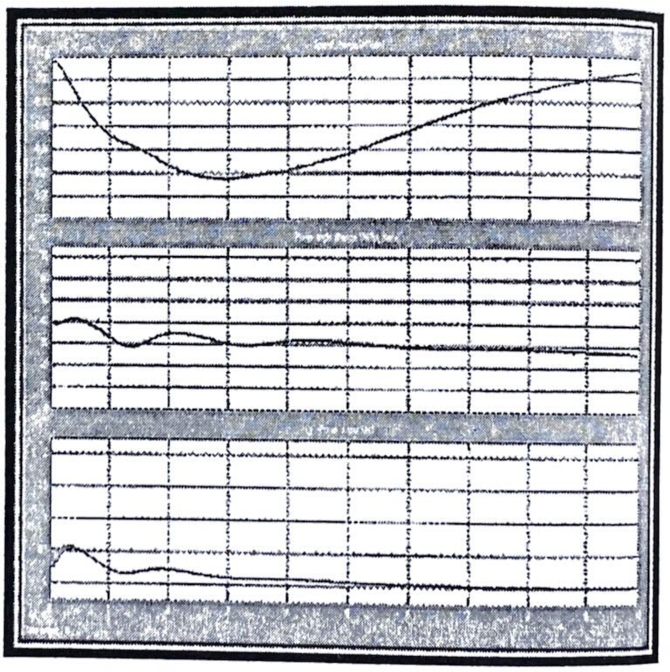

Fig. 10: Speed, Power angle and Power output of SM1 with TCSC(fault at 0 to 0.2 sec)

5. CONCLUSIONS

The MATLAB/SIMULINK model of a two area two machine power system with a TCSC controller presented in the paper provides a means for carrying out power system stability analysis and for explaining the generator dynamic behavior as effected by a TCSC. This model is far more realistic compared to the model available in open literature, since the synchronous generator with field circuit and one equivalent damper on q-axis is considered to improve the performance of power system subjected to a disturbance.. The controller is tested on standard IEEE Single Machine Infinite Bus power system subjected to various large and small disturbances. The simulation results show that, the standard tuned TCSC controller improves the stability performance of the power system and power system oscillations are effectively damped out. Hence, it is concluded that the proposed model is suitable for carrying out power system stability studies in cases where the dynamic interactions of a synchronous generator and a TCSC are the main concern.

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APPENDIX

A1 230KV TEST SYSTEM

The simulation studies in this thesis are based on a simple 23o kV power system model in which the two networks Area 1 and Area are connected through a 300 km long transmission line , comprising two transmission lines in parallel as shown in one line diagram in Figure A1.1.

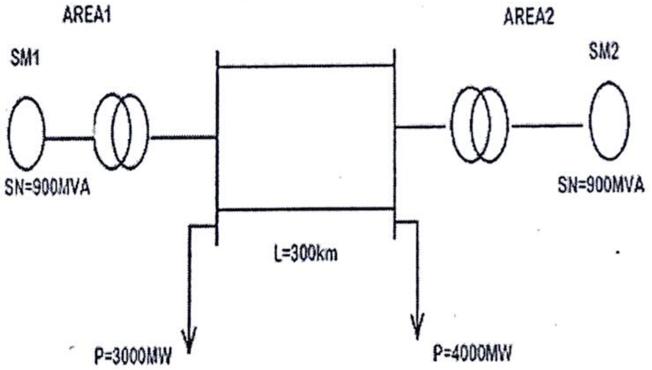

Fig. A1.1: 230 kV test system single line diagram Un=230kV & f_N = 60 Hz.

The transmission lines comprises two parallel circuits , each characterized by the following parameters:

(1) r = 0.018 ohm/km
(2) X= 0.34 ohms/km
(3) b = 4.9e-6 S/km
(4) L = 300 km
(5) F = 60 Hz.

DATA	Area 1	Area 2
Generating capacity	900MVA	900MVA
Type of generation	Hydro	Thermal
Equiv.Generator	SM1	SM2
SN	900MVA	900MVA
H	4.0S	4.0S
Xd	1.8	1.8
Xd'	0.3	0.3
Xd"	0.025	0.025
Xq	1.7	1.7
Xq'	0.55	0.55
Xq"	0.25	0.25
Xl	0.2	0.2
Td0'	8.0	8.0
Tdo"	0.03	0.03
Tqo'	0.4	0.4
Tq0"	0.05	0.05
DATA	Area 1	Area 2
Excitation	standard	Standard
Prime mover	Turbine Regulator	Turbine Regulator
Transformer Rating	900MVA	900MVA
Reactance	0.15pu	0.15pu
Local Load	413MW	800MW
Load Voltage	proportional	proportional
Bus Voltage	1.03pu	1.0pu

A2. A transmission line connects the two buses A and B. The source connected to each one of these buses may be an individual machine or a large network. The transmission line has the effective reactance X, that includes the line reactance and also the reactance of any series capacitor. In order to simplify the analysis , the shunt susceptance of the line has been negelected.(This is only justified for "short" transmission lines and the computer simulation includes a complete long line corrected line representation).If the line reactance is X_L and the compensating reactance (if included) is *Xc*, the total reactance is given by equation A2.1 shown in Figure A2.1 & A2.2.

$$X = X_L - X_C \tag{A2.1}$$

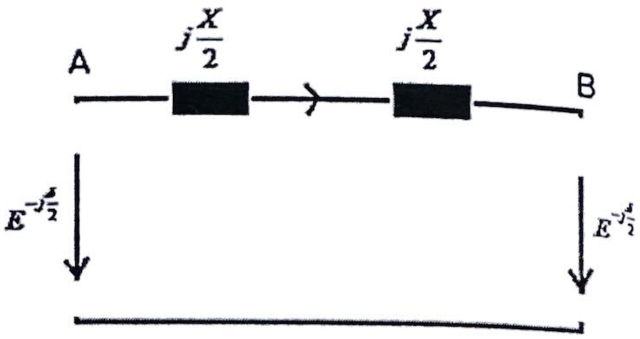

Fig. A 2.1: Simplified Line Model

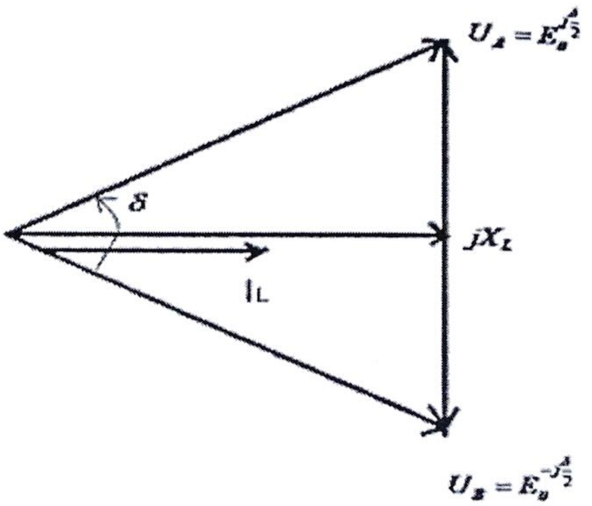

Fig. A2.2: Phasor diagram

It is assumed that the resulting reactance of the transmission line is big compared with the source impedances, in order that the bus voltages may be regarded as stiff voltages sources. It is further assumed that the amplitudes of the bus voltages are equal (E) and that a phase difference between the voltage phasors is S. Under these circumstances the current flowing in the transmission line is given by equation A2.3.

$$I_L \quad \frac{2jE\sin\frac{}{2}}{jX} \quad \frac{2E\sin\frac{}{2}}{X} \tag{A2.2}$$

The current, being real, is in phase with the voltage in the electrical midpoint of the line. The power flowing on the line is then given by the product of the current and the voltage in the midpoint and it equals, P as given by equation A2.3.

$$P = I_L U_m = \frac{2E\sin\frac{\delta}{2}\,E\cos\frac{}{2}}{X} = \frac{E^2\sin\delta}{} \qquad \text{(A2.3)}$$

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