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Transient Stability Improvement Of Power System With Phase Shifting Transformer

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ABSTRACT: Transient stability of a power system is concerned with the system's ability to remain in synchronism after the disturbance is cleared. Occurrence of a fault in a power system causes transients. The disturbances subjected to the system may be occurrence of fault, sudden change in load etc. This paper describes the improvement of transient stability with phase shift insertion by phase shifting transformer. A 3-phase to ground fault is created on the line to analyze the effect of fault and to find the critical clearing time. Then by inserting phase-shifting transformer, a series of simulations are carried out to find the appropriate angle of PST to achieve rotor angle stability using MiPower Software.

Keywords: Phase-shifting transformer (PST), Transient stability, MiPower Software.

1 INTRODUCTION

Over the past decade, the scenario of the power industry has gone under significant change. The increase in power consumption has demanded higher requirements from the power industry that has led to numerous changes including deregulation in many countries. It is essential for generating companies to plan their operations efficiently, so as to minimize their operating cost. Generation and distribution of power must be accomplished at minimum cost with maximum efficiency which involves scheduling of real and reactive power in such a way to minimize the total operating cost of the system. In this paper we are trying to improve transient stability of the system by controlling the active and reactive power flow by using Phase Shifting Transformer (PST). The control of active power flow is achieved by adjusting the phase angle of the voltages at the phase-shifting transformer terminals. A winding in series with a network branch is used to insert the regulated voltage that, when added with the appropriate phase to the source terminal phase-to-neutral voltage, sets up the desired direction of the active power flow between the transformer terminals.In the modern era, power system stability has become an important aspect in power system operation & control. Developed society of today need an ever-increasing supply of electrical power and the demand has been increasing every year. The planning, construction and operation of such system become exceedingly complex. Successful operation of a power system depends on the load feeding ability of a power system without any perturbations. Rotor angle stability is one of the main concerns in the power system stability. Ideally, the loads must receive reliable power supply at constant voltage and frequency.

II. PRINCIPLE OF OPERATION OF A PHASE SHIFTER

The phase shifter is installed in a transmission line between two buses as shown in the fig.1, the power system external to the phase shifter is represented by voltage phasors Vs and V_R and the corresponding impedances Zs and Z_R respectively[1]-[2]. Power circuitry of the phase shifter is comprised of

- Exciting Transformer
- Boosting Transformer
- Converter circuit

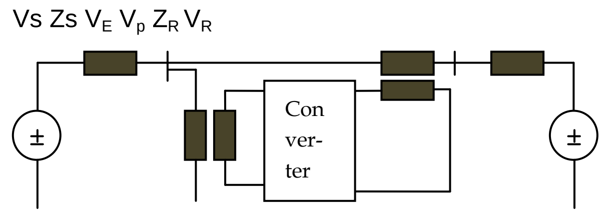

Fig1: *Two-machine power system with a phase angle regulator*

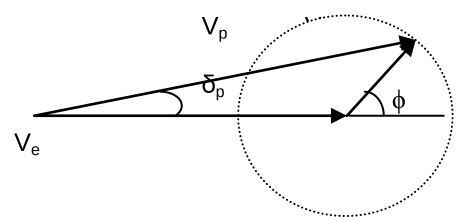

Fig2: *Phasor diagram*

Phasor relationship among V_E, V_P and V_B is also illustrated in the fig. 2.The circle identifies a region where the tips of V_P and V_B can be located. Magnitude and the relative phase angle of the injected voltage i.e $|V_B|$ and ϕ are used to control voltage at bus B and real power transfer, p of the line shown by equation 1 below.

$$P = (|V_S||V_R|/X_{cq}) \sin(\delta_S - \delta_R - \delta_p) \quad (1)$$

Where X_{cq} is the net equivalent reactance of the line, δ_S and δ_R are phase angles of phasors V_S and V_R. Based on the above equation the angle δ_P is the dominant variable for power flow control. The range of angle δ_P that a phase shifter can provide, primary depends on the characteristics of the converter circuitry. The converter section of a conventional phase shifter comprises mechanical switches, which are usually embedded within the exciting transformer and may not be readily identifiable as a separate unit. A conventional phase shifter can vary the angle δ_P approximately within $\pm 30^\circ$ in discrete steps of about 1 or 2 degrees.

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III. PHASE ANGLE CONTROL BY PST

In practical power system, it occasionally happens that the transmission angle required for the optimal use of a particular line would be incompatible with the proper operation of the overall transmission system. Phase shifter or phase angle regulation is frequently applied when power between two buses are intertied whose prevailing angle difference is insufficient to establish the desired power flow[3].

$P= (V^2/X) \sin(\delta \pm\sigma)$ (2)

Consider the circuit shown which represents the equivalent circuit of a transmission line shown in fig.3 .

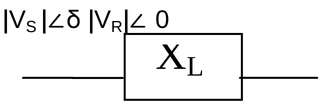

Fig.3

V_s= Sending end voltage
V_R=Receiving end voltage
X_L= Line impedance
X_P = PST impedance
δ = Load angle
α= Phase shifting angle
It can be shown that the real(P) & reactive power(Q) flow at the receiving end and sending end are given by [10]-[12]
$P=(Vs.Vr/X_L).\sin \delta$ (3)
$Q=(Vs^2- Vs.Vr.\cos \delta)/X_L$ (4)

After the insertion of PST in the line as shown in fig.4:

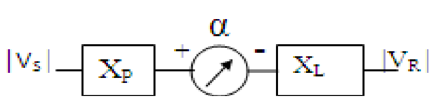

Fig.4

$P=(Vs.Vr/(X_L + X_P)).\sin (\delta +\alpha)$ (5)

$Q=(Vs^2- Vs.Vr.\cos (\delta+\alpha))/(X_L + X_P)$ (6)

Therefore, by changing PST angle we can regulate the active power flow[4]. Benefits of utilizing PST in electrical transmission systems can be summarized as follows:

- Reduction of overall system losses through the elimination of loop flows.
- Increased stability of the system.
- Better power flows in all the transmission lines.
- Improvement of circuit power factor.
- Control over Active & Reactive power.
- Increased power transfer capability.

PSTs built for transmission grids are generally a three-phase, two-terminal pair design. PSTs are effective and capable of increasing power transfer capability of line, as thermal limits permits, while maintaining the same degree of stability. An Interconnected power network is frequently subjected to the disturbances like short circuits. This may cause the loss of synchronism of the generators. This paper describes the improvement of the power transmission capacity of the network with the help of PST. Before the fault occurs, the power flow the line is shifted to other lines by PST, the transient stability of the system can be improved by restraining the tripping of the generator which improves the power transmission capacity of the network[5]-[6].

IV.TRANSIENT STABILITY

The phase shift insertion causes the decrease in effective power angle between the machine and infinite bus bar from δ and δ- α as shown in fig.5 [7]. The equations corresponding to these angles are

$P=(Vs.Vr/X_L).\sin \delta$ (7)

$P=(Vs.Vr/X_L).\sin(\delta - \alpha)$ (8)

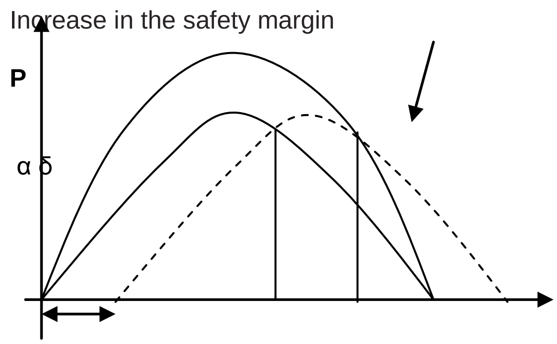

Fig.5:*Transient stability with Phase shift α*

V. DESIGN ASPECTS OF PST

Phase-shifting transformer design consists of symmetric phase-shifting transformers and asymmetric phase-shifting transformers. These are the most conventional design used in power systems applications. In Symmetric phase-shifting transformers, the amplitudes of the no-load winding voltages do not change during the phase shifting operation whereas in asymmetric phase-shifting transformer, amplitude of the no-load winding voltages varies. Asymmetric phase-shifting transformer works in three modes:

1) **In phase Voltage Boosting:** In this mode of operation, the injected voltage is in phase with line to neutral voltage. It will have an impact on the reactive power only, because here we are controlling the magnitude of the voltage.
2) **Quadrature voltage boosting**: In this mode of operation, injected voltage has a phase of ± 90°. It will have an impact on real power flow.
3) **Voltage injection at 60° phase shift**: In this mode of operation, injected voltage will be at 60° leading or lagging to line to neutral voltage. It will have an impact on both real and reactive power flow.

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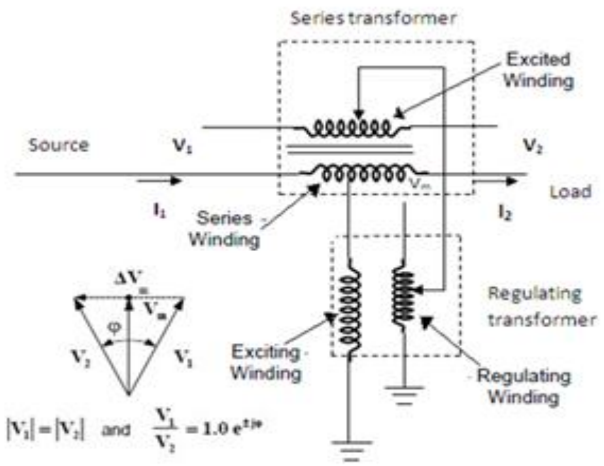

***Fig.6:**Symmetric-Phase-shifting-Transformer*

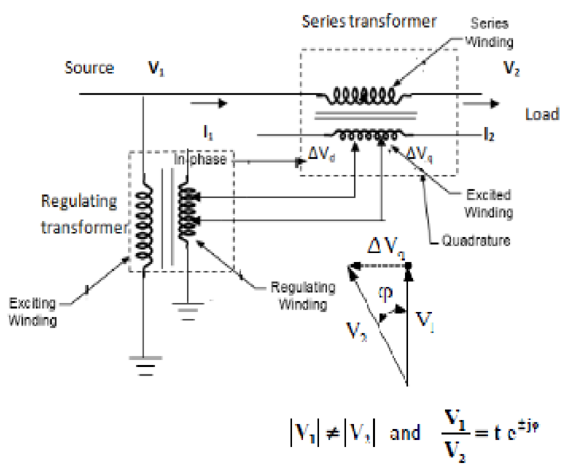

***Fig.7:** Asymmetric Phase-shifting transformer*

VI.INTRODUCTION TO MiPower SOFTWARE

MiPower is the state-of-the-art Windows based Power Systems Software. **MiPower** is highly interactive, user-friendly software for all analysis, planning, design and simulation of any given Power System irrespective of the geographical and environmental constraints. **MiPower** is widely used by Consultants, Power utilities, State Electricity Authorities and Academic & Research Institutes for **more than a decade**. **MiPower** is armed with robust power system engine in the backend and a lucid top-notch Windows GUI in the front-end. Approach, technique & methodology employed are field proven & time-tested. These conforms with standard **ANSI, IEEE, IEC** and other world wide accepted standards. All power system data is centrally maintained with an industry standard relational database. It helps in dealing with a wide range of power system problems.

VII. SYSTEM FOR STUDIES

A 3-unit six-bus model system has been considered for the simulation studies as shown in Fig.8. The line impedance and parameters of each generator are shown in table A1 of appendix. The loads connected at bus 1, 2 and 3. All the further studies are done considering this system as the base system [8].

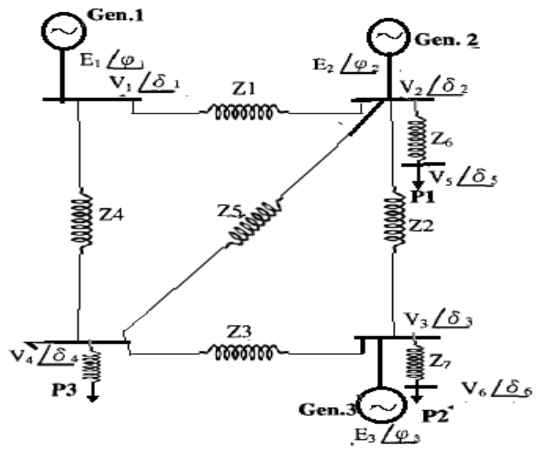

***Fig.8:**Six-bus model System*

Table 1& 2 show the results of the load flow study on the model system mentioned.

***Table 1:** Bus Voltages*

Items / Bus	Injection power (in pu)	Voltage (in pu)
1	2.770	1.0
2	2.0	1.0
3	0.5	0.9763
4	1.520	0.9616
5	1.920	0.9878
6	1.760	0.9591

***Table 2:** Loading Pattern of Transmission Lines*

Items / Lines	Power flows (in pu)
Line 12	0.948
Line 23	0.872
Line 34	0.391
Line 41	1.821
Line 42	0.128
Line 25	1.920
Line 36	1.759

Table 1& 2 show the results of the load flow study on the model system mentioned.

VIII. TRANSIENT STABILITY ANALYSIS

With reference to the base system as shown in Fig.8, a 3-phase fault is simulated in line-12 the effect of this fault on the transient stability is analyzed. Repeated studies are done with the increase of fault clearing time, Tcr varying from 1.1s to 1.7s & accordingly swing curve is plotted and analyzed. At Tcr = 1.65s, The generator 2 at bus 2 is falling out of synchronism as shown in fig 9 [9].

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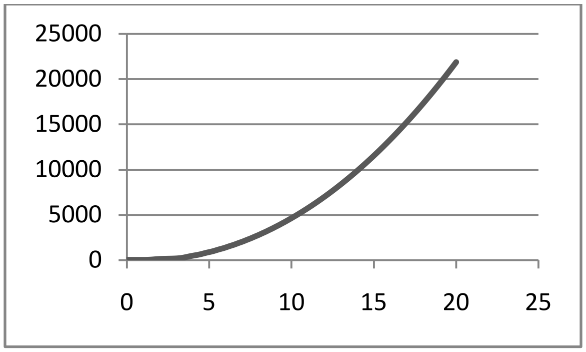

Fig. 9: *swing curve at Tcr=1.65s*

To retain the generator back to its stable position, a PST is allocated in the line-12 as shown in fig 10.

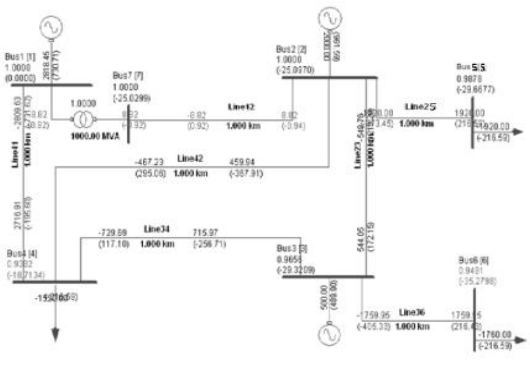

Fig 10: *system with PST in line-12*

It gets stabilized at an Phase shifting angle of 10°, 20°& 25°. At 20° of phase shift the swing curve is shown in Fig. 11.

Graph plotted (load angle v/s time)

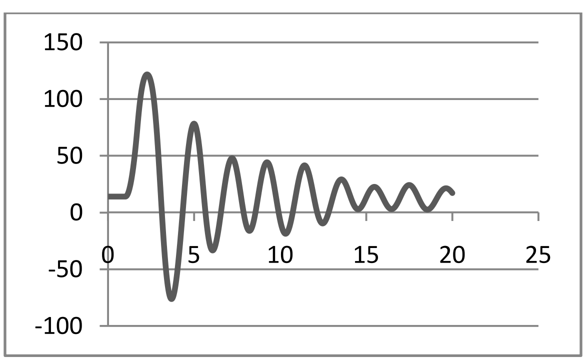

Fig 11: *swing curve at 20°*

Further with the reduction of fault clearing time, the study is repeated. The system retains the stability without the allocation of PST as shown in fig.12.

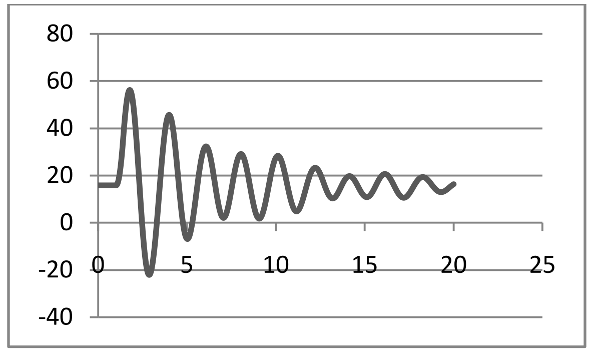

Fig 12: *swing curve at Tcr=1.4s*

IX.CONCLUSION

With the above studies, it is evident that PST improves the transient stability of the power system by shifting the boundary points of the stability limit. Further, the power transfer capability of the system can be improved. The enhancement of the studies can be done to check the dynamic performance of PST.

X. APPENDIX

TABLE A1

(i) Line impedance and the line length of the model system

Unit / line	Impedance [pu]	Length [km]
Z1	0.0185+j0.185	152
Z2	0.0135+j0.135	108
Z3	0.0221+j0.225	180
Z4	0.0110+j0.110	88
Z5	0.0210+j0.210	167
Z6	0.0+j0.041	33
Z7	0.0+j0.054	43

Base $_{MVA}$=1000MVA V_{base}=500kV f_{max}=50 Hz

(ii) Generator parameters

Items / Unit	Rated capacity[pu]	Inertial constant [MJ/MVA]
Gen.1	5.0	200
Gen.2	2.0	50
Gen.3	0.5	50

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