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Modelling & Performance Comparison Of Different Types Of SSSC-Based Controllers

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Abstract

This paper presents some new & different types of SSSC controller & compare their performance for different types of faults during transient conditions to improve the voltage level of a large scale power system. In this method, the network differential equations were replaced by a set of algebraic equations at a fixed frequency which dramatically reduced the simulation time. Moreover, this paper contributes to the improvement of transient stability of multi-machine machines power system system by using different types of SSSC controllers i.e. POD, PI, PID, PLL & generic controller. The system response was simulated and evaluated during single and three phase faults applied to the terminals. This work is presented to improve the voltage stability & Damp out the oscillation by using SSSC with & without controllers & compare their performance to enhance the stability of power system. Simulation results show that SSSC with controllers enhance the stability of multi-machine power system effectively.

Keywords- *Static Series Synchronous Compansator (SSSC), voltage regulator, PI,POD,PID, generic controller, IGBT, MATLAB Simulink.*

1. Introduction

Stability improvements is very important for large scale power system. SSSC is one of the important members of FACTS family which can be installed in series in the transmission lines[1]. Traditionally, fixed or mechanically switched shunt and series capacitors, reactors and synchronous generators were being used to damped out oscillation[2]. However, there are some restrictions as to the use of these conventional devices. For many reasons desired performance was being unable to achieve effectively[3]. A SSSC is an electrical device for providing fast-acting reactive power compensation on high voltage transmission networks and it can contribute to improve the voltages profile in the transient state[5]. A SSSC can be controlled externally by designing PI, PID, POD, PLL & generic controller which can improve the dynamic & steady state performance of a large scale power system. The dynamic nature of the SSSC lies in the use of thyristor devices (e.g. GTO, IGCT) [4].Therefore, this paper presents thyristor based SSSC controllers to improve the performance the multi-machine power system.

2. Control Concept Of SSSC

the SSSC does not use any active power source, the injected voltage must stay in quadrature with line current. By varying the magnitude V_q of the injected voltage in quadrature with current, the SSSC performs the function of a variable reactance compensator, either capacitive or inductive. The variation of injected voltage is performed by means of a Voltage-Sourced Converter (VSC) connected on the secondary side of a coupling transformer. The VSC uses forced-commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesize a voltage $V_{\_conv}$ from a DC voltage source that shown in fig.1[6].

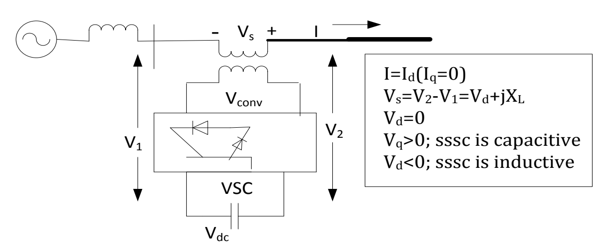

Fig.1 Connection diagram of SSSC with transmission Line

A capacitor connected on the DC side of the VSC acts as a DC voltage source. A small active power is drawn from the line to keep the capacitor charged and to provide transformer and VSC losses, so that the injected voltage Vs is practically 90 degrees out of phase with current I. In the control system block diagram V_{d_conv} and V_{q_conv} designate the components of converter voltage V_{q_conv} which are respectively in phase and in quadrature with current.
The control system consists of:-

A phase-locked loop (PLL) which synchronizes on the positive-sequence component of the current I. The output of the PLL (angle T=wt) is used to compute the direct-axis and quadrature-axis components of the AC three-phase voltages and currents (labeled as V_d, V_q or I_d, I_q on the diagram).Measurement systems measuring the q components of AC positive-sequence of voltages V_1 and V_2 (V_{1q} and V_{2q}) as well as the DC voltage V_{dc}. AC and DC voltage regulators which compute the two components of the converter voltage (V_{d_conv} and V_{q_conv}) required to obtain the desired DC voltage (V_{dcref}) and the injected voltage (V_{qref}). Fig.2 represents that control concept[6]. The V_q voltage regulator is assisted by a feed forward type regulator which predicts the $V_{\_conv}$ voltage from the I_d current measurement.

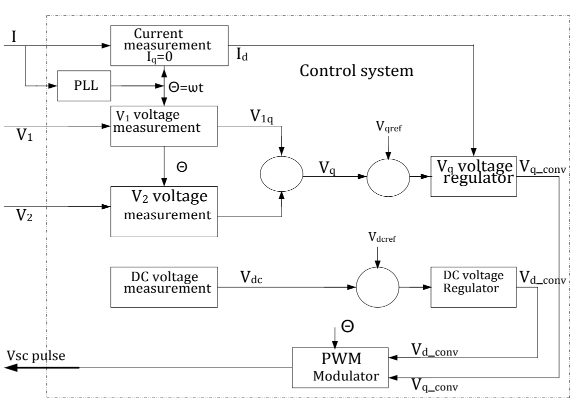

Fig.2 SSSC based control system

3. Power System Model With SSSC

This example described in this section illustrates modeling of a simple transmission system containing 2-hydraulic power plants [Fig.2]. The power grid consists of two power generation substations and one major load center at bus B3.Complete simulink model is shown in Fig.3.

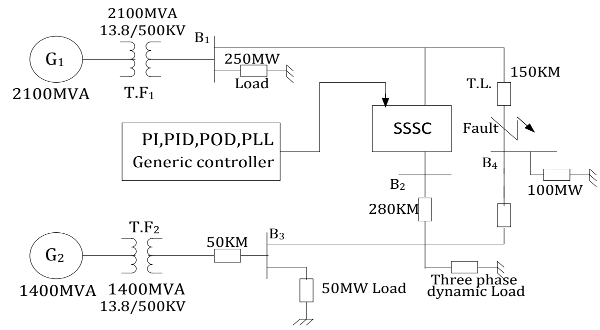

Fig.2 Single line diagram of 2-machine power system with different types of SSSC controller

The first power generation substation (G_1) has a rating of 2100 MVA, representing 6 machines of 350 MVA and the other one (G_2) has a rating of 1400 MVA, representing 4 machines of 350 MVA. The load center of approximately 2200 MW is modeled using a dynamic load model. The generation substation G_1 is connected to this load by two transmission lines L_1 and L_2. L_1 is 280-km long and L_2 is split in two segments of 150 km in order to simulate a three-phase fault at the midpoint of the line. The generation substation G_2 is also connected to the load by 50-km line (L_3). When the SSSC is bypass, the power flow towards this major load is as follows: 664 MW flow on L_1 (measured at bus B_2), 563 MW flow on L_2 (measured at B_4) and 990 MW flow on L_3 (measured at B_3). The SSSC, located at bus B1, is in series with line L1. If it has a rating of 100MVA then it is capable of injecting up to 10% of the nominal system voltage. This SSSC is a phasor model of a typical three-level PWM SSSC. Machine, POD & SSSC parameters value was taken from reference[6].

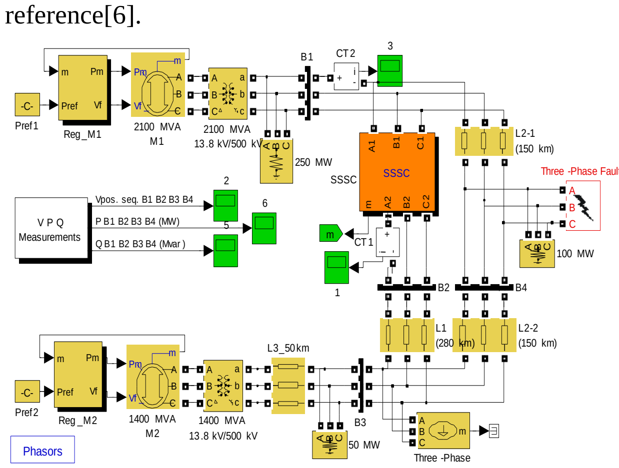

Fig.3 Complete simulink model (without SSSC controller)

3.1. Simulation Results: Two types of faults: 3.1.1Single line to ground fault & 3.1.2 Three-phase faults have been considered.

3.1.1 Single line to ground fault: During single line to ground fault occurred at 0.1s & circuit breaker is opened at 0.2s (3-phase 4-cycle fault),If no SSSC is used then system becomes unstable[Fig.3(a)].But, If SSSC is applied then system voltage becomes stable within 0.65s[Fig.3(b)].

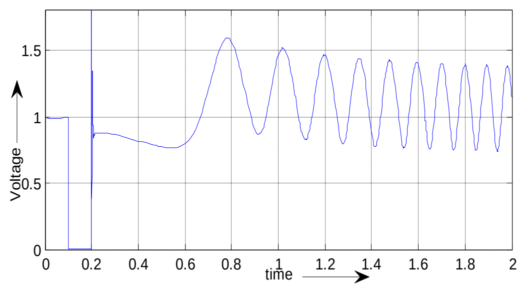

Fig.3(a) Bus voltage(B_1) in p.u.(without SSSC)

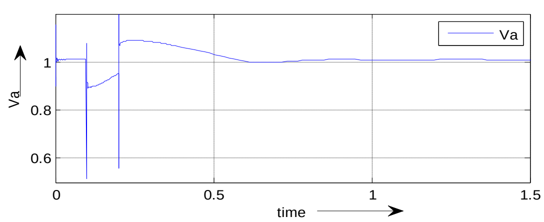

Fig.3(b) Bus voltage(B_1) in p.u for 1-phase fault (with SSSC)

3.1.2 Three-phase faults: During 3-phase faults, If SSSC is applied then at t=0.7s system voltage becomes stable within 6% damping[Fig.3(c)].

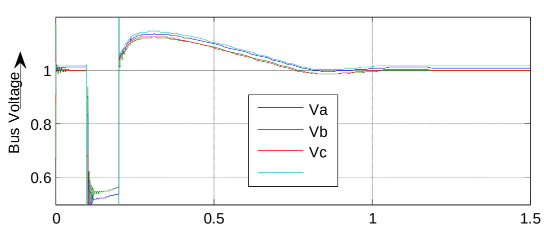

Fig.3(c) Bus voltages in p.u for 3-phase faults

4. SSSC Model with PI controller

SSSC with proportional Integral (PI) controller is shown in Fig.4. The angular speed deviation dω & mechanical power P_m has been taken as an input parameter. When any faults occurred in the network ,then both machines angular speed dω mechanical power P_m & bus voltages will be changed & oscillated. But, when SSSC with PI controller is applied then all parameters becomes stable & it's performance becomes higher then without controller.

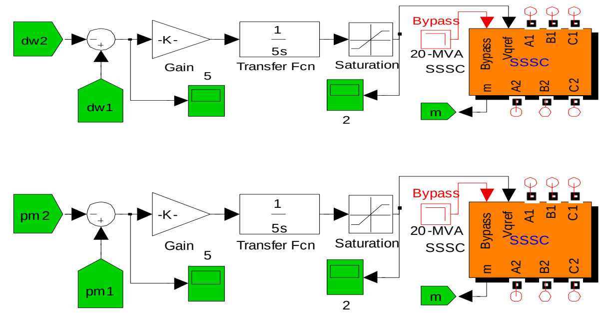

Fig.4 Simulink diagram of SSSC P.I. controller

4.1 Simulation Results: Here also two types of faults: 4.1.1 Single line to ground fault & 4.1.2 Three-phase faults have been considered.

4.1.1 Single line to ground fault: If PI controller is used as SSSC controller then, the system oscillation (delta dω or p_m) becomes stable within 8s with 0.01% damping[Fig.4(a)] & Bus voltage becomes stable within 0.6s with 0% damping [Fig.4(b)].

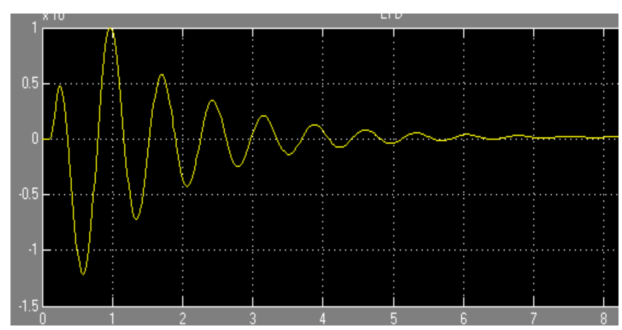
Fig.4(a) Oscillation, V_{qref} in pu for 1-phase faults

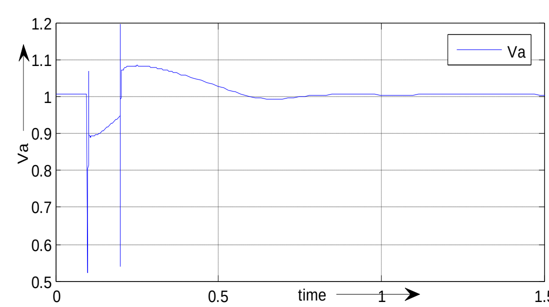

Fig.4(b) Bus voltage in P.U. for 1-phase faults

4.1.2 Three-phase faults: Machines Oscillation (delta dω or delta p_m) becomes stable within 7s with 0.01% damping[Fig.4(c)] & Bus voltage becomes stable within 0.85s with 0% damping [Fig.4(d)]

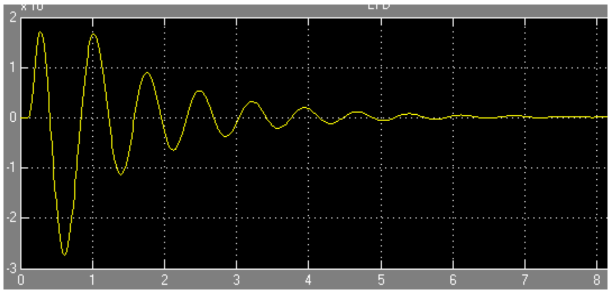

Fig.4(c) Oscillation, V_{qref} in pu for 1-phase faults

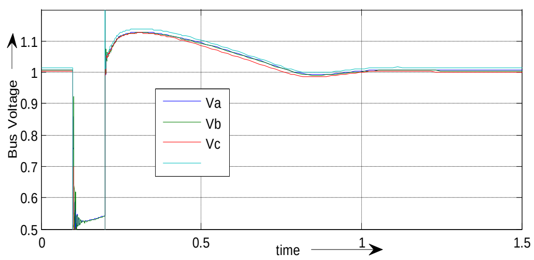

Fig.4(d) Bus voltages (in p.u.) for 3-phase faults

5. SSSC Model with PID controller

Proportional Integral Derivative(PID) controller is one of the most power full controller which takes angular speed deviation(dω),mechanical power difference P_m as input & after taking successively multiplication ,integration & derivative, the parameters related with this network becomes stable. The PID controller simulink model is shown in Fig.5

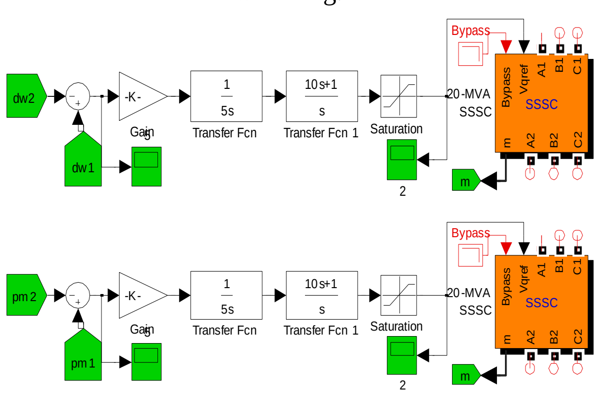

Fig.5 Simulink model of SSSC with PID controller

5.1 Simulation Results: Two types of faults has been considered.

5.1.1 Single line to ground fault: During 1-phase faults, the system oscillation (delta dω or p_m) becomes stable within 7s with 0.01% damping[Fig.5(a)] & Bus voltage becomes stable within 0.6s with 0% damping [Fig.5(b)].

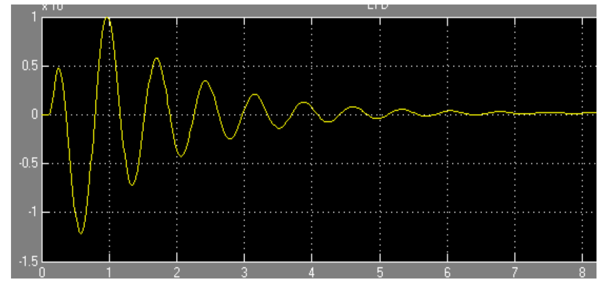

Fig.5(a) Oscillation, V_{qref} in pu for 1-phase faults

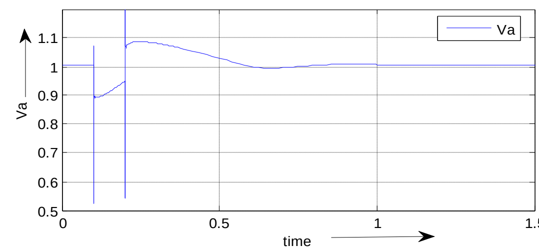

Fig.5(b) Bus voltage(B_1) in p.u for 1-phase fault

5.1.2 Three-phase faults: During 3-phase faults, Oscillation (delta dω or delta p_m) becomes stable within 7s with 0.01% damping[Fig.5(c)] & Bus voltage becomes stable within 0.7s with 0% damping [Fig.5(d)]

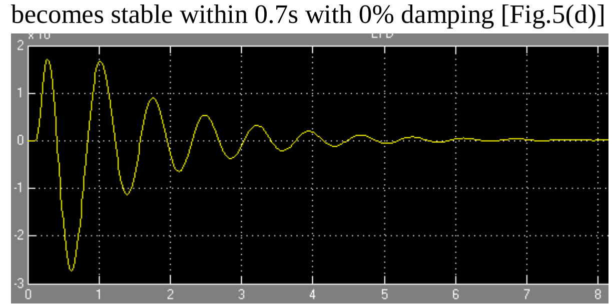

Fig.5(c) Oscillation, V_{qref} in pu for 3-phase faults

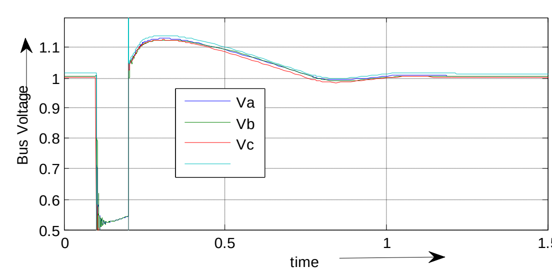

Fig.5(d) Bus voltages (in p.u.) for 3-phase faults

6. SSSC Model with POD controller

Power Oscillation Damping (POD) controller is also one of the most power full control system Which externally injects V_{qref} to the SSSC. The POD controller consists of an active power measurement system, a general gain, a low-pass filter, a washout high-pass filter, a lead compensator, and an output limiter. All parameter values has been taken from [6].

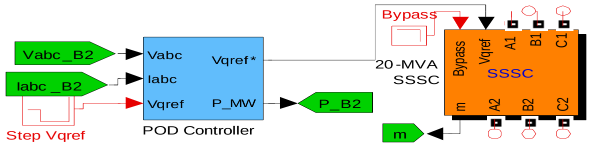

Fig.6 Simulink model of SSSC with PID controller

6.1 Simulation Results:

Two types of faults has been considered.

6.1.1 Single line to ground fault: During 1-phase faults, the system power becomes stable within 0.2s with 0.05% damping[Fig:6(b)] & Bus voltage becomes stable within 0.52s with 0.05% damping [Fig.6(a)].

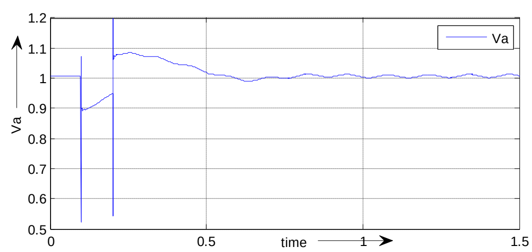

Fig.6(a) Bus voltage(B_1) in p.u. for 1-phase fault

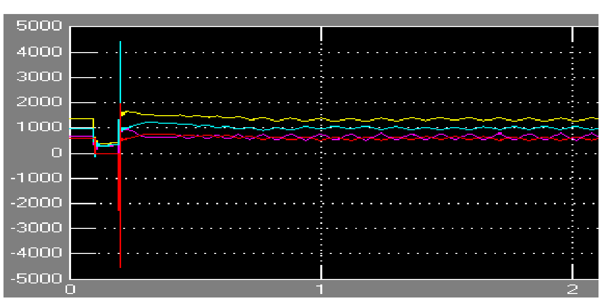

Fig:6(b)Bus power (MW) for 1-phase fault

6.1.2 Three-phase faults: During 3-phase faults, System power becomes stable within 0.2s with 0.05% damping[Fig:6(d)] & Bus voltage becomes stable within 0.8s with 0% damping [Fig.6(c)]

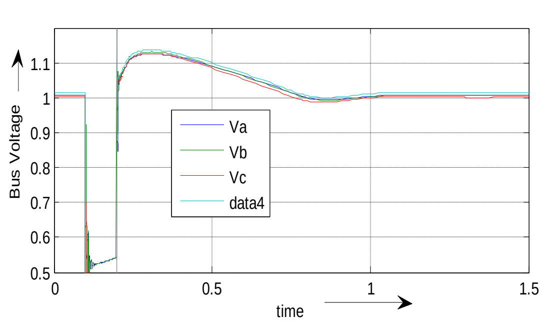

Fig.6(c) Bus voltage(B_1 B_2 B_3) in p.u. for 3-phase faults.

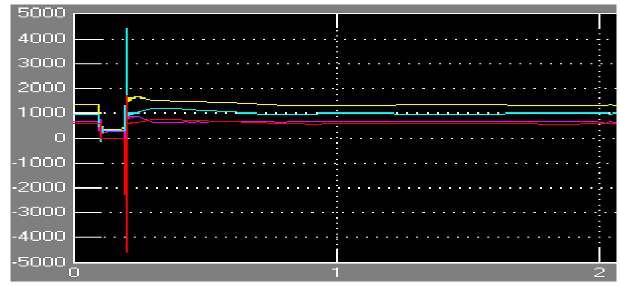

Fig.6(d) Bus power (MW) for 3-phase fault

7. SSSC Model with Generic controller

The block diagram of generic SSSC controller is shown in Fig:7

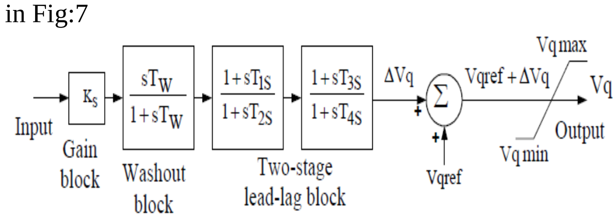

Fig. 7 Generic SSSC controller block diagram

The input of this controller is also the speed deviation of two machines & deviation of P_m. Here, T_ω=10,T_2=T_4=0.3 has been taken as constant & gain,K,T_1 & T_3 can be selected by properly trail & error methods. For this network, the optimum value was, K=65.49,T_1=0.5527 & T_3=0.2563.

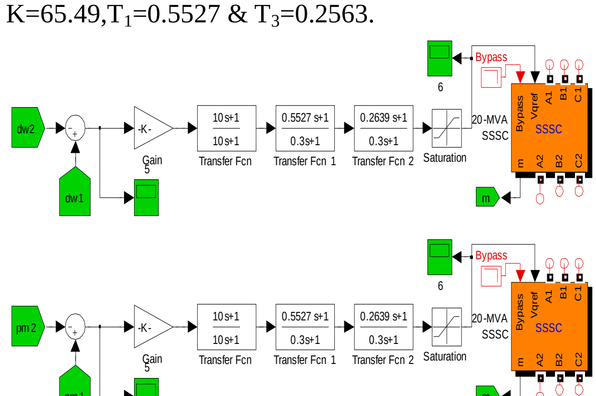

Fig.8 Simulink model of generic SSSC controller

7.1 Simulation Results:

Two types of faults has been considered.

7.1.1 Single line to ground fault: During 1-phase faults, if PI controller is used as SSSC controller then, the system oscillation (delta dω or p_m) becomes stable within 2s with 0% damping[Fig:8(a)] & Bus voltage becomes stable within 0.6s with 0% damping [Fig.8(b)].

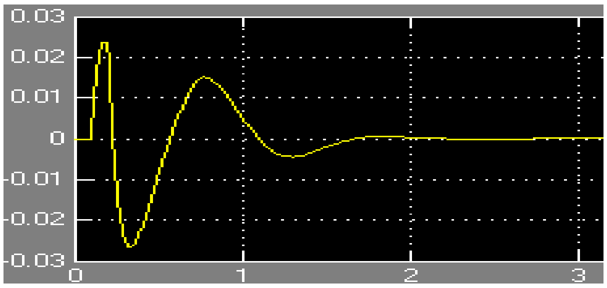

Fig.8(a) Oscillation, V_{qref} in pu for 1-phase faults

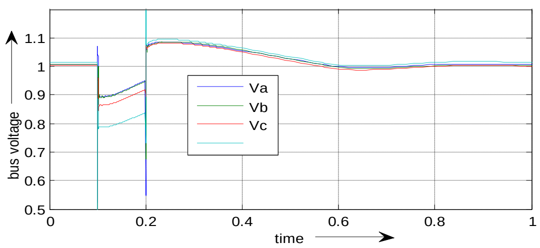

Fig.8(b) Oscillation, V_{qref} in pu for 3-phase faults

7.1.2 Three-phase faults: During 3-phase faults, Oscillation (delta dω or delta p_m) becomes stable within 2.2s with 0% damping[Fig:8(c)] & Bus voltage becomes stable within 1s with 0% damping [Fig.8(d)]

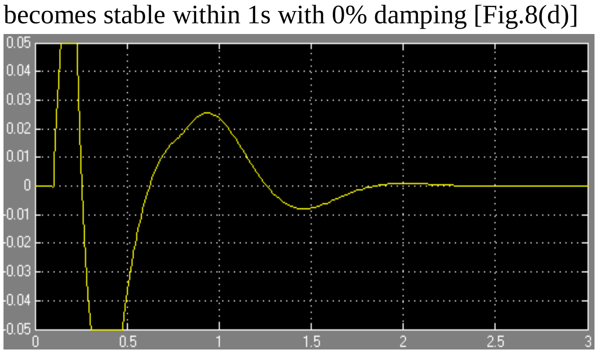

Fig.8(c) Oscillation, V_{qref} in pu for 3-phase faults

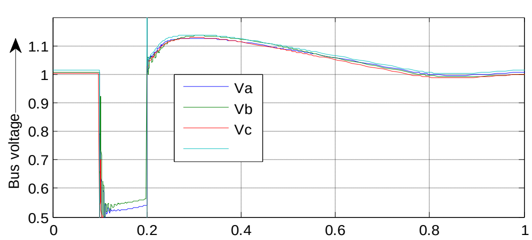

Fig.8(d) Bus voltages (in p.u.) for 3-phase faults

8. Results & Discussions

The performance of different types of SSSC controller taking same 500KV transmission line are summarized below. In this table SSSC rating is represents in MVA, Syatem stability time is in Seconds, Damping is in percentage(%).

Table-I

Performance Comparison of SSSC with Controllers

		Stability Time			Damping	
Controller	SSSC Rating	**Volt (3ph)**	**Volt (3ph)**	**V_{qref}**	Volt (max)	**V_{qref}(min)**
Without	100	0.6s	0.7s	No	5%	0%
PI	80	0.6s	0.8s	8s	11%	0.01
PID	50	0.6s	0.7s	6.5	9%	0.01
POD	30	0.52s	0.8s	No	9%	No
Generic	20	0.55s	0.6s	2s	8%	0%

9. Conclusion

In this paper, the voltage level of two machines power system has been improved by using SSSC with different types of controller for 1-phase & 3-phase faults by Phasor simulation method. Same 500KV transmission line has been simulated & observed the transient response for different types of SSSC controller. Above all, SSSC with Generic controller is very suitable because of shorter stability time, small damping, small rating of SSSC , All controller parameters has been selected by trial & error methods normally, but those parameters can be selected by FSO, Neural network or Genetic algorithm techniques. Those controllers special advantages is that it can be used any robust multi-machine power system network with very easily & cheaply. In this paper, only dω & pm has been taken as input parameters of those controllers. But when any fault occurred, then voltage, current, power, p_m, dω everything will change. So, future work should be taken all of the above parameters as input parameters of those controllers & controller parameters can be tuned with any newly deigned algorithm.

10. References

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