Using Power System Stabilizers (Pss) And Shunt Static Var Compensator (Svc) For Damping Oscillations In Electrical Power System

Dr. Hussein Thani Rishag
Department of Electromechanical Engineering,
University of Technology/Baghdad

Abstract:

The power system stabilizer (PSS) is a control device provides a maximum power transfer and optimal power system stability. PSS has been widely used to damp electromechanical oscillations that occur in power systems due to disturbances. If no adequate damping is available, the oscillation will increase result in instability case. Shunt static var compensator (SVC) is also used to improve system stability because of its role in decreasing the reactive power in electrical transmission lines.

This paper presents an application of (SVC) in electrical transmission lines and PSS in two areas, two generator test power system. Using mat lab software to design and implements control system and study the effect of damping oscillations in stability power system after proposed faults in transmission lines of research model that used (PSS - generic & multiband) types and automatic voltage regulator (AVR).

Keywords:Power System Stabilizer (PSS), Shunt Static Var Compensator (SVC), Automatic Voltage Regulator (AVR), Transient Stability.

أستخدام موازن نظام القدرة (PSS) والمعوضات الساكنة المتوازية (SVC) لإخماد التذبذبات في منظومة القدرة الكهربائية

د. حسين ثاني رشك
قسم الهندسة الكهروميكانيكية/ الجامعة التكنولوجية

المستخلص:

يعتبر موازن نظام القدرة (PSS) احد اجهزة السيطرة التي تجهز منظومة القدرة بأعظم قدرة نقل واستقرارية مثالية لنظام القدرة. يستخدم موازن نظام القدرة (PSS) بنطاق واسع لإخماد التذبذبات الكهروميكانيكية التي تحدث في نظام القدرة بسب ب الاضطرابات وإذا لم يتوفر نظام اخماد في المنظومة فان التذبذبات سوف تزداد مما يقود النظام الى حالة عدم الاستقرارية.

كذلك تستخدم المعوضات الساكنة المتوازية (SVC) لزيادة استقرارية النظام بسبب دورها في تقليل القدرة المفاعلية الموجودة في خطوط النقل الكهربائية.

يقدم البحث الحالي تطبيق المعوضات الساكنة المتوازية (SVC) في خطوط النقل الكهربائية وموازن نظام القدرة (PSS) في نظام سيطرة المولد لمنطقتي عمل ومولدي اختبار نظام القدرة، استخدم برنامج ماتلاب لتصميم وتنفيد نظام ودراسة تاثير اخماد التذبذبات في استقرارية نظام القدرة بعد افتراض اعطال في خطوط النقل موديل البحث الذي يستخدم سيطرة موازن نظام القدرة العام والمتعدد (PSS - generic & multiband) وسيطرة تنظيم الفولتية (AVR).

1. Introduction

Instability problems are mainly caused by the power and, frequency and voltage oscillations in the interconnected power system network. Damping of these oscillations in interconnected power system are essential for both a secure and stable operation of the system in addition to high gain excitation system with AVR will damp out the oscillations of low frequency (0.2 to 2.5 Hz). This is important to improve a steady state stability rather than dynamic stability. [1]

The excitation system and turbine governor are some of the systems that are used to control power generation at desired level in complexity power systems (systems that use continuing growth in interconnections which works with new technologies and controls in highly stressed conditions), in addition, increasing of power oscillation can cause collapse of these power system.

In systems work with PSS we must study the concepts of power system stability, excitation system of a single generator, Automatic Voltage Regulator (AVR) and Power System Stabilizer (PSS). In this paper and depending on the above information, we will describe and illustrate modeling of transmission system containing two power plant in addition to using Static Var Compensator (SVC) and Power System Stabilizers (PSS) to improve and damp oscillation of power and frequency. [2]

2. Power System Oscillation

In an interconnected power system, the synchronous generators should rotate at the same speed and the power flows over tie-lines which change according to the changes loads and systems situation should remain constant under normal operating conditions. The oscillations of low electromechanical frequency which occurred in case of disturbance can be observed in most power system variables like bus voltage, line current, generating rate and power. Power system oscillations will be observed in interconnected systems that provide more generation capacity to a power system. These interconnected systems observed to swing against each other at frequencies of around (1-2 Hz). Damper windings on the generator’s rotor were used to prevent the amplitude of oscillations from increasing. After high gain excitation systems that prevent the generators from loosing synchronism following a system is fault, it was noticed that this kind of excitation system always tends to reduce the damping of the system oscillations. Power System Stabilizers (PSS) which is the excitation system based damping controllers defined as the ability of an electric power system for a given initial operating condition to regain a state of operating equilibrium after being subjected to a physical disturbance with all system variables bounded so that the system integrity is preserved. [3]

Power system oscillations are generally associated with the dynamics of generators, turbine governors and excitation systems and can be represented by the linearized swing equations (1, 2) of a synchronous generator around an operating condition as follows: [4]

$$\frac{d}{dt}\Delta\omega_r = \frac{1}{2H}(\Delta T_m - \Delta T_e - D\Delta\omega_r) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

$$\frac{d}{dt}\Delta\delta = \omega_0\Delta\omega_r \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Where:
$\Delta\omega_r$: is the speed deviation of the generator (radians/sec).
$\Delta\delta$: is the rotor angle deviation (radians).
$\omega_{0:}$ is the base rotor electrical speed (radians/second).
T_m, Te: are the mechanical torque and electrical torque, respectively.
H: is the inertia of the generator.
D: is the inherent damping coefficient.

The electrical torque can be further represented as equation (3):

$$\Delta Te = K_S(s)\Delta\delta + K_D(s)\Delta\omega_r \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

Where (K_S) and (K_D) are synchronizing and damping torques, respectively. They are sensitive to generator operating conditions, power system network parameters, and excitation system parameters. By substituting (2) and (3) into (1), with $\Delta T_m = 0$, we obtain:

$$\frac{2H}{\omega_0}\Delta\delta^{\cdot\cdot} + (D + K_D)\Delta\delta^{\cdot} + K_S\Delta\delta = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

The characteristic for equation (4) is given by:

$$S^2 + \frac{K_D + D}{2H}S + \frac{K_S\omega_0}{2H} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5)}$$

The standard work of system can be described in this text so: for the system to be stable, (K_D+*D*) and (*K_S*) have to be positive. If (*K_S*) is negative, the system will have at least one positive real root and the generator will slip out of synchronism without any oscillation. If (K_D+*D*) is negative, the system will have at least one root with positive real part. Normally, the effect of AVR in an excitation system with moderate or high response is to introduce a positive synchronizing torque component and a negative damping torque component. Therefore, (*K_S*) is positive and (K_D+*D*) could be negative. In the case of (K_D+*D*) being negative, the system will have complex roots with

positive real parts and exhibit oscillations with increasing magnitude. This paper explores the controller designs for enhancing the damping of low frequency power oscillations. [5]

3. Stability Power System Concept

Power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact. Definitions of stability can be studied with the rigorous mathematical theory of stability of dynamic systems so voltage & frequency stabilities and inter-area oscillations which become a greater concern of systems stability than in the past and must be understood with the definition and classification of power system stability. A clear understanding of different types of instability and how they are interrelated is important to achieve a satisfactory design and operation of power system stabilizer. As well, consistent use of terminology is required for developing system design and operating criteria, standard analytical tools, and study procedures. Power system stability is similar to the stability of any dynamic system, and has fundamental mathematical underpinnings. [6, 7]

4. The Static Var Compensator (Svc) Concepts:

a- Static Var Compensator (SVC) Description

The static var compensator (SVC) is a shunt device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow and improve transient stability on power grids. [8]

The SVC regulates voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the SVC generates reactive power (SVC capacitive). [9]

When system voltage is high, it absorbs reactive power (SVC inductive). The variation of reactive power is performed by switching three-phase capacitor banks and inductor banks connected on the secondary side of a coupling transformer. Each capacitor bank is switched on and off by three thyristor switches (Thyristor Switched Capacitor or TSC). Reactors are either switched on-off (Thyristor Switched Reactor or TSR) or phase-controlled (Thyristor Controlled Reactor or TCR). [10, 11]

b- Single-Line Diagram of SVC and its Control System

Figure (1) shows a single-line diagram of a static var compensator and a simplified block diagram of its control system which consists of:

i) A measurement system measuring the positive-sequence voltage to be controlled. A fourier-based measurement system using a one-cycle running average is used.

ii) A voltage regulator that uses the voltage error (difference between the measured voltage Vm and the reference voltage Vref) to determine the SVC susceptance B needed to keep the system voltage constant.

iii) A distribution unit that determines the TSCs (and eventually TSRs) that must be switched in and out, and computes the firing angle α of TCRs.

iv) A synchronizing system using a Phase-Locked Loop (PLL) synchronized on the secondary voltages and a pulse generator that send appropriate pulses to the thyristors.

[12, 13, 14]

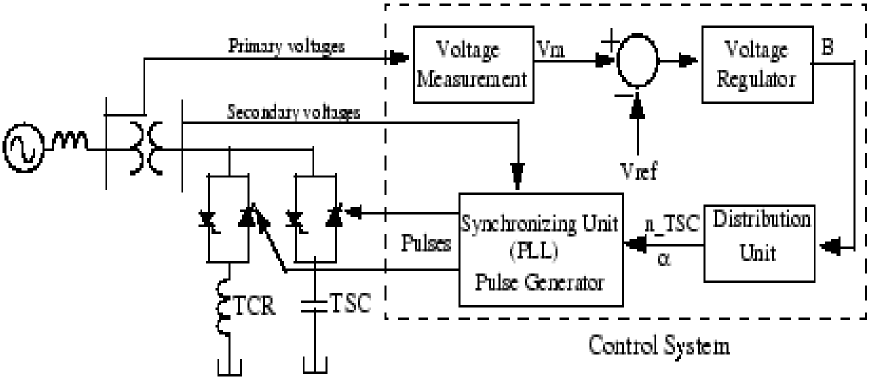


Figure (1): The single-line diagram of SVC control system

5. Power System Modeling

Power system used in this research is addressed by sets of structural and function subdivisions. These subdivisions precisely reveal the interrelations/interactions among the individual components as well as the computational structure for describing real large power systems. Modern power systems are characterized by complex dynamic behaviors owing to their size and complexity. [15]

Any modeling of these power systems should have background knowledge in order to understand the actual processes that take place in the power system in order to design a power system stabilizer as effective as possible. [16]

6. The Excitation Control

The basic function of an exciter is to provide a dc source for field excitation of a synchronous generator. A control on exciter voltage results in controlling the field current, which, in turn, controls the generated voltage. When a synchronous generator is connected to a large system where the operating frequency and the terminal voltages are largely unaffected by generator, its excitation control causes its reactive power output to change. In older power plants, a dc generator, also called an exciter, was mounted on the main generator shaft. A control of the field excitation of the dc generator provided a controlled excitation source for the main generator. In contrast, modern stations employ either a brushless exciter (an inverted 3-phase alternator with a solid-state rectifier connecting the resulting dc source directly through the shaft to the field windings of the main generator) or a static exciter (the use of a station supply with static rectifiers).

An excitation-control system employs a voltage controller to control the excitation voltage. This operation is typically recognized as an Automatic Voltage Regulator (AVR), figure (2). [17]

Because an excitation control operates quickly, several stabilizing and protective signals are invariably added to the basic voltage regulator. A Power-System Stabilizer (PSS) is implemented by adding auxiliary damping signals derived from the shaft speed, or the terminal frequency. Figure (3) shows the functionality of an excitation-control system. [18, 19]

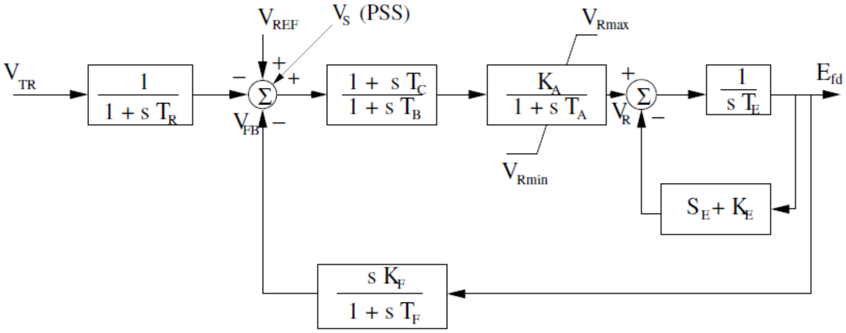


Figure (2): AVR and exciter model for synchronous generator

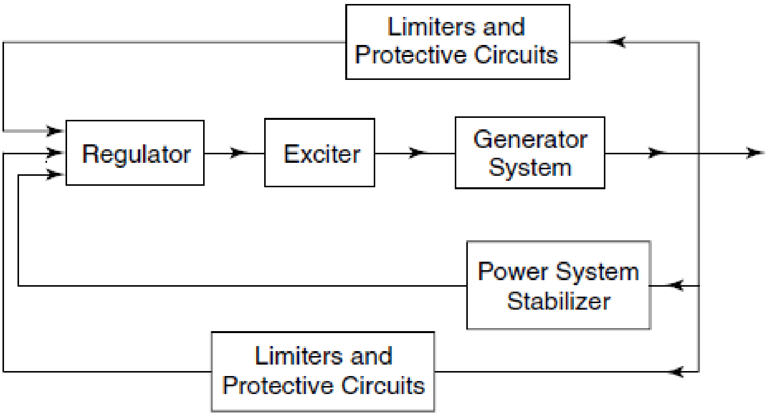


Figure (3): A conceptual block diagram of a modern excitation controller

7. Power System Stabilizer Pss Model

A PSS is an additional control block used to enhance the system stability. This block is added to the AVR, and uses stabilizing feedback signals such as shaft speed, terminal frequency and/or power to change the input signal of the AVR. The three basic blocks of a typical PSS model, are illustrated in figure (4). The first block is the stabilizer Gain block, which determines the amount of damping.

The second is the Washout block, which serves as a high-pass filter, with a time constant that allows the signal associated with oscillations in rotor speed to pass unchanged, but does not allow the steady state changes to modify the terminal voltages. The last one is the phase compensation block, which provides the desired phase-lead characteristic to compensate for the phase lag between the AVR input and the generator electrical (air-gap) torque; in practice, two or more first-order blocks may be used to achieve the desired phase compensation.

The PSS is designed to introduce an electrical torque in phase with the rotor speed variations (damping torque). This is achieved by a supplementary stabilizing signal ΔV_S applied to the automatic voltage regulator (AVR) of the generator as shown in figure (5). This figure also exemplifies the PSS basic structure to promote phase compensation to the phase lag introduced by generator, excitation system and transmission system. Basically, this controller is composed of a static gain K_{pss} which is adjusted to obtain the desired damping for unstable or poorly damped modes. The time constant T_w represents in washout block with range of (1 to 20 seconds) so it works as a filter for low frequencies (0.8 to 2 Hz). The time constants T_1, T_2, T_3 and T_4 defined in two blocks lead-lag of the input signal. [20]

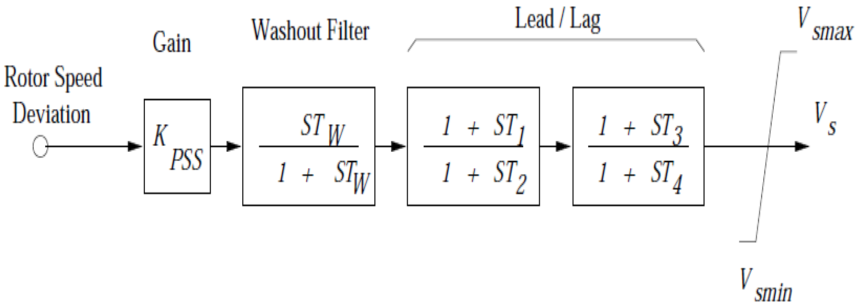


Figure (4): Basic block PSS diagram

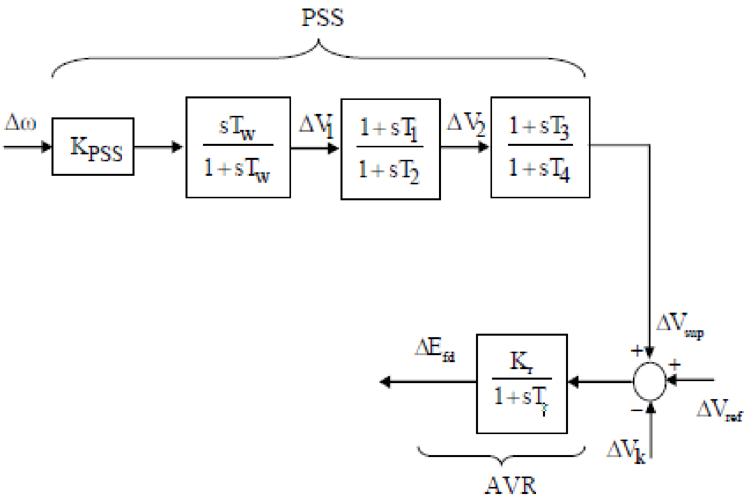


Figure (5): (PSS) Basic structure and supplementary signal to (AVR).

8. Test System

This paper describes and illustrates the modeling world system of two generators, three bus-bar, two transmission lines (250 & 400) km between two area systems (G, AVR & PSS) and shunt static var compensation which are simulated in mat lab Toolbox, ver 8 (R 2009 a). In addition the load center is modeled by a (5000 MW) resistive load which is fed by the remote of (1000 MVA - plant G_1) and a local generation of (5000 MVA - plant G_2). A load flow has been performed on this system for G_1 and G_2 with generating rate of (950 MW & 4046 MW) respectively while the line carries (944 MW) which is closed to its surge impedance loading (SIL = 977 MW). The shunt compensated used in this research is with rate of (200 Mvar) to maintain system stability after faults. The SVC does not have a power oscillation damping (POD) unit.

G_1 and G_2 are equipped with a Hydraulic Turbine and Governor (HTG), excitation system, and Power System Stabilizer (PSS). The single line diagram to interconnect the two area systems shown in figure (6). G_1 and G_2 are provided with additional control components which consist of turbine governor, excitation system and power system stabilizer. Two standard types of stabilizer models can be connected to the excitation system: *Generic* model using the acceleration power (Pa which is the difference between mechanical power (Pm) & electrical output power (Peo)) and *Multiband* model which use a speed deviation (dw).

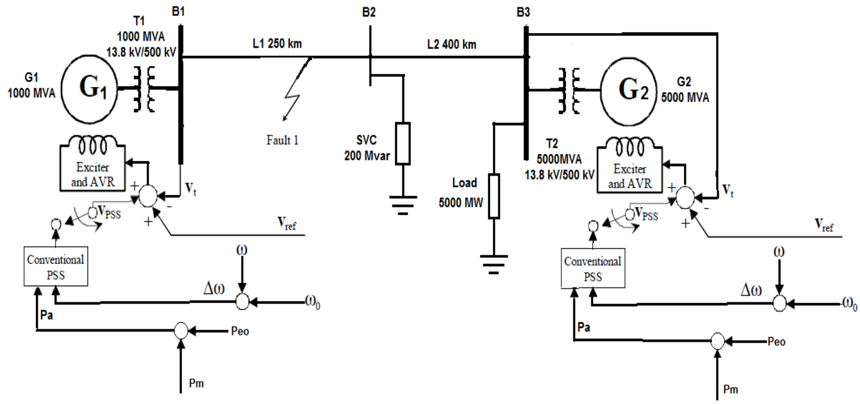


Figure (6): Single line diagram to interconnect the two area system

9. Simulation And Calculation Results

The model used in this research which has 2-G, 3-bus-bar and two area systems is modeled in mat lab. G_1 is simulated with defined of (PV) generation bus (V=13800 V, P=950 MW) while G_2 is simulated with defined of swing bus (V=13800 V, 0 degrees). The effect of PSS (*Generic* & *multiband*) and SVC on system stability are simulated after 3-phase fault occurred on (L_1) of the system used in this research at (t=0.3 s). The fault is cleared at (t=0.5 s).

Figure (7) shows the results without in impact PSS and SVC for stabilizing the model. Tables (1, 2) contain the analysis steady –state voltages, currents and research load flow.

Figure (8) shows the effect of PSS type *generic* without the effect of SVC when 3-phase fault occurred on (L_1) at (t=0.3 s) and cleared at (t=0.4 s) where the voltages (V_{B1}, V_{B2}, V_{B3}) are stable to (1p.u) after cleared fault (t=0.4 s) figure (8-a). Figure (8-b) shows the effect of PSS and line power stable (950 MW) on transmission line. Figure (8-c) shows the rotor angle difference theta 1-2 stable (43°) after cleared fault (t=0.4 s). Figure (8-d) shows the machine speeds (w_1, w_2) for G_1

& G_2 respectively which reached to (1 p.u). Figure (8-e) shows the positive-sequence terminal voltage (V_{t1} & V_{t2}) which reached to (1 p.u). Figure (8-f) shows the voltage at SVC bus-bar. Figure (8-g) shows susceptance (B) SVC which is constant at zero.

Figure (9-a & b) shows the effect of PSS type *multiband* without effect of SVC when 3-phase fault occurred on (L_1) at (t=0.3 s) and cleared at (t=0.4 s) with rotor angle difference theta 1-2 and machine speeds (w_1, w_2) for G_1 & G_2 respectively.

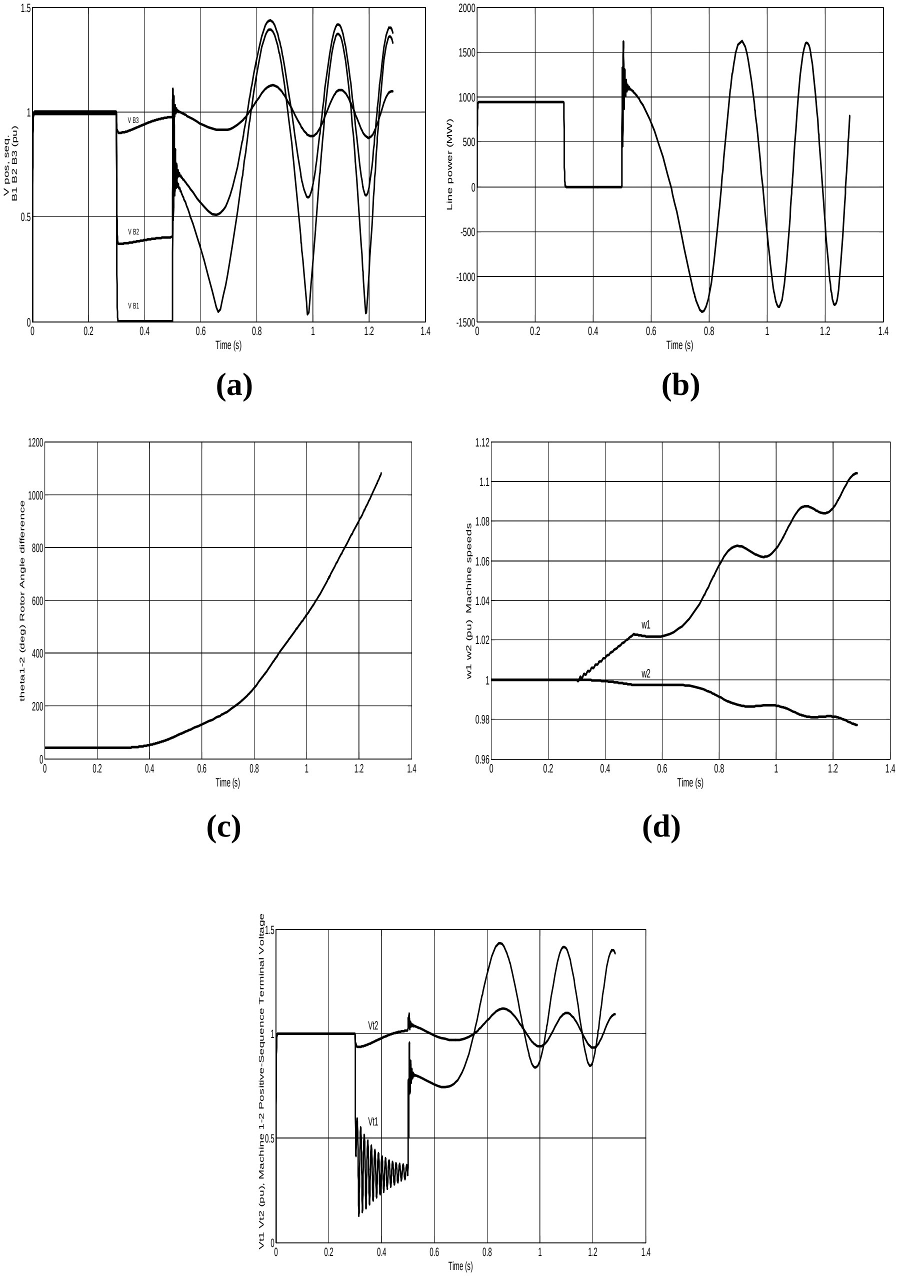
Figure (10) shows the effect of PSS *generic* type with effect of SVC when 3-phase fault occurred on (L_1) at (t=0.3 s) and cleared at (t=0.4 s) where the voltages (V_{B1}, V_{B2}, V_{B3}) are stable to (1p.u) after cleared fault (t=0.4 s) figure (10-a). Figure (10-b) shows the effect of PSS and line power stable (1000 MW) on transmission line. Figure (10-c) shows the rotor angle difference theta 1-2 stable (42°) after cleared fault (t=0.4 s). Figure (10-d) shows the machine speeds (w_1, w_2) for G_1 & G_2 respectively which reached to (1 p.u). Figure (10-e) shows the positive-sequence terminal voltage (V_{t1} & V_{t2}) which reached to (1 p.u). Figure (10-f) shows the voltage at SVC bus-bar which is constant at (1 p.u). Fig (10-g) shows susceptance (B) SVC which reached to zero.

Table (1)
Steady – State Voltages And Currents

Bas-Bur	Voltage in phase A (V)	Voltage in phase B (V)	Voltage in phase C (V)	Current in phase A (A)	Current in phase B (A)	Current in phase C (A)
B_1	**407920.30∟62.39°**	**407919.39∟57.61°**	**407920.11∟177.61°**	**1548.81∟67.16°**	**1548.81∟52.84°**	**1548.81∟172.84°**
B_2	**409014.34∟47.62°**	**409013.41∟72.38°**	**409013.92∟167.62°**	**1516.69∟51.20°**	**1516.69∟68.80°**	**1516.69∟171.20°**
B_3	**404882.73∟24.43°**	**404882.04∟95.57°**	**404882.16∟144.43°**	**6607.59∟155.74°**	**6607.57∟84.26°**	**6607.57∟35.74°**

Table (2)
The Machine Load Flow

Machine	G_1 1000 MVA	G_2 5000 MVA
Nominal	1000 MVA 13.8 kV rms	5000 MVA 13.8 kV rms
Bus Type	P&V generator	Swing generator
Van phase	38.92°	Van phase: 0.00°
Vab	13800 Vrms [1 pu] 68.92°	13800 Vrms [1 pu] 30.00°
Vbc	13800 Vrms [1 pu] -51.08°	13800 Vrms [1 pu] -90.00°
Vca	13800 Vrms [1 pu] -171.08°	13800 Vrms [1 pu] 150.00°
Ia	39766 Arms [0.9505 pu] 37.05°	1.6974e+005 Arms [0.8114 pu] -5.86
Ib	39766 Arms [0.9505 pu] -82.95°	1.6974e+005 Arms [0.8114 pu] -125.86°
Ic	39766 Arms [0.9505 pu] 157.05°	1.6974e+005 Arms [0.8114 pu] 114.14°
P	9.5e+008 W [0.95 pu]	4.036e+009 W [0.8072 pu]
Q	3.1075e+007 Vars [0.03108 pu]	4.1437e+008 Vars [0.08287 pu]
Pmec	9.5258e+008 W [0.9526 pu]	4.0454e+009 W [0.8091 pu]
Torque	9.7029e+007 N.m [0.9526 pu]	4.1206e+008 N.m [0.8091 pu]
Vf	1.4557 pu	1.4054 pu

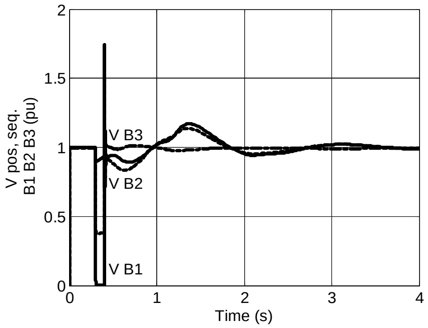


(a) (b)

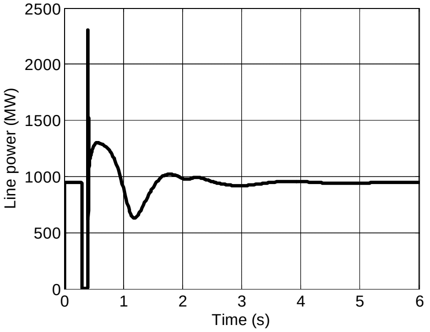
(c) (d)

(e)

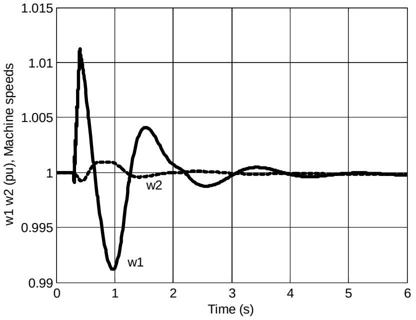
Figure (7): Three-phase fault in (L_1) without control (PSS) and (SVC)


V pos, seq.
B1 B2 B3 (pu)
V B3
V B2
V B1
2
1.5
1
0.5
0
0
1
2
3
4
Time (s)

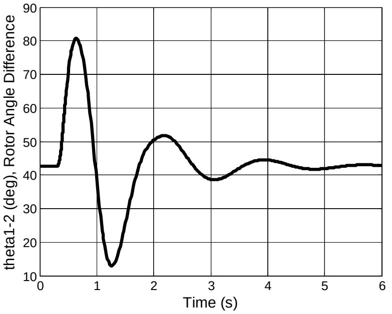
(a)


Line power (MW)
2500
2000
1500
1000
500
0
0
1
2
3
4
5
6
Time (s)

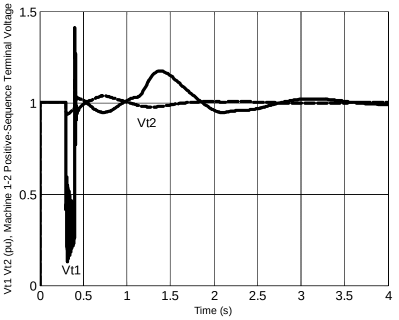
(b)


w1 w2 (pu), Machine speeds
1.015
1.01
1.005
1
0.995
0.99
w2
w1
0
1
2
3
4
5
6
Time (s)

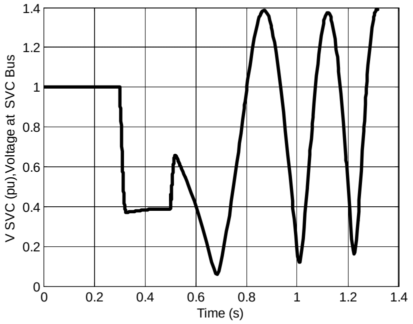
(c)


theta1-2 (deg), Rotor Angle Difference
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
Time (s)

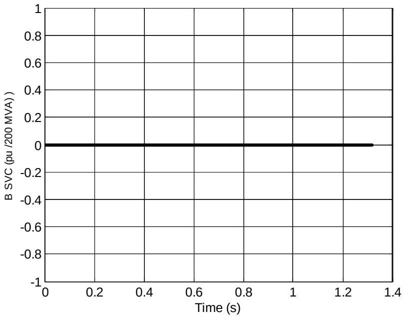
(d)


Vt1 Vt2 (pu), Machine 1-2 Positive-Sequence Terminal Voltage
1.5
1
0.5
0
Vt2
Vt1
0
0.5
1
1.5
2
2.5
3
3.5
4
Time (s)

(e)

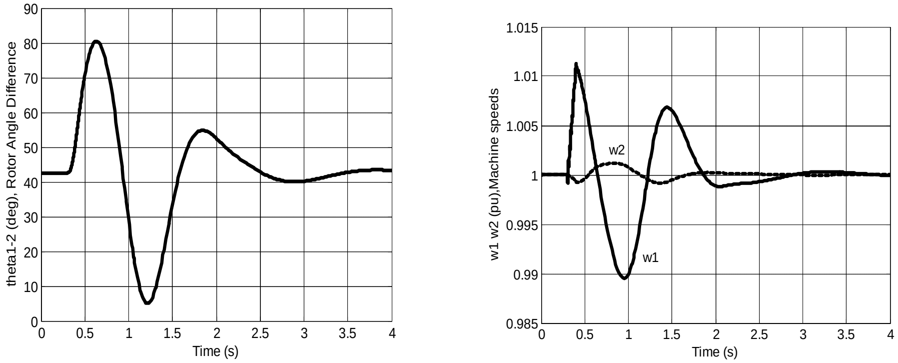

V SVC (pu),Voltage at SVC Bus
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Time (s)

(f)



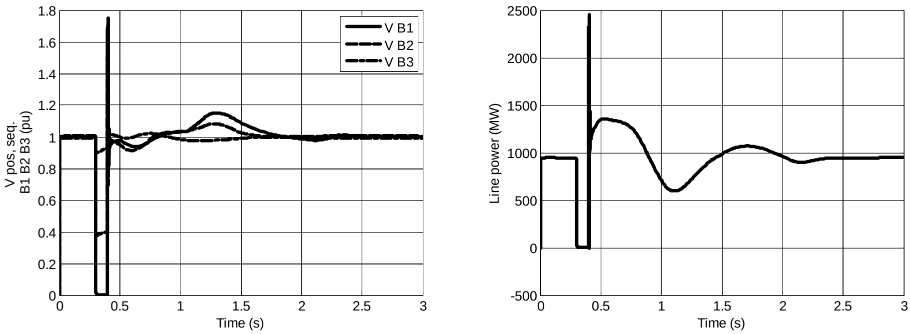
(g)

Figure (8): Three-phase fault in (L_1) with impact control (PSS) generic type and without (SVC)

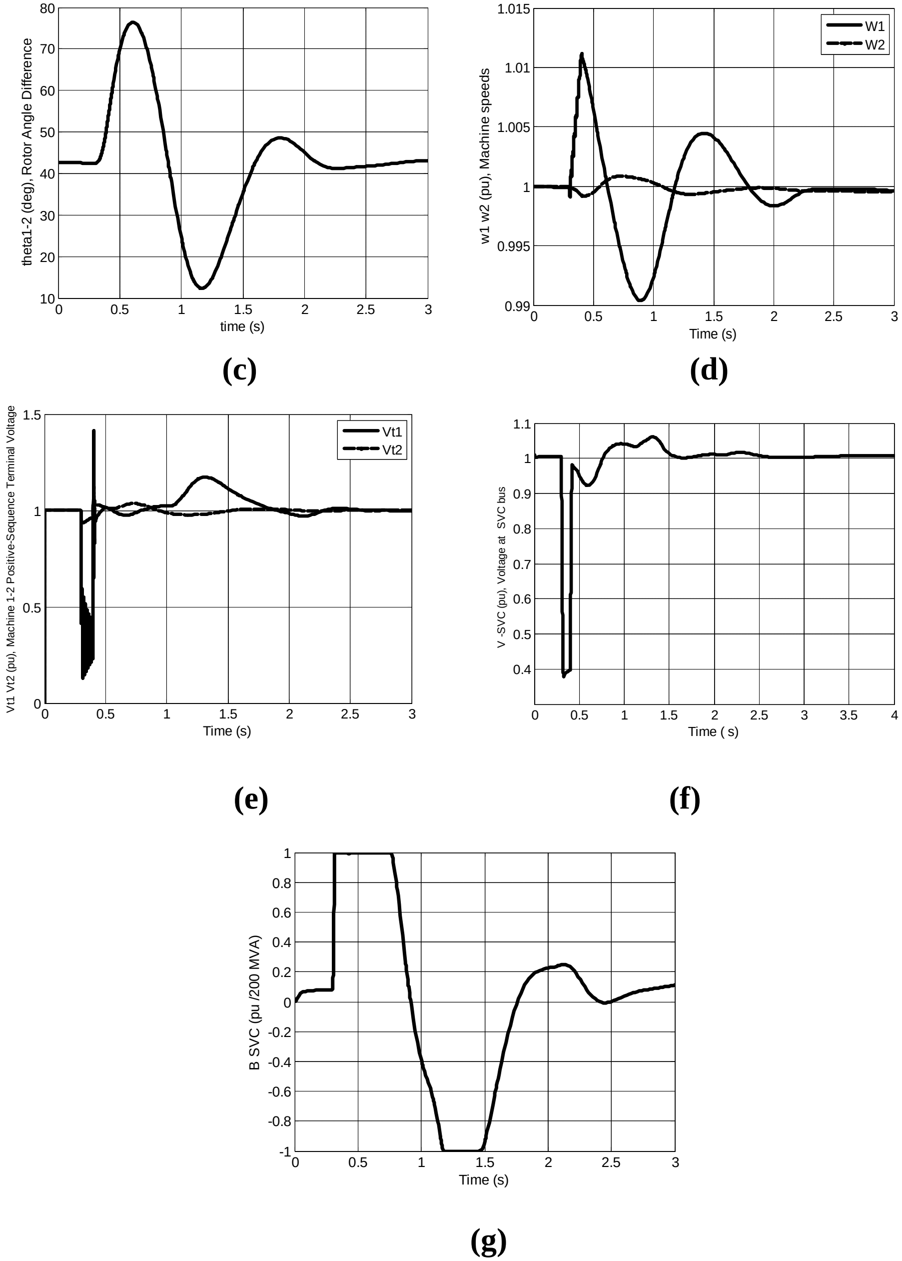


(a) (b)

Figure (9): Three-phase fault in (L_1) with impact (PSS) multi-band type and without (SVC)



(a) (b)



(c) **(d)**

(e) **(f)**

(g)

Figure (10): Three-phase fault in (L_1) with impact control (PSS) generic type and impact (SVC)

10. Conclusion

This paper proposed a model for power system stabilizer (PSS - generic & multiband) types and static var compensator (SVC) to improve transient stability. The basic structure of (PSS) is operating under typical control generator while the basic structure of (SVC) is operating under typical bus voltage control. The proposed controller is used (PSS) & (SVC) under abnormal system conditions.

From simulation results of proposed model we can conclude:

1) **The proposed model is oscillation and instable with absence effects of (PSS) & (SVC).**
2) **Using effects of (PSS) & (SVC) will increase the stability of proposed model after occurred and cleared faults.**
3) **The selective of (PSS) are capable of proving sufficient damping to the steady state oscillation and transient stability voltages performance over a wide range of operating conditions and various types of disturbances of the system used in proposed model.**
4) **Compare working two types of (PSS), the multiband type oscillation is quickly damped that which in generic type.**

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