Enhancement of Small Signal Stability of a Two-Machine System Using Power System Stabilizers (PSS) and Static Var Compensator (SVC)

Anazia Emmanuel A.[1], Abolaji Stephen K.[2], Kebiru Abu[3] and Comfort Ikpotokin[4]
[1] *Department of Electrical Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria*
[2, 3, 4] *Department of Electrical/Electronic Engineering Technology, Auchi Polytechnic, Auchi, Edo State, Nigeria*

Abstract: **This paper presents the enhancement of small signal stability of a two-machine system using power system stabilizer (PSS) and static var compensator (SVC). To achieve this, a power system stabilizer and static var compensator of a two-machine electric power system was modeled in MATLAB/SIMULINK environment and analyzed. A single-phase to ground fault was applied to the system at a response time of 5 seconds without the inclusion of the PSS and SVC. This process was repeated with inclusion of the power system stabilizer (PSS) and static var compensator (SVC) and the results noted. Also a three phase fault was initiated and response time noted. When a single phase fault is applied to the system, the speed of the generator stabilized at about 3seconds with the PSS in operation. The multiband (MB) PSS damped faster than the Generic (Pa) PSS. For a three phase fault, the generator speed stabilized at about 3.5 seconds and the voltage of the line normalized at 2 seconds. The results indicated an improvement in overall stability of the system using PSS and SVC with reduced response time.**

Keywords: **Stability, Compensator, Stabilizer, Oscillation, Transmission, Single Phase, Controllers, Power System**

I. INTRODUCTION

Today's world is continuously growing so that generation, distribution and transmission of power are also simultaneously required to increase in same manner to fulfill the requirement. Power system stability may be broadly defined as that property of a power system that enables it to remain in a state of operating equilibrium under normal operating condition and to regain an acceptable state of equilibrium after being subjected to a disturbance [1]. Stability of this system needs to be maintained even when subjected to large low-probability disturbances so that the electricity can be supplied to consumers with high reliability.

Certain system disturbances may cause loss of synchronism between a generator and the rest of the utility system, or between interconnected power systems of neighboring utilities [2]. Various control methods and controllers have been developed over time that has been used for this purpose. Recently, there has been a surge of interest in the development and use of FACTS controllers in power transmission systems.

These controllers utilize power electronics devices to provide more flexibility to AC power systems [3].

The most popular type of FACTS devices in terms of application is the SVC. This device is well known to improve power system properties such as steady state stability limits, voltage regulation, and damp power system oscillations [4]. The SVC is an electronic generator that dynamically controls the flow of power through a variable reactive admittance to the transmission network, also the SVC regulates voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system [5]. When system voltage is low the SVC generates reactive power (SVC capacitive). When system voltage is high, it absorbs reactive power (SVC inductive) [6]. It is known that the power-system stabilizers PSS for generators and the supplementary controllers for flexible AC transmission system (FACT) devices are efficient tools for improving the stability of power systems through damping of low frequency modes [7], where the frequency of these modes ranges from 0.2 to 2.5 Hz. Power System Stabilizer (PSS) devices are responsible for providing a damping torque component to generators for reducing fluctuations in the system caused by small perturbations. This aim of this paper is to incorporate power system stabilizers (PSS) and static var compensator (SVC) for the enhancement of small signal stability of a two-machine electrical power system.

This rest of the paper is organized as follows: Section II discusses stability and types of power system stability; Section III describes the application of two machine system using Sapele/Geregu power station as case study. Data presentation and results are presented in Section IV. We conclude the paper in section V by highlighting the main findings of the paper.

II. LITERATURE REVIEW

2.1 Stability

The tendency of a power system to develop restoring forces equal to or greater than the disturbing forces to maintain the state of equilibrium is known as Stability. If the forces tending to hold machines in synchronism with one another are sufficient to overcome the disturbing forces, the system is said to remain stable (to stay in synchronism).

The stability problem is concerned with the behavior of the synchronous machines after a disturbance. A large power system consists of a number of synchronous machines operating in synchronism. It is necessary that they should maintain perfect synchronism under all steady-state conditions. When the system is subjected to some form of disturbance, there is tendency for the system to develop force, to bring it to a normal or stable condition.

2.1.1 Types of Power System Stability

The stability of the power system is mainly divided into two types depending upon the magnitude of disturbances

- Steady state stability
- Transient stability

2.1.1.1 Steady-state stability – It refers to the ability of the system to regain its synchronism after slow and small disturbance which occurs due to gradual power changes. Steady-state stability is subdivided into two types

- *Dynamic Stability* – It denotes the stability of a system to reach its stable condition after a very small disturbance (disturbance occurs only for 10 to 30 seconds). It is also known as small signal stability. It occurs mainly due to the fluctuation in load or generation level.
- *Static Stability* – It refers to the stability of the system that obtains without the aid (benefit) of automatic control devices such as governors and voltage regulators.

2.1.1.2 Transient Stability – It is defined as the ability of the power system to return to its normal conditions after a large disturbance. The large disturbance occurs in the system due to the sudden removal of the load, line switching operations; fault occurs in the system, sudden outage of a line, etc.

2.2 Review of Related Works

In this section some selected research papers related to two area power system stability enhancement using PSS and FACTS controllers are reviewed as: Mahmud et al., (2013), described the real and reactive power flow control through a transmission line by placing a FACT (UPFC) device at sending end of an electrical power transmission system. Matlab/Simulink shows the performance of UPFC. Power flow control performance of UPFC was compared with other FACTS devices like SVC, STATCOM and SSSC.

Waldner and Erlich (2014), discussed the problem of designing the damping controller for low frequency oscillations in power system under dynamic uncertainty. They applied H mixed sensitivity technique to design robust damping controllers for unified power flow controller in uncertain conditions.

Nguimfack-Ndongmo et al., (2014), Presents a comprehensive review on the research and developments in power system stability enhancement using FACTS damping controllers. They discussed about the several technical issues that may create hindrance in FACTS devices installations. They conclude that with the use of FACTS controllers, maximum power can be transferred while maintaining dynamic stability and security.

Khalid (2015), described the analysis and enhancement of transient stability using shunt-controlled FACTS controllers. They briefly described that FACTS devices open up new opportunities for controlling power and enhancing the usable capacity in existing system. Results show the basic simulation of STATCOM for enhancing the transient stability of a two-machine system using Matlab. The system was simulated under three phase fault condition and transient stability was predicted before and after the use of FACT device i.e. STATCOM.

Anil kumar and Ramesh (2016), presented a review of enhancement of transient stability by FACTS devices. They also described about the coordination problem that likely to be occur among different control schemes. They investigate the system under fault conditions by using equal area criterion method.

Omar et al (2016), presents the effects of FACTS controller line compensation on power system stability. They described the effects of line compensation of SMIB power system using FC-TCR type TCSC or SVC for transient stability enhancement. They presented a novel method for analysis of line compensation by SVC. The maximum power transfer for a line depends on degree of compensation. The results indicate the effectiveness of SVC for stability enhancement is increased if the degree of compensation is increased.

Bian et al (2016), described the improvement in power system transient stability with an off-center location of shunt FACTS devices. Their study deals with the placement of Shunt FACTS devices to improve the transient stability of a long transmission line with predefined direction of real power flow. They proved the validity of mid-point location of shunt FACTS devices.

Milla and Duarte-Mermoud (2016), presents the application of FACTS controllers in power system for enhances the power system stability. They predicted different kind of stabilities with various FACTS devices. He presents the current status of research and developments in the field of the power system stability such as rotor angle stability, frequency stability, and voltage stability enhancement by using different FACTS controllers in an integrated power system network.

Kunju Muhammed et al., (2016), present the transient stability using UPFC and SVC. They thoroughly described the damping of power system oscillations after a three phase fault and also analyze the effect of UPFC and SVC on transient stability performance of power system. They developed a general program for transient stability studies using modified portioned approach. The modeling of SVC and UPFC were studied and tested on a 10-generator, 39-bus, and New England test generator. Results indicate that the SVC helps in improving the system performance by improving critical clearing time.

Kose and Irmak (2016), presented the use of FACTS devices for power system stability enhancement. They thoroughly describe the research on the development of new techniques for analysis and control of power systems using flexible AC transmission systems (FACTS) devices for both voltage and transient stability time frames. Results indicate that the FACTS devices are widely used to increase system stability margins by permitting control intervention during a system disturbance.

Alrifai et al (2016), described the effects of series and shunt FACTS devices in transient stability enhancement of multi-machine system. They described the injection model of unified power flow controller and series quadrature voltage injection. Results indicate that the shunt compensation was used for power oscillation damping and effects of series and shunt compensation on transient stability was discussed.

Bakhshi (2017), presented a detailed study on power system stability enhancement like frequency stability, rotor angle stability and voltage stability by using different FACTS controllers like SVC, TCSC, SSSC, STATCOM, UPFC and IPFC in an integrated power system networks. They conclude about the essential features of FACTS controllers and their potential to enhance the system stability.

III. METHODOLOGY

3.1 Application of Two Machine System Using Sapele/Geregu Power Station as Case Study

Considering a Two-machine power system for Sapele/Geregu power station as a case study, the transient stability of the power system can calculated after the faulty line is cut off through simultaneous tripping of circuit breakers on both sides of the line at point f.

3.1.1 Parameters of the transformer T_1

Rated Power S_{T_1}= 90MVA, Percentage Reactance $X_{T1}\% =$ 10%, $Transformer\ Constant\ K_{T_1=}{}^{15.75}/_{330}$

3.1.2 Parameters of the transformer T_2

Rated Power S_{T_2}= 90MVA, Percentage Reactance $X_{T2}\% =$ 10%, Transformer Constant $K_{T_2=}{}^{330}/_{15.75}$

3.1.3 Parameters of the Transmission Line L

$Line\ Voltage\ V_L = 330KV$, Transmission Length L = 200KM, Line Resistance R= 1.95, Line Reactance X=1.655 Ω/Km, $Zero\ Sequence\ Reactance\ X_{Lo} = 4X_L$

Operation:

$$Operating\ Voltage\ V_o = 100KV, Operating\ Power\ P_o = 100MW, Operating\ Power\ Factor\ Cos\theta_o = 0.98$$

3.2 Calculation of network parameters and operating parameters:

$Based\ MVA\ S_b = 100MVA, V_{BIII} = 100KV,$

$$V_{BII} = V_{BIII} \times K_{T_2} = 100 \times \frac{330}{15.75} = 2{,}095KV$$

$$V_{B1} = V_{BII} \times K_{T_1} = 2095 \times \frac{15.75}{330} = 100KV$$

Per unit values are as follows after reduction of component parameters

$$X_d = 2.4 \times \frac{100 \times 0.9}{120.573} \times \left(\frac{15.75}{100}\right)^2 = 0.044$$

$$X_q = 1.54 \times \frac{100 \times 0.9}{120.573} \times \left(\frac{15.75}{100}\right)^2 = 0.028$$

$$X'_d = 0.215 \times \frac{100 \times 0.9}{120.573} \times \left(\frac{15.75}{100}\right)^2 = 0.004$$

$$X_{T_1} = 0.10 \times \frac{100}{90} \times \left(\frac{330}{2095}\right)^2 = 0.0028$$

$$X_L = 1.655 \times 200 \times \frac{100}{330^2} = 0.304$$

$$X_{Lo} = 4 \times X_L = 4 \times 0.30 = 1.22$$

$$X_{T2} = 0.10 \times \frac{100}{90} \times \left(\frac{132}{2095}\right)^2 = 0.00044$$

$$X_2 = 0.243 \times \frac{100 \times 0.9}{120.573} \times \left(\frac{132}{2095}\right)^2 = 0.00072$$

$$T_J = 8.6 \times \frac{120.573}{0.90 \times 90} = 12.80s$$

The equivalent circuit during the normal operation of the system is shown in figure 1 and integrated impedances of the system are as follows:

$$X_{TL} = X_{T_1} \times X_L + X_{T_2} = 0.0028 + 0.304 + 0.0028 = 0.0456$$

$$X_{d\in} = X_d \times +X_{T_L} = 0.044 + 0.0456 = 0.0896$$

$$X_{q\in} = X_q \times +X_{T_L} = 0.028 + 0.0456 = 0.0736$$

$$X'_{d\in} = X'_d \times +X_{T_L} = 0.004 + 0.0456 = 0.0496$$

3.3 Calculation results of per unit values of operating parameters are as follows:

$$P_0 = \frac{P}{S_B} = \frac{100}{100} = 1.0$$

$$V_0 = \frac{V_0}{V_{BX1}} = \frac{100}{100} = 1.0$$

$$Q_0 = P_0 tan\theta_0 = P_0 \tan(Cos^{-1}0.98) = 0.203$$

$$E_0 = \sqrt{\left(V_0 + \frac{Q_0 X'_{d\in}}{V_0}\right)^2 + \left(\frac{P_0 X'_{d\in}}{V_0}\right)^2} = \sqrt{(1 + 0.203 \times 0.0496)^2 + (1 \times 0.0496)^2}$$

$$E_0 = 1.023$$

$$\delta_0 = tan^{-1}\left(\frac{\frac{P_0 X'_{d\in}}{V_0}}{V_0 + \frac{Q_0 X'_{d\in}}{V_0}}\right) = tan^{-1}\left(1 + \frac{0.00689}{0.203 \times 0.00689}\right)$$

$$\delta_0 = 40.4°$$

3.4 Calculation of transferring impedance and power characteristic of the system.

The equivalent circuit during the normal operation of the system, negative sequence and zero sequence equivalent networks in the case of three-phase short circuit at the point f, equivalent network in the case of short circuit and equivalent networks after clearing of short circuit are shown in fig. 1 a, b, c, d, and e, respectively below.

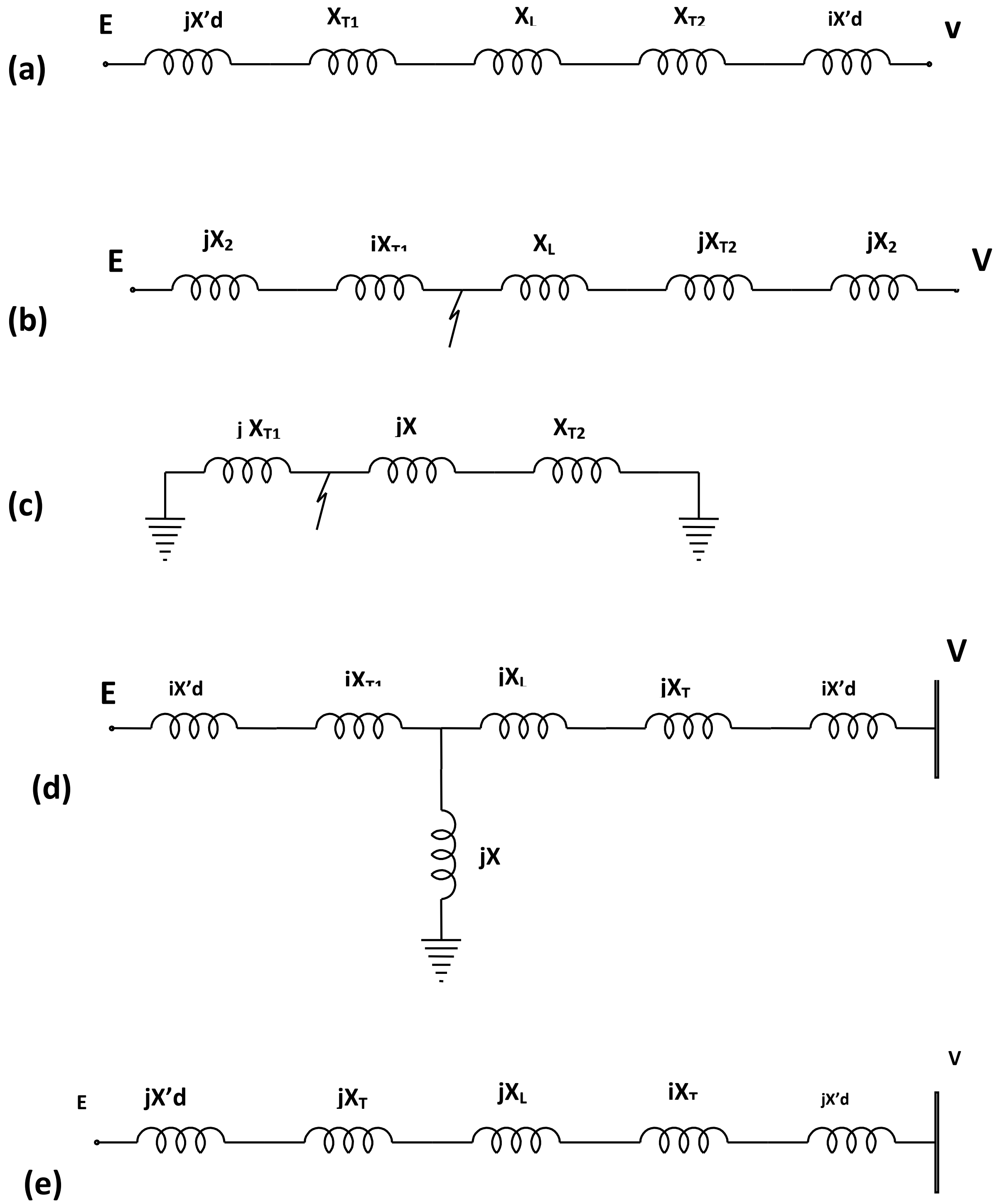

Fig. 1. Equivalent Circuit Operation of the Power System (Reactance diagram)

As seen in (b) negative sequence network and (c) zero sequence network in Fig. 1, the negative sequence and zero sequence equivalent reactance at the short circuit point are:

$$X_{2\epsilon} = \frac{(X_2+X_{T1})(X_L+X_{T2}+X_2)}{X_2+X_{T1}+X_L+X_{T2}+X_2}$$

$$= \frac{(0.00072 \quad .0028)(0.304+0.00044+0.00072)}{0.00072+0.0028+0.304+0.00072} = 0.0035$$

$$X_{0\epsilon} = \frac{X_{T1}(X_{L0}+X_{T2})}{X_{T1}+X_{L0}+X_{T2}} = \frac{0.0028(1.22+0.00044)}{0.0028+1.22+0.00044} = 0.00279$$

The additional reactance at the short circuit point in the 2 case of three-phase short circuit is

$$X_\Delta = \frac{X_{0\epsilon}X_{2\epsilon}}{X_{0\epsilon}+X_{2\epsilon}} = \frac{0.00279 \times 0.0035}{0.00279+0.0035} = 0.00155$$

From (d) equivalent network in the case of short circuit in Fig. 1, the transferring impedance and power characteristic of the system are:

$$X_{II} = X'_d + X_{T1} + X_L + X_{T2} + X'd + \frac{(X'_d + X_{T1})(X_L + X_{T2} + X'd)}{X_\Delta}$$

$$X_{II} = 0.004 + 0.0028 + 0.304 + 0.00044 + 0.0028 + \frac{(0.004 + 0.0028)(0.304 + 0.00044 + 0.0028}{0.00186}$$

X_{II} = 1.662,

$$P_{II} = \frac{E_O V_O}{X_{II}} = \frac{1.023\times 1}{0.1662}\sin\delta = 0.6155\sin\delta$$

From (e) equivalent network after clearing of short circuit, the transferring impedance and power characteristic of the system are:

$X_{III} = X'_d + X_{T1} + X_L + X_{T2} + X'_d = 0.004 + 0.0028 + 0.304 + 0.00044 + 0.0028$

$$X_{III} = 0.314$$

$$P_{III} = \frac{E_0 V_0}{X_{III}} sin\delta = \frac{1.023 \times 1}{0.314} sin\delta = 3.26 sin\delta$$

3.5 Calculation of Limit Clearing Angle:

The limit clearing angle δ_{CM} can be calculated using the equal area criterion:

$$\delta_{CM} = cos^{-1}\frac{P_0(\delta_m-\delta_0)+P_{IIIM}cos\delta_m - P_{IIM}cos\delta_0}{P_{IIIM}-P_{IIM}} \text{ or } cos^{-1}\frac{\frac{\pi}{180}P_0(\delta_m-\delta_0)+P_{IIIM}cos\delta_m - P_{IIM}cos\delta_0}{P_{IIIM}-P_{IIM}}$$

Where $\delta_o = 40.4° \ as\ calculated\ and$

$$\delta_m = 180^o - sin^{-1}\frac{P_0}{P_{IIIM}} = 180^0 - sin^{-1}\frac{1}{3.26} = 162.1^o$$

$$\delta_{CM} = cos^{-1}\left[\frac{\frac{\pi}{180}(162.1^o - 40.4^o) + 0.326cos162.1^0 - 6.155cos40.4^o}{0.326 - 6.155}\right]$$

$$\delta_{CM} = 60.5°$$

3.6 Calculation of Critical Clearing Time:

$$t_c = \sqrt{\frac{2H(\delta_c - \delta_o)}{\pi f_0 P_m}}$$

$$\sqrt{\frac{2 \times 1.37 \times 1000(1.055 - 0.705)}{\pi \times 50 \times 1}}$$

$$t_c = 2.47s$$

3.7 Stability of an Electric Power System Employing PSS and SVC

The Sim Power Systems software was used in analyzing a simple transmission system containing two hydraulic power plants. A static var compensator (SVC) and power system stabilizers (PSSs) were used to improve transient stability and power oscillation damping of the system. The phasor simulation method was employed to demonstrate the effectiveness of either controller.

3.7.1 Description of the Two Machine Electric Power System

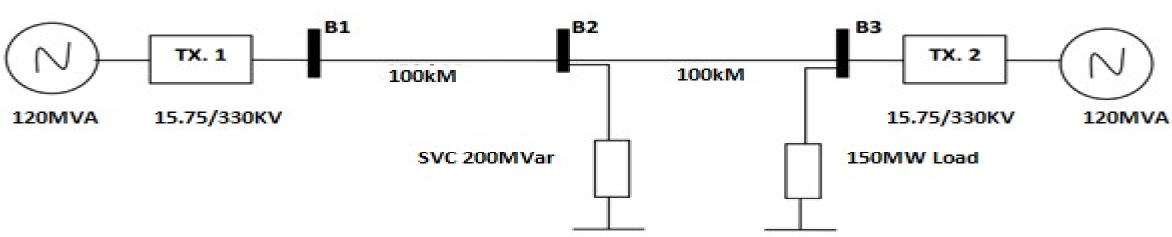

Fig. 2: Line Diagram of the Power System under Study

The test system consisted of a 120 MW hydraulic generation plant (machine M1-say Sapele G.S) connected to a load centre through a 330 KV, 200 KM transmission l22ine. The load centre was modeled by a 150 MW resistive load. The load was fed by the remote 150 MW plant and a local generation of 120 MW (machine M2- say Geregu G.S). The system had been initialized so that the line carried 150 MW which was its surge impedance loading. In order to maintain system stability after faults, the transmission line was shunt compensated at its centre by a 200-Mvar Static Var Compensator (SVC). The two machines were equipped with a Hydraulic Turbine and Governor (HTG), Excitation system and Power System Stabilizer (PSS). (These blocks are located in the two 'Turbine and Regulator' subsystems of the simulation block diagram. Two types of stabilizers could be selected: a generic model using the acceleration power (Pa type) and a Multi-band stabilizer (MB PSS) using the speed deviation(dw). During the simulation, faults were applied on the system and the impact of the PSS and SVC on system stability observed.

Figure 2 shows the use of the phasor solution for transient stability analysis of multi-machine systems which is a Simulink model of Fig. 4 It analyzes the enhancement of transient stability of a two-machine transmission system with Power System Stabilizers (PSS) and Static Var Compensator (SVC).

As stated above a 120MW hydraulic generation plant (machine M1-Sapele G.S) is connected to a load center through a long 330KV, 200KM transmission line. The load center is modeled by a 150MW resistive load. The load is fed by the remote 150.00MW plant and local generation of 120MW (machine M2-Geregu G.S). The system has been initialized so that it carries 150MW which is close to its Surge Impedance Loading (SIL = 250 MW). In order to maintain system stability after faults, the transmission is shunt compensated at its center by a 200-Mvar Static Var Compensator (SVC). Notice that this SVC model is a phasor model valid only for transient stability solution. The SVC does not have a Power Oscillation Damping (POD) unit. The two machines are equipped with a Hydraulic Turbine and Governor (HTG), Excitation system and Power System Stabilizer (PSS). These blocks are located in the two 'Turbine and Regulator' subsystems. Two types of stabilizers can be selected:

a) A generic model using the acceleration power ($\mathrm{p_a}$ = difference between mechanical power $\mathrm{p_m}$ and output electrical power $\mathrm{p_{eo}}$) and

b) A Multi-band stabilizer using the speed deviation (dw).

The stabilizer type can be selected by specifying a value $(0 = \text{No PSS}, 1 = \mathrm{p_a}\ \text{PSS or}\ 2 = \text{dw MB PSS})$ in the PSS constant block.

Different faults were applied on the 330KV transmission system and the impact of PSS and SVC on the system stability observations noted.

IV. RESULTS AND DISCUSSION

4.1 Impact of PSS and SVC on Two Machine System with Single-Phase Fault

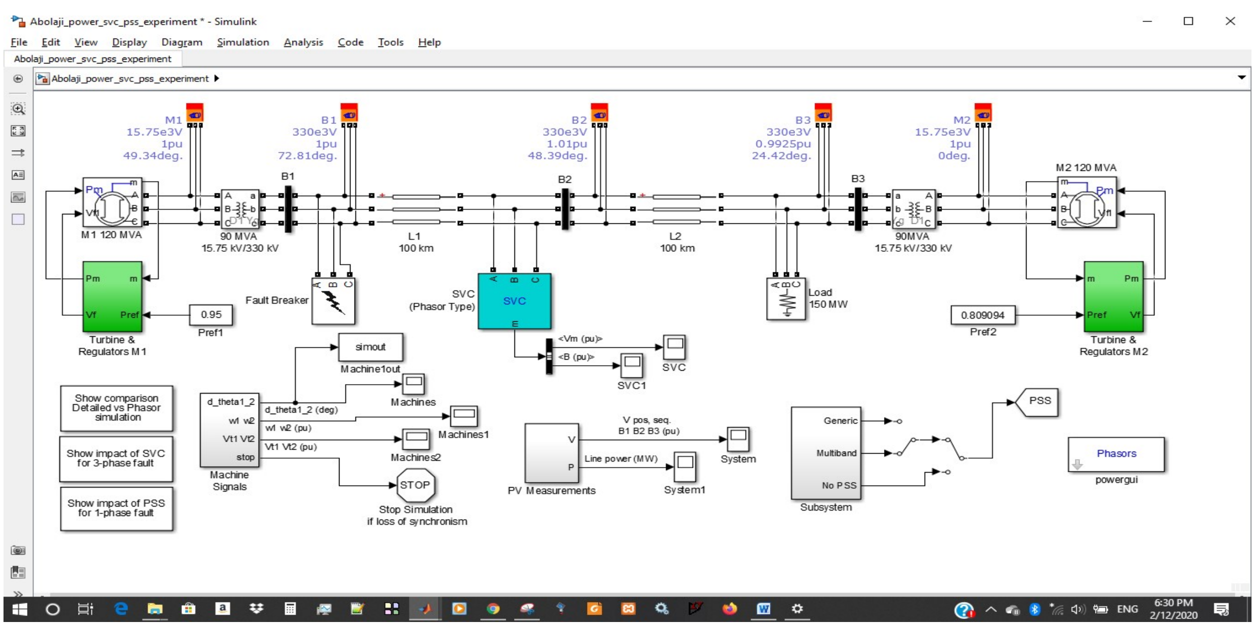

Fig. 3: MATLAB Snapshot of Small Signal Stability of Generating Station of a two-machine Electric Power System with Power System Stabilizers (PSS) and Static Var Compensator (SVC)

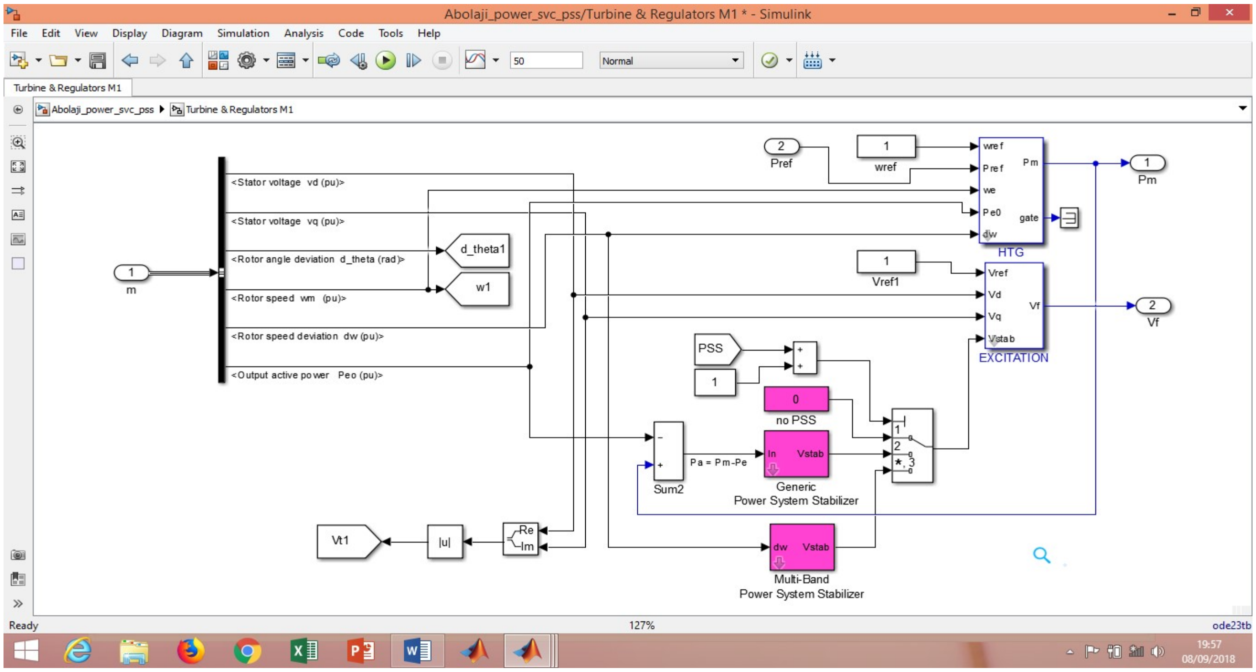

Fig. 4: Turbine and Regulator M1

4.1.1 without either PSSs or SVC

A single-phase fault was applied to the system in the transition time of 5.0s to 5.1s. Without the application of either PSSs or SVC, the oscillation of the system was as indicated in Fig. 5.

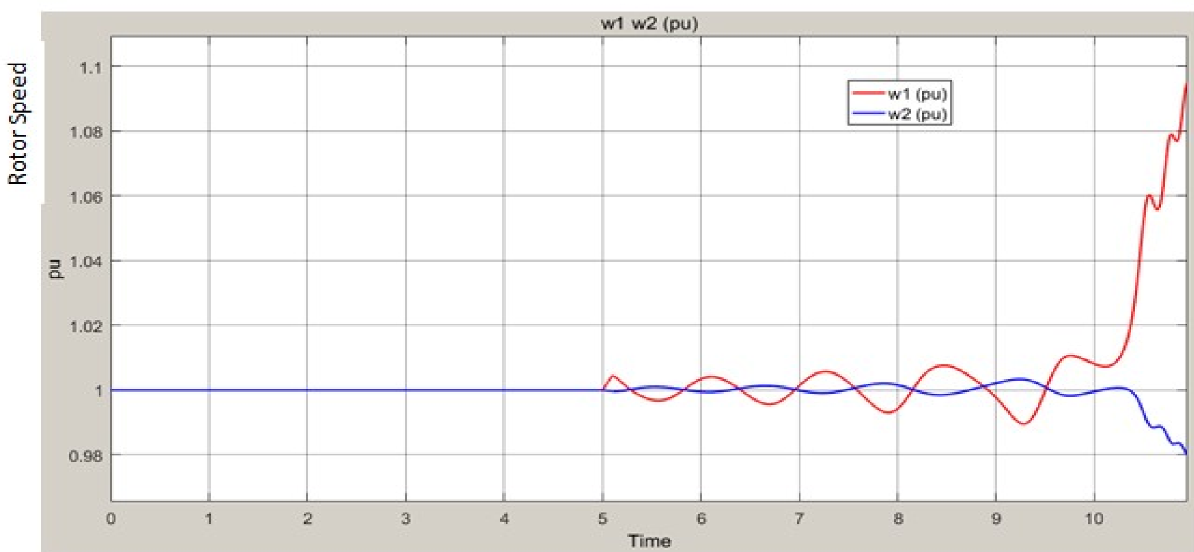

Fig. 5: Rotor Speed of the two machines M1 and M2 (w_1 and w_2 respectively) without either PSSs or SVC

Fig. 5. Shows the response of the angular speed of machine M1 and M2 during the occurrence of a single line-to-ground phase fault. There are two lines on the graph: the red line represents machine M1 while the blue line represents machine M2. The oscillations in the machine speeds were evidently shown to have refused to die out after the fault was cleared at 5.1s; therefore the system has remained unstable.

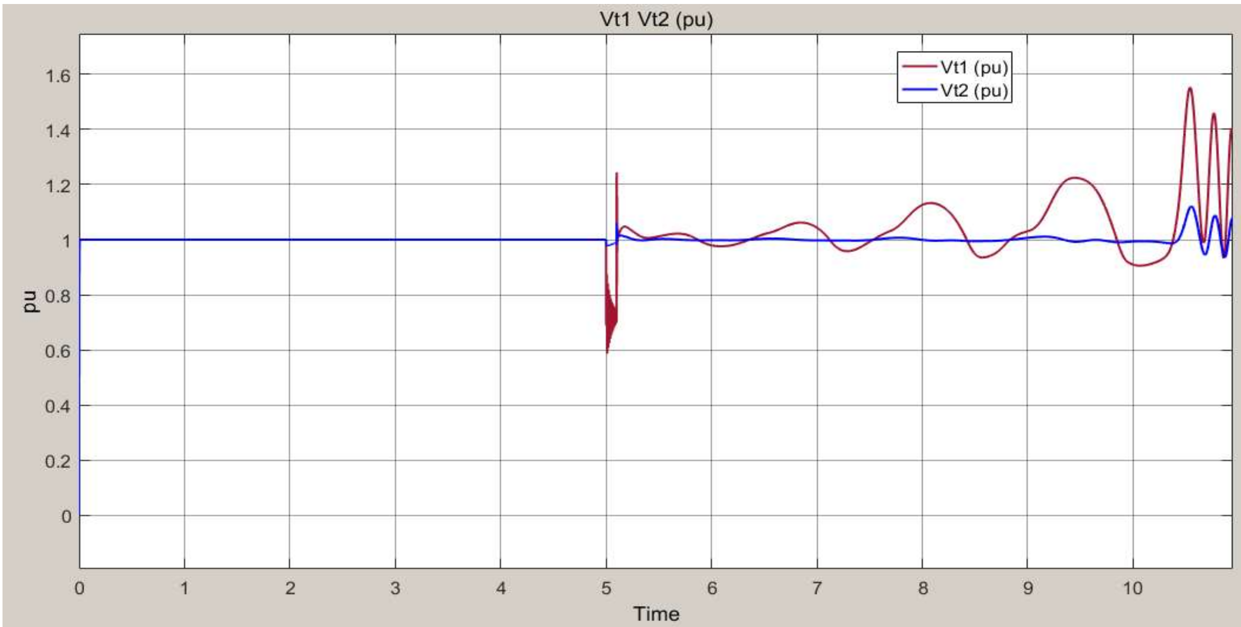

Fig. 6. Terminal Voltages of the two machines M1 and M2 without either PSSs or SVC

Fig. 6 shows the response of the terminal voltages of machine M1 and M2 during the occurrence of a single line-to-ground phase fault. There are two lines on the graph: the red line represents machine M1 while the blue line represents machine M2. The oscillations in the terminal voltages were evidently shown to have refused to die out after the fault was cleared at 5.1s, therefore the system has remained unstable.

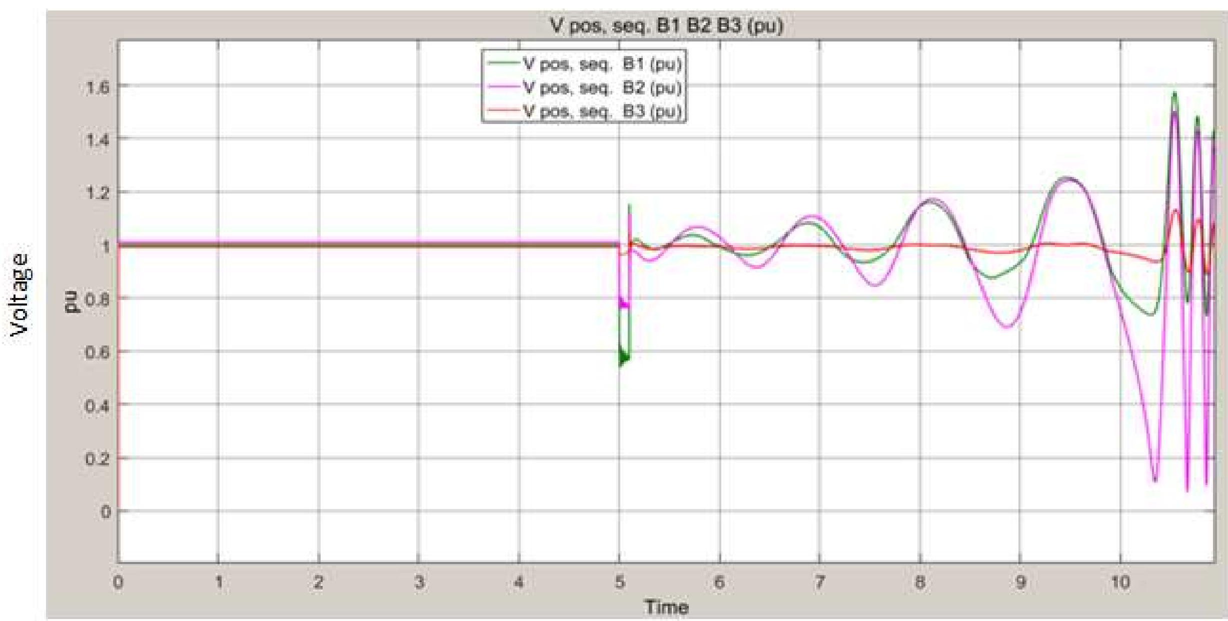

Fig. 7: Bus Voltages without either PSSs or SVC

Fig. 7 shows the response of the positive sequence voltages of the three buses; B1, B2 and B3 during the occurrence of a single line-to-ground phase fault. There are three curves on the graph: the green curve represents bus B1, the pink curve represents bus B2 and red curve represents bus B3. The oscillations in the bus voltages were evidently shown to have persisted after the fault was cleared at 5.1s, thereby making the bus voltages unstable.

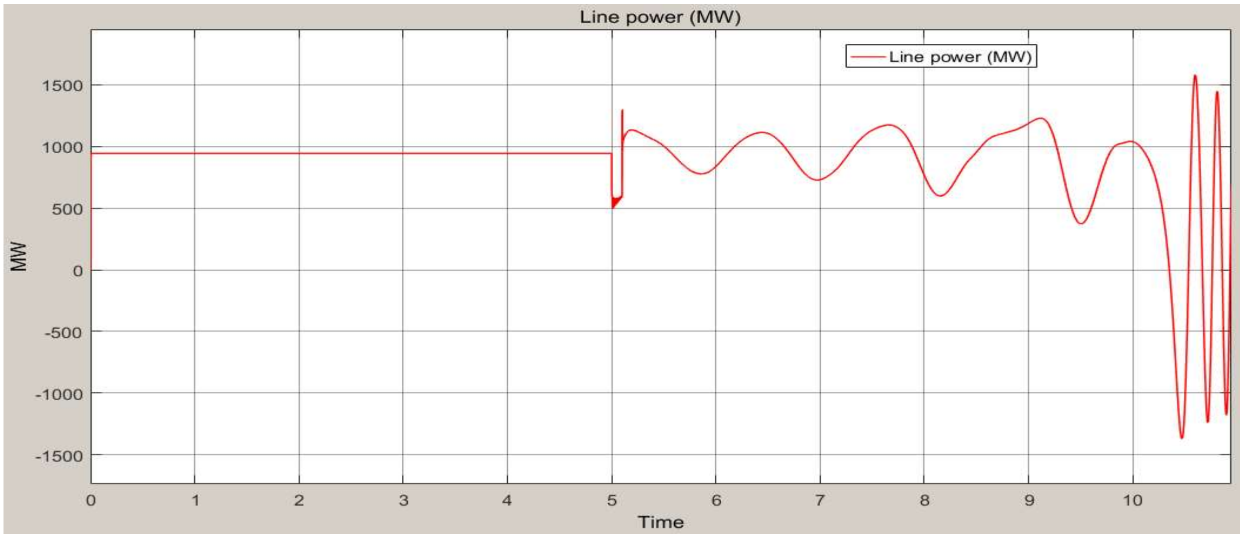

Fig. 8: Line Power of the system without either PSSs or SVC

Fig.8 shows the effect of single line-to-ground fault on the system line power. It can be seen that the line power transfer was lost after the 0.8 Hz oscillation was damped after fault clearance at 5.1s.

4.1.2 With PSS and without SVC

Thereafter, with the SVC put out of service ('Fixed Susceptance' mode with βref = 0) but with the two PSSs (Pa type) in service, the simulation was started and signals observed on the 'Machines' scope. For this type of fault, the system was stable without the SVC. After fault clearing, the 0.8 Hz oscillation was quickly damped, Fig. 9.

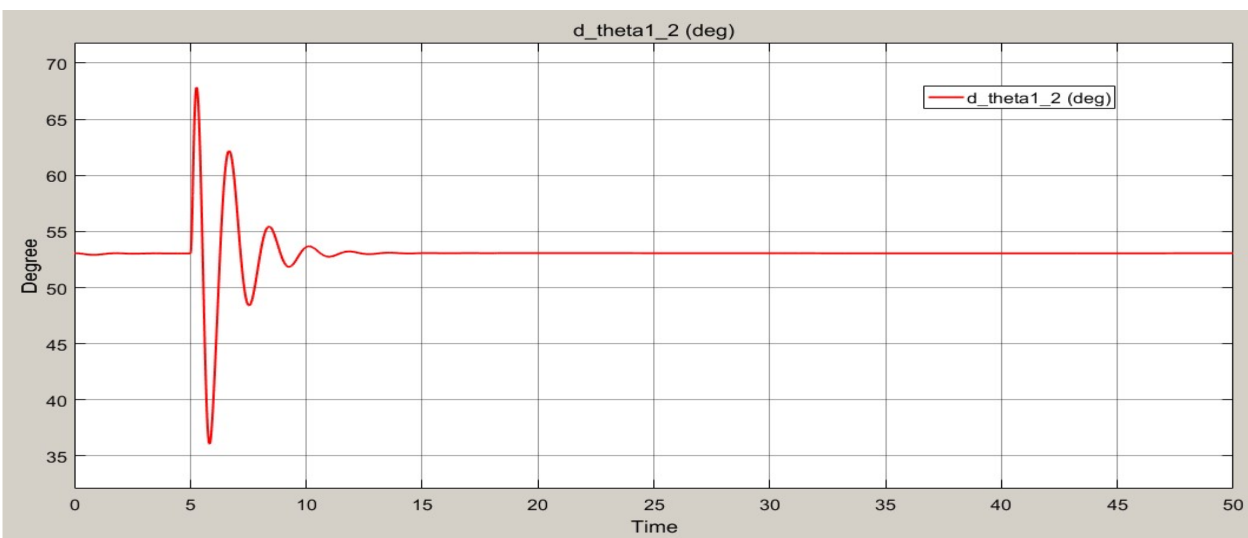

Fig. 9: Rotor angle difference of the two machines M1 and M2 with PSS and without SVC

Fig. 9 shows the rotor angle difference ''d_theta1_2'' between the two machines. Power transfer was maximum when this angle reached 90 degrees. This signal was a good indication of system stability. If d_theta1_2 exceeded 90 degrees for too long a period of time, the machines would lose synchronism and the system would become unstable.

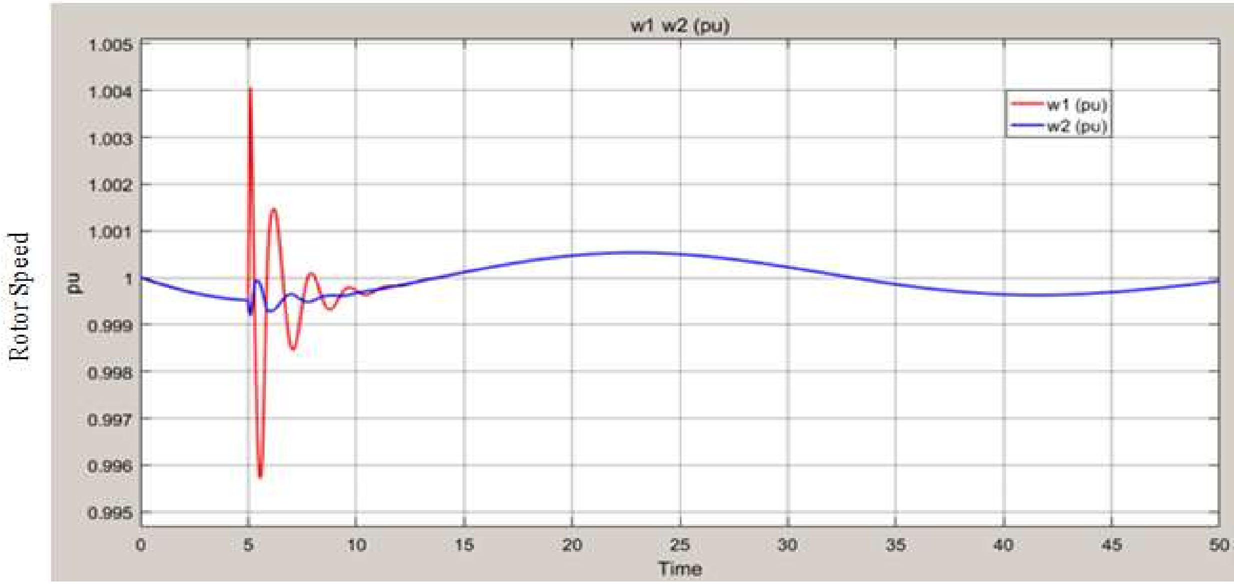

Fig. 10: Rotor Speed of the two machines M1 and M2 with PSS and without SVC

Fig. 10 shows the machine speeds. The machine 1 speed increased during the fault because during that period its electrical power was lower than its mechanical power. By simulating over a long period of time (50 seconds) it was noticed that the machine speeds oscillate together at a low frequency (0.025 Hz) after fault clearing, Fig.4.2 The two PSS (Pa type) succeed to damp the 0.8 Hz mode but they are not efficient for damping the 0.025 Hz mode. Selecting the Multi-band PSS resulted in both the 0.8Hz and 0.025 mode oscillations being damped.

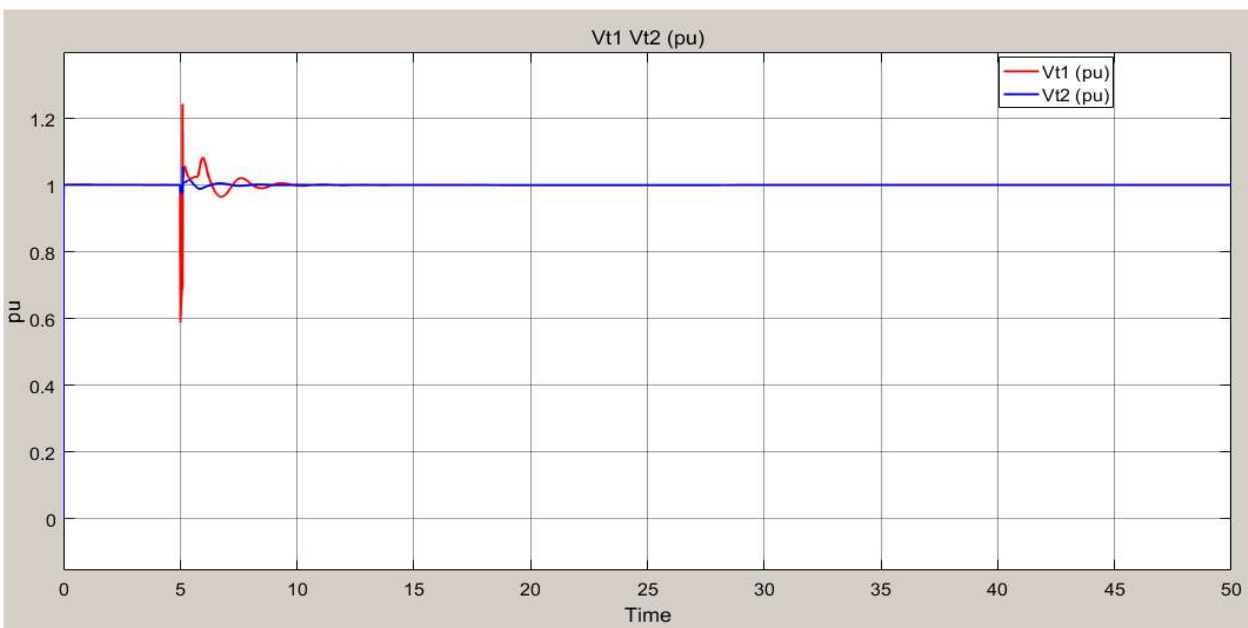

Fig. 11: Terminal Voltages of the two machines M1 and M2 with PSS and without SVC

Fig. 11 shows the response of the terminal voltages of machine M1 and M2 during the occurrence of a single line-to-ground phase fault. There are two lines on the graph: the red line represents machine M1 while the blue line represents machine M2. The terminal voltages were evidently shown to have regained stability after the fault was cleared at 5.1s.

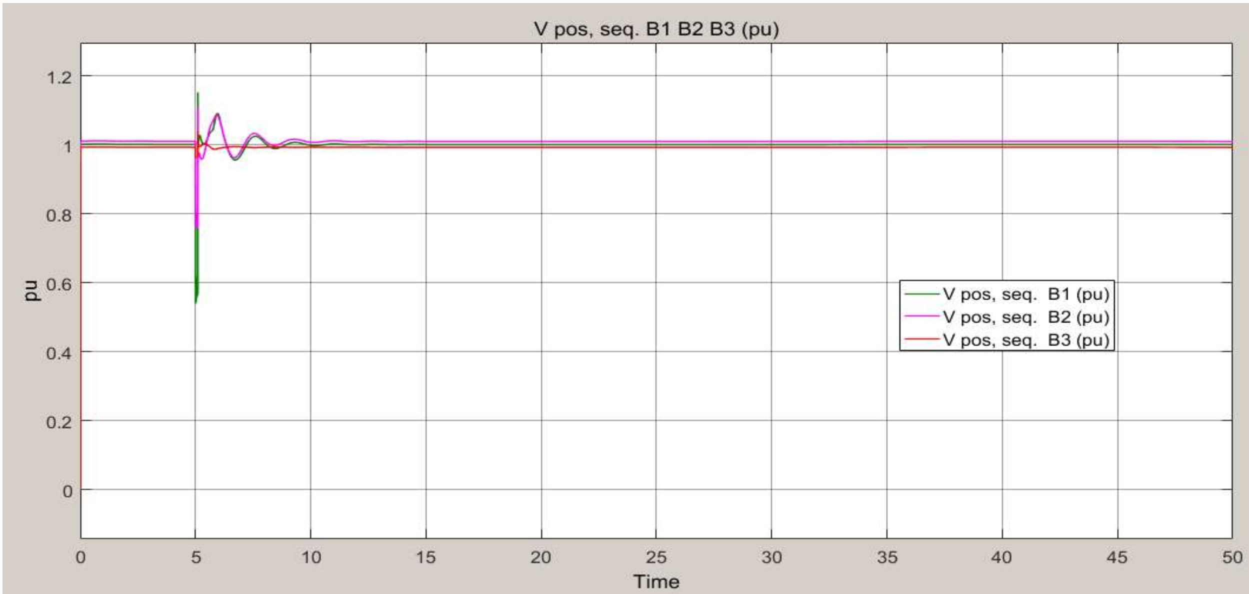

Fig. 12: Bus Voltages with PSS and without SVC

Fig. 12 shows the response of the positive sequence voltages of the three buses; B1, B2 and B3 during the occurrence of a single line-to-ground phase fault. There are three curves on the graph: the green curve represents bus B1, the pink curve represents busB2 and red curve represents bus B3. The oscillations in the bus voltages were evidently shown to have died off after the fault was cleared at 5.1s, hence making the bus voltages stable again.

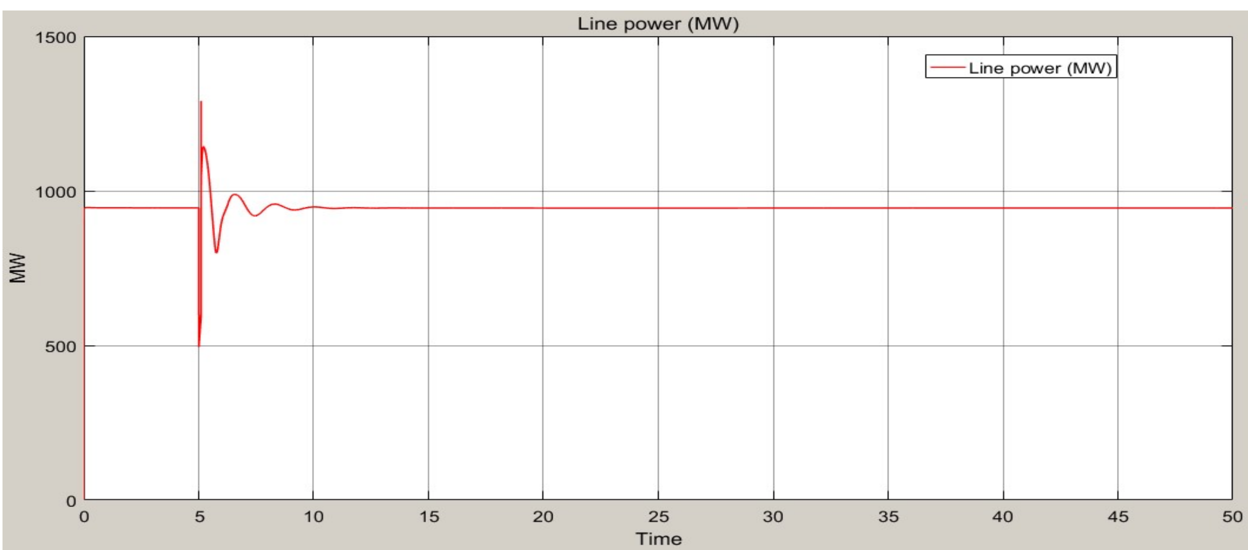

Fig. 13: Line Power of the system with PSSs and without SVC

Fig. 13 shows the effect of single line-to-ground fault on the be seen that the line power transfer was not lost after the oscillation was damped after fault clearance.

It is evident from Fig. 5 - 13, that when a single-phase fault was applied to the system in the transition time 5.0s to 5.1s, the system regained its stability after the fault was cleared at

system line power. It can 5.1s. This oscillation mode was typical of inter-area oscillations in a large power system. It can be seen that without either PSSs in services, the oscillation of system was unstable but after fault clearing, the 0.8 Hz oscillation was quickly damped when the two types of PSSs were put into service.

It is worthy of note that from the simulation studies the system is naturally unstable without PSS, even for small

up after a few seconds. This is vividly illustrated in Fig. 14.

disturbances. For example, when the fault was removed (by deselecting phase A in the Fault Breaker) and a Pref step of 0.05 pu was applied on the machine 1, instability was slowly built

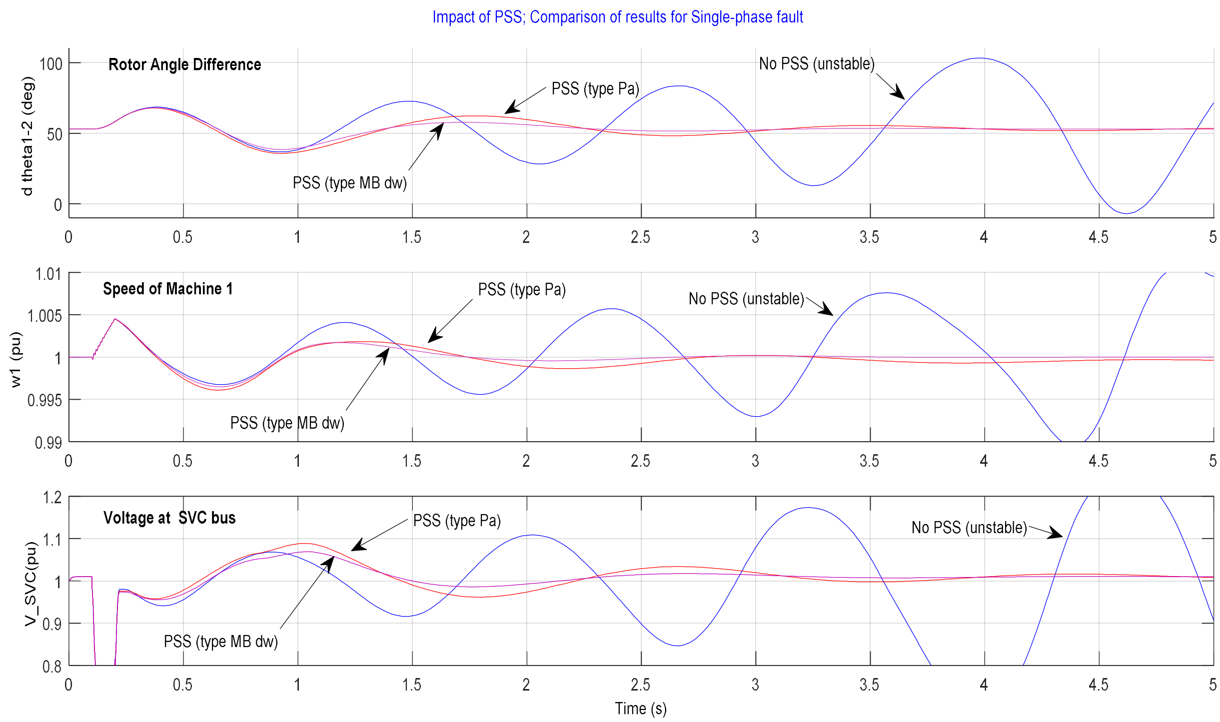

Fig. 14. Impact of PSS; Comparison of results for Single-phase fault

Fig. 14 shows the comparison of the simulation results obtained when the two types of PSS (Generic and Multiband PSS) were put into services. It can be seen from the Fig. 14 that performance of the Multiband PSS was better than that of Generic PSS as it offered less oscillation. As indicated by the blue curve the system became unstable without either PSSs.

V. CONCLUSION

A study of Power System Stabilizer (PSS) and Static Var Compensator (SVC)-based controllers has been carried out. In the PSS design, Particle Swarm Optimization (PSO) was employed where the search for the optimal controller parameter settings that optimize the objective function was done. To guarantee the robustness of the proposed controller, the design process was carried out considering a wide range of operating conditions: Heavy, normal and light loading. The SVC design process employed gate turn-off thyristors and dc voltage-control of the studied controllers, the SVC is the most versatile FACTS controller finding wide application in the operation and control of power systems, such as scheduling power flow; decreasing unsymmetrical components; reducing net loss; providing voltage support; limiting short-circuit currents; mitigating sub-synchronous resonance (SSR); damping power oscillations; and enhancing transient stability. Meanwhile, the SVC enhances system stability by controlling the amount of reactive power injected into or absorbed from the power system. On the other hand, the PSS has for a long time found application in the exciters of synchronous machines as an effective means of damping the generator unit's characteristic electromechanical oscillations by modulating the generator excitation. A simulation was carried out to demonstrate the effectiveness of the PSS and SVC in damping power oscillations. Results obtained clearly highlighted the reasons behind the fast spreading use of Power Oscillation Damping controllers in power systems worldwide: In Nigeria, Gencos employs PSSs in its excitation systems while Discos is due to roll out SVCs in its transmission and distribution systems. Thus, PSSs and FACTS are fast becoming a necessity in power system stability enhancement rather than an option to be considered.

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