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Impact of Power System Stabilizer on Transient Stability of Power Networks

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ABSTRACT: *The study focused on the impact of Power System Stabilizers (PSS) on the transient stability of the Port Harcourt zone 2 power transmission network. The single line diagram was modelled with Electrical Transient Analyzer Program (ETAP) software, the system was simulated with 3-phase fault on bus 1 and the transient stability analysis was carried out without and with PSS in order to investigate its impact on the system's stability. The simulation plots for the generator speed, generator relative power angle, bus voltage, generator terminal current show that the introduction of PSS, the oscillatory nature of the system parameters after fault clearing, were quickly damped, transient period reduced and the system attained stable and steady state position. But without PSS, the response of the system parameters was oscillatory after fault was cleared. The simulation results showed that PSS improves the transient stability of the power systems.*

Keywords: *Transient stability, ETAP, PSS, Rotor angle.*

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I. INTRODUCTION

Power system stability has been identified as a critical and difficult issue for secure system operation of power systems when small or significant disturbances occur in an interconnected power system. The impact of significant disturbances brought on by power system faults is what transient stability is concerned with. A synchronous power system has transient stability if, after a large sudden disturbance, it can regain and maintain synchronism. A sudden large disturbance includes application of faults, clearing of faults, switching on and off the system elements (transmission lines, transformers, generators, loads etc.).

Usually, transient stability studies are carried out over a relatively short-time period that will be equal to the time of one swing. Normally, the time period will be one second or less. The analysis is carried out to determine whether the system loses stability during the first swing or not. In case the power system remains stable, it is assumed that subsequent swings will diminish [1].

The machine power angles, speed deviations, frequency, power flow of the machines, lines, transformers, and bus voltage levels are all determined by transient stability studies [2].

II. REVIEW OF RELATED WORKS

The numerous numerical methods in the time domain used to solve the swing equation include the Euler method, Modified Euler method, Runge-Kutta method employing implicit integration, equal area criterion, point by point approach, and Transient Energy Function (TEF) method, according to [3]. The Runge-Kutta method is used to evaluate a power system's initial swing stability limit by looking for peaks in the rotor angles of significantly disturbed generators during the post-fault period [4].The transient energy function technique, a crucial tool, must be used in power system transient analysis [5]. The equal area criterion predicts power system stability and determines the critical clearing angle, but it is only relevant to systems with one or two machines connected to an infinite bus bar [6]. Three-phase short circuits at the generator bus are the most severe kind of fault [7].The electrical power system theory, including the PSS, AVR, and governor system, has been demonstrated in [8]. A thorough analytical study was carried out in [9] to establish the features of power system stabilizers for a large generating facility. Software programs like Matlab/Simulink and the Electrical Transient Analyzer Program (ETAP) are used to analyze the transient stability of power systems.

III. MATERIALS AND METHOD

The relevant equations required for this studyare the swing equation, torque equation, equal area criterion, critical clearing angle and the Runge-Kuttanumerical method for solving the swing equation. These method and equations are stated below.

Runge-Kutta Numerical Method

The general formula for the fourth order Runge-Kuttanumerical method is given as:

$$\delta_{n+1} = \delta_n + \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4) \quad (1)$$

Where

$$k_1 = f(\delta_n, t_4)\Delta t \quad (2)$$

$$k_2 = f(\delta_n + \frac{k_1}{2}, t_n + \frac{\Delta t}{2})\Delta t \quad (3)$$

$$k_3 = f(\delta_n + \frac{k_2}{2}, t_n + \frac{\Delta t}{2})\Delta t \quad (4)$$

$$k_4 = f(\delta_n + k_3, t_n + \frac{\Delta t}{2})\Delta t \quad (5)$$

The physical meaning of the above solution is as follows

k_1 = (slope at the beginning of time step)Δt

k_2 = (first approximation to slope at mid-step)Δt

k_3 = (Second approximation to slope at mid-step)Δt

k_4 = (slope at the end of step)Δt

$$\Delta\delta = \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4) \quad (6)$$

$where\ n = number\ of\ iterations$

According to the Tailor Series expansion, using this approach is equivalent to taking into account up to fourth derivative terms. It has an error in the order of Δt^5 [2]

Swing Equation For Rotor Angle Determination

The swing equation, which is shown below, is the fundamental equation used to calculate rotor dynamics in transient stability studies.

$$M\frac{d^2\delta}{dt^2} + D\left[\frac{d\delta}{dt}\right] = P_m - P_e = P_a \quad (7)$$

Where:

M = angular momentum (joules-sec/rad)

D = damping coefficient

P_m = mechanical power; $P_m = P_{mo} - \Delta P_{mo}$

P_{mo} = input mechanical power

ΔP_{mo} = change in input mechanical power due to governor action

P_a = net accelerating power

δ = power angle

T = time

P_e = electrical power

Equal Area Criteria

According to [10], equal area criteria shows that all kinetic energy gained by the rotor during acceleration when δ changed from δ_0 to δ_1 is returned back to the system by the rotor during deceleration. The equation is given below:

$$E_1 = \int_{\delta_0}^{\delta_{cr}} (P_m - P_e) d\delta = A_1 \quad (8)$$

$$E_2 = \int_{\delta_{cr}}^{\delta_m} (P_e - P_m) d\delta = A_2 \quad (9)$$

Let us assume there are no losses, the energy gained is equal to the energy lost; therefore, area A1 is equal to $A2$.This forms the basis for the equal area criterion. It helps us to determine the maximum swing of δ and the stability of the system without computing the time response through formal solution for the swing equation.

The critical clearing time is given as:

$$t_{cr} = \sqrt{(\delta_{cr} - \delta_0).\frac{4H}{\omega_0 P_m}} \quad (10)$$

IV. RESULTS AND DISCUSSION

The single line diagram of Port Harcourt 132kV distribution network used as a test case for transient stability studies was modelled in Electrical Transient Analyzer Program (ETAP 19.0). Fig.1 shows the diagram and simulations carried out using the transient stability analysis tool embedded in ETAP software. A three-phase fault was applied at bus 1 with an initiation time of 0.8seconds and clearing time of 0.85seconds and simulations were carried out with PSS and without PSS to investigate the impact of PSS on the transient stability of the network. A simulation time step of 0.001 was used in the ETAP software and the simulation lasted for 10seconds.

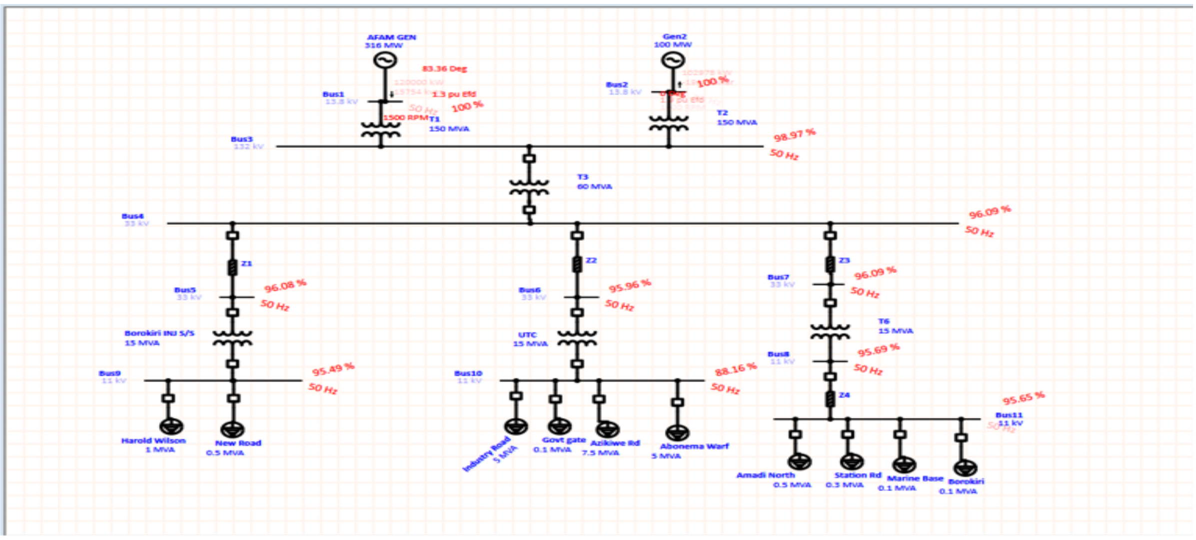

Fig 1: Single line diagram of Port Harcourt Zone 2 network after simulation

Table 1: Bus voltage (kV)

S/N	BUS ID	BUS TYPE	NOMINAL (kV)	PRE-FAULT	DURING-FAULT (kV)	POST- FAULT (kV)
1	BUS 1	GEN	13.8	13.8	0	13.59
2	BUS 2	GEN	13.8	13.8	4.95	13.56
3	BUS 3	LOAD	132	130.6	23.58	128.5
4	BUS 4	LOAD	33	31.71	5.75	31.15

5	BUS 5	LOAD	33	31.71	5.75	31.15
6	BUS 6	LOAD	33	31.67	5.75	31.15
7	BUS 7	LOAD	33	31.71	5.75	31.15
8	BUS 8	LOAD	11	10.53	1.91	10.34
9	BUS 9	LOAD	11	10.52	1.79	10.32
10	BUS 10	LOAD	11	9.7	1.91	9.5
11	BUS 11	LOAD	11	10.52	1.91	10.33

Table 1 shows the bus voltages at pre-fault, during fault and post-fault scenario. It was shown that the bus voltages were deviating from the statutory limit of 13.11kV- 14.49kV for the 13.8kV bus, 125.4 kV-138.6 kV for the 132kV bus, 31.35kV- 34.65kV for the 33kV bus and 10.45kV-11.55kV for the 11kV bus when fault was initiated. After fault clearing, the oscillation was damped gradually till after 10 seconds. Bus1, Bus 2, and Bus 9 were mostly affected during fault and their corresponding bus voltages are 0kV, 4.95kV, 1.79kV respectively.

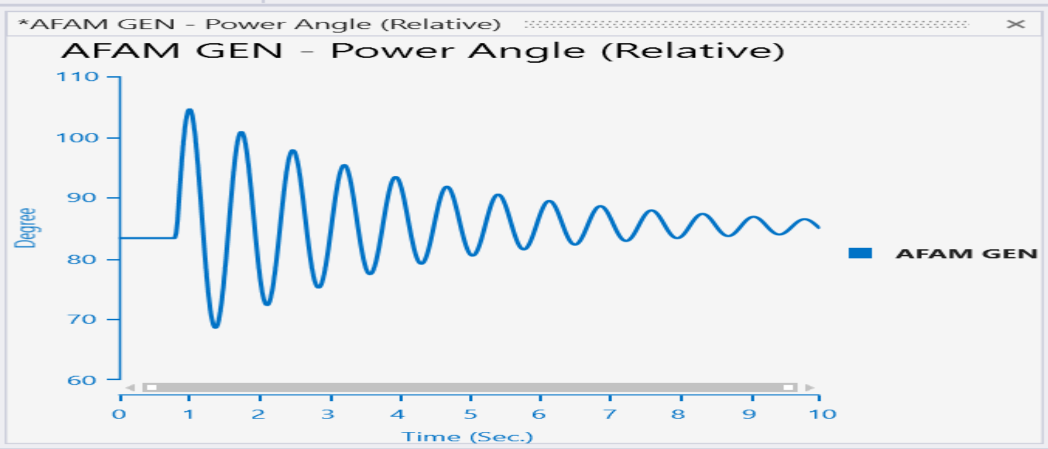

Fig 2: Plot of Generator relative Power angle against time

Fig. 2 is the plot showing the generator's relative power (rotor) angle deviation with time without PSS. From the plot, it can be observed that from 0.00-0.79 second there were no power oscillations which indicates that the generator was running at synchronous speed. Then, at 0.8 second, a 3-phase fault was initiated and it can be observed from the plot that due to the 3-phase fault, there was a power swing of the generator. The fault was cleared at 0.85 second, the system was stable but oscillatory.

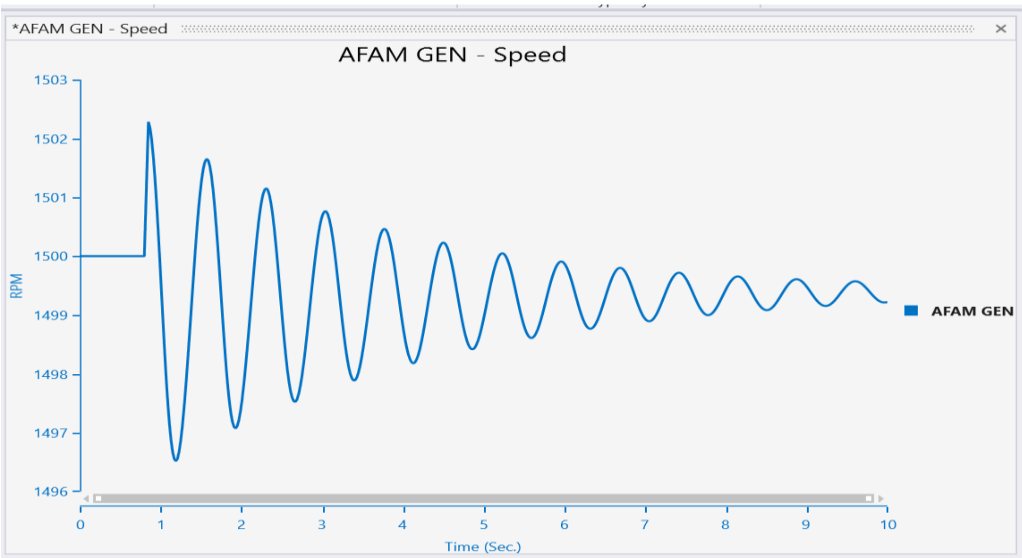

Fig 3: Plot of Generator speed against time

Fig. 3 is the plot showing the generator's speed against time without PSS. From the plot, it can be observed that from 0.00-0.79 second there were no power oscillations which indicates that the generator was running at synchronous speed. Due to fault initiated at 0.8 second and cleared at 0.85 second, it can be observed from the plot that the speed of the generator increased beyond its rating of 1500 rpm and then maintained stability after 10 seconds as the oscillations decayed gradually.

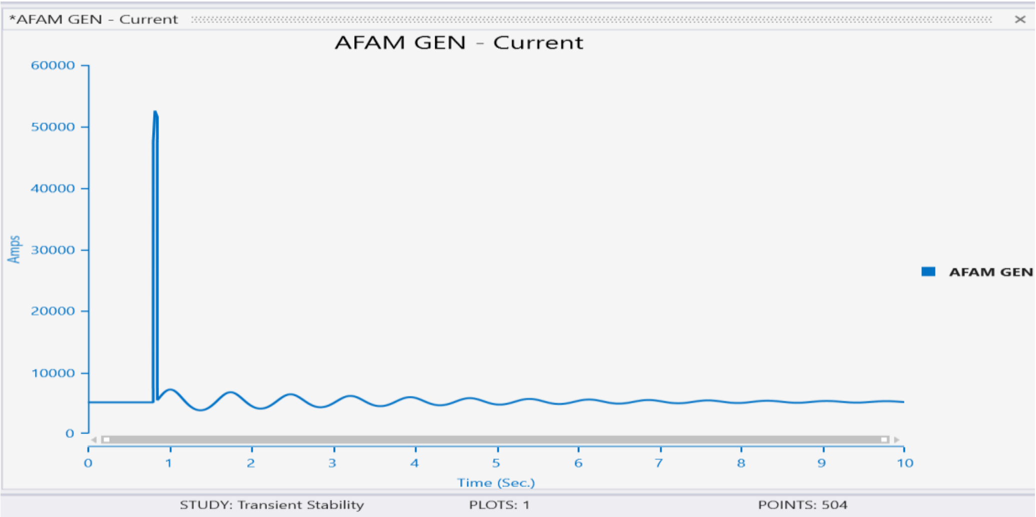

Fig 4: terminal current of generator against time

Fig. 4 shows the plot of generator terminal current against time without PSS. It can be observed from the plot that there was a sudden rise in generator's terminal current when a 3-phase fault was initiated. After the fault was cleared the oscillations in the terminal current reduced and decayed gradually with time reaching a stable operating condition after 10 seconds.

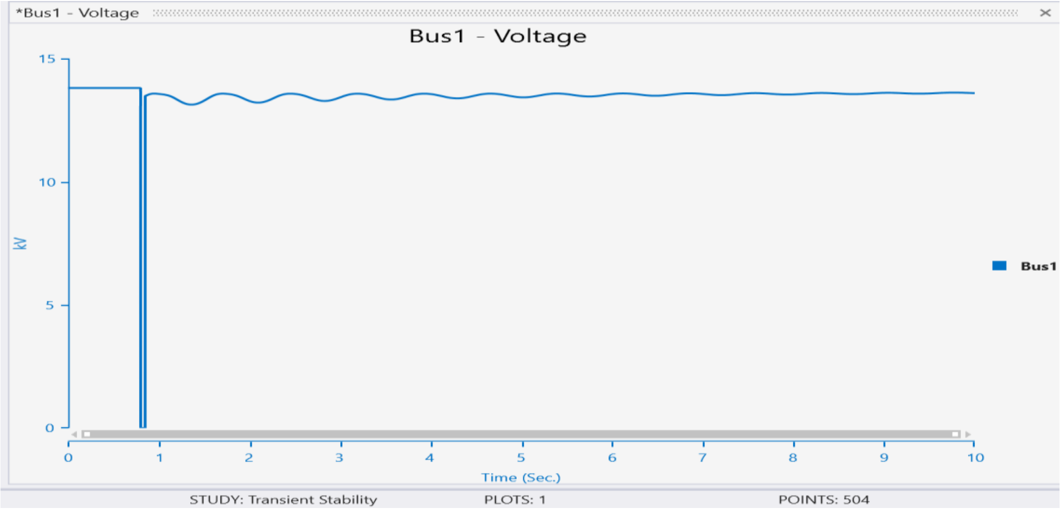

Fig 5: Generator bus voltage without PSS

Fig. 5 shows the plot of generator bus voltage against time without PSS. It can be observed from the plot that there was a sudden decrease in generator bus voltage to zero (0 kV)when a 3-phase fault was initiated. After the fault was cleared the system became stable and the oscillations in the bus voltage reduced and decayed gradually with time.

Impact of PSS on system oscillations after fault clearing

A user defined model of PSS added to the generator bus to enhance the transient stability performance of the network. It has been observed that without PSS the response of the network parameters is oscillatory.However, with the introduction of PSS, the oscillatory nature of the parameters has been reducedand reaches stable and steady state position quickly. With PSS, there is reduced power loss, improvement in the damping system and dynamic stability of a system.

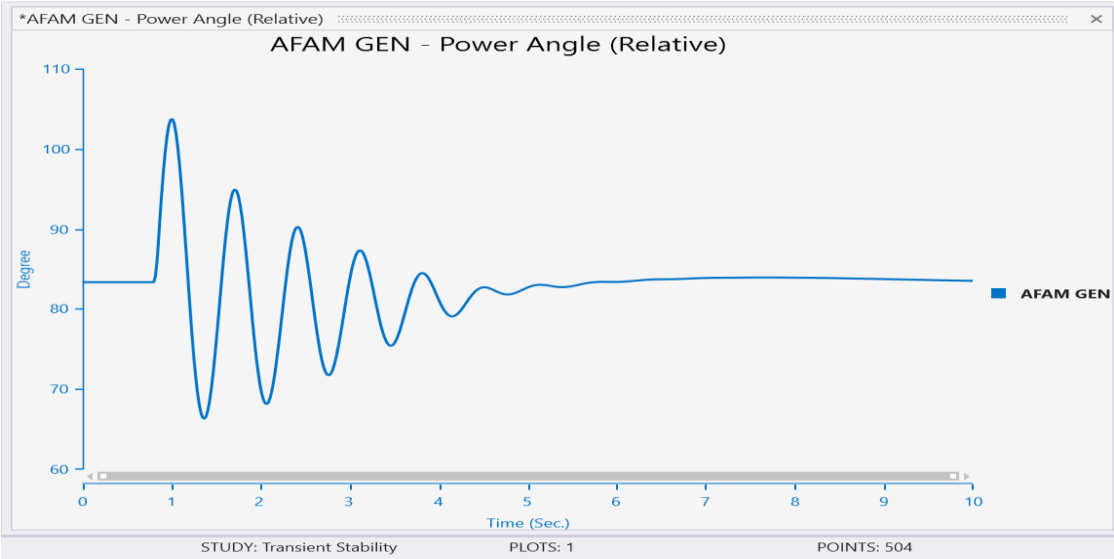

Fig 6: relative rotor angle deviation with PSS

Fig. 6 shows that with the introduction of PSS to the generator, there was improvement in the oscillation damping of the rotor angle of the generator after the 3-phase fault was cleared. The oscillations damping was quick and transient period was reduced to 5 seconds reaching a stable and steady operating condition.

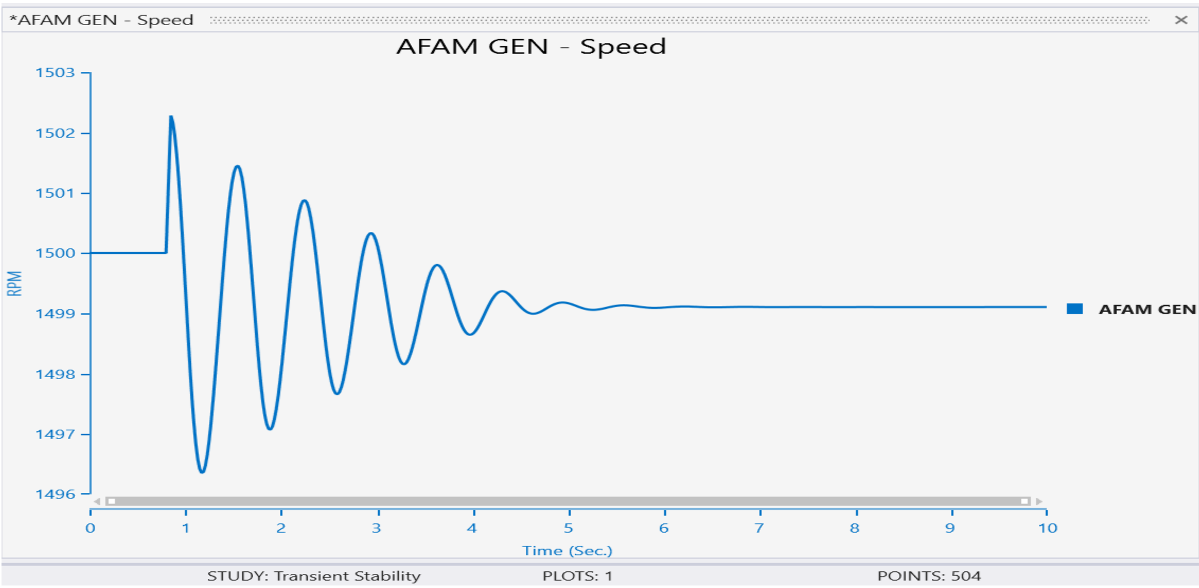

Fig 7: generator speed with PSS

Fig. 7 shows that with PSS in the system, there was improvement in the oscillation damping of the speed of the generator after 3-phase fault was cleared at 0.85 second. The oscillations decayed completely at 6seconds reaching a stable and steady operating condition.

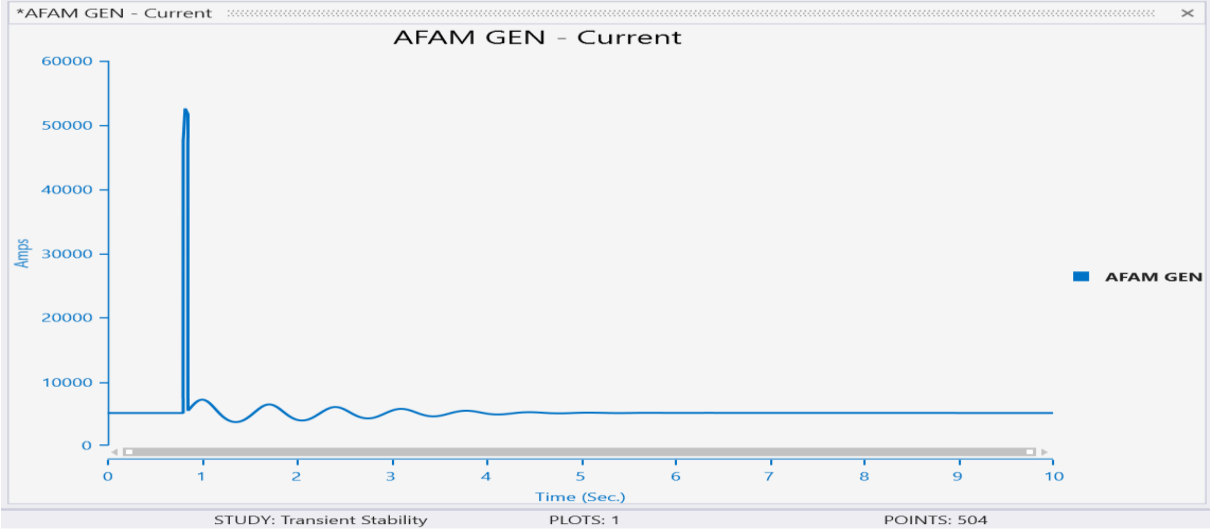

Fig 8: Terminal current of generator against time

Fig. 8 shows that the introduction of PSS caused a significant improvement in the oscillation damping of the terminal current after 3-phase fault was cleared leading to a stable operating condition. The oscillation damping was quick. This shows that PSS can improve the transient stability of the power network.

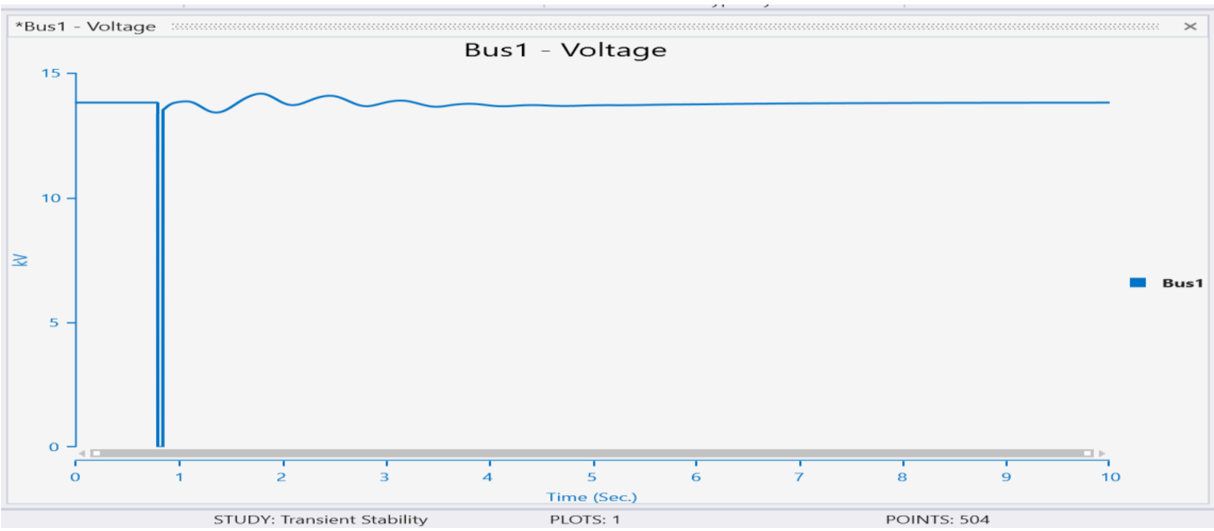

Fig 9: generator bus voltage with PSS

Fig. 9 shows that the incorporation of PSScaused aquick oscillation damping of the generator bus voltage after 3-phase fault was cleared leading to a reduction in the transient period.

V. CONCLUSION

The impact of Power System Stabilizer (PSS) on transient stability of power system was studied. The simulation has been carried out using ETAP19.0software and the plots for the generator speed, generator relative power angle, bus voltage, generator terminal current without and with PSS presented. From the plots shown in fig. 2, 3, 4, and 5, It can be seen that without PSS, the system's response is oscillatory after the three-phase fault was cleared. However, with application of PSS, the system was stable and oscillation damping was quick leading to a reduction in the transient period.

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