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Impact of Static Var Compensator (SVC) on Transient Stability of Power Network in Nigeria

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***Abstract* - The effect of the Static Var Compensator (SVC) on the transient stability of the Nigerian 330kV power transmission network connecting Afam to Port Harcourt was the main focus of this study. Software called the Electrical Transient Analyzer Program (ETAP) was used to create the network's single-line diagram and simulation. The experiment involved a thyristor-controlled reactor fixed capacitor (TCR-FC) type SVC. To allow for network instability, a three-phase short circuit fault was created in bus 5 at 0.8 seconds. At 0.9 seconds, the circuit breakers opened to clear the fault. The transient stability plot in figure 3 without SVC installation and before fault initiation at 0.8 seconds revealed that the system was running at synchronous speed with a rotor angle of 61.08 electrical degrees between 0.00 and 0.79 seconds. The rotor angle then climbed to 64.5 electrical degrees when the fault was first detected at 0.8 seconds. As seen from the first swing in figures 4 and 8, the addition of SVC of 75 MVAR rating at bus 12 reduced the maximum power angle deviation during a fault, from 64.5 electrical degrees (without SVC) to 64.1 electrical degrees (with SVC). This demonstrates how SVC significantly improved the transient stability of the network. By reducing the maximum power-angle deviation, the use of SVC will help maintain synchronism in some grave situations, such as more severe failures.**

Keywords: SVC, ETAP, transient stability, rotor angle, swing equation.

I. INTRODUCTION

Transmission networks have been overloaded and stressed to the point of instability in recent years. This occurs as a result of an increase in electricity demand brought on by population growth. The security of the electrical grid can be negatively impacted by this. Power system security is defined as the network's capacity to tolerate disturbances without breaking down [1]. One of the indicators for evaluating a power system's security is transient stability analysis. Transient stability refers to the power system's ability to maintain synchronism in the face of a severe disturbance. These disturbances include issues like a short circuit in a transmission line, generator failure, an abrupt drop in load on a generator, an abrupt increase in load on a generator, transmission network failure, starting a motor that is too large for the system's generating capacity, and switching operations [2]. System impedance, which takes into account the transient reactance of all generating units, has an impact on transient stability. Phase angle and synchronizing power flow are impacted by this. Transient stability is influenced by fault duration, circuit breaker speed, and relay configurations. Critical Clearing Time of a fault is typically regarded as the best indicator of a contingency's severity and is thus frequently used to rank contingencies according to their severity [3]. According to an IEEE publication, the Critical Clearing Time is the greatest period between the fault commencement and it’s clearing such that the power system is transiently stable. The transient stability limits refer to the maximum power that can be delivered through a system point while maintaining stability [4]. It has been determined that using Flexible AC Transmission Systems (FACTS) devices is the most cost-effective way to increase transient stability without building new transmission lines [5].

II. REVIEW OF PREVIOUS WORKS

The following FACTS devices have been recommended for enhancing the performance of the power system:

The Static Var Compensator (SVC), Phase Shifter (PS), Series Capacitors (SC), Thyristor Controlled Series Capacitors (TCSC), Unified Power Flow Controller (UPFC), Inter-phase Power Flow Controller (IPFC), Static Synchronous Series Controller (SSSC), STATCOM [6].

According to [7], when properly sized, SVC is one of these many FACTS devices that is effective for improving transient stability. In his paper, he used SVC with Fuzzy logic control to improve transient stability. SVCs are essentially shunt linked and often put at the transmission line's midway or its ends through a coupling transformer [8]. By properly adjusting its production of reactive power, it can enhance transient stability [9].

[10] Proposed a dynamic of the IEEE test system for a multi machine power system. After a serious contingency, it evaluated and carried out a transient stability analysis. According to [11], an investigation of the IEEE 30-bus

system's transient stability based on the ETAP-Software was presented. It suggested and implemented the stability of the power system in the face of multiple disturbances.

According to [12], a power system stabilizer and increasing inertia was used to achieve transient stability improvement of the 30-bus multimachine power system. It was improved by adding a power system stabilizer and boosting the machine's inertia while staying within a predetermined range. The study created complete dynamic models for all test systems by defining dynamic machine models and their associated parameters for each IEEE test bed system. In their study, the parameters of the suggested test system are based on typical data. The test systems are subjected to significant disturbances, and for each test system, a case study is offered that looks at the frequency, angle, and voltage stability. Power World simulation software was used to build the suggested dynamic IEEE test system.

[13] Utilized ETAP 19.0 software to concentrate on the effect of Power System Stabilizers (PSS) on the transient stability of the Port Harcourt zone 2 power transmission network in Nigeria. The simulation plots for the generator speed, generator relative power angle, bus voltage, and generator terminal current demonstrated that the system's oscillatory characteristics were quickly dampened by the addition of PSS, the transient period was shortened, and the system reached a stable and steady state position. Yet, in the absence of PSS, after the problem was fixed, the system parameters responded in an oscillating manner. The outcomes of the simulation demonstrated that PSS enhances the power systems' transient stability.

In light of [14], Static Var Compensator (SVC) was employed in Nigeria's 132/33kV Benin network to make up for reactive power losses, enhancing the voltage profile, lowering transformer loading and thus enhancing the stability of the network.

[15] Proposed the integrated Nigerian power system's transient stability and in the study, they stated that between generating stations and buses in the network, there was a significant disruption. The study performed transient stability analysis on the 64 transmission lines, 52 buses, and 17 generating units that make up the 330 kV integrated power network in Nigeria. The analysis took into account how a three-phase short circuit fault at the biggest generating station (EGBIN) would affect the network's overall stability. The results showed that four generators lost synchronism when a fault started, but that after the fault was cleared, the generators' stability was restored.

[16] Used ETAP software to analyze the transient stability of the IEEE 39 bus system with 10 generators. In his work, he subjected the interconnected power system to a severe disturbance and then analyzed the transient stability by applying various contingency scenarios and models. To improve the transient stability, he used IEEE type-1 exciter and turbine governor on all the generators in the network, except on generator 10 connected to bus 39. According to the findings, the grid-connected generators underwent variations in power input during contingency analysis, and those that were closer to the area of the fault had a larger power deviation.

[17] Carried out a transient stability analysis on a five-bus system with three single-phase generators, a single-phase transformer and two loads. The system's base frequency is 50 Hz, the base voltage is 230 volts, and the base MVA is 100 MVA. The paper presented and discussed the impact of a three-phase to-ground fault on a power system's transient stability. The disturbance in Gen 1 is taken into account in the power network, and then an analysis of transient stability using Mi Power was performed on the entire system. Following the simulation, the foregoing result led to the conclusion that when a generator failure occurs, the system becomes unstable as a result of machine 1's rotor angle continuously increasing. While the status of machine 2 is stable. As long as the fault persists, the system is unstable.

Having reviewed various kinds of literature on power systems' transient stability and their contributions, it is observed that most of the literature used the IEEE test system for transient stability analysis. Hence, my research paper focuses on the transient stability improvement of a section of the Nigerian 330kV power network linking Afam to Port Harcourt using the static var compensator (SVC) technique when the power system is subjected to a three-phase short circuit fault as a way to avoid building new transmission lines which are capital intensive.

Modelling of Static Var Compensator (SVC)

Thyristor-controlled reactor fixed capacitor (TCR- FC) type VAR compensator is the SVC used in this study. It is depicted in fig 1 and has two branches: purely capacitive and purely inductive branches.

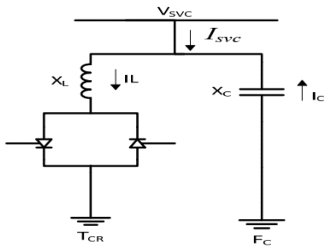

Figure 1: Thyristor-controlled reactor fixed capacitor (TCR-FC) type SVC

The SVC does not utilize active power, but it may either use reactive power to lower the voltage of the system by consuming it through the inductive branch (TCR), or it can inject reactive power into the system by using the capacitive branch (FC) to raise the voltage. When the bus voltage drops below the reference voltage, the SVC is built to turn off the TCR, and when it rises above, it turns on. Consequently, the maximum reactive power used by the thyristor-controlled reactor (TCR) and fixed capacitor (FC) is given as

$$Q_{SVC}^{max} = B_{SVC}(\propto) \times V_{SVC}^2 \qquad (1)$$

$$Q_{SVC}^{min} = -\frac{1}{X_c} V_{SVC}^2 \qquad (2)$$

ETAP (Electrical Transient Analyzer Program)

The analysis, simulation, monitoring, control, optimization, and automation of electrical power systems are the focus of the full-spectrum analytical engineering software package ETAP. The entire power system suite provided by ETAP software is the best and most complete, from modeling through the operation. It is mostly employed in the generating, transmission, distribution, industrial, transportation, low-voltage, etc. sectors. It is an excellent research tool since it is especially helpful for examining the effects of nonlinearity on the behavior of the system [18].

III. MATERIALS AND METHOD

The network used in this study is a part of the Nigerian 330kV network linking Afam to Port Harcourt. The single-line diagram of the network is shown in fig. 2. Three-phase short circuit fault was initiated on bus 5 and a transient stability study was carried out with and without TCR-FC type SVC to examine its impact on the generator's rotor angle and, terminal current. Terminal voltage and the entire transient stability of the network. Runge-Kutta numerical technique was the method used to solve the swing equation and the analysis was done using the equal area criteria method embedded in ETAP software.

Swing Equation

The rotor axis and the magnetic field axis of the stator are fixed on one another under typical operating conditions. The load angle, which is dependent on the machine's loading, is the angle formed between the two. When the synchronous machine's shaft is loaded or unloaded, the rotor decelerates or accelerates in response to the stator field's synchronous rotation, and a relative motion begins. With relation to the stator field, the rotor is now considered to be swinging. The swing equation is the equation that describes the relative motion of the rotor (load angle) concerning the stator field as a function of time [19]. The equation is given as

$$M\frac{d^2\delta}{dt^2} = P_m - P_E \qquad (3)$$

Where,

M = inertia constant of the machine.
Pm = mechanical power input (shaft power)
Pe = Pa sin δ = electrical power output
Pa = amplitude for the power angle curve.
δm = mechanical power angle.

Equal Area Criteria

This method can be applied to make an immediate stability prediction. This approach uses a graphical representation of the energy held by the spinning mass as a tool to assess whether the machine maintains stability in the face of a disturbance. Only systems with one machine connected to an infinite bus or systems with two machines can use the method [20]. The equation is expressed as

$$E_1 = \int_{\delta_o}^{\delta_{cr}} (P_m - P_e)\,d\delta = A_1 \qquad (4)$$

$$E_1 = \int_{\delta_{cr}}^{\delta_m} (P_e - P_m)\,d\delta = A_2 \qquad (5)$$

The expression for the critical clearing time is given as:

$$t_{cr} = \sqrt{(\delta_{cr} - \delta_o)\frac{4H}{\omega_o P_m}} \qquad (6)$$

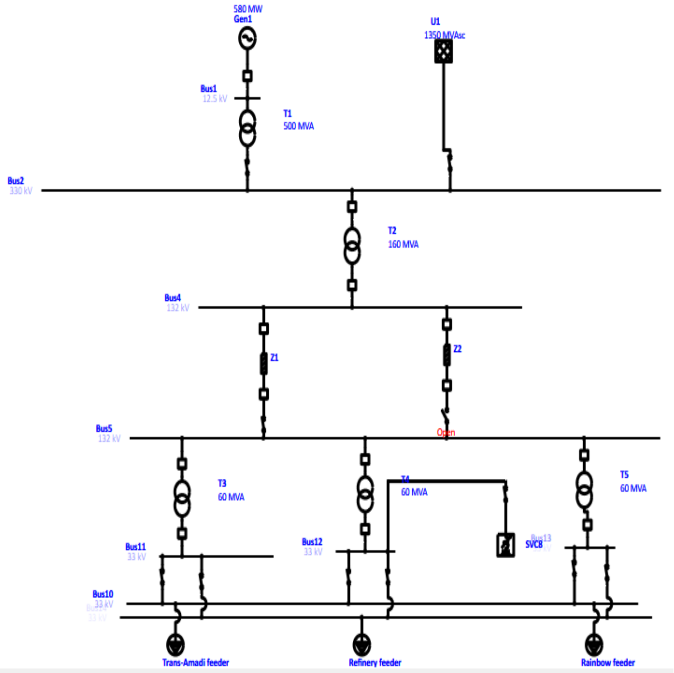

Figure 2: Single line diagram of Afam-Port Harcourt network before simulation

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IV. RESULTS AND DISCUSSION

The single-line diagram of the Afam - Port Harcourt 330kV distribution network shown in fig. 3 was used as a test case for transient stability research was modeled using the Electrical Transient Analyzer Program (ETAP 19.0). Figure 3 displays the diagram and simulation outcomes from the transient stability analysis tool included in the ETAP software. A three-phase fault was created at bus 5 with an initiation time of 0.8 seconds and a clearance time of 0.9 seconds to investigate how SVC influences the network's transient stability. The simulations were carried out with and without SVC. At a simulation time step of 0.001, the ETAP software ran the simulation for 10 seconds.

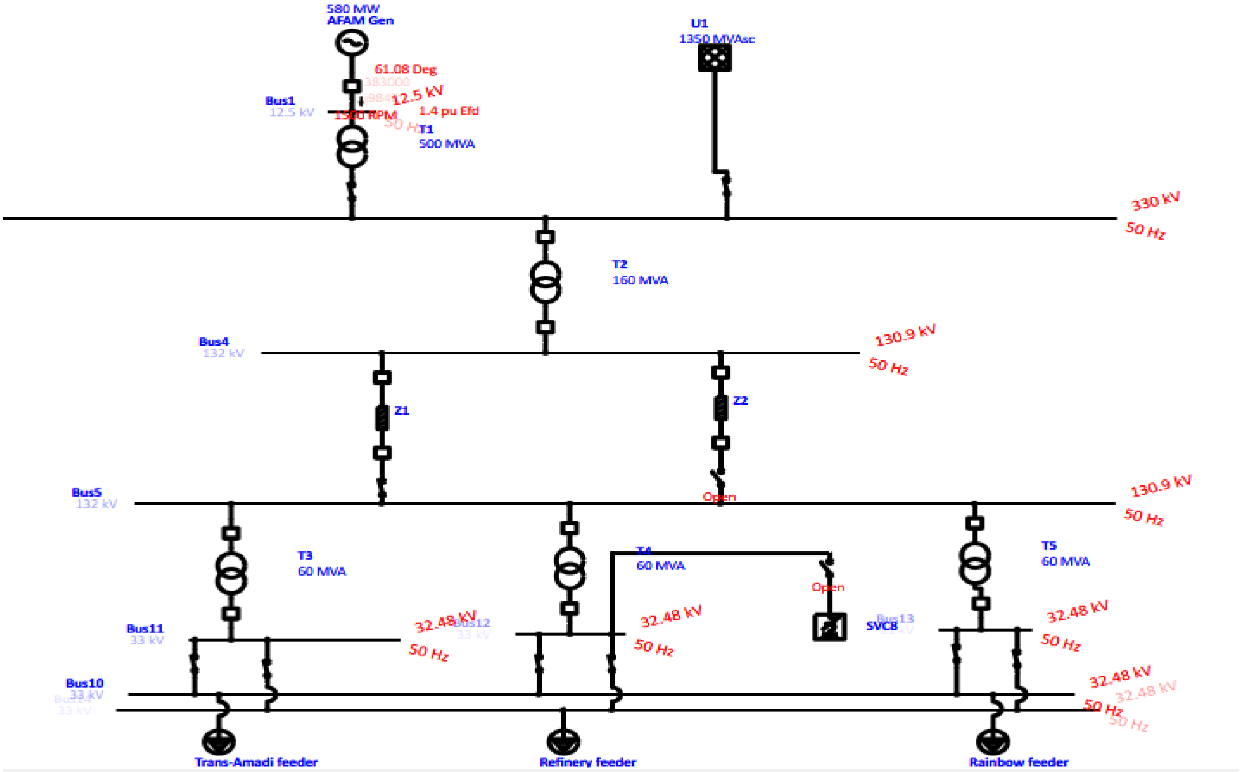

Figure 3: Single line diagram of Afam - Port Harcourt 330kV transmission network without SVC

Table 1: Bus voltage (kV)

S/N	BUS ID	BUS TYPE	NOMINAL (kV)	PRE-FAULT VOLTAGE (kV)	DURING-FAULT VOLTAGE (kV)	POST-FAULT VOLTAGE (kV)
1	BUS 1	GEN	12.5	12.5	9.19	12.47
2	BUS 2	LOAD	330	330	211.4	329.5
3	BUS 4	LOAD	132	130.9	0.334	130.7
4	BUS 5	LOAD	132	130.9	0	130.7
5	BUS 10	LOAD	33	32.48	0	32.43
6	BUS 11	LOAD	33	32.48	0	32.43
7	BUS 12	LOAD	33	32.48	0	32.43
8	BUS 13	LOAD	33	32.48	0	32.43

The bus voltages are displayed in Table 1 for the pre-fault, fault, and post-fault scenarios. When the fault was initiated, it was discovered that the bus voltages were outside of the regulatory limits of 11.88 kV to 13.13 kV for the 12.5 kV bus, 313.5 kV to 346.5 kV for the 330 kV bus, 125.4 kV to 138.6 kV for the 132 kV bus, and 31.35 kV to 34.65 kV for the 33 kV bus. After the fault was removed, the oscillation progressively decreased.

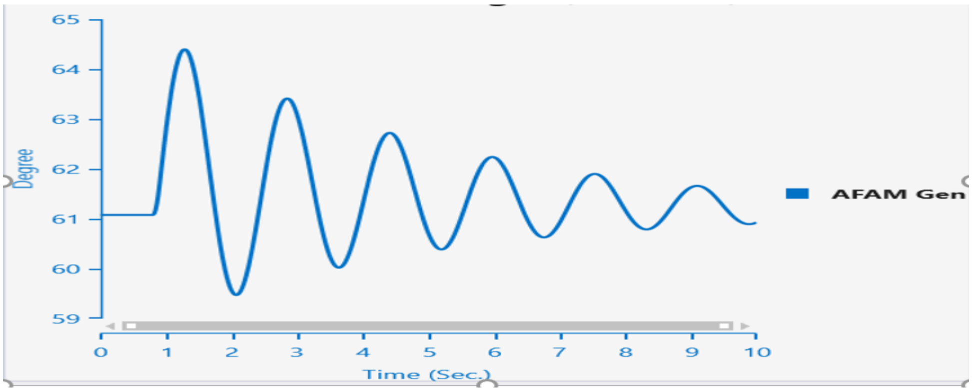

Figure 4: Plot of Relative Power Angle against Time without SVC

The plot in Fig. 4 depicts the relative power (rotor) angle variation with time for the generator without SVC. The plot shows that there were no power oscillations between 0.00 and 0.79 seconds, indicating that the generator was operating at synchronous speed. Later, around 0.8 seconds, a 3-phase fault started, and it is clear from the plot that the generator's power was swinging as a result of the 3-phase fault. The system was oscillatory but steady once the fault was cleared at 0.9 seconds. During the fault, the rotor angle moved from 61.1 electrical degrees to 64.50 electrical degrees.

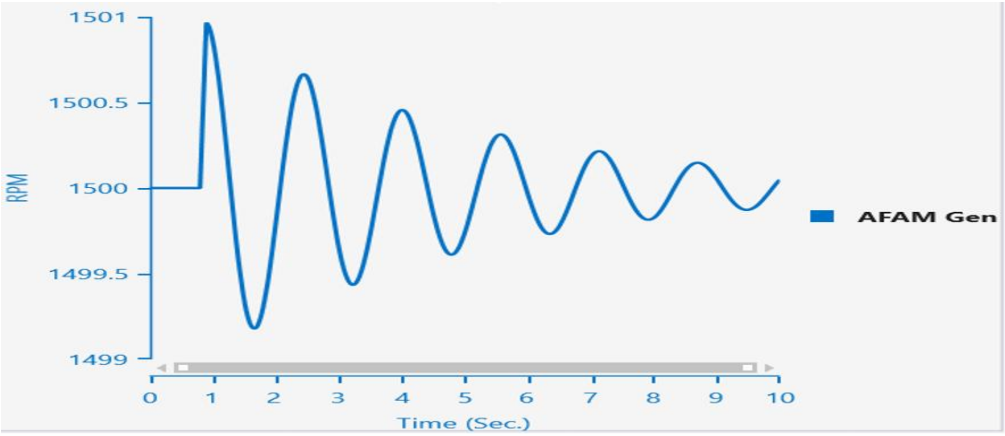

Figure 5: Generator speed against time without SVC

The generator's speed vs time without SVC is plotted in Fig. 5. The plot shows that there were no power oscillations during 0.00-0.79 seconds, proving that the generator was operating at synchronous speed. It can be seen from the plot that the fault started at 0.8 seconds and cleared at 0.9 seconds so 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.

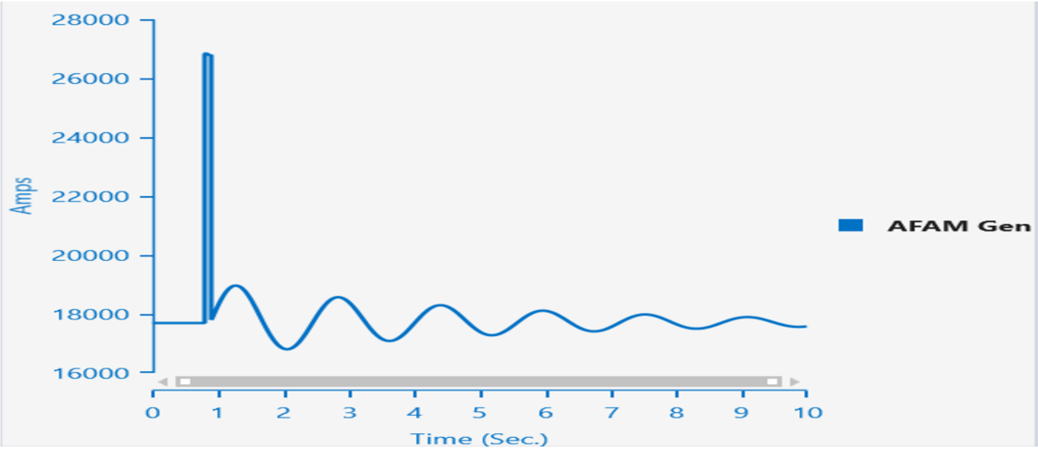

Figure 6: generator terminal current against time without SVC

The plot of the generator terminal current against time without SVC is shown in Fig. 6. The plot shows that when a 3-phase fault started, there was an abrupt increase in the generator's terminal current. The oscillations in the terminal current progressively decreased and dissipated once the fault was fixed, achieving a stable operating condition after 10 seconds.

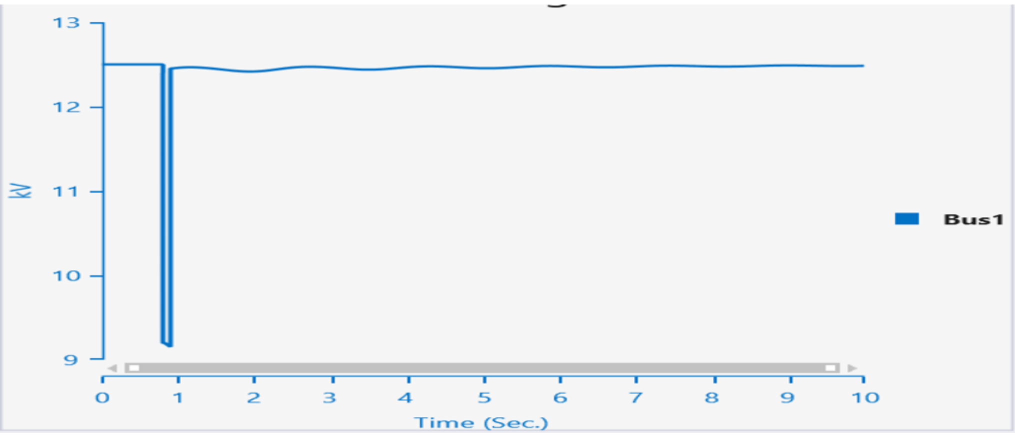

Figure 7: Generator bus voltage without SVC

The plot of the generator bus voltage against time without SVC is shown in Fig. 5. The graphic clearly shows how the generator bus voltage abruptly dropped to 9.19 kV when a 3-phase fault was initiated. After the fault was cleared, the system stabilized, and the bus voltage oscillations diminished and eventually disappeared.

Analysis of Result with SVC

The first swing's observation depicted in fig. 8 reveals that the addition of SVC with a rating of 75 MVAR at bus 12 decreased the maximum power angle deviation during a fault, from 64.5 electrical degrees (without SVC) to 64.1electrical degrees (with SVC). This shows that SVC substantially enhanced the network's transient stability. The usage of SVC will aid in maintaining synchronism in some dire circumstances, such as more severe faults, by lowering the maximum power-angle deviation.

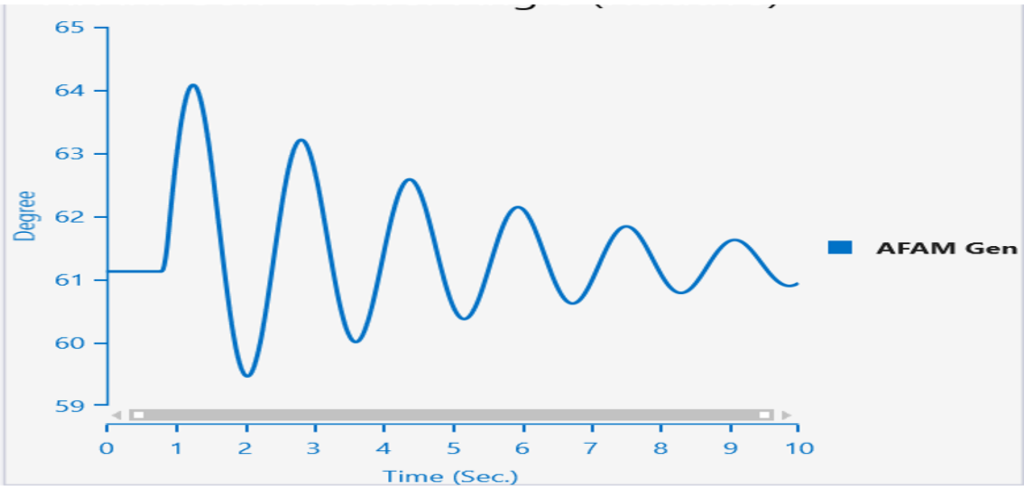

Figure 8: relative rotor angle deviation with SVC

IV. CONCLUSION

Analysis was done on the effect of Static Var Compensator (SVC) on system faults. Based on the results, it can be said that ETAP is a program that can simulate power quality issues. The findings indicated that SVC has a great deal of potential to enhance the system’s performance. SVC's introduction decreased the amount of maximum power (rotor) angle deviation, greatly enhancing the system's transient stability. Due to the decrease in the maximum power-angle deviation, the usage of SVC will aid in maintaining synchronism in some dire circumstances, such as more severe faults.

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