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Comparison of TCSC and STATCOM for Damping Power System Oscillations

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Abstract

Power system oscillation damping remains as one of the major concerns for secure and reliable operation of power systems. Power system oscillations occur due to the lack of damping torque at the generators' rotors. The oscillation of the generators' rotors causes the oscillation of other power system variables such as bus voltage. Flexible ac transmission systems (FACTS) devices with a suitable control strategy have the potential to increase the system stability margin. The damping problem is analyzed based on eigenvalue analysis and time-domain simulation. Case studies have been demonstrated on Myanmar National Grid using Power System Analysis Toolbox (PSAT). The oscillation damping by installing FACTS devices such as TCSC and STATCOM are studied in this paper and performance analysis of TCSC and STATCOM are compared in voltage supporting and power system oscillation damping.

Keywords: Eigenvalue analysis; Power system oscillation damping; PSAT; STATCOM; TCSC; Time-domain simulation.

1. Introduction

Damping of oscillations has been recognized as important in electric power system operation from the beginning. In response to a continual increase in demand, power systems are driven closer to their limits, especially those of transmission capacity. The oscillations may be local to a single generator or generator plant (local oscillations), or they may involve a number of generators widely separated geographically (inter-area oscillations).

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Inter-area oscillations may appear as the systems loading is increased across the weak transmission links in the system which characterize these oscillations. If not controlled, these oscillations may lead to total or partial power interruption [7].

Flexible ac transmission systems (FACTS) controllers are capable of controlling the network conditions in a very fast manner, and this feature of FACTS can be exploited to solve many power system problems, to improve power system stability, to enhance system controllability, to increase power transfer capability, etc. FACTS devices can be divided into shunt connected, series connected and combination of both. Static Var Compensator (SVC) and Static Synchronous Compensator (STATCOM) are shunt connected devices which inject or absorb reactive power. Thyristor Controlled Series Compensator (TCSC) and Static Synchronous Series Compensator (SSSC) are series connected devices. Unified Power Flow Controller (UPFC) is combination of shunt and series devices [1].

This paper presents the comparison of STATCOM and TCSC to improve the small signal stability, voltage stability and enhance the transient stability in three phase faulted condition. TCSC is one of the most popular FACTS controllers which allow rapid and continuous modulation of the transmission line reactance. TCSC is connected in series with transmission lines. STATCOM is a shunt connected controlled reactive-power source. It generates a balanced set of three phase sinusoidal voltages at the fundamental frequency, with rapidly controllable amplitude and phase angle [9].

In this paper, the simulations are done by using Power System Analysis Toolbox (PSAT) software. PSAT is educational open source software for power system analysis studies. PSAT is a MATLAB toolbox and the toolbox covers fundamental and necessary routines for power system studies such as power flow, small signal stability analysis, and time-domain simulation as well as several static and dynamic models, including non-conventional loads, synchronous and asynchronous machines, regulators and FACTS. PSAT is a suitable candidate as power system analysis software which is capable of performing stability analyses [10].

Rest of the paper is organized as follows: Section II gives the basic background about the small-signal stability and transient stability analysis. In Section III, dynamic modelling is presented. Proposed approach and case study are briefly stated in Section IV. The main conclusions and contributions of the paper are mentioned in Section V.

2. Basic background

A set of important dynamic properties of power systems are related to small-signal (or linear) stability. Understanding dynamic responses of a power system is a vital key in assessing the system’s characteristics. Once these characteristics of the system have been well-understood, the response of the system to some disturbances may be anticipated. This allows for the design of countermeasures that would limit the negative impact of these disturbances. The small-signal dynamic behaviour of power systems can be determined by eigen analysis, which is a well-established linear-algebra analysis method, if a dynamic power system model is available.

2.1 Small-signal Stability Analysis

Small-signal stability is defined as the ability of a power system to maintain its synchronism after being subjected to a small disturbance [14]. Small signal stability analysis reveals important relationships among state variables of a system and gives an insight into the electromechanical dynamics of the network. Eigen analysis, a well-established linear-algebra analysis method, is employed to determine the small-signal dynamic behaviour of the study system. Applying the technique to the linearized model of the system, small-signal stability is studied by analysing eigenvalues. In eigen analysis, the linearized model of a power system is represented in a state-space form as [14]

$$\Delta\dot{x}_P = A_P \Delta x_P + B_P \Delta u_P \tag{1}$$

$$\Delta y_P = C_P \Delta x_P + D_P \Delta u_P \tag{2}$$

where vectors Δx_P, Δy_P, and Δu_P represent the state variables, the output variables, and the inputs, respectively. The eigen values, λi, are computed from the AP-matrix from

$$det(\lambda I - A_P) = 0 \tag{3}$$

The eigenvalues are used to determine the system stability. The real eigenvalues are related to non oscillatory mode and complex eigenvalues are related to oscillatory mode. A negative eigenvalue shows the stability in the system and a positive eigenvalue shows the instability in the system. The damping is represented by real part of the eigenvalues. The frequency of the oscillation is represented by imaginary part of the eigen values. For complex pair of the eigenvalues:

$$\lambda = \sigma + \omega \tag{4}$$

The frequency of the oscillation is signified by

$$f = \frac{\omega}{2\pi} \tag{5}$$

The damping ratio is signified by

$$\xi = \frac{-\sigma}{\sqrt{\sigma^2 + \omega^2}} \tag{6}$$

The rate of the decay is concluded through the damping ratio. The parameters σ and ω are used to analyze the effects of damping in power system. The damping ratio and the frequency of oscillation are the main factors to calculate the damping of the system. If the damping ratio is more, the system will give more damping to oscillate [13].

2.2 Transient Stability Analysis

Transient stability is defined as the ability of a power system to maintain its synchronism after being subjected to a large disturbance. One of the most commonly used to assess the transient stability of a power system is to apply a fault at a node and observe the corresponding responses. Three phase fault should be applied at a bus in such way that the nonlinear behavior of the model can be evaluated. Any disturbance in the system will cause the imbalance between the mechanical power input to the generator and electrical power output of the generator to be affected. As a result, some of the generators will tend to speed up and some will tend to slow down. Time domain simulations have been traditionally used to assess stability [12].

3. Dynamic modeling

Dynamic models of synchronous generators, exciters, turbines, governors, TCSC and STATCOM for system are implemented in PSAT. All models used are documented in the PSAT Manual.

1) Generator Models:

Two synchronous machine models are used in the system: three-rotor windings for the salient pole machines of hydro power plants and four-rotor windings for the round-rotor machines of thermal plants. These two types of generators are described by five and six state variables, respectively. All generators have no mechanical damping and saturation effects are neglected [11].

2) Automatic Voltage Regulator Models:

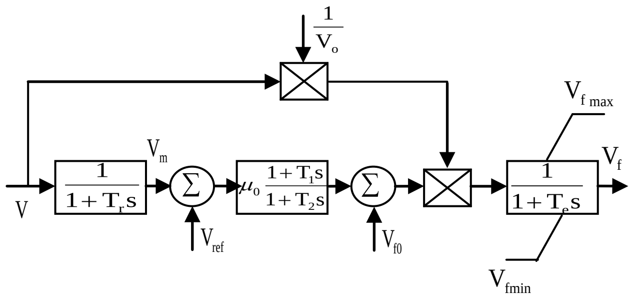

Figure 1: Exciter model.

The same model of AVR, as shown in Figure 1, is used for all generators but with different parameters. The field voltage v_f is subject to an anti-windup limiter [11].

3) Turbine and Governor Models:

In PSAT there are two models of turbine and governors; namely Model 1 and Model 2: the former being a thermal generator model while the latter a simplified model. As such, the system's hydro generator is temporarily represented by Model 2 while that of the thermal is represented by Model 1. Block diagrams of turbine and governor models for Model 1 and Model 2 are depicted in Figure 2 and 3, respectively [11].

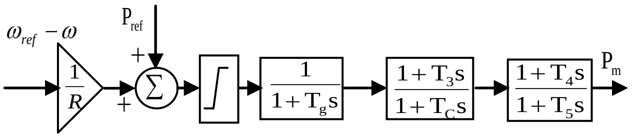

Figure 2: Turbine Governor Model used for thermal generators: Model 1.

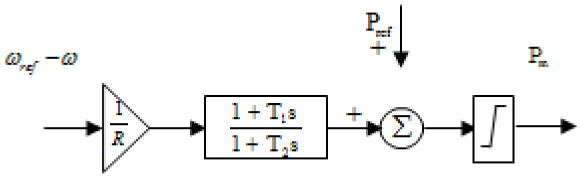

Figure 3: Turbine Governor Model used for hydro generators: Model 2.

4) Modelling of Thyristor Controlled Series Capacitor (TCSC):

The basic Thyristor-controlled Series Compensator (TCSC) configuration consists of a fixed series capacitor bank C in parallel with a TCR as shown in Figure 4. This simple model utilizes the concept of a variable series reactance. The series reactance is adjusted through appropriate variation of the firing angle, to allow specified amount of active power flow across the series-compensated line. By controlling the trigger angle of the back to back thyristors, it is possible to vary the effective inductive reactance of the TCR, and hence control the reactance provided by the TCSC [4].

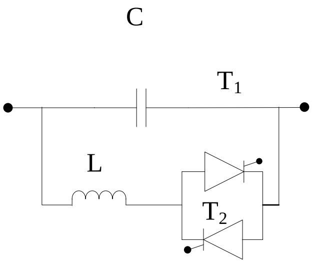

Figure 4: Basic TCSC Scheme [4]

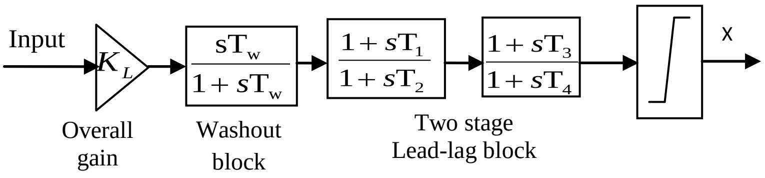

Figure 5: Structure of TCSC-based controller

The general structure of the stability controller is shown in Figure 5. It consists of a washout filter, a dynamic compensator, and a limiter. The washout filter is used to avoid a controller response to the dc offest of the input signal. The dynamic compensator consists of two (or more) lead-lag blocks to provide the necessary phase-lead characteristics. Finally, the limiter is used to improve controller response to large deviations in the input signal [8].

5) Modelling of Static Synchronous Compensators (STATCOM):

The basic electronic block of a STATCOM is the Voltage Source Converter (VSC), which in general converts an input dc voltage into a three-phase output voltage at fundamental frequency, with rapidly controllable amplitude and phase angle. In addition to this, the controller has a coupling transformer and a dc capacitor as shown in Figure 6. The control system can be designed to maintain the magnitude of the bus voltage constant by controlling the magnitude and/or phase shift of the VSC output voltage [7].

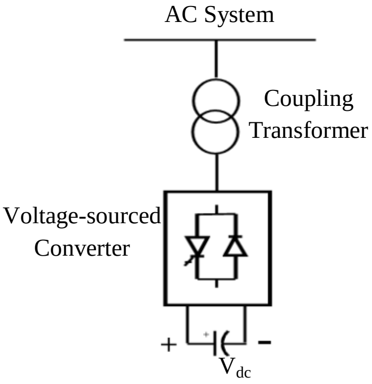

Figure 6: Schematic Diagram of Static Synchronous Compensator [8]

When the amplitude of the output voltage is raised over the system voltage, then the current flows via reactance from the inverter to the AC system and the inverter produces capacitive power for the AC grid. On the other hand, if the output voltage amplitude is decreased under that of the AC grid, then the reactive current flows from the AC system to the inverter and the inverter draws inductive power. In addition, when the output voltage amplitude is balanced to the AC grid voltage, the reactive power flows become zero. The structure shown in Figure 7 consists of a gain block, a signal washout block and two-stage phase-compensation block.

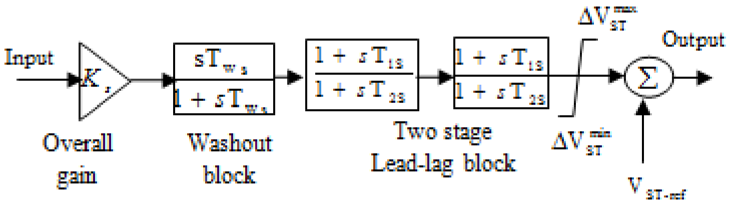

Figure 7: Structure of STATCOM-based controller

4. Proposed approach and case study

This section will discuss about Myanmar National Grid that is used to analyse the effect of TCSC and

STATCOM on voltage stability, small signal stability, and transient stability in the system. The single line diagram of Myanmar National Grid is shown in Figure 8. The system has 123 transmission lines and 104 buses with 31 generator buses. The voltage levels of the test system are 230 kV, 132kV, 66kV and 33kV respectively.

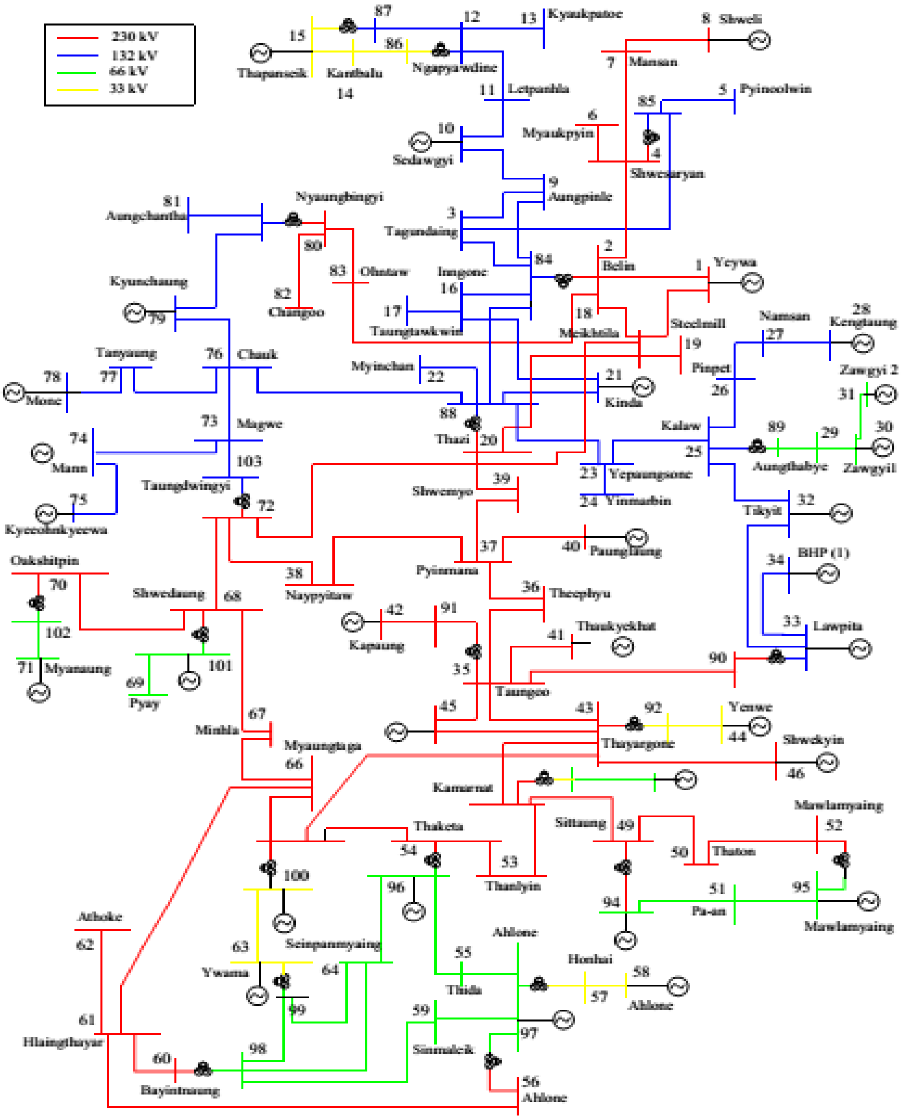

Figure 8: Single line diagram of Myanmar National Grid

Once the power flow in electric network has been solved, Hlaingthayar (Bus-61) is found as the weakest bus of the system. So, Bus-61 is the suitable place to install STATCOM and TCSC is installed in the line of Ahlone-Hlaingthayar, 230 kV. To evaluate the transient stability of the test system, a three fault is applied at Bus- 97 (Ahlone Station).

4.1 Eigen Value Analysis of the system

The eigen values analyses are taken after the time domain simulation for the system shown in Figure 9. All 228 eigenvalues and one positive eigenvalue are obtained. This shows the system is in unstable condition due to the disturbance. The system has three cases, without any FACTS, with TCSC and with STATCOM. Fig. 9 shows some eigenvalues of the system without FACTS.

To maintain small signal stability FACTS devices are installed in the suitable place. The advantage of the proposed approach is that eigenvalues are shifted from positive real axis to negative real axis. It gives more damping to reduce oscillations and high precision results in determining the stability of the system. The results for installing TCSC and STATCOM devices are compared in Table 1, from the results the positive eigens are reduced and negative eigens are increased. Therefore, the system is maintained stable by installing FACTS devices.

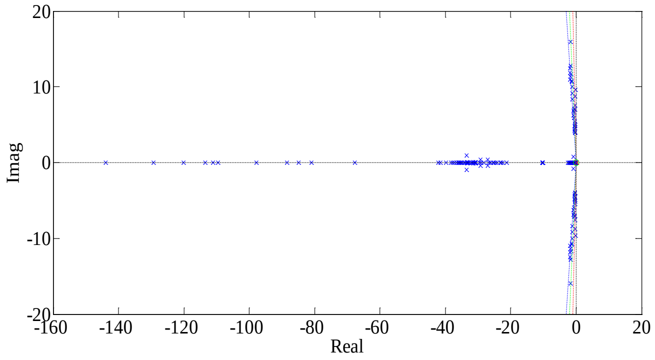

Figure 9: Plot of Eigen values without FACTS

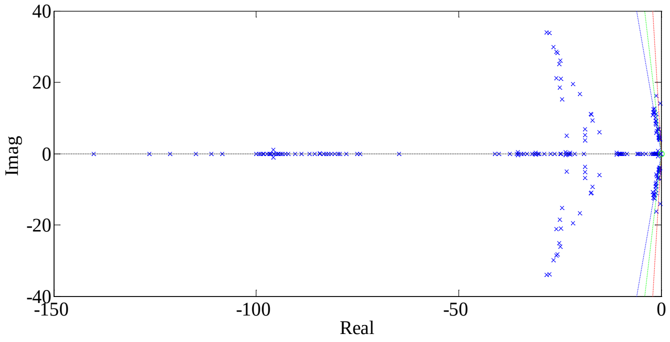

Figure 10: Plot of Eigen values with TCSC

Eigenvalues are in complex number, represent oscillatory mode. The real part provides damping coefficient and imaginary part show oscillation frequency. The negative values at real part provide a better result of damping oscillation. The installation of TCSC changes the number of eigenvalues from 228 to 323 and STATCOM increases to 331. The plot of eigenvalues with TCSC and with STATCOM is shown in Figure 10 and 11.

4.2 Time Domain Simulation of the system

To capture the general behaviour of the system, one approach is to apply a three-phase fault at a bus as a perturbation and study the dynamic response from a time domain simulation. The time domain simulations have been carried out at disturbances specified above. It is observed the voltage profile of the Bus-61 (Hlaingthayar) is the lowest voltage profile.

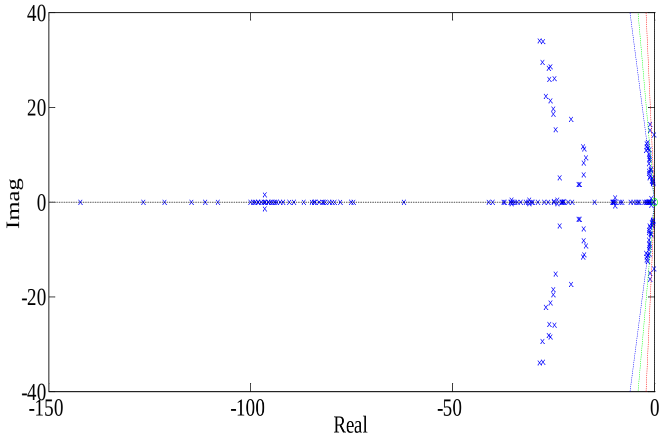

Figure 11: Plot of Eigen values with STATCOM

Table 1: Eigenvalue Analysis of the System Without and With FACTS Devices

	Without FACTS	With TCSC	With STATCOM
Dynamic Order	228	323	331
Buses	104	104	104
Positive Eigens	1	0	0
Negative Eigens	226	322	330
Complex Pairs	37	60	61
Zero Eigens	1	1	1

Because of the over loading, the voltage profiles of the bus have been affected without FACTS and the profile is shown in Figure 12. This is to measure the performance of the system itself, without the consideration of any FACTS controllers. The stabled voltage by installing FACTS devices are shown in Figure 13 and 14.

The transient oscillations in rotor speed of all synchronous generators without FACTS are shown in Figure 15. Once the TCSC device is installed and the time domain simulation is carried out to find the stability of the system and the graphs are plotted in Figure 16. The Graph shows the relative angular speeds of all synchronous generators with respect to time. From the results, with installation of TCSC the oscillations are died out rapidly and the transient stability is improved as compared to without FACTS devices.

The plot of angular speeds with STATCOM is shown in Figure 17. There are oscillations in the system when fault occurs but this figure indicates the capability of STATCOM in reducing settling time and damping the oscillation. Comparing these two simulations, the system with STATCOM recovers to steady state faster than that with TCSC.

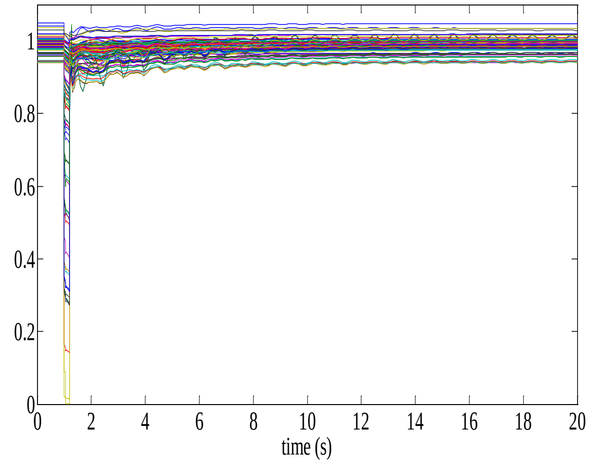

Figure 12: Graph of voltage against time without FACTS

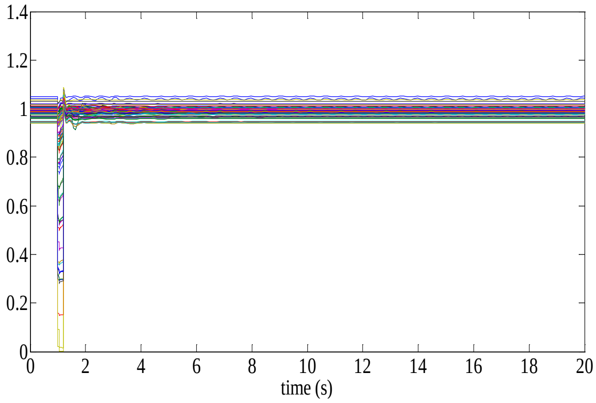

Figure 13: Graph of voltage against time with TCSC

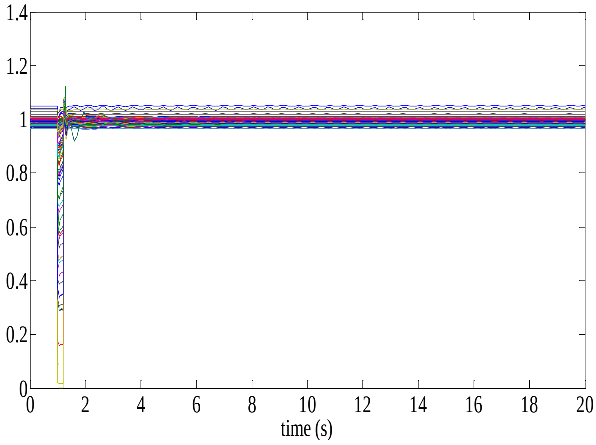

Figure 14: Graph of voltage against time with STATCOM

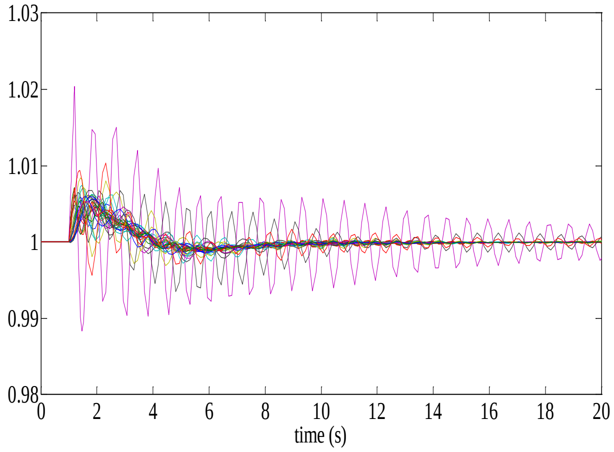

Figure 15: Time domain response of generator speed oscillation without FACTS

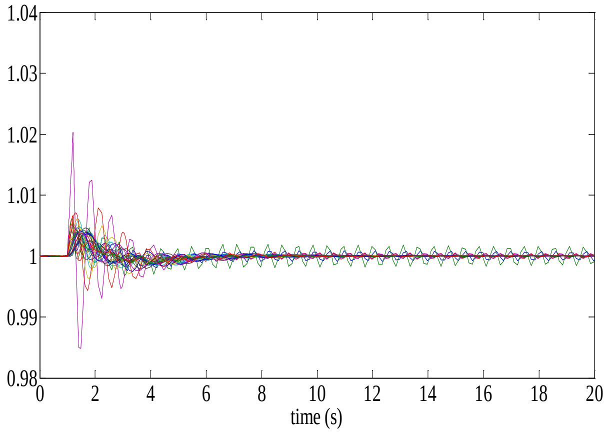

Figure 16: Time domain response of generator speed oscillation with TCSC

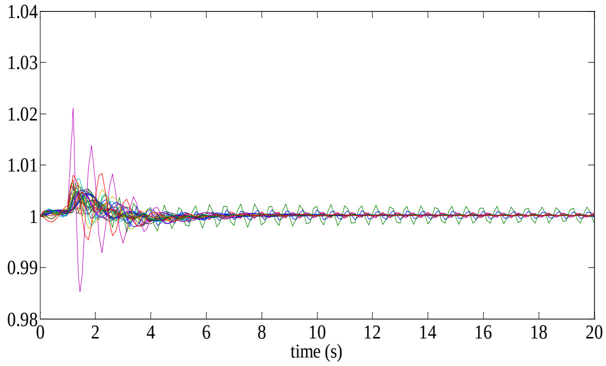

Figure 17: Time domain response of generator speed oscillation with STATCOM

The effect of different control modes is separately illustrated in Table 2. It is clear that by installing STATCOM, it is possible to achieve higher level of damping compared to the installation of TCSC.

Table 2: Comparison of Damping Ratio Without and With FACTS Devices

Mode of Control	Critical Swing Mode	Damping Ratio
Without Control	-0.11269 ± 9.6421	0.0117
With TCSC	-1.3382 ± 9.144	0.1448
With STATCOM	-1.3929 ± 9.0828	0.1516

5. Conclusions and recommendations

This paper has laid out important concepts for power system stability analysis. Myanmar National Grid is implemented in a free and open source software: the Power System Analysis Toolbox (PSAT), and is used as a test system to illustrate the concepts investigated throughout the work. After analyzing the results obtained in the implemented tests, the performance of TCSC and STATCOM is compared in their effectiveness for damping oscillation at the real system. TCSC and STATCOM provide excellent dynamic performance in improving voltage stability, small signal stability, and transient stability of the system. The value of damping ratio for the installation of TCSC and STATCOM are respectively, obtained as 0.1448 and 0.1516. It has been found that with the installation of a STATCOM, the damping of the critical swing mode increases and simultaneously oscillation decreases.

FACTS devices are so costly that it is not possible to put FACTS devices in every line or at buses. The sensitivity analysis criterion should be considered for the optimal placement of FACTS devices to be fully utilized. Power system stabilizers (PSSs) are auxiliary control devices on synchronous generators, used in conduction with their excitation systems to provide control signals toward enhancing the system damping. The interaction among PSSs and FACTS devices may enhance or degrade the damping of certain modes of rotor's oscillation. It is recommended Flexible AC Transmission System (FACTS) devices should be coordinated with PSSs to improve power system stability.

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