Transverse stability improvement by FACTS devices: A Comparison between STATCOM and SSSC in an extra high voltage transmission system

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Abstract. Loss of 500 kV A–B transmission line causes voltage instability in surrounding subsystem. This condition may cause further disturbance in the whole interconnected system. Improvement of voltage stability can be handled by adding FACTS devices, such as Static Synchronous Series Compensator (SSSC) and Static Synchronous Compensator (STATCOM). SSSC and STATCOM have the capability of dynamically controlling the power flow through a line. This paper aims to compare the performance of both devices to increase system stability. These methods are compared by analyzing the bus voltage, active power in line and rotor angle. As a result, this paper shows that the implementation of STATCOM is more stable in state of SSSC.

1. Introduction
In a modern interconnected power system, transmission lines are more heavily loaded than ever before to meet the growing demand. One of the most consequences of such a stressed system in transmission lines is the threat of losing stability following a disturbance. One of the important issues in power system operation is improvement of first swing stability limits. If the angle of all machines in the center of angle (COA) reference frame increases (decreases) until a peak (valley) is reached a power system can be considered as first swing stable where the angle starts returning to the stable equilibrium point. [1]

Basically, reactive power is used in loads that have inductive and capacitive properties. The greater the capacitive load installed will cause the system to overload the reactive power which is capacitive. While the greater the inductive load installed will cause the system to be over inductive reactive power. This factor can then affect the system which can reduce the amount of real power (active power) sent to the load and worsen the power factor. [2]

Adding equipment that serves as an additional load on the system is one way to handle the amount of reactive power (VAR). We can see this method that used capacitors bank to reduce inductive reactive power. However, given the fluctuating nature of the electricity load, this will be difficult to do with systems with fluctuating loads. If at any time the system has a large capacitive load, it will cause the system to have a large reactive power value which will reduce the quality of the system. [2]

To improve both stability and damping of a power system by dynamically controlling the power-angle curve of the system, Flexible AC Transmissions System (FACTS) are found to be very effective [3]. There are various forms of FACTS devices, some of which are connected in series with a line and the others are connected in shunt [4]. This paper determines and compares the first swing voltage...
stability limit of a simple system in the presence of a SSSC and STATCOM by injected reactive power to the system in order to maximize stability in Gitet G.

This paper is organized as: section 1 presents the research introduction, section 2 proposes problem identification of disturbance in both of A–G transmission lines, section 3 provides methodology and test procedures between STATCOM and SSSC, section 4 shows the result and analysis and section 5 is conclusion of this paper.

For security reason, the identity of the 500 kV substation on this paper are adjusted.

2. Problem Identification

Electric transmission is one part that takes an important role in the electricity system [5]. Failure on the transmission side will cause a power outage which results in a large loss on the consumer side. Thus, transmission systems have to operate reliably. Beside system reliability, power quality is another concern which needs to be considered. Power quality generally discusses variations in voltage values, transient voltage and current, harmonic values and others. This problem is a factor that takes a big role in the overall electricity problem, with the value of reactive power in the system being one of the main causes [6].

Problem identification is discussed where the test is done to find out the differences impact between STATCOM and SSSC. The fault which this paper discusses firstly appeared when A–B extra high voltage line trips and resulted in 25 generators trip with total load of 3,846 MW and consumer outages of 1,917.5 MW. Disconnection of A–B lines are caused by trees entering the clearance of 500 kV A–B line which caused a short circuit to flow through the tree to the ground. The breakdown of the A–B line has an impact on the G–H line, resulting in overvoltage on the line and finally the breaker is turned on to disconnect the line. At G also experienced voltage instability after a disturbance line, before finally the connection of A substation to one of subsystems in interconnected system was totally blackout and G was separated from the Interconnected System. The scope of problem that discusses in this paper is the stability of Extra High Voltage Substation 500 kV in G and considered Substation 150 kV have been stable.

Figure 1 shows the location of the G substation, A substation and A – B lines which was affected by a disruption in Interconnected transmission network. As shown in the Interconnected system and the fault that appears, also G Subsystem that will be discussed in this paper is shown by the figure 1. The G substation experiences excess voltage that exceeds the standard voltage stability based on grid code rules after a disturbance on A – B line. This disorder causes the G substation to be released from the A’s substation and ultimately blackout.

| Substation | Condition |
|------------|-----------|

Table 1. Voltage condition in substation G.
Based on table 1, there is voltage instability after the fault appears in G. $\Delta V = 34.168$ kV. At the 500 kV G, the initial voltage value is 499.982 kV and after a short circuit disturbance on the A – B line, the G’s voltage value increases by +6.8% to 534.15 kV while the tolerant fault appears was 5% form the nominal voltage [7]. G’s voltage value rises from the nominal voltage because after a disturbance on the A – B line is cut off by high voltage switch, then the main power transfer to G is increase double than before, so the voltage value extremely increase. In this paper, will look the stability of G system by voltage bus 500 kV G, by using FACTS devices such as STATCOM and SSSC.

### 3. Methodology and Test Procedure

In this section, the procedure is discussed to obtain the information of how STATCOM and SSSC have been used in order to control voltage stability by seeing in graph the voltage bus, active power of transmission line and rotor angle.

#### 3.1. Static Synchronous Compensator (STATCOM)

A STATCOM is a voltage-sourced converter (VSC) based shunt FACTS device capable of Injecting controllable reactive power into the system [8]. Considering that a STATCOM is used by using software digsilent, there are several parameters that have to define, such as Power Oscillation Damping (POD), STATCOM Frame, and STATCOM Controller that shown in figure 2.

![Figure 2. STATCOM model control.](image)

STATCOM is basically a shunt connected whose output is adjusted to capacitive and inductive power system, typically bus voltage. The reactive power injection of a SVC connected to bus is given by (1) [9]

$$Q_{k} = V_{k}^{2} B_{svc}$$

Where

- $Q_{k} =$ Reactive Power injected in bus K (Mvar)
- $V_{reff} =$ Voltage References (500kV) (kV)
- $B_{k} =$ Sustenantsi (U)

With SVC, Power Oscillation damping (POD) is achieved by dynamic control of the system voltage in such a way that during upward portions of the voltage over time profile [10]. While STATCOM frame and STATCOM controller is set for static generation in Digsilent in order to be able injected the reactive power to the bus k.
3.2. Static series synchronous compensator (SSSC)

A SSSC is a Static Series Synchronous Compensator based series FACTS device capable of injecting a controllable voltage in series with the transmission line voltage [11]. Same as STATCOM, SSSC has to define alike in order to capable injecting the controllable voltage, shown in fig 3.

Considering the voltage value thus injected in SSSC must be the same parameter as STATCOM value, the voltage injection of a SSSC is given by equation (2) and (3)

\[ I_{se} = \frac{V_{se}}{Z_{km}} \]  
\[ S_{m} = V_{m}I_{se}^* \]

where \( I_{se} \) is current series (A), \( V_{se} \) is voltage series (V), \( Z_{km} \) is impedance (Ω), and \( S_{m} \) is apparent power (VA).

**Figure 3. SSSC model control.**

4. Result and Discussion

Based on equations (1) and (2), the injection values at STATCOM and SSSC can be calculated to improve the voltage stability of the G substation.

4.1. Fault condition

In this research, the short circuit was given in the first 3 s and circuit breaker is on at 3.1 s are shown in figure 4. The graphic is time vs. kV at the first 30 s. In this paper appears the instability by graphic bus voltage. The fault condition appears at the first 3 s in the simulation until 30 s.
Based on fig 4 after the fault condition appears the graphic simulation become extremely unstable in first 30 s. When the short circuit simulation is on, the voltage became extremely decrease at the first, and then become unstable until 30 s.

4.2. Voltage recovery using STATCOM

STATCOM is applied in order to improve voltage stability in bus G. Based on figure. 5, the bus voltage 500 kV in G shows after the fault condition was given, graphic become unstable. Graphic start to approach stable in the first 17 s with voltage value 475.215 kV. and the percent oscillation given by the bus voltage is calculate by equation (2) and the value of percent oscillation after STATCOM is 34.02 %. Based on calculated (4)

\[
\text{% Oscillation} = \frac{t_{\text{max}} - t_{\text{min}}}{t_{\text{avg}}} \times 100\% = \frac{523.248 - 371.09}{447.169} \times 100\% = 34.02\%
\]

The result of the voltage profile recovery using the STATCOM show significant stability as shown in figure 5. The STATCOM installation is placed on the A 500 kV bus, which is the closest bus to the disturbance aimed at seeing system stability after being given a reactive power injection by STATCOM.

4.3. Voltage recovery using SSSC
In this section, SSSC (Static Series Synchronous Compensator) is applied to transmission line A-G series with booster transformer connected to the line A-G in order to supply the active power. The calculation is based on equation 2 and 3. Based on figure 6, bus voltage on G 500 kV after injected by SSSC, by the figure, it shows there are extremely unstable after the fault condition appears at the first 3 s and the circuit breaker is on at 3.1 s. The graphic shows that bus voltage in G is unstable at the first 30 s after injection by SSSC.

\[
\text{% Oscillation} = \frac{t_{\text{max}} - t_{\text{min}}}{t_{\text{avg}}} \times 100% = \frac{562.836 - 300.586}{431.711} \times 100% = 60.74\%
\]

(5)

And based on percent Oscillation (5), graphic in figure. 6 has 60.74% values of oscillation. The results of the recovery of the voltage profile using SSSC show fairly significant stability at first as shown in figure 5, but the graph shows that there is still a ripple which indicates that the voltage is still not stable. Installation of SSSC is placed on the A–G line, which is the line connecting the A and G substation closest to the disturbance.

Based on all calculation and graphic simulation, we can conclude all the data that appears in Table 2.

| FACTS Devices | Oscillation Bus 500 kV G (%) | Fault Condition (pu) | After FACTS (pu) |
|---------------|-----------------------------|---------------------|-----------------|
| STATCOM       | 34.02                       | 1.06                | 0.93            |
| SSSC          | 60.74                       | 1.06                | 0.81            |

Based on table 2, we can see the recovery of the voltage values of the G 500 kV bus before and after the installation of STATCOM and SSSC. Based on equation (1) the STATCOM injection value is 458.5459 MVAR, Pf 0.8 and 791.667 MVA which aims to recover the voltage on the G 500 kV bus, and the recovery voltage of the 500 kV G bus changes from 1.06 pu to 0.93 pu. Then, based on equation (2), the value of SSSC injection is Pf 0.8, V 10 pu, and 791.667 MVA obtained to be able to improve the voltage profile on the 500 kV G bus, and the voltage recovery value using SSSC is changed from 1.06 pu to 0.81 pu. We can also see with STATCOM and SSSC percent Oscillation. Percent Oscillation is a technique used to see the stability of a system represented in percent. Based on calculation (4) we can see percent oscillation of the installation STATCOM that show approximately under 50%, while with SSSC, percent oscillation approximately upper than 50%.

5. Conclusions
A technique of optimizing the transient stability of a 500 kV subsystem with a device FACTS; STATCOM and SSSSC is presented. The stability limit is considered by a bus voltage appears at substation G. It is found that by simulation in this research STATCOM can provide more stability accelerating by parameter, bus voltage. Thus, a STATCOM can be considered as more effective that SSSC by percent Oscillation and by the standard of Grid Code, STATCOM can is found acceptable to run, while with SSSC condition, it is better to black out rather than keep running. And then with the installation STATCOM makes system stability increase compared to the system without STATCOM because of a controller that helps reduce oscillation. When a disturbance occurs, the voltage will change and stability will be achieved faster with STATCOM, this could happend because reactive power supplied by STATCOM change the power factor into the normal condition, since the STATCOM is worked by capacitive and inductive mode.

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