Static VAR compensator for improving voltage profiles and transmission losses: Case study in Batam

S Yunus\textsuperscript{1,2}, Y I Rahmi\textsuperscript{1}, R Nazir\textsuperscript{1}, Aulia\textsuperscript{1}, and U G S Dinata\textsuperscript{2}

\textsuperscript{1}Department of Electrical Engineering, Engineering Faculty, Andalas University
\textsuperscript{2}Mechanical Engineering Department, Engineering Faculty, Andalas University

E-mail: syukriyunus@eng.unand.ac.id

Abstract. Batam has companies engaged in the industry and requires a good quality of electrical power supply. FACTS Devices such as SVC can be mounted to absorb/produce reactive power to control the flow of power to the electrical system of Batam to solve the voltage drop in power transmission in Batam. Newton Raphson method is one method of power flow that is available in the ETAP to simulate the Batam electrical system before and after the addition of the SVC. The Simulation result suggested installing an SVC on bus 20 kV GI Tj. Uban with generated QC and QL values are 15,699.2 kVAR and 31,358.18 kVAR. With these values, the voltage can be improved about 1.132 kV with an active power difference of 6 kVAR.

1. Introduction
The need for people to consume electrical energy causes the addition of industrial and household loads to the system. Electricity demand is constantly increasing, on the other side of the expansion of power generation and the construction of new transmission lines is very limited. This pattern leads to the loading imposed on electric power generation and transmission systems which resulted in losses in the system becomes larger [1].

A power system must be able to distribute electric power with voltage value that does not exceed the tolerance limits as well as the loss - a small electric power loss. Problems electric load growth is not matched by an increase in capacity of the electric power system can lead to an unstable power system [2]. Therefore, the distribution of electrical power required by the power quality and power factor are fixed so that the condition becomes stable power flow.

The voltage drop problem and transmission loss is a very common problem in the power system caused by an increase in the amount of load that is not comparable with the expansion of power generation systems [3]. However, this can be avoided by the pattern of electrical power distribution that fits the boundaries of the transmission line and the fulfillment of community needs. Several methods can improve the quality of electric power systems, one using the potential of the use of equipment FACTS. When compared with other FACTS devices, SVC had a better performance in improving the ability to carry the load.

Batam is one of the industrial areas that continues to grow along with the economic growth of the community. To date, many new industries in Batam are also in need of electricity to operate. Therefore, a power flow analysis is required that can continue to supply electrical power in a stable state without being followed by a significant voltage drop.
Previously, SVC installations had been simulated for SUMBAGUT transmission networks, which had an impact on improving the voltage profile [4]. However, to determine where to place the SVC, it is used in this study ETAP program 12.6.0. By using ETAP 12.6.0 program, it can be seen modeling Batam electrical system in detail with the flow of power that occurred at the time before and after the addition of SVC.

2. Methodology
The working principle of SVC is how to set up the firing angle of thyristors so that it can regulate reactive power output of the SVC. Rated voltage is input to the control system, which then will adjust the firing angle of thyristors[12]. A very important component in operation of the SVC is a thyristor switch that must be turned on and stop on time by the desired firing angle. Thyristorswitchcurrent flow only in one direction, therefore, takes two thyristors as shown in Figure 1. The thyristor switch must be able to block the opposite voltage in the desired direction until the voltage value is several kV [1].

![Figure 1. System configuration SVC [13]](image)

Reactive power injection may include the addition of FACTS devices such as SVC provides active compensation. Reactive power absorbed or supplied automatically adjusted to maintain the bus voltage is connected with the equipment, and together with the plant to maintain the voltage at the specified point of the power system [14].

SVC equipment can be used to control power flow. Optimal power flow can be achieved by determining the exact location and size SVC (rating) as appropriate. SVC performance (performance) is much better in improving the system load [[ability compared with other FACTS devices [15]].

SVC works to provide rapid reactive power compensation on high voltage power transmission networks. The term "static" in the SVC is based on the fact that during operation or make changes to compensation on the network, no part SVC moving, because the compensation process entirely controlled by a power electronics system [16].

2.1. The theory and working principles of SVC
A Static VAR Compensator (SVC) consists of capacitors, reactors, and thyristors that act as switches. Thyristor which works as switches that are timed to open and closes by controlling the angle of ignition through the lattice voltage. Figure 2. can be seen through the circuit with a current SVC condenser constant.
Figure 2. The circuit SVC with constant condenser flow [18].

Where:
- $V_{SVC}$ = Voltage SVC
- $I_{\alpha 1}$ dan $I_{\alpha 2}$ = Current through the switch Thyristor
- $C$ = Condenser
- $L$ = Coil
- $I_{SVC}$ = Total current through SVC

The SVC-generated reactive power curve of the SVC mounted bus voltage is shown in the following Figure 3.

Figure 3. The SVC-generated reactive power curve of the SVC mounted bus voltage [19]:

Where:
- $Q_C$ = Capacitive reactive power (VAR)
- $Q_L$ = Inductive reactive power (VAR)
- $V$ = Voltage (V)
- $V_1$ = Initial Voltage (V)
- $V_2$ = Voltage end (V)
- $\Delta V$ = Voltage change (V)
- $B$ = Suspension (Siemens)

1. The first work area is located between the $V_1$ and $V_2$. In this area, SVC is capacitive or inductive. Reactive power generated changing according to system requirements.
2. The second work area, when the bus voltage exceeds $V_1$. In this area, SVC has inductive characteristics. Reactive power that generated varies as a needed system.
3. The third work area when the voltage is less than $V_2$. In this area, SVC only works as a fixed capacitor.
2.2. Parameters in SVC
Based on the theory, the bus indication is a candidate as a place SVC placement is the bus that has the voltage profile below the allowable voltage, i.e., down over 5% of the nominal voltage under SPLN 1 of 1995. This is attempted to get the same voltage at the load end with the end of the source or $V_{SVR}$. Based on the known power factor and power factor desired, then most of the $Q$ (reactive power) can be obtained by the equation:

$kVAR$ before SVC (*Static Var Compensator*)

$$Q_1 = P \tan \theta_1$$  \hspace{1cm} (1)

$kVAR$ desired by PF=0.999

$$Q_{lim} = P \tan \theta_2$$  \hspace{1cm} (2)

Based on the equation (1) and equation (2) it can be made $Q$ value by equation (3) below:

$$Q_{svc} = Q_1 - Q_{lim}$$  \hspace{1cm} (3)

Where:

- $Q_1$ = $kVAR$ before SVC
- $Q_{lim}$ = $kVAR$ desired

To calculate the parameters of the SVC on ETAP 12.6.0, first calculated value susceptance $B_{svc}$ with the formula:

$$B_{svc} = \frac{Q_j}{V_j^2}$$  \hspace{1cm} (4)

Where:

- $Q_j$: Reactive power at bus $j$ (kVAR)
- $V_j$: Voltage at bus $j$

Parameters $Q_c$ can be obtained by the formula:

$$Q_c = B_c \times V_j^2$$  \hspace{1cm} (5)

While the value of $Q_L$ is calculated by obtaining a $B_L$ with the following formula:

$$Q_L = B_L \times V_j^2$$  \hspace{1cm} (6)

3. Results and analysis
3.1. Analysis of power flow before added SVC
The values of simulation results and the direction of power flow shown in the table can be seen directly in *Figure 4*. 
Figure 4. Data 12.6.0 ETAP simulation results before the addition of SVC

V(kV)

Figure 5. Chart voltage on the bus 20 kV

V(kV)

Figure 6. Graph of voltage on bus 150 kV

ID bus
Figure 5 and 6 show that bus experiencing marginal conditions, critical, or buses are operating normally, either in a state of overvoltage or under-voltage. In this power flow simulation, obtained the bus who suffered under voltage and passes the critical limit, i.e., 20 kV substation bus Tj. Uban.

Bus 20 kV GI Tj. Uban decrease active power value calculated by the equation:

\[
\Delta P = 5305 - 5274 = 31 \text{ kW}
\]

The value of losses in the appendix A5, 20 kV substation bus Tj. Uban has a value of active power by 30, 7 kW and reactive power by 1380 KVAR. Therefore, to fix the 20 kV voltage on the bus, then the SVC installation by performing the calculation of the parameters.

3.2. Determination of parameters SVC
In determining SVC parameters the ETAP program 12.6.0, it takes the value of the voltage \(V_{\text{SVC}}\), inductive reactive power \(Q_L\) and capacitive reactive power \(Q_C\). From the simulation results, we get the location of load bus located on bus 20 kV GI Tj. Uban. The bus suffered critical condition, a condition in which the voltage on the bus is far below the minimum operating voltage.

SVC parameter calculation begins with determining the value of \(B_{\text{SVC}}\) with equation 2.10, namely:

\[
B_{\text{SVC}} = \frac{15659}{18,157^2} = -47,498
\]

After determining the value of \(B_{\text{SVC}}\), the determined value of the reactive power that will be included in the SVC by using formula 2.8 as below:

\[
Q_{\text{lim}} = 5274 \times 0,044 = 273,33 \text{ kVAR}
\]

By obtaining the value of \(Q_{\text{lim}}\) and \(B_{\text{SVC}}\), then the value of \(Q_{\text{SVC}}\) can be calculated by following equation 2.9:

\[
Q_{\text{SVC}} = 15659 - 273,33 = 15385,67 \text{ kVAR}
\]

\(Q_{\text{SVC}}\) parameter values in the ETAP 12.6.0 program is divided into two, namely inductive reactive power value \(Q_L\) and capacitive reactive power value \(Q_C\). \(Q_L\) and \(Q_C\) values can be contested by the formula 2.11 and 2.12 of the following:

\[
Q_C = 47,62 \times 18,157^2 = 15699,2 \text{ kVAR}
\]

\[
Q_L = 95,118 \times 18,157^2 = 31358,18 \text{ kVAR}
\]

3.3. Power flow analysis after addition of SVC
In Figure 7 it can be seen that the voltage used in the SVC at 20 kV, the \(Q_C\) value is 15,699.2 kVAR and \(Q_L\) value is 31,358.18 kVAR. As for the maximum value is given a value of 80 MVAR based on the number of iterations performed with Newton-Raphson Method.
The voltage changes that occur in this system can be seen more clearly with Figure 8.

Where:
- : Before SVC installation
- : After SVC installation
Installation of SVC is given bus 20 kV GI Tj. Uban which has an initial voltage of 18.157 kV voltage under critical conditions. Determination of SVC parameters was done based on bus 20 kV GI Tj. Uban. After simulation of ETAP 12.6.0 program with calculated parameters, the result of bus voltage 20 kV GI Tj. The rising to 19.289 kV.

From Figure 8 and Figure 9 can be seen that there is an increase in voltage on each transmission bus or distribution bus. A significant change occurred at 20 kV bus Tj. Uban that experienced a voltage increase of 1.132 kV. Installation of this SVC impact on the stability of power flow in Batam electrical system.

Based on simulation done can be seen the percentage of difference of active power value happened at bus 20 kV GI Tj. Uban after the addition of SVC formula:

\[
\%P_{\text{loss}} = \frac{5953 - 5274}{5953} \times 100\% = 11.4\%
\]

Therefore 20 kV bus substation Tj. Uban decrease active power value calculated by the equation:

\[
\Delta P = 5959 - 5953 = 6 \text{ kW}
\]

Calculation of active power value difference from bus 150 kV to bus 20 kV GI Tj. Uban after the addition of SVC is 6 kW. In contrast to the difference in value at the time before the addition of SVC of 31 kW, this shows the influence of the addition of SVC in the system so that the difference in power reduction at 20 kV substation bus Tj. Uban becomes smaller.

4. Conclusion
After analyzing before and after the installation of SVC, then it can be taken conclusion:
1. The result of power flow after the addition of SVC succeeded in raising the voltage on each bus with a significant increase in bus 20 kV GI Tj. Uban of 1,132 kV, from the previous voltage of 18,157 kV to 19,289 kV.
2. SVC additions do not affect the direction of power flow but reduces losses in the 20 kV substation bus Tj. Uban, with the value of the initial losses amounting 30.7 kW and 1380 KVAR to 5.6 kW 253.7 KVAR.

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