Improvement Of Voltage Collapsed using Static VAR Compensator and Series Capacitor in Power System

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Abstract- **This paper presents an analysis of combining series capacitor with static VAR compensator (SVC) method to improve voltage that was collapsed due to changing of reactive power at load bus as well as to increase voltage stability in electrical power system. The series capacitor and static VAR compensator were injected on the weakest bus that is determined heuristically. Load flow analysis is used to simulate a voltage profile of this system. The simulations were tested on IEEE 6-bus and IEEE 30-bus system. MATLAB programming version 7.8 was used for simulation.**

Keywords-Power system, reactive load, voltage stability, series capacitor, static VAR compensator, load flow

I. INTRODUCTION

Nowadays electrical demand is always increased as a load increased. Electricity is needed to make life easier. Transmission systems carry large amounts of electrical energy to consumption areas. Longer distance of transmission line will make voltage stability become decreased.

Voltage collapse or decay of system voltage is refer to drop of voltage at one or more load bus or even over a significant portion of the network as a response to load variations and generations structure disturbances has been observed in power system worldwide [8].

Voltage stability in power system considered when the system can maintain or reestablish the initial state after any disturbance manifested as a deviation from the initial parameter values for the system's operation.

Voltage Stability is becoming an increasing source of concern to secure the operation of power systems. A lot of works have been done to improve voltage stability [1]. It is an important factor to be considered in power system planning. Voltage stability refers to the ability to properly maintain steady, acceptable voltage levels at all buses in the network at all times, even after being subjected to a disturbance or contingency. When there are disturbance, operating condition, load demand will change and will cause voltage instability. Voltage instability is also characterized by gradually decreasing voltage levels at one or more nodes in the power system. The objective of this study is to study load flow and solution in power system and also to reduce the voltage collapsed effect due to changing of reactive power at load bus as well as to improve voltage stability using series capacitor and Static VAR Compensator (SVC).

II. SERIES CAPACITOR

Series compensation has been utilized for many years with excellent results in AC power transmission in a number of countries all over the world [4].

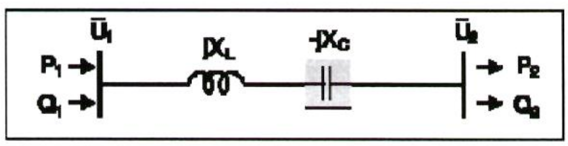

Figure 1:Transmission line series capacitor

U=Voltage

Series capacitor is used to increase the power transfer capability. Series capacitors are also installed in distribution systems to improve the voltage stability. The effect of series capacitor to the power transfer capability is shown in equation 1 [2]:

$$P_{12} = \frac{V_1 V_2}{X_{12}} \sin(\delta 1 - \delta 2) \qquad (1)$$

δ1=phase angle for node 1

δ2=phase angle for node 2

Besides that, series capacitor can reduce the overall line reactance, and hence allow a larger stable transfer of power. Series capacitors can also be applied to obtain better load division on parallel lines having different conductor resistances. In general, series capacitors appear to be economical for increasing the stability limit of lines about 200 miles or longer. There has been, however, some divergence of opinion as to the most economical location for the series capacitors in the transmission system [3].

III. STATIC VAR COMPENSATOR (SVC)

SVC is one of the controllers based on Power Electronics and other static devices known as FACTS (Flexible AC Transmission Systems) Controllers which it could be used to increase the capacity and the flexibility of a transmission network. [5].

SVC is built up with reactors and capacitors, controlled by thyristor valves which are in parallel with a fixed capacitor bank. It is connected in shunt with the transmission line through a shunt transformer and shown in Figure 2 [6]:

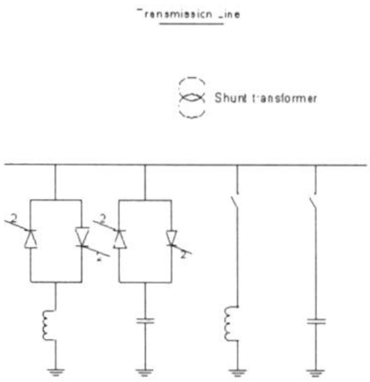

Figure 2: Single line diagram of SVC

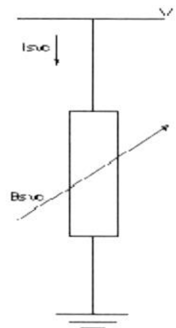

Figure 3: Equivalent circuit of SVC

The SVC fall into Shunt Controllers category and it function as fast generators or as a fast absorber of reactive power, with the purpose so as to maintain or control specific parameters of the electric power systems (typically bus voltage).

There are four Characteristics of SVC. First is about its speed of response: The Thyristor Controlled Reactor (TRC) has a control in its firing angle α that varies between 90° and 180°. Its speed of response is sufficiently quick in applications caused by rapidly fluctuating loads. In power system, it is important that the control of the TRC is stable and exact.

The second characteristic is about Independent Phase Control: Three-Phase TRC used in the SVC, can be independently controlled the three-phase of a power system, so that it can balance any unsymmetrical three-phase load when it are presented [3].

The third characteristic is about under unbalance conditions, a TRC can generate more harmonics compare to under balanced conditions. It is necessary because to place passive filter LC, it is used for the same compensation capacitors. In this case, the injection of the reactive power of the SVC is due to the filters and the fixed capacitors.

Lastly is about Response to Overvoltage and under voltage: This is one of the most important characteristics of the SVC, because it compensates the voltage when conditions of very high or very low voltage are presented in the bus where the compensator is placed. In that case, it injects the reactive power necessary to restore the normal voltage magnitude [5].

IV. LOAD FLOW ANALYSIS

A power system engineer is always concerned with adopting newer and better mathematical model for solving system problem more efficiently and effectively. Power flow study is one such sub problem, which is so vital for almost all power system studies. Besides that, power flow studies attempt to determine the voltages, currents, real and reactive power flows in power system under a given set of load conditions.

Network equations can be formulated systematically in a variety of forms. However, the node-voltage method, which is the most suitable form for many power system analyses, is commonly used. The formulation of the network equations in the nodal admittance form results in complex linear simultaneous algebraic equations in terms of node currents. When node currents are specified, the set of linear equations can be solved for the node voltages. However, in power system, powers are known rather than currents. Thus, the resulting equations in terms of power, known as power flow equation, become nonlinear and must be solved by iterative techniques. Power flow studies, commonly referred to as load flow, are the backbone of power system analysis and design. They are necessary for planning, operation, economic scheduling and exchange of power between utilities. In addition, power flow analysis is required for many other analyses such as transient stability and contingency studies [7].

Standard equation of load flow was shown by equation 2 and 3:

$$Pi = \sum_{j=1}^{n} [Vi][Vj][Yij] \cos(\theta ij - \delta i + \delta j) \qquad (2)$$

$$Qi = \sum_{j=-1}^{n} [Vi][Vj][Yij] \sin(\theta ij - \delta i + \delta j) \qquad (3)$$

V. METHODOLOGY

For this study, MATLAB program was used to simulate load flow analysis by injecting series capacitor and static VAR compensator. Reactive power was injected to each load bus to determine the weakest or sensitive bus.

When the weakest bus was determined, series capacitor was applied to the line that connected the weakest bus. Series capacitor was injected until it reached a certain limit. A suitable value of series capacitor was injected on that line.

After that, static VAR compensator (SVC) was injected on weakest bus separately until it reaches a certain limit.

Finally, both series and static VAR compensator was combined to find the best compensation both of series capacitor and Static VAR Compensator (SVC) to reduce effects of voltage collapsed as well as to increased voltage stability.

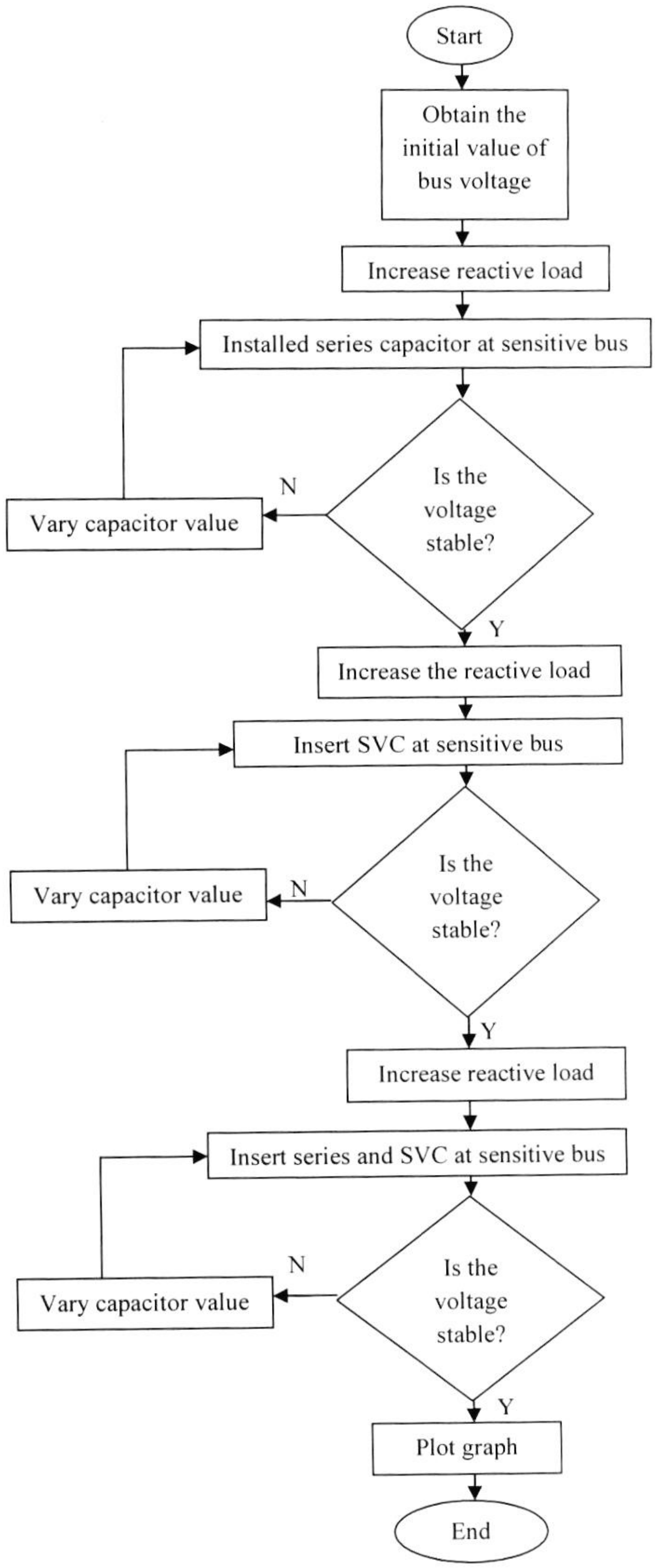

Figure 4: Flow chart of the full operation

VI. RESULTS AND DISCUSSION

A. 6 Bus systems

Using heuristic method, it was found that bus 5 is the weakest bus. Bus 5 shows the steepest slope. Figure 5 shows voltage profile when reactive load was injected. Figure 6 shows losses profile when reactive load was injected. Besides that, maximum loadability for bus 5 is 27MVAR where the voltage was drop until 0.555 p.u.

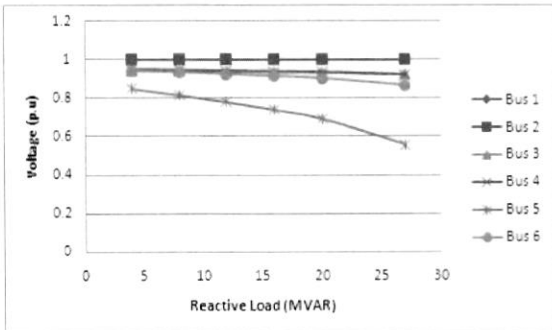

Figure 5: Voltage profile with injected reactive load

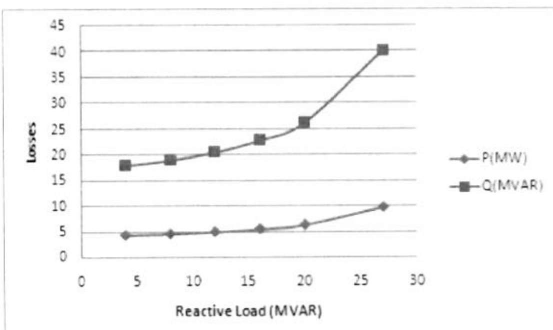

Figure 6: Total losses with injected reactive load

With maximum loadability value, series capacitor at line 2-5 was injected. The voltage was improved with increasing value of series capacitor. Figure 7 shows the voltage increase by injecting series capacitor. Losses reduce was shown in figure 8. The series capacitor injected until 0.7 p.u.

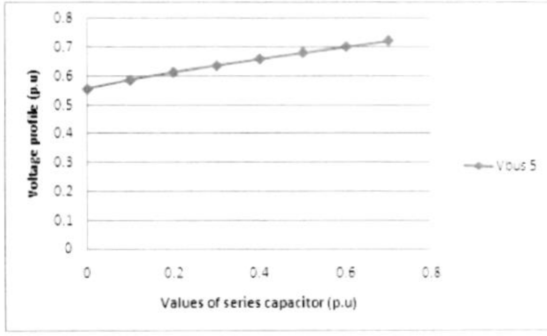

Figure 7: Voltage profile when series capacitor are injected

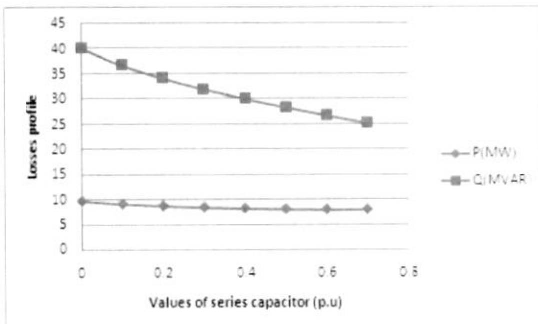

Figure 8: Total losses when series capacitor are injected

Next step is to inject static VAR compensator (SVC) at bus 5. Figure 9 shows the increasing voltage by injecting static VAR compensator and the losses reduced as shown in figure 10. The SVC injected until 35MVAR.

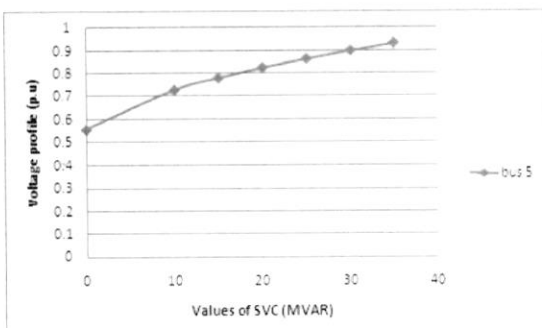

Figure 9: Voltage profile when static VAR Compensator (SVC) are injected

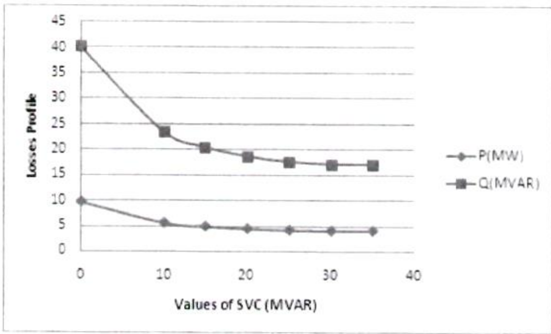

Figure 10: Total losses when static VAR Compensator (SVC) are injected

The final step is to combine series capacitor and Static VAR Compensator (SVC). The graph in figure 11 shows by combining these two methods, voltage is more stable. By combining methods, the slope is less compared to single compensation.

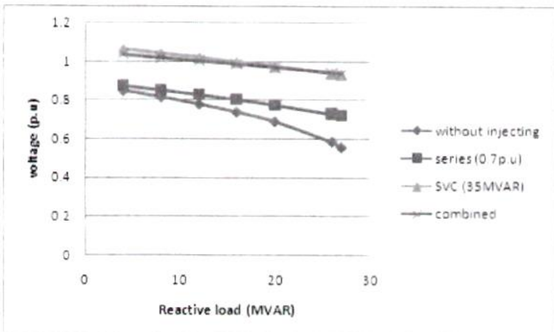

Figure 11: Voltage profile when series capacitor and static VAR compensator (SVC) are combined

From the results obtained, it can be seen that with combined of compensation, the voltage approach to 1.0 p.u.

Table I: Final voltage profile using both methods with 27MVAR at bus 5

Methods	Voltage (p.u)
Without Compensation	0.555
Series Capacitor Compensation	0.722
SVC Compensation	0.932
Combined compensation	0.937

B. 30 Bus Systems

Similar steps are taken to determine the weakest bus. The weakest bus or sensitive bus is bus 26. From the graph, it can be seen that bus 26 gives the steepest slope. So bus 26 was choose for analysis. Figure 12 shows voltage profile as load increase. Besides that, maximum load ability for bus 26 is 30MVAR and the voltage drop until 0.68 p.u. Figure 13 shows the total losses with reactive load.

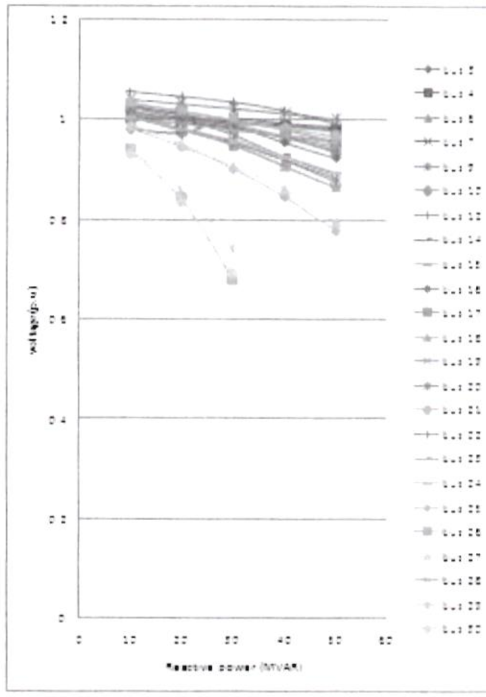

Figure 12: Voltage profile with injected reactive load

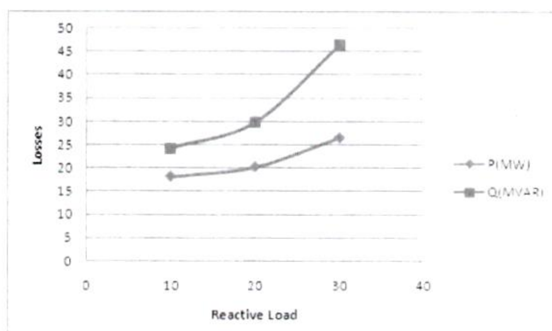

Figure 13: Total losses with injected reactive load

With maximum loadability value, series capacitor at line 25-26 was injected. It can be seen from figure 14, the voltage was improved with increasing value of series capacitor. The losses reduces with increasing series capacitor was shown in Figure 15. The compensated value of series capacitor was 0.3 p.u.

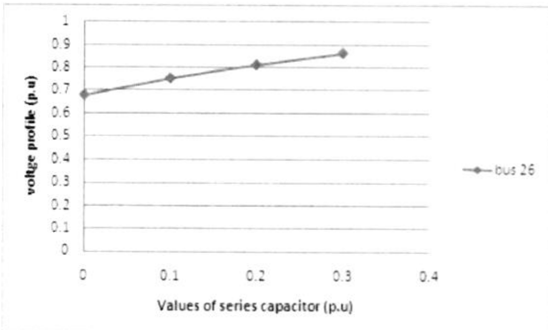

Figure 14: Voltage profile when series capacitor are injected

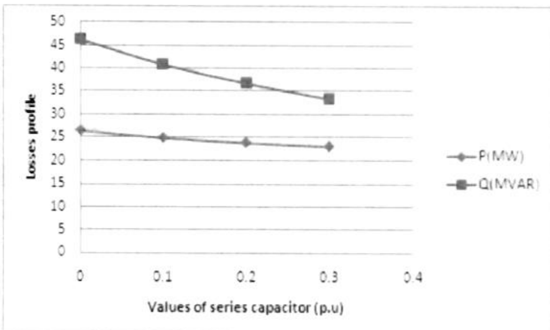

Figure 15: Total losses when series capacitor are injected

Next step is to inject static VAR compensator at bus 5. Figure 16 shows the increasing voltage by injecting static VAR compensator and the losses reduced as shown in figure 17. The SVC injected is 25MVAR.

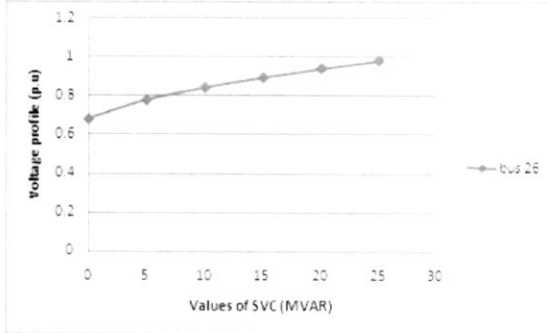

Figure 16: Voltage profile when static VAR Compensator (SVC) are injected

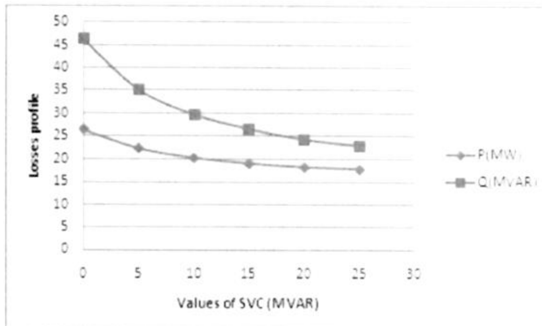

Figure 17: Total losses when static VAR Compensator (SVC) are injected

The final step is to combine series capacitor and Static VAR Compensator (SVC). The graph in figure 18 shows by combining these two methods, voltage is more stable. By combining methods, the slope is less compared to single compensation.

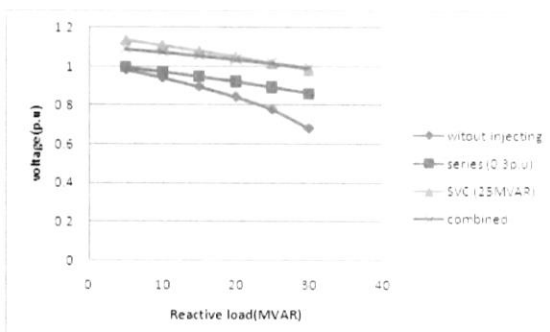

Figure 18: Voltage profile when series capacitor and static VAR compensator (SVC) are combined

From the results obtained, it can be seen that with combined of compensation, the voltage approach to 1.0 p.u.

Table II: Final voltage profile using both methods with 30MVAR at bus 26

Methods	Voltage (p.u)
Without Compensation	0.68
Series Capacitor Compensation	0.862
SVC Compensation	0.981
Combined compensation	0.996

VII. CONCLUSION

From the results obtained, it can be seen that by using Static VAR Compensator (SVC) and series capacitor, the voltage can be improved to almost 1.0 p.u. For a 6 bus system, by injecting 35MVAR of SVC and 0.7p.u of series capacitor, the voltage is improved to 0.937p.u. For 30 bus system, by injecting 25MVAR of SVC and 0.3p.u of series capacitor, the voltage is improved to 0.996p.u. Combined of Static VAR Compensator and series capacitor was proven method to reduce the effects of voltage collapsed due to changing of reactive power at load bus as well as to increase voltage stability.

VIII. RECOMMENDATION FOR FUTURE WORK

For future development, Artificial Intelligent such as Genetic Algorithm or Bees Algorithm can be used to determine the size of capacitor and the capacitor more approximately. Sensitivity Index can be used to determine the weakest bus in these systems.

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