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IMPROVING VOLTAGE STABILITY BY USING *FACTS* DEVICES

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ABSTRACT

The present day power system is a large complex interconnected network that consists of thousands of buses and hundreds of generators. The network is increasing everyday with the increase in demand and to meet this, either new installation of power generating stations and transmission lines is required or the existing infrastructure operation has to be extended to limits. The laying of new lines or installation of new generating stations imposes many environmental and economical constraints. As a result the existing transmission lines are more heavily stressed than ever before and which in turn can leave power system exposed to instabilities. Voltage instability is of the phenomena which result in a major blackout. Moreover, with the fast development of restructuring, the problem of voltage instability has become a major concern in deregulated power systems. To maintain security of such systems, it is desirable to plan suitable measures to improve power system security and increase voltage stability margins. FACTS devices can regulate active and reactive power control as well as adaptive to voltage-magnitude control simultaneously because of their flexibility and fast control characteristics.

In this paper the effect of two FACTS controllers – SVC and STATCOM on voltage stability are studied. The IEEE-6bus system is simulated with continuation power flow feature of PSAT (Power system Analysis Toolkit) software. The advantage of this simulated method is to develop a simple, fast and convenient procedure which can be applied effectively to enhance the voltage stability.

KEYWORDS: Steady State Voltage Stability, SVC, STATCOM, Continuation Power Flow, Voltage Collapse, PSAT

INTRODUCTION

Power System Stability is defined as the ability of a power system that enables it to remain in stable operating equilibrium under normal operating conditions and to regain an acceptable state of equilibrium after being subjected to a disturbance (1).A criteria of voltage stability is the ability of a system to maintain steady acceptable voltages at all the buses in the system at all conditions. The ability to transfer reactive power from production source to consumption areas during steady state operating conditions is a major problem of voltage stability. A system mainly enters a state of voltage instability when a disturbance, increase in load demand or change in system condition cause a progressive and uncontrollable decline in voltage.

Voltage instability (2) can be avoided by a) appropriate load shedding on Consumer Network, b) on load tap changers and c) reactive compensation (Series & Shunt).

A key contributing factor in voltage collapse is the rapid and progressive loss of voltage controllability due to reactive limit violations.

There are two types of voltage stability based on the time frame of simulation: static voltage stability and dynamic voltage stability (7). The voltage stability problem can be analyzed with the conventional PV or QV curves.

The recent development and use of Flexible Alternating Current Transmission Systems (FACTS) in the bulk power transmission system has led to many applications where these devices are not only able to improve the voltage and angle stability but are also able to provide flexible operation capabilities. (8).

This paper mentions the application of two such FACTS devices that are more used for voltage stability problem. SVC & STATCOM are used for this purpose along with continuation power flow method in the environment of PSAT software.

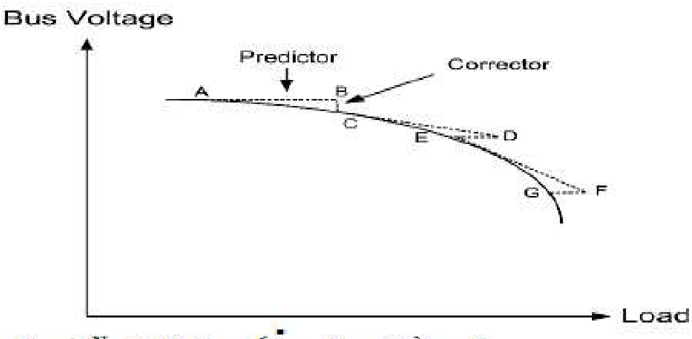
STEADY STATE VOLTAGE STABILITY

Steady State Voltage Stability and Dynamic Voltage Stability are two types of voltage stability defined based on the time frame of simulation (7). Since the steady state analysis only involves the solution of algebraic equations it is computationally less extensive than dynamic analysis. Slow variations in the power system that eventually lead to voltage collapse is analyzed in the steady state voltage study. This can be seen from the plot of the power with the voltage at the bus also known as the “P-V curve” or “nose” curve. Figure 8 is a typical P-V curve plot. It can be seen from the figure that as the power transferred increases, the voltage at the receiving end decreases, eventually reaching a nose point where any further increase in the power transfer leads to rapid decline in voltage magnitude. The region above the nose point is referred to as the stable region and region below is the unstable region.

The voltage reduction can be improved by either decreasing the reactive load or by increasing the reactive power supply before voltage collapse point. Flexible control and operation of various FACTS devices can be effectively used for this purpose. Of various existing FACTS devices, this paper addresses the improvement by installing STATCOM & SVC at the weakest buses

Continuation Power Flow

The conventional power flow has a problem in the Jacobean matrix which becomes singular at the voltage stability limit. This problem can be overcome by using Continuation power flow (2). Figure 1show the predictor-corrector scheme used in Continuation power flow.



$$P_i - \sum_{j=1}^{N} Y_{ij} V_i V_j \cos(\delta_i - \delta_j - \theta_{ij}) = 0$$

$$Q_i - \sum_{j=1}^{N} Y_{ij} V_i V_j \sin(\delta_i - \delta_j - \theta_{ij}) = 0$$

Figure 1: The Predictor-Corrector Scheme

The new load flow equations consists of load factor (λ) are expressed as:

$P_{Li} = P_{Lo} + \lambda (K_{Li} S_{\Delta\ base} \cos\varphi i)$

$Q_{Li} = Q_{Lo} + \lambda (K_{Li} S_{\Delta base} \sin\varphi i)$

Where P_{Lo},Q_{Lo}= original load at bus i, active and reactive power respectively

K_{Li}= multiplier to designate the rate of load change at bus i as λ changes

$S_{\Delta base}$ = a given quantity of apparent power which is chosen to provide appropriate scaling of λ

The power flow equations can be written as F (δ, V, λ) = 0Then the active power generation term can be modified to

$P_{Gi} = P_{Go}(1+ \lambda K_{Gi})$

Where

P_{Go}= the initial value of active power generation

P_{Gi}= the active power generation at bus i

K_{Gi} = the constant of changing rate in generation

To solve the problem, the continuation algorithm starts from a known solution and uses a predictor-corrector scheme to find subsequent solutions at different load levels.

VOLTAGE STABILITY IMPROVEMENT AND CONTROL

Reactive power compensation is the most effective method to improve both voltage stability and power transfer capability of the system. The control of voltage bus level is accomplished by controlling the generation, absorption and flow of reactive power. Voltage stability and load ability of a bus in the power system is mainly depends on the reactive power support that the bus can receive. When the system approaches the maximum loading point then the real and reactive power losses are increasing rapidly. Therefore the sufficient reactive power supports have to be given to maintain the voltage stability.

FACTS DEVICES

FACTS devices mentioned in the introduction have their own characteristics and limitations. This section gives a brief introduction to each of these devices.

Static VAR Compensator (SVC)

Static VAR compensator (SVC) is a shunt connected static var generator /load, whose output is adjusted according the required capacitive or inductive current. The basic structure of SVC is shown in figure 2. It can be seen that the model of a SVC is represented by a controllable reactor and fixed capacitor. Through a suitable coordination of the capacitors and the controlled reactors the bus reactive power injected (or absorbed) by the SVC can be continually varied in order to control the voltage or to maintain the desirable power flow in the transmission network either over normal operating or under disturbances conditions. For steady state analysis, SVC is represented as a controllable susceptance.

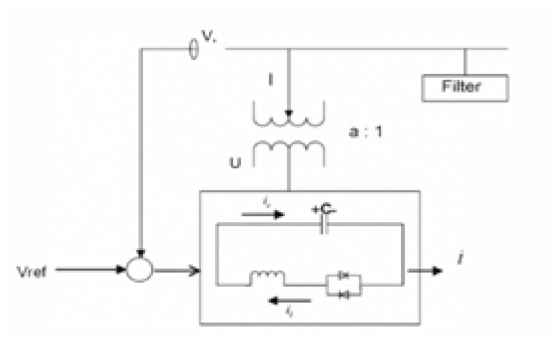


Figure 2: Basic Structure of SVC

Static Synchronous Compensator (STATCOM)

STATCOM is a static synchronous generator operated as a shunt connected static var compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage. STATCOM is one of the key FACTS controllers. A STATCOM is a controlled reactive power source. It provides voltage support by generating or absorbing capacitor banks. It regulates the voltage at its terminals by compensating the amount of reactive power in or out from power system. Figure 3 shows the basic structure.

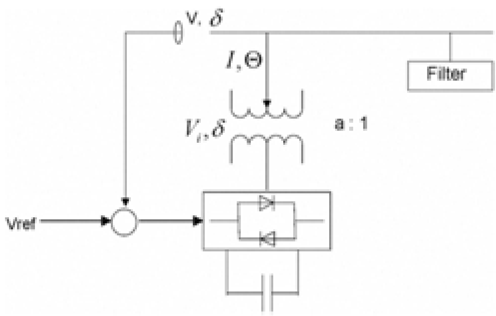


Figure 3: Basic Structure of STATCOM

STATCOM exhibits constant current characteristics when the voltage is low / high, under /over the limit. This allows STATCOM to deliver constant reactive power to the system.

Reactive power absorbed or supplied by STATCOM is automatically adjusted so as to maintain voltages of the buses to which they are connected. The advantages of STATCOM are small size, lower costs & flexible regulation from capacitive range to inductive range.

SIMULATION RESULTS AND DISCUSSION

A 6 – bus test system as shown in figure 4 is used for this paper. The test system consists of three generators & three PQ bus (or load bus). The simulation uses PSAT simulation software. PSAT is power system analysis software, which has many features including power flow and continuation power flow. Using continuation power flow feature of PSAT, voltage stability of the test system is investigated.

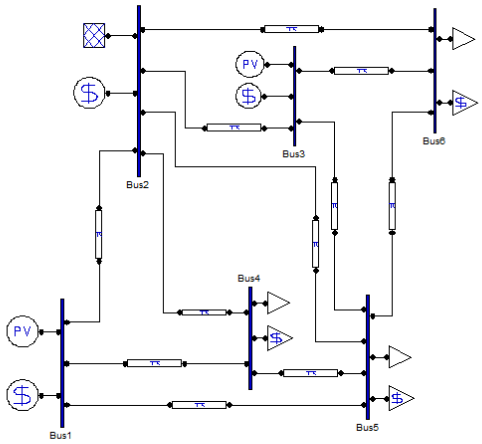


Figure 4: Six Bus Test System

Base Case

The continuation power flow analysis using PSAT is run for the test system shown in figure 6 and the voltage profile and "NOSE" curve for bus 4, 5, 6 without any FACTS devices is obtained as shown in figure 5& figure 8

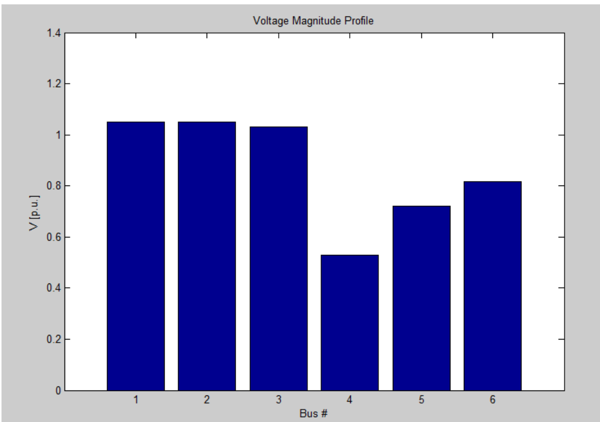


Figure 5: Voltage Profile

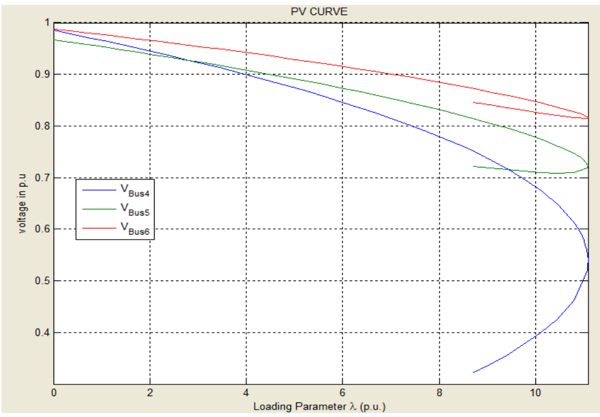


Figure 6: P-V Curve

Figure 7 shows the voltage profile for bus 4, 5, 6 with FACTS device such as SVC inserted at respective buses.

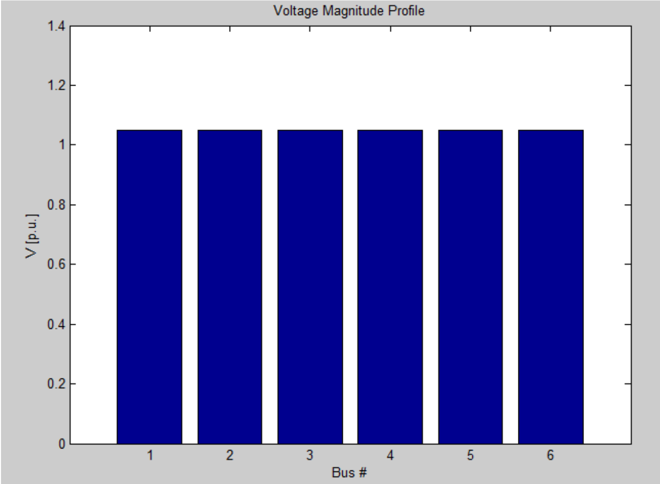


Figure 7: Voltage Magnitude Profile

With SVC: - Next insert the SVC at bus 4 and then repeat to create PV curve and voltage profile again Figure 8 & 9 .Repeat the same at bus 5 (figure 10&11).

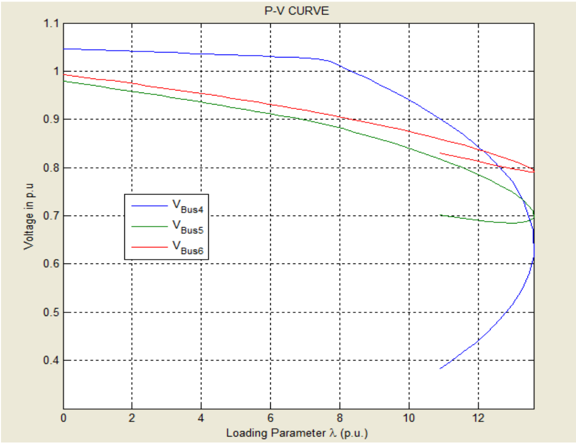


Figure 8: PV Curve (bus 4)

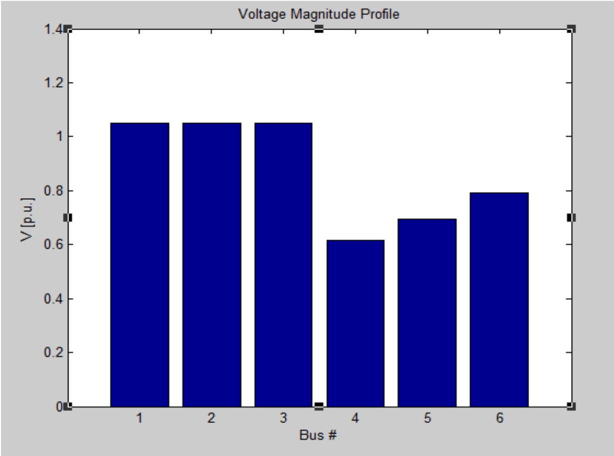


Figure 9: Voltage Profile

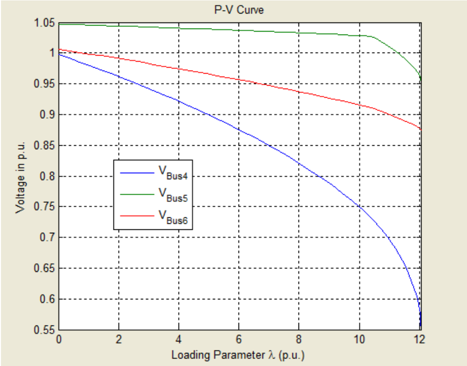


Figure 10: PV Curve (bus5)

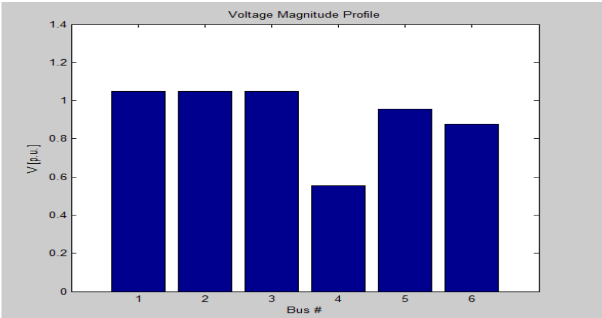


Figure 11: Voltage Profile

With STATCOM: -Then remove SVC, and insert STATCOM at bus 5 & repeat the simulation. Respective PV curves & voltage profile is shown in figure 12& 13.

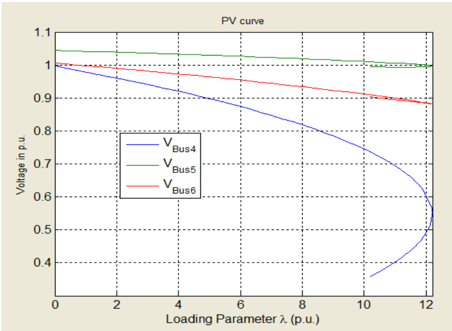


Figure 12: PV Curve

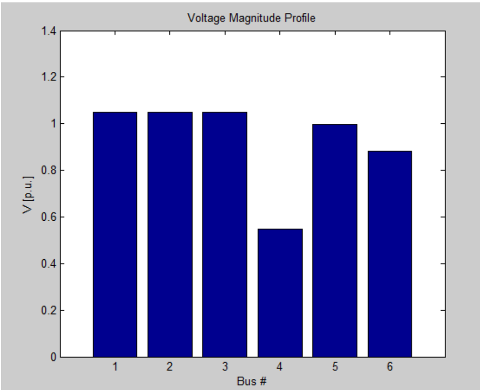


Figure 13: Voltage Profile

COMPARISON OF SVC & STATCOM

Next insert SVC at bus 4 & STATCOM at bus 5 & repeat the simulation. Respective PV curve & voltage profile is shown in Figure 14 & 15. Comparison of both shows that voltage profile has been improved by use of STATCOM

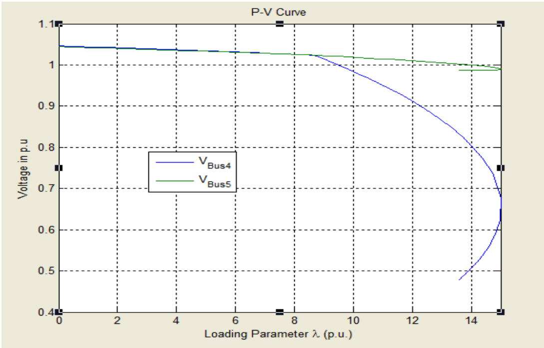


Figure 14: PV Curve

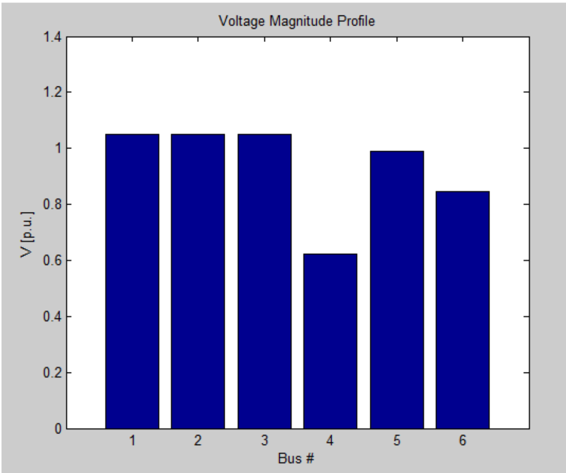


Figure 15: Voltage Profile

CONCLUSIONS

A comparison study of SVC & STATCOM in static voltage stability margin enhancement is presented. SVC and STATCOM increase static voltage stability margin and power transfer capability. In this paper adequate models for the SVC & STATCOM in the steady state studies are presented and thoroughly discussed. The results of simulations on 6 bus test system in the environment of PSAT have clearly shown that how SVC and STATCOM devices Increases the bus voltage & power limits of the network. The results of simulations also show that with the insertion STATCOM, steady state stability of the system is more than the case when the SVC is inserted in the system.

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