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Maintaining Voltage Stability in Power System using FACTS Devices

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Abstract: *Modern power systems are prone to widespread failures. With the increase in power demand, operation and planning of large interconnected power system are becoming more and more complex, so power system will become less secure. Operating environment, conventional planning and operating methods can leave power system exposed to instabilities. Voltage instability is one of the phenomena which have result in a major blackout. Moreover, with the fast development of restructuring, the problem of voltage stability 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 the active and reactive power control as well as adaptive to voltage-magnitude control simultaneously because of their flexibility and fast control characteristics. Placement of these devices in suitable location can lead to control in line flow and maintain bus voltages in desired level and so improve voltage stability margins. Performance evaluation is supported by the simulation results on IEEE 14 bus system under different loading conditions using MATLAB.*

Index Terms- FACTS, MATLAB, STATCOM, TCSC, Voltage Collapse Proximity index (VCPI).

I. INTRODUCTION

In vertically integrated utility structure, all entities such as generation, transmission and distribution of electrical power are within the aegis of central energy management company. Generation is carried in order to achieve the least operational cost. Electric power industry restructuring has moved generation investment and operations decisions into the competitive market but has left transmission as a collective resource in the regulated environment.

Due to increase in demand, the transmission system becomes more stressed, which in turn, makes the system more vulnerable to voltage instability. Voltage stability has become an increasingly important phenomenon in the operation and planning of the present day power systems. Voltage collapse is a process in which the appearance of sequential events together with the voltage instability in a large area of system can lead to the case of unacceptable low voltage condition in the network [1]. Load increasing can lead to excessive demand of reactive power, system will show voltage instability. If there are not sufficient reactive power resources and the excessive demand of reactive power can lead to voltage collapse.

With real-world involvements and academic research works, major contributory factors to voltage instability are power system configuration, including location of reactive power resources, load pattern and generation pattern. So as to overcome voltage instability due to power system configuration, configuration or topology can be modified by adding shunt capacitors and Flexible AC Transmission System (FACTS) controllers at the suitable locations [2].

This paper addresses the static modeling of Static Synchronous Compensator (STATCOM) and Thyristor Controlled Series Compensator (TCSC), and their capabilities to improve the voltage profile and power flow of the bus to that it is connected is evaluated.

II. 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 capacitors banks. It regulates the voltage at its terminals by compensating the amount of reactive power in or out from the power system [3].

When the system voltage is low the STATCOM injects the reactive power to and when the voltage is high it absorbs the reactive power [4]. The reactive power is fed from the Voltage Source Converter (VSC) which is connecting on the secondary side of a coupling transformer as shown in the Fig 1. By varying the magnitude of the output voltage the reactive power exchange can be regulated between the convertor and AC system. STATCOM is such a device in which the modern power electronic converters have been employed.

These converters are capable of generating reactive power with no/very little need for large reactive energy storage elements.

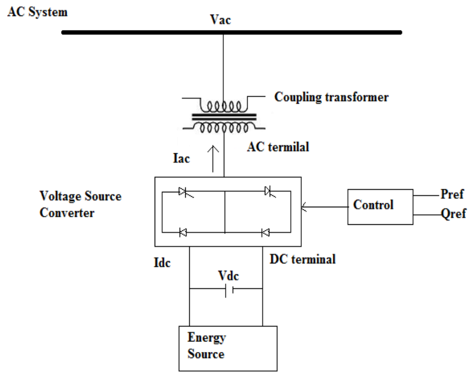

Fig 1: Functional block diagram of STATCOM

2.1 OPERATING PRINCIPLE

The STATCOM generates a balanced 3-phase voltage whose magnitude and phase can be adjusted rapidly by using semiconductor switches. The STATCOM is composed of a voltage-source inverter with a dc capacitor, coupling transformer, and signal generation and control circuit [5].

Let V_1 be the voltage of power system and V_2 be the voltage produced by the voltage source (VSC). During steady state working condition, the voltage V_2 produced by VSC is in phase with V_1 (i.e. =0) in this case only reactive power is flowing. If the magnitude of the voltage V_2 produced by the VSC is less than the magnitude of V_1, the reactive power is flowing from power system to VSC (the STATCOM is absorbing the reactive power). If V_2 is greater than V_1 the reactive power is flowing from VSC to power system (the STATCOM is producing reactive power) and if the V_2 is equal to V_1 the reactive power exchange is zero. The amount of reactive power can be given as:

$$Q = \frac{V_1 (V_1 - V_2)}{X} \longrightarrow \quad (1)$$

2.2 V-I CHARACTERISTICS OF STATCOM

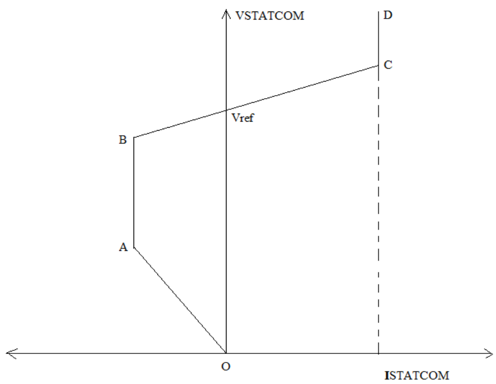

Fig 2: V-I Characteristics of STATCOM

From Fig 2, STATCOM exhibits constant current characteristics when the voltage is low/high under/over the limit. This allows STATCOM to delivers constant reactive power at the limits compared to SVC. Since SVC is based on nominal passive components, its maximum reactive current is proportional to the network voltage. While for STATCOM, its reactive current is determined by the voltage difference between the network and the converter voltages and therefore, its maximum reactive current is only limited by the converter capability and is independent of network variation.

III.THYRISTOR CONTROLLED SERIES COMPENSATOR (TCSC)

The basic Thyristor Controlled Series Capacitor scheme was proposed in 1986 by Vithayathil with others as a method of "rapid adjustment of network impedance". A TCSC can be defined as a capacitive reactance compensator which consists of a series capacitor bank shunted by a thyristor-controlled reactor in order to provide a smoothly variable series capacitive reactance [6]. In a practical TCSC implementation, several such basic compensators may be connected in series to obtain the desired voltage rating and operating characteristics. However, the basic idea behind the TCSC scheme is to provide a continuously variable capacitor by means of partially canceling the effective compensating capacitance by the TCR. The basic conceptual TCSC module comprises a series capacitor, C, in parallel with a thyristor controller reactor, as shown in Fig.3

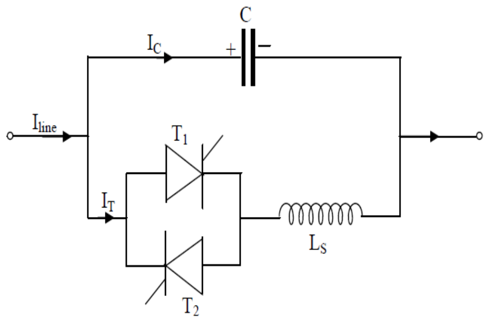

Fig 3: Structure of TCSC

3.1 PRINCIPLE OF OPERATION

A TCSC is a series-controlled capacitive reactance that can provide continuous control of power on the ac line over a wide range. From the system viewpoint, the principle of variable-series compensation is simply to increase the fundamental-frequency voltage across a Fixed Capacitor (FC) in a series compensated line through appropriate variation of the firing angle, α [7]. This enhanced voltage changes the effective value of the series-capacitive reactance. A simple understanding of TCSC functioning can be obtained by analyzing the behavior of a variable inductor connected in parallel with an FC. The maximum voltage and current limits are design values for which the thyristor valve, the reactor and capacitor banks are rated to meet specific application requirements.

3.2 CHARACTERISTICS OF TCSC

Fig 4 shows the characteristics of TCSC. α is the delay angle measured from the crest of the capacitor voltage or equivalently, the zero crossing of the line current. Therefore, with the usual TCSC arrangement in which the impedance of the TCR reactor X_L is smaller than that of the capacitor, X_C, the TCSC has two operating ranges around its internal circuit resonance.

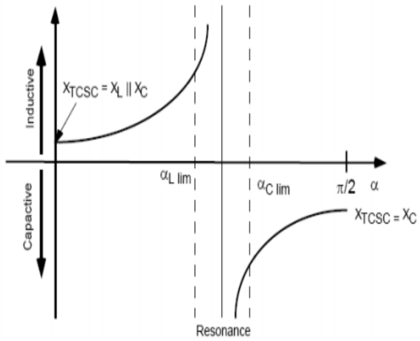

Fig 4: Characteristics of TCSC

IV. WEAK BUS IDENTIFICATION

Pilot bus or weak bus is defined as the bus which, when supported, improves voltage profile at all the buses and also ensures additional security to the system, in terms of increased loading margin. Usually, placing adequate reactive power support at the weakest bus enhances static voltage stability margins. The bus which is close to experience voltage collapse is the weakest bus. Changes in voltage at each bus for a given change in system load is available from the tangent vector, which can be readily obtained from the voltage collapse proximity index prediction index (VCPI) is calculated at every bus [8]. The value of the index determines the proximity to voltage collapse at a bus.

The technique is derived from the basic power flow equation, which is applicable for any number of buses in a system. The power flow equations are solved by Newton Raphson method, which creates a partial matrix. By setting the determinant of the matrix to zero, the index at bus k is written as follows:

$$VCPI_k = \left| 1 - \frac{\sum_{m=1, m \neq k}^{N} V_m'}{V_k} \right| \longrightarrow (2)$$

Where,

$$V'_m = \frac{Y_{km}}{\sum_{j=1, j \neq k}^{N} Y_{kj}}$$

V_m is the phasor voltage at bus m
V_k is the phasor voltage at bus k
Y_{km} is the admittance between bus k and m
Y_{kj} is the admittance between bus k and j
k is the monitoring bus
m is the other bus connected to bus
N is the bus set of the system.

By finding the VCPI index we can find the weak bus and weakest bus. Thus for these weak bus and weakest bus we are implementing the FACT device like STATCOM and TCSC.

V. SIMULATION RESULTS AND DISCUSSION

The simulation results of the FACTS devices like STATCOM and TCSC is carried out by using MAT lab programming. Here the voltage profile of an IEEE 14 bus system is evaluated with and without the use of compensating devices. The voltage collapse in the power system can be compensated by using FACTS devices.Using voltage collapse proximity index(VCPI) the weakest bus is identified and the FACTS devices are provided to the weak and weakest bus. Fig 5 and 6 shows the results using STATCOM device. In Fig 5 bus 4 is identified as weakest bus. In absence of STATCOM, voltage magnitude at bus 4 is 0.96 pu while with provision of STATCOM it remains at 1 pu. By suitably providing reactive power support at other bus, voltage profile can further be improvised. In the Fig 6 the weak bus and weakest bus is identified as bus 5 and bus 4 respectively and the voltage profile with and without STATCOM is mentioned. With the implementation of STATCOM the voltage profile is maintained as 1 p.u.

Fig 7 and 8 shows the results using TCSC device. In Fig 7 bus 3 is identified as weakest bus. Similarly in absence of TCSC, voltage magnitude at bus 3 is 0.98 pu while with provision of TCSC it remains 1 pu. In the Fig 8 the weak bus and weakest bus is identified as bus 3 and bus 8 respectively and the voltage profile with and without TCSC is mentioned. With the implementation of TCSC the voltage profile is maintained as 1 p.u.

Thus the simulation result proves that voltage stability maintaining of the power system with the implementation of FACTS devices like STATCOM and TCSC.

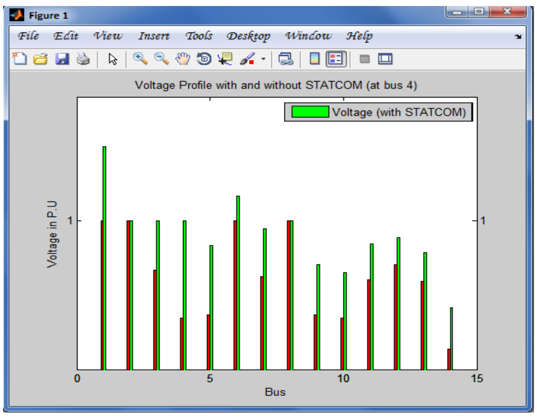

Fig 5: Voltage profile with and without STATCOM (in weakest bus 4)

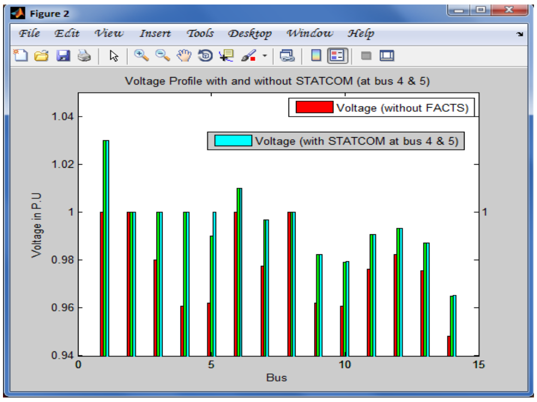

Fig 6: Voltage profile with and without STATCOM (at weakest bus 4 and weak bus 5)

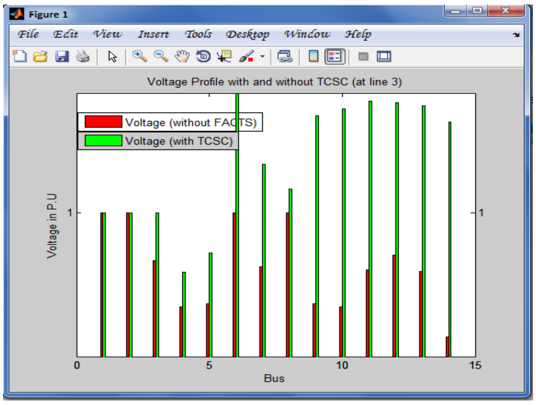

Fig 7: Voltage profile with and without TCSC (at weakest bus 3)

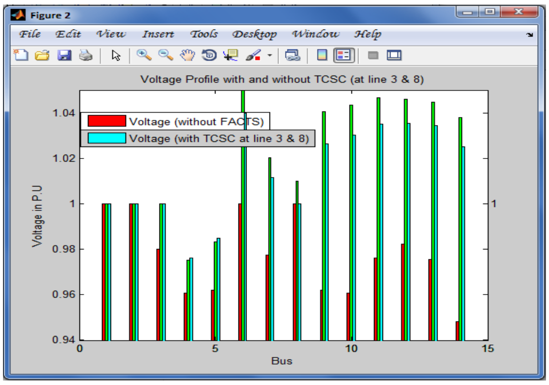

Fig 8: Voltage profile with and without TCSC at weakest bus 3 and weak bus 8

VI. CONCLUSION

FACTS devices are helpful for maintaining voltage stability during load variation, for increasing loadability of power system as a whole and to maintain stability of power system. With ever increasing demand of power, optimum use of existing power infrastructure is must. FACTS devices provide enormous opportunity for optimized usage of existing infrastructure with usage of power system near its stability limit. In this paper, only technical aspect of reactive power support is considered. Identification of weak bus is considered through voltage collapse proximity index (VCPI), although there are several other methods which can be used. Similarly, for placement of STATCOM and TCSC, no optimization algorithms or economic aspects are considered. This paper has immense potential for further studies corresponding to placement of series and shunt FACTS devices for improving voltage profile of power system.

The exact placement, methods to increase loadability and stability with incorporation of one or more type of FACTS devices can further be developed. Reactive power support as an ancillary service is also one of the developing criterion today which may further be developed in conjunction with FACTS devices.

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