Enhancement of Voltage Stability in Transmission System Using SSSC

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Abstract— **Reactive power control is the basic requirement for maintaining the voltage levels thereby the stability of the interconnected power system. Voltage stability is the ability of the power system to maintain steady acceptable voltages at all buses in the system under normal operating conditions and after being subjected to a disturbance (reactive power balance). Modern power systems are at risks of voltage instability problems. The main cause of voltage instability may be due to the shortage of reactive power in power system. The voltage stability can be improved by increasing the reactive power. Many approaches used to prevent voltage instability, such as Placement of FACTS Controllers, Placement of series and parallel capacitors, Rescheduling of the generation, Under-voltage load shedding. The placement of FACTS controller can improve the voltage stability. Static Synchronous series compensator (SSSC) can increasing or decreasing the overall reactive voltage drop across the line and thereby controlling the transmitted electric power. The bus voltage magnitude will increase with the use of SSSC. In this work, the Newton Raphson iterative algorithm was adopted due to its ability to converge after a few iterations. Simulation of power flow solutions without and with SSSC was done using MATLAB based programme. The model is validated on IEEE 30-bus system.**

Keywords— **Power flow, Voltage stability, FACTS Devices, SSSC, Transmission system**

I. Introduction

Modern power systems are at dangers of voltage instability problems due to highly stressed operating conditions caused by increased load demand and economical and environmental constraints in the transmission lines [1]. Many approaches used to prevent voltage instability [2]. The conventional methods can be broadly classified into the following types [3]. P-V curve method, V-Q curve method and reactive power reserve, Methods based on singularity of power flow Jacobin matrix at the point of Voltage collapse, Continuation power flow method, application of reactive power-compensation devices, control of network voltage and generator reactive output, coordination of protections. In Present scenario the applications of the power electronics devices in power systems are very much augmented [4]. The FACTS devices are introduced in the power system transmission for the reduction of the transmission line losses [5], Increases Power System Stability and also to increase the transfer capability [6].

FACTS controllers are a power electronic device which is used to enhance controllability and increase power transfer capability. It is mainly used for solving various power system steady state control problems, enhancement of voltage stability and transient stability [7]. The FACTS controllers are capable of supplying/absorption of reactive power at faster rates.

FACTS devices can basically be sub-divided into three categories [8]: Shunt devices such as Static Var Compensator (SVC); Series devices such as Thyristor Controlled Series Capacitors (TCSC), Static Synchronous series compensator (SSSC); combined series-shunt controllers such as Unified Power Flow Controller (UPFC).

A SSSC is a static synchronous generator operated without an external electric energy source as a series compensator. Its output voltage is in quadrature with the line current for the purpose of increasing or decreasing the overall reactive voltage drop across the line .The SSSC can directly control the current, and indirectly the power flowing through the line by controlling the reactive power exchange between the SSSC and the AC system [6]. A SSSC is an electrical device for providing fast-acting reactive power compensation on high voltage transmission networks [9]. It can improve the voltages profile in the transient state. The main advantage of this controller is that it does not significantly affect the impedance of the transmission system and therefore, there is no danger of having resonance problem [5].

II. OPERATING PRINCIPLE OF FACTS DEVICE

A. Operating Principle of SSSC

The SSSC, sometimes called the S3C, is a series-connected synchronous-voltage source that can vary the effective impedance of a transmission line by injecting a voltage containing an appropriate phase angle in relation to the line current. SSSC consists of a capacitor, an inverter and a coupling transformer [7]. The inverter contains several gate turn off thyristor switch-based valves. Its primary role is to control the magnitude and the angle of the injected voltage in order to maintain the controlled parameter at its target value. When the series injected voltage leading the line current, it emulates an inductive reactance causing the power flow and

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the line current to decrease as the level of compensation increases; once the series injected voltage lagging the line current, it emulates a capacitive reactance causing the power flow and the line current to increase as the level of compensation increases[11] . The SSSC may have four basic control modes. These are bus voltage control, line power flow control, line reactance control and series voltage control. A series capacitor compensates the transmission-line inductance by presenting a lagging quadrature voltage with respect to the transmission-line current. This voltage acts in opposition to the leading quadrature voltage appearing across the transmission-line inductance, which has a net effect of reducing the line inductance.

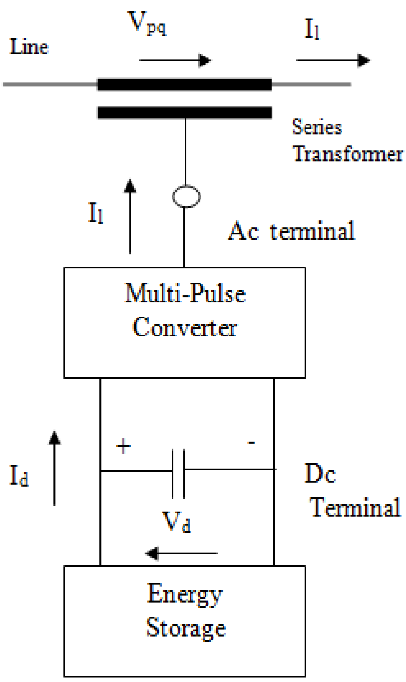

Fig.1. Generalized series-connected synchronous-voltage source employing a multi-pulse converter with an energy-storage device [5]

Similar is the operation of an SSSC that also injects a quadrature voltage, V_c, in proportion to the line current but is lagging in phase:

$V_C = -jKX_C I_C$

Where,

V_c → the injected compensating voltage
I_c → the line current
X_c → the series reactance of the transmission line
K → the degree of series compensation

III. MODELING OF FACTS DEVICES

A.Modeling of SSSC

According to the equivalent circuit, suppose $V_{se} = V_{se}\angle\theta_{se}$ .The voltage of bus m is taken as the reference vector, $V_m = V_m\angle\theta_m$ [10]. The voltage source, Vse, is the series injected voltage, and it is controllable in both its magnitudes and phase angles and is also the control variable of the SSSC. $V_n = V_n\angle\theta_n$ is the voltage at bus n.

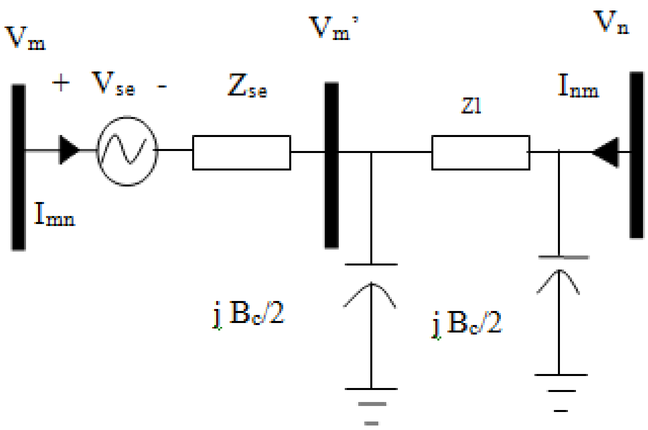

Fig.2. Equivalent circuit of the embedded SSSC using voltage source [6]

$Z_{se} = R_{se} + jX_{se}$ is the impedance of the series coupling transformer [6]. B_C and $Z_l = R_l + jX_l$ are the charging susceptance and the impedance of the line respectively [12]. From Fig.2,

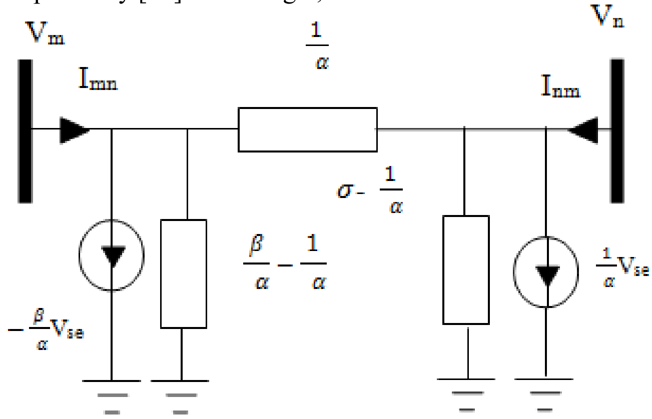

Fig.3. Representation of the SSSC using current source [6].

$$\alpha = j\frac{B_C}{2}Z_{se}Z_l + Z_l + Z_{se} \quad (1)$$

$$\beta = \left(1 + j\frac{B_C}{2}Z_l\right) \quad (2)$$

$$\alpha = Z_{se}\beta + Z_l \quad (3)$$

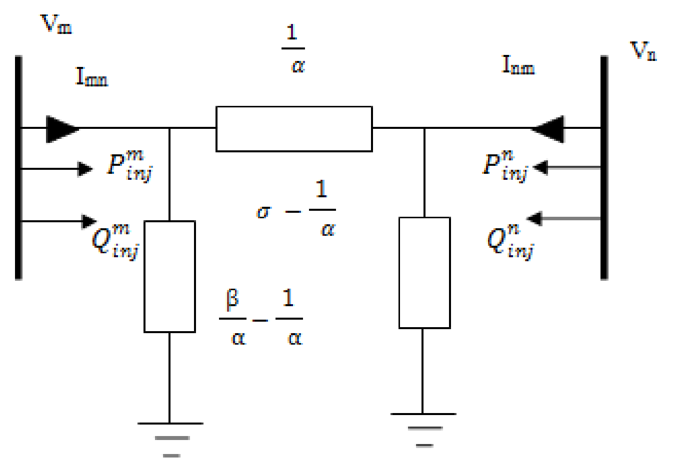

Fig.4. The power injection π-model of embedded SSSC [6].

From Fig.3, Considering the following vectors:

$V_{se} = V_{se} \angle \theta_{se}$

$V_m = V_m \angle \theta_m$

$V_n = V_n \angle \theta_n$

$\beta = \beta \angle \theta_\beta$

From Fig.4 the real and reactive power injections at the sending and receiving bus: P^m_{inj}, Q^m_{inj}, P^n_{inj}, Q^n_{inj} can be calculated as follows[6]:

$$S^{m*}_{inj} = V^*_m\left(-\frac{\beta}{\alpha}V_{se}\right) = -AV_mV_{se}\angle\left(\theta_{se} - \theta_m + \theta_A\right)$$

$$\frac{\beta}{\alpha} = A = A\angle\theta_A \tag{4}$$

$$P^m_{inj} = -AV_mV_{se}\cos\left(\theta_{se} - \theta_m + \theta_A\right) \tag{5}$$

$$Q^m_{inj} = -AV_mV_{se}\sin\left(\theta_{se} - \theta_m + \theta_A\right) \tag{6}$$

$$S^{n*}_{inj} = V^*_n\left(\frac{1}{\alpha}V_{se}\right) = \frac{AV_nV_{se}}{\beta}\angle\left(\theta_{se} - \theta_n + \theta_A - \theta_\beta\right)$$

$$P^n_{inj} = \frac{AV_nV_{se}}{\beta}\cos\left(\theta_{se} - \theta_n + \theta_A - \theta_\beta\right) \tag{7}$$

$$Q^n_{inj} = \frac{AV_nV_{se}}{\beta}\sin\left(\theta_{se} - \theta_n + \theta_A - \theta_\beta\right) \tag{8}$$

The admittance Y^u_m and Y^u_n can be written by [13],

$$Y^u_m = \frac{P^u_{mi} - jQ^u_{mi}}{\left(V^u_m\right)^2} \tag{9}$$

$$Y^u_n = \frac{P^u_{ni} - jQ^u_{ni}}{\left(V^u_n\right)^2} \tag{10}$$

IV. RESULT

MATLAB based program was developed for the load flow analysis of IEEE-30 bus systems without and with FACTS devices.

Table.4.1 Voltage stability analysis with and without FACTS Devices

Voltage (p.u)					
Bus .No	Without FACTS	With FACTS			
		1 (1-2)	2 (1-3)	11 (6-9)	18 (12-15)
1	1.060	1.060	1.060	1.060	1.060
2	1.043	**1.053**	1.043	1.033	1.043
3	1.022	1.023	**1.042**	1.014	1.021
4	1.013	1.015	**1.024**	1.003	1.012
5	1.010	1.010	1.010	1.000	1.010
6	1.012	1.014	**1.016**	0.999	1.012
7	1.003	1.005	**1.006**	0.992	1.003
8	1.010	1.010	1.010	1.000	1.010
9	1.051	1.052	1.054	**1.074**	1.052
10	1.044	1.045	1.048	**1.055**	1.048
11	1.082	1.082	1.082	1.082	1.082
12	1.057	1.059	**1.061**	1.058	1.051
13	1.071	1.071	1.071	1.071	1.071
14	1.043	1.044	1.047	1.045	**1.049**
15	1.038	1.040	1.043	1.042	**1.048**
16	1.045	1.046	1.048	**1.050**	1.042
17	1.039	1.040	1.042	**1.048**	1.041
18	1.028	1.032	1.034	**1.038**	1.035
19	1.025	1.030	1.032	**1.039**	1.031
20	1.029	1.035	1.037	**1.044**	1.034
21	1.032	1.033	1.035	**1.042**	1.036
22	1.033	1.034	1.036	**1.042**	1.037
23	1.027	1.029	1.032	1.032	**1.350**
24	1.022	1.023	1.025	**1.027**	1.026
25	1.019	1.020	**1.023**	1.019	**1.023**
26	1.001	1.003	**1.005**	1.001	**1.005**
27	1.026	1.027	**1.029**	1.021	**1.029**
28	1.011	1.012	**1.014**	0.999	1.011
29	1.006	1.007	**1.010**	1.002	**1.010**
30	0.994	0.996	**0.998**	0.990	**0.998**

The voltage stability analysis is made for IEEE 30 bus test system. In this, a new injection power model of SSSC for power flow analysis is proposed. This model is established in such way that the original admittance and the Jacobin matrix are kept unchanged and anew Jacobin corresponding to the SSSC Device is added to the original Jacobian .The voltage stability was analysed with and without SSSC. Table 4.1 shows that without FACTS the Voltage is 1.043 at bus 2 and the voltage is 1.053 at the same bus when FACTS Device is included. The bus voltage will increase more when FACTS Device is added in line no.11.The SSSC device will reduce the losses and improve the efficiency of transmission line.

V.CONCULSION

In this paper, a power flow analysis was carried out using MATLAB. FACTS devices, which are connected in transmission lines, improves the power transfer capability and control the power flow in the power system. The effect of SSSC was demonstrated. With the presence of SSSC, the voltage will be increase in particular bus.

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