Determination of Optimal Placement Point for Voltage Stability Using SSSC in Power System

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***Abstract*—Voltage Stability is defined as the relationship between the bus voltage and the maximum load parameter value depending on the operating condition of the system. The placement of Flexible Alternating Current Transmission System (FACTS) devices in the appropriate places increases the operating limits of the system in terms of voltage stability. In this study, the effects of Static Synchronous Series Compensator (SSSC) in IEEE 14 bus power system were investigated. The voltage and the maximum loading parameter relationships of the SSSC which is connected to different transmission are interpreted. Furthermore, the effects of SSSC on the bus voltage profile have been investigated. The study on the multi buses power system was analyzed in the Power System Analysis Toolbox (PSAT) program. As a result of the study on IEEE 14 bus power system, the loading parameter value has been increased when the SSSC is connected to all transmission lines. In particular, it has been observed that the best results are obtained by connecting SSSC in transmission lines 2-3.**

***Keywords*— SSSC, Voltage Stability, Optimal Placement Point, PSAT**

I. Introduction

The loadability summarizes voltage stability of the power system. The loadability condition depends on the voltage collapse point, active and reactive power loss. The loadability of power systems has been improved by FACTS devices [1]. The value of the parameter loading parameter of SSSC, which is one of the FACTS, is based on line current and impedance control. There are many studies in the literature about SSSC. SSSC is used to provide active and reactive power balance between the load buses in continuous load flow analysis. The efficient use of the Jacobian matrix at the single point provides good results in active power-voltage control of the load buses. [2-3]. In a different study, voltage and angle control of the load buses for voltage stability analysis was provided by using SSSC in the power system. The effects of the multi-layered design of the inverter circuit used in the SSSC circuit have been investigated [4-5]. In continuous state analysis with SSSC, the operating characteristics and capacity were evaluated for voltage and reactive power. Improvements in the voltage stability in the system have been identified by providing series compensation in a multi-machines power system [6]. In the voltage stability analysis of the power system, control variable status expressions were used instead of d-q axis transformation with SSSC. By using the control variable, it has been seen that SSSC is effective in damping the power system oscillations in terms of voltage stability [7]. Another factor used as control variables with SSSC in voltage stability is saddle-node bifurcation theory. It has been observed that the control models increase the maximum load parameter value with precise accuracy. SSSC is preferred for line power flow control and stability improvement operation in power systems. SSSC, which is developed according to Lyapunov stability criteria, has impressive results in terms of voltage stability in a single machine infinite bus system [9]. One of the other factors affecting voltage stability in multi-bus power systems is static and dynamic load models. Based on different power coefficients, static load models and constant impedance, constant current and constant active power value of dynamic load models with different parameter value effects on the system were investigated with SSSC. In terms of the voltage-maximum load parameter, the operation point is maintained in the stable zone when using SSSC in static and dynamic load models [10-11]. In terms of the voltage-maximum load parameter, the operating point is maintained in the stable zone when using SSSC static and dynamic load models. In general, in the power system with SSSC increases the voltage-maximum load parameter value according to the current state of the system. At the moment of change in the system state, there is a possibility that the steady state operating zone may become unstable. For this purpose, it is desirable for the SSSC to operate between better lines in the multi-bus power system.

In this study, the best load parameter of the system is obtained by using SSSC which is connected between all lines in IEEE 14 bus power system. In order to determine the optimum point, continuous load flow analysis was examined for 9 different situations. The load parameter value has increased in all the scenarios. The best result was obtained by connecting SSSC to the transmission line 2 and 4.

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II. Voltage Stability and Continuous Load Flow

Voltage stability is evaluated depends on the reactive power change. By providing reactive power, the operating conditions of the load bus are improved. If the reactive power supply is below the specified limits and the voltage drop starts, the system collapse. In order to prevent this, voltage compensation depending on reactive power is an important condition for voltage stability. The relationship between the voltage-maximum load parameter of the system and the active power and reactive power value of the bus is shown in equation 1 and equation 2.

$$P_L = P_{L0}(1+\lambda) \tag{1}$$

$$Q_L = Q_{L0}(1+\lambda) \tag{2}$$

Where, P_L and Q_L are the active power and reactive power value of the load, P_{L0} and Q_{L0} are the initial active power and reactive power values of the load, λ is the maximum load parameter value [12]. In the continuous load flow, the relationship between the voltage and the maximum load parameter is used. In continuous load flow analysis, it is far superior to analysing specific challenges without supporting certain system models. Besides, it has the ability to automatically change voltage against adverse situations that will be generated by the individual analysis situation in system equations. The use of strategy in continuous load flow is shown in Figure 1.

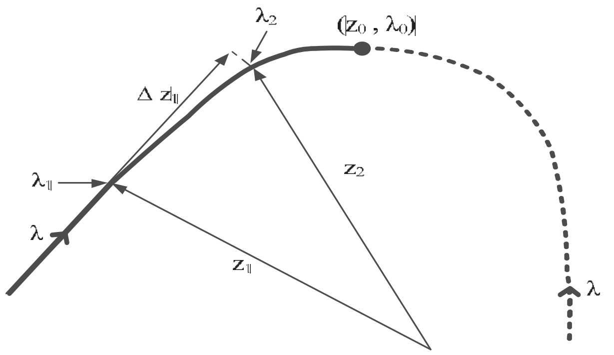

Fig. 1. Continuation load flow method

Here, (z_1, λ_1) is the condition known as balance points, $\Delta\lambda_1$ is used in system parameter value change and Δz1 vector analysis. In the first step, estimation is performed. Initially, $z_1+\Delta z_1$, $\lambda_1+\Delta\lambda_1$ values are produced. These generated values are used to regulate the new equilibrium points $z_2+\Delta z_2$ in the system profile.

III. Static Synchronous Series Compensator (SSSC)

Static Synchronous Series Compensator (SSSC) is composed of voltage source converter, DC capacitor, control unit and coupling transformer. SSSC is connected as series to the transmission line. Generally, SSSC is used for active and reactive power control in the power system. The line current can be controlled directly with SSSC. Voltage and line currents change depending on the generated reactive power. The SSSC circuit model is shown in Figure 2.

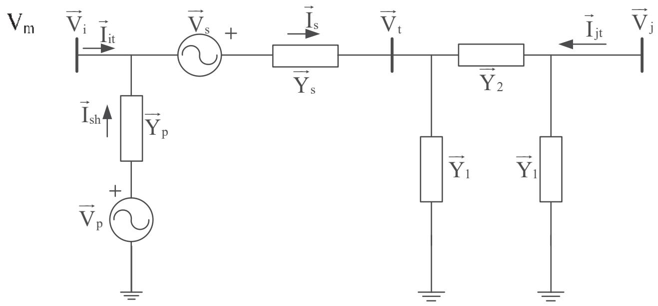

Fig. 2. SSSC circuit model

SSSC can operate in inductive mode and capacitive mode. In the case of inductive operation of SSSC, inductive line impedance reduces in depending on voltage. Correspondingly, the V voltage increases the line impedance of the system. The change in the active power injected into the system is shown in Equation 3.

$$P = \frac{V^2}{X}\sin\delta + \frac{V}{X}V_s\cos\frac{\delta}{2} \tag{3}$$

Consequently, in the case of capacitive operation of SSSC, the power transmitted from the line increases and in the case of inductive operation decreases. From the change in voltage amplitude, we can say that the SSSC has a larger control range than the controllable series capacitor with the same power capacity [13]. Control variables used in SSSC are shown between equation 4 and equation 6.

$$I - I_{ref} = 0 \tag{4}$$

$$V_{dc} - V_{dcref} = 0 \tag{5}$$

$$\frac{P - V_{dc}^2}{RC - RI^2} = 0 \tag{6}$$

Where, I measurement current, I_{ref} reference current, V_{dc} DC link voltage, V_{dcref} reference DC voltage, P active power, C capacitor, R resistance. The current and admittance representation of the SSSC during connection to the transmission line is shown in Equations 7 and Equation 8.

$$I_{it} = \frac{Y_{SSSC}\left(Y_i + Y_j\right)V_i - Y_i V_j}{Y_{SSSC} + Y_i + Y_j} \tag{7}$$

$$Y_{TCSC,SSSC} = \frac{1}{jX_{SSSC}} \tag{8}$$

IV. Simulation Study

In the study, IEEE was analysed in 14 bus power system. The Power Systems Analysis Toolbox (PSAT) was used in this analysis [10,14]. The circuit model of the IEEE 14 bus power system is shown in Figure 3.

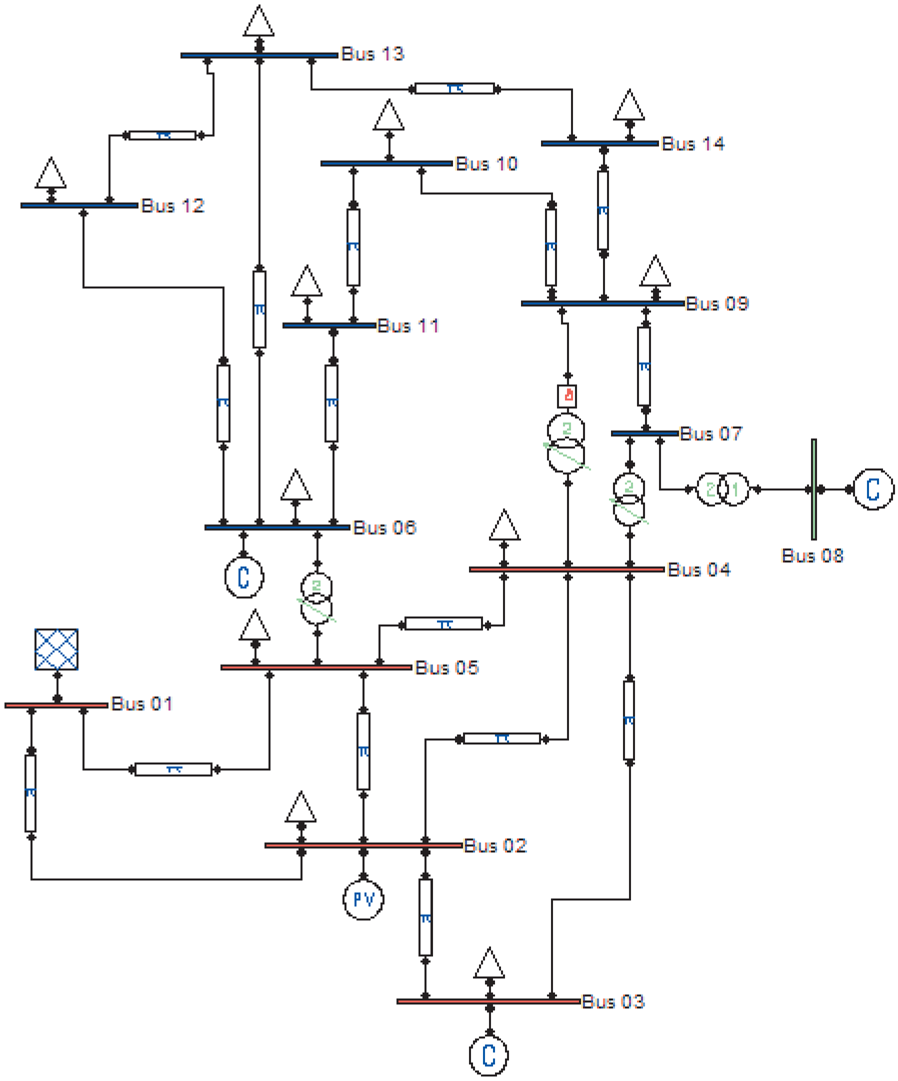

Fig. 3. IEEE 14 bus power system

In IEEE 14 bus power system, when bus number 1 is used as slack bus, bus 2, 3, 6 and 8 are used as generator bus. The rest of 9 buses are used as load buses. In the IEEE 14 bus power system 5-6, 4-8 and 4-9 transmission lines, voltage reducing transformers are used. In transformers between the transmission lines 5-6 and 4-9, tap change and phase shift operations are performed. 100 MVA SSSC has been used in the IEEE 14-bus power system. Firstly, the maximum load parameter value of the system in the absence of SSSC is obtained. Afterward, the maximum load parameter values of the system have been obtained by connecting SSSC to the different transmission lines for the optimal placements of SSSC. All results obtained were interpreted.

V. Simulation Study Results

In order to obtain simulation results, firstly the situation where 100 MVA SSSC with power is not used is examined. Transmission lines between generator and load buses are preferred when connecting to SSSC transmission lines. In subsequent analysis, the SSSC was connected to 1-2 lines, 2-3 numbers, 9-14, 9-10, 10-11, 12-13 and 13-14 respectively. Continuous load flow analysis results in the maximum load parameter of 2.8286 in the case where SSSC is not used. For subsequent analyses, by connecting SSCC to 1-2, 2-3, 9-14, 9-10, 10-11, 12-13 and 13-14 transmission lines respectively, the maximum load parameter values have been obtained as 2.955, 3.1362, 2.8547, 2.8324, 2.8656, 2.834 and 2.8874. In the analysis of voltage-maximum load parameter values, 4 buses were analysed. The voltage-maximum load parameter values on the buses 4,5, 9 and 14 are shown between Figure 4 and Figure 10.

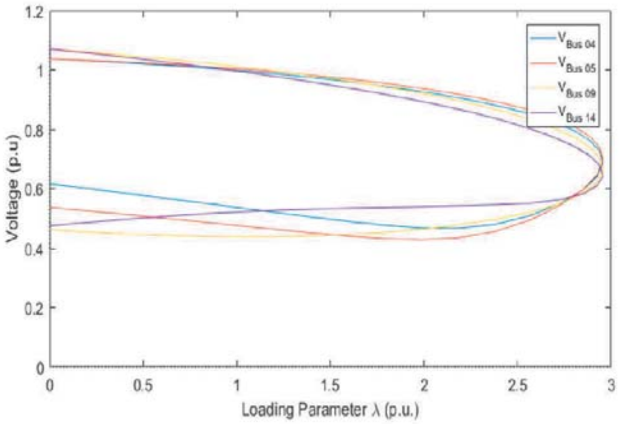

Fig. 4. Loading parameter value of the system with SSSC connected to transmission line 1-2 (2.955)

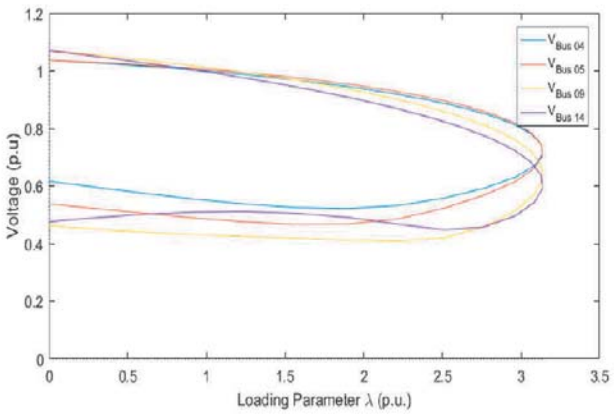

Fig. 5. Loading parameter value of the system with SSSC connected to transmission line 2-3 (3.1362)

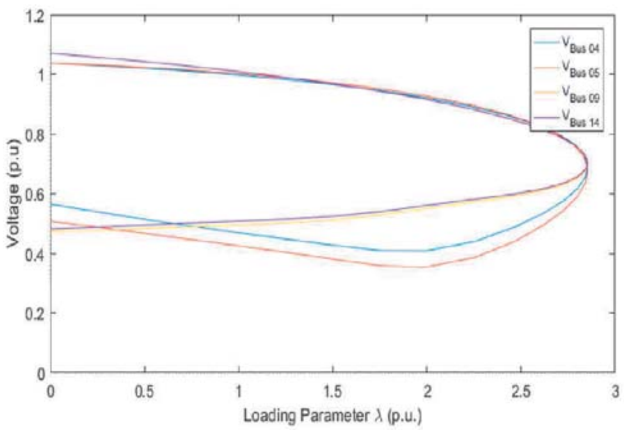

Fig. 6. Loading parameter value of the system with SSSC connected to transmission line 9-14 (2.8547)

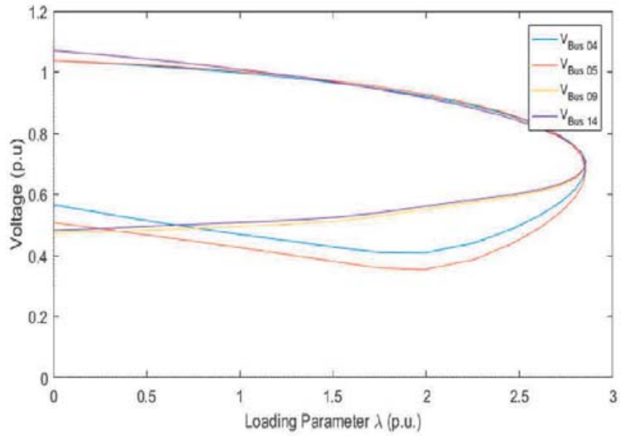

Fig. 7. Loading parameter value of the system with SSSC connected to transmission line 9-10 (2.8324)

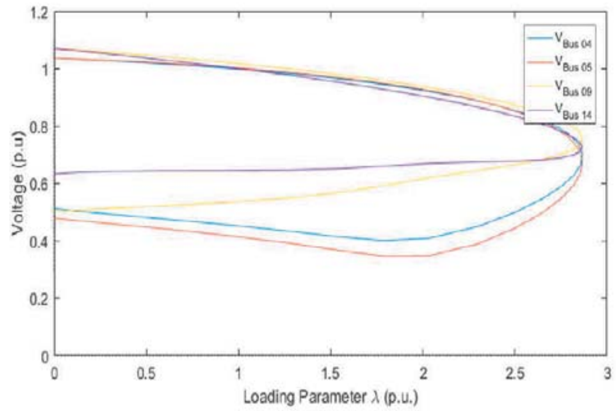

Fig. 8. Loading parameter value of the system with SSSC connected to transmission line 10-11 (2.8656)

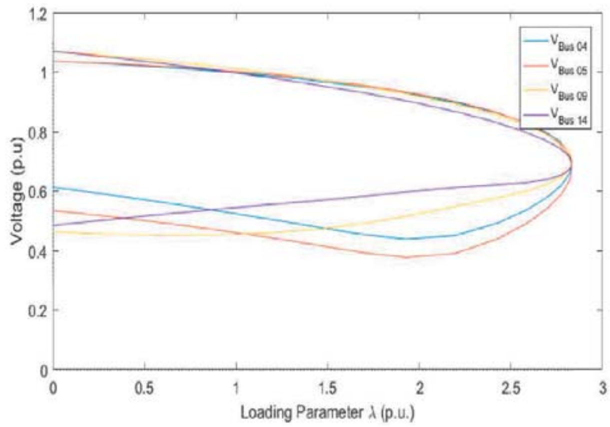

Fig. 9. Loading parameter value of the system with SSSC connected to transmission line 12-13 (2.834)

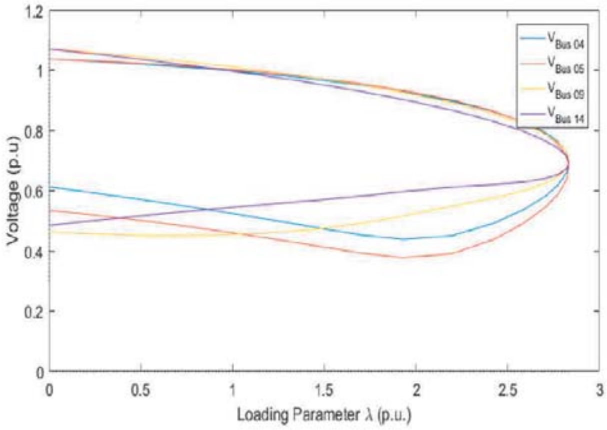

Fig. 10. Loading parameter value of the system with SSSC connected to transmission line 13-14 (2.8874)

It has seen that 100 MVA SSSC connected to 7 different transmission lines increases the maximum load parameter values of the system in all scenarios. The situation where the maximum load value exceeds 3 is the analysis of the connection of the SSSC between the transmission lines numbers 2 and 3. The loading condition with little variation is the analysis of SSSC connecting to the transmission line 9 to 10.

VI. Conclusions

In this study, the effects on voltage-maximum load parameter in IEEE 14 bus power system of SSSC were investigated. SSSC analyses connected to 7 different transmission lines were provided by continuous load flow analysis. The system has been found to be the most optimal placement point of loading with connection to transmission line 2-3 of the SSSC. The least loading point of the system archives with place of SSSC between transmission line 9 and 10. With the SSSC analysis of the bus voltage profiles have a better position. The highest loading point value is 3.1362. The least loading point value is 2.8324. It was seen that the capacity and operating limits of the all transmission line were improved with SSSC. This study leads to the application and analysis of static-dynamic stress analysis with different FACTS devices besides SSSC to different power systems.

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