Optimal Placement of TCSC SSSC and UPFC on Power Systems for Maximum Loading Parameter and Minimum Line Losses

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***Abstract*— In this study, effects of Thyristor Controller Series Compensator (TCSC) Static Synchronous Series Compensator (SSSC) and United Power Flow Controller (UPFC) on power systems are investigated. In 65 buses system, effects of the points where voltage stability is Maximum Loading Parameter (MLP) and the Minimization Line Losses(MLL) are investigated by FACTS devices. Relations between voltage and maximum load parameters and power losses between the lines are illustrated by figure. According to the acquired results; UPFC are more efficient than SSSC and TCSC in terms of both voltage stability and line losses.**

***Keywords*— SSSC, TCSC, UPFC, MLP, MLL**

I. INTRODUCTION

As a result of increasing demand of the consumers and reconstruction of the power sector, the working conditions of the power systems became harder. Problems that may occur in this working conditions cause system instability. For high capacity transmission line and so as to decrease line losses Flexible AC Transmission System (FACTS) devices are used [1]. FACTS devices are generally consist of Static Synchronous Compensator (STATCOM), Static Var Compensator (SVC), Static Synchronous Series Compensator (SSSC), Thyristor Controller Series Compensator (TCSC) and Unified Power Flow Controller (UPFC). This study is emphasized on SSSC, TCSC and UPFC. If we review the previous study in literature; in different modes, the effects of the transient stability and small signal stability of SSSC which has series converter in are analyzed. It is seen that with the use of SSSC in power systems it has effects on voltage and phase angle [2-3]. Optimum control is provided to improving the energy functions with SSSC in power systems. It’s success on critical clear angle and elimination of the harmonics is observed [4-5]. Another area which SSSC is used is Power System Stabilizer (PSS). SSSC gives very well results in c of inter-area oscillations in various load distributions [6-7]. Trajectory Sensitivity Analysis (TSA) is investigated with TCSC which has simpler construction than SSSC in various types of fault. In power systems depends on the fault states optimum placement of TCSC is determined [8]. It is seen that TCSC is efficient in a transient stability situations such as line block out that may occur [9]. As TCSC is effective in power flow, it is seen after the study that TCSC is used efficiently in the optimal load flow analysis [10]. TCSC progresses the bus voltage profiles with improving different programming techniques [11]. In a similar way, TCSC protects the power systems against the sequential distributions with improving different control methods [12]. It is observed that UPFC which has both series and parallel converter circuit is used effectively in first swing stability analysis [13]. In UPFC by series converter circuit line active and reactive power flow, by parallel converter the bus voltage and reactive power control is provided successfully [14-15]. In this study, at minimizing voltage instability and line losses processes optimal places of SSSC, TCSC and UPFC are investigated depending on the different approaches. In 65 bus system, maximum loading parameter, bus voltage profiles and changes in line losses are investigated.

II. THYRISTOR CONTROLLER SERIES COMPENSATOR (TCSC)

Thyristor Controller Series Compensator (TCSC) is connected to transmission line in series and consist of Thyristor Controller Reactor (TCR) and Thyristor Switched Capacitor (TSC). Generally is used for the aim to current control in transmission lines. TCSC control and circuit model are seen in Fig. 1.

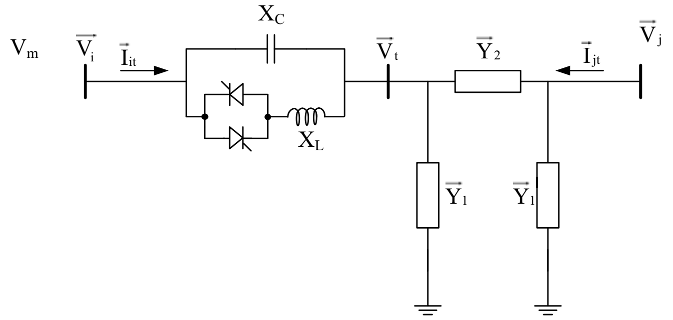

Fig. 1 TSSC Models

The difference between reference current and measured current value is considered by unit of controller triggering angles of thyristors are determined. TCSC system control is expressed by the following equation;

$$P + V_i V_j B_e \sin(\delta_i - \delta_j) = 0 \tag{1}$$

$$-V_i^2 B_e + V_i V_j B_e \cos(\delta_i - \delta_j) - Q_i = 0 \tag{2}$$

$$-V_j^2 B_e + V_i V_j B_e \cos(\delta_i - \delta_j) - Q_j = 0 \tag{3}$$

$$B_e - B_e(\alpha) = 0 \tag{4}$$

$$P + jQ_i - IV_i = 0 \tag{5}$$

where, P active power, V_i i bus voltage, V_j j bus voltage, B_e suseptance, δ_i i bus voltage angle, δ_j j bus voltage angle, Q_i i bus reactive power, I measurement current, B_e *(α)* thyristor depend new suseptance [16]. TCSC current and admittance equation 6 and equation 7 are seen.

$$I_{it} = \frac{Y_{TCSC}(Y_i + Y_j)V_i - Y_i V_j}{Y_{TCSC} + Y_i + Y_j} \tag{6}$$

$$Y_{TCSC} = \frac{1}{jX_{TCSC}} \tag{7}$$

III. Static Synchronous Series Compensator (SSSC)

Static Synchronous Series Compensator (SSSC) is consist of voltage source converter (VSC) circuit which is connected series to the transmission line. Current control of transmission line provided by DC link voltage. SSSC control and circuit model are illustrated in Fig. 2.

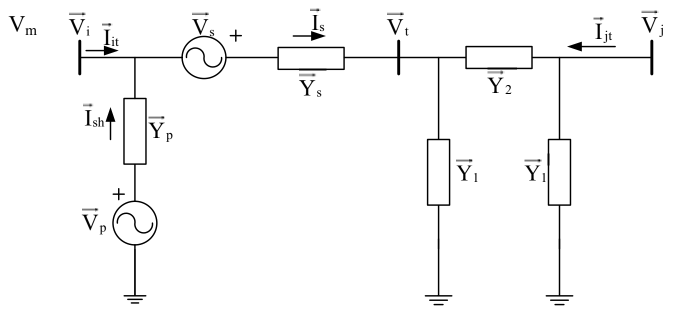

Fig. 2 SSSC Models

The difference between reference current V_{dc} and measured current V_{dcref} value is considered by unit of controller triggering angles of thyristors are determined. SSSC system control is expressed by the following equation [17].

$$I - I_{ref} = 0 \tag{8}$$

$$V_{dc} - V_{dcref} = 0 \tag{9}$$

$$P - V_{dc}^2 / RC - RI^2 = 0 \tag{10}$$

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.

SSSC current and admitance equations are seen at 11 and 12.

$$I_{it} = \frac{Y_{SSSC}(Y_i + Y_j)V_i - Y_i V_j}{Y_{SSSC} + Y_i + Y_j} \tag{11}$$

$$Y_{TCSC,SSSC} = \frac{1}{jX_{SSSC}} \tag{12}$$

IV. Unified Power Flow Controller (UPFC)

UPFC is consist of series and parallel voltage source converter (VSC) circuits. With combination of STATCOM and SSSC, to transmission line; to series bus are connected to parallel. They made the active and reactive power arrangement in system [18]. Control and circuit model of UPFC are illustrated in Fig. 3.

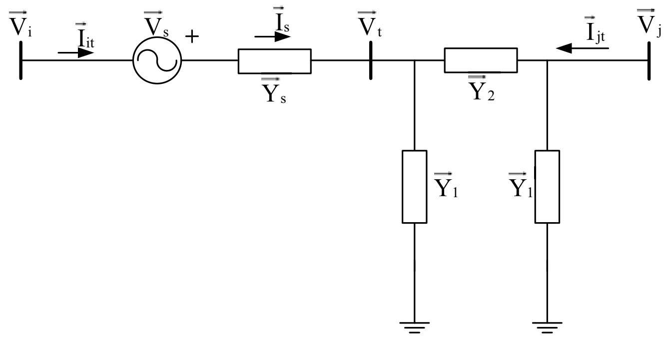

Fig. 3 UPFC Models

Depending on the V_{dc} triggering of series and parallel converters are provided by comparing both current and voltage references. In that way, current of line and bus voltage can be controlled. STATCOM system control can be expressed by the following equations.

Depending on this, the visible power between the lines is expressed as;

$$V - V_{ref} + XI = 0 \tag{13}$$

$$V_{dc} - V_{dcref} = 0 \tag{14}$$

$$P - V_{dc}^2 / RC - RI^2 = 0 \tag{15}$$

If we rewrite the SSSC system control with UPFC;

$$I - I_{ref} = 0 \tag{16}$$

$$V_{dc} - V_{dcref} = 0 \tag{17}$$

$$P - V_{dc}^2 / RC - RI^2 = 0 \tag{18}$$

Voltage equations of UPFC are expressed as;

$$V_t = \frac{Y_s(V_i + V_s) + Y_1 V_j}{Y_s + Y_1 + Y_2} \tag{19}$$

V. Maximum Loading Parameter and Line Losses Minimization

Studies The maximum loading parameter is provided by adding the FACTS devices on the system. Relation between voltage and maximum loading parameter is illustrated in Fig. 4 [19].

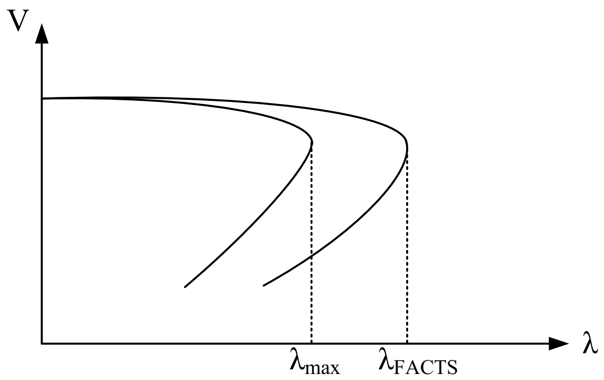

Fig. 4 Relation Voltage-Maximum Loading Parameter with FACTS

In power system, relation between the active power and reactive power maximum loading parameter is expressed as;

$$P_{gi} = P_0(1+\lambda) \tag{20}$$

$$Q_{gi} = Q_0(1+\lambda) \tag{21}$$

where, P_{gi} new active power after adding FACTS, P_0 initial active power and λ maximum loading parameter index. If we express the active and reactive power losses between the lines in power systems;

$$P_{lossij} = I_{ij}^{\ 2} \times r_{ij} \tag{22}$$

$$P_{lossji} = I_{ji}^{\ 2} \times r_{ji} \tag{23}$$

$$P_{netloss} = P_{lossij} - P_{lossji} \tag{23}$$

$$Q_{lossij} = I_{ij}^{\ 2} \times jX_{ij} \tag{24}$$

$$Q_{lossji} = I_{ji}^{\ 2} \times jX_{ji} \tag{25}$$

$$Q_{netloss} = Q_{lossij} - Q_{lossji} \tag{26}$$

After adding TCSC, SSSC and UPFC on power systems, there will be change in reactance value. After adding FACTS devices on power systems obtained new power losses expressions expressed as;

$$Q_{lossij} = I_{ij}^{\ 2} \times j(X_{ij} + X_{TCSC,SSSC,UPFC}) \tag{27}$$

$$Q_{lossji} = I_{ji}^{\ 2} \times j(X_{ji} + X_{TCSC,SSSC,UPFC}) \tag{28}$$

VI. System Analysis

In this study which is on 65 bus system in Turkey, optimum placement points of SSSC, TCSC and UPFC is found depending on where the line losses are minimum and where the maximum loading parameter takes the most proper value. 65 bus system is illustrated in Fig. 5 [20].

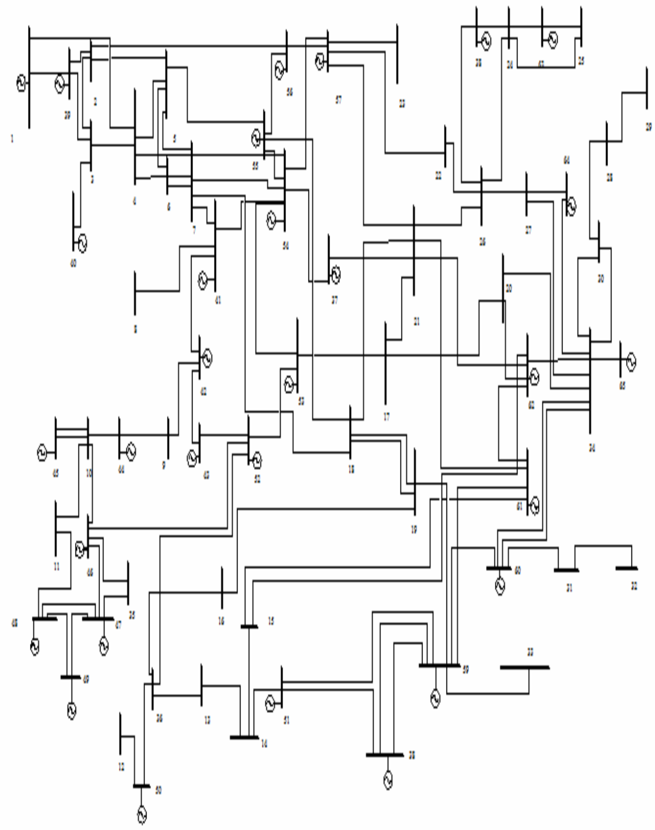

Fig. 5 65 Bus System

This system is consist of 1 slack bus, 28 bus generator and 35 load bus. Firstly, power flow analysis is made by 65 bus system. According to the voltage profiles, buses with very low voltage values are observed. Secondly, continuously power flow analysis is made by 65 bus system. As a result of continuous power flow analysis maximum loading parameter of the system and total line loss data are obtained. 100 MVA TCSC, 100 MVA SSSC and 100 MVA UPFC are series connected between two bus which has lowest voltage value. Finally, approach analysis, FACTS devices are series connected to the buses with has most line losses. The effects on primarily TCSC, then SSSC and finally UPFC on both maximum loading parameter and on line loss are investigated [21].

VII. SIMULATION RESULTS

In 65 bus system, bus voltage profiles and maximum loading states are illustrated as a result of load flow in Fig. 6 and Fig. 7.

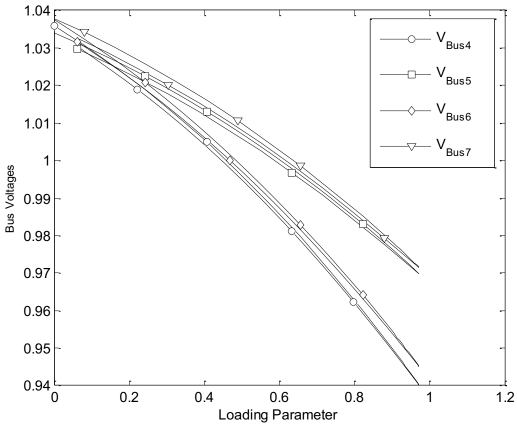

Fig. 6 Without FACTS 4, 5, 6, 7 Bus Loading Parameter

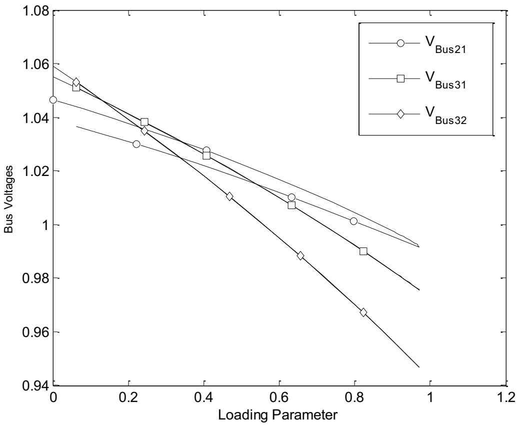

Fig. 7 Without FACTS 21, 31, 32 Bus Loading Parameter

As a result of load flow analysis, in 65 bus system the buses which have the lowest voltage profiles are 37 and 54 buses. Maximum loading parameter value is 0.97125. Except the buses which are connected to slack bus, lines which have most losses are 4 and 5. At the state when TCSC was connected to the buses which has the lowest voltage profiles, buses number 37 and 54, obtained voltage profile and maximum load ability are illustrated in Fig. 8 and Fig. 9.

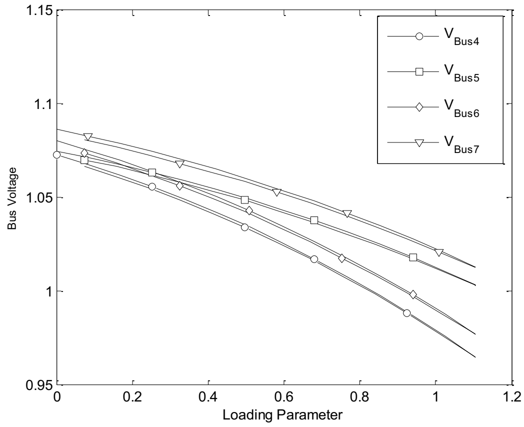

Fig. 8 With TCSC 4, 5, 6, 7 Bus Loading Parameter

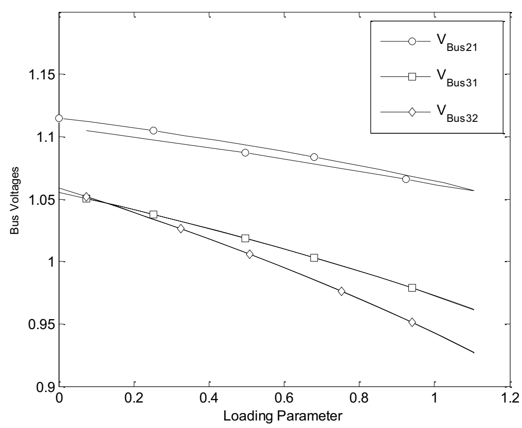

Fig. 9 With TCSC 21, 31, 32 Bus Loading Parameter

After replacing TCSC between bus number 37 and 54, system maximum loading parameter is increased to 1.1059. At the state when SSSC was connected to the buses which has the lowest voltage profiles, buses number37 and 54, obtained voltage profile and maximum load ability are illustrated in Fig. 10, and Fig. 11.

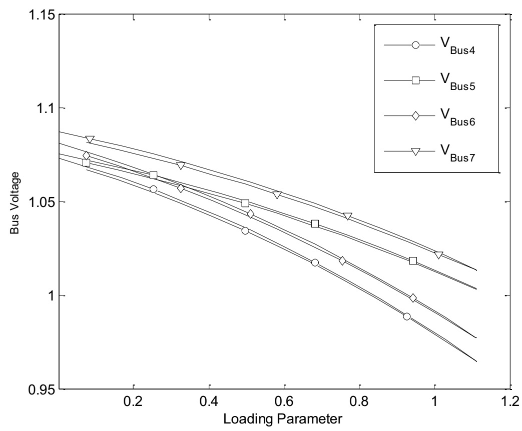

Fig. 10 With SSSC 4, 5, 6, 7 Bus Loading Parameter

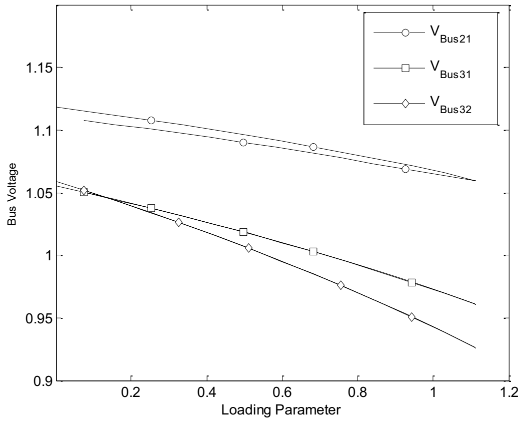

Fig. 11 With SSSC 21, 31, 32 Bus Loading Parameter

After replacing SSSC between bus number 37 and 54, system maximum loading parameter is increased to 1.1111. At the state when UPFC was connected to the buses which has the lowest voltage profiles, buses number 37 and 54, obtained voltage profile and maximum load ability are illustrated in Fig. 12 and Fig. 13.

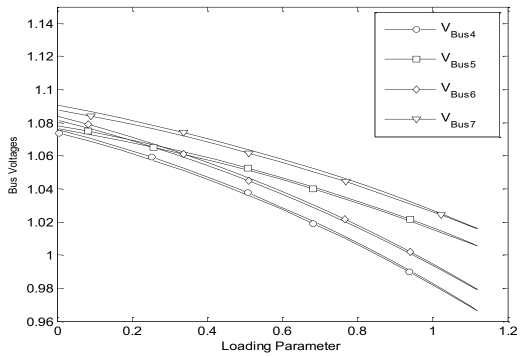

Fig. 12 With UPFC 4, 5, 6, 7 Bus Loading Parameter

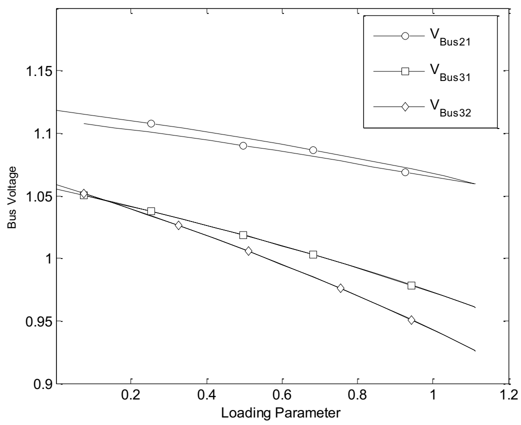

Fig. 13 With UPFC 21, 31, 32 Bus Loading Parameter

After replacing UPFC between bus number 37 and 54, system maximum loading parameter is increased to 1.1187. As a result, with the usage of TCSC, SSSC and UPFC maximum loading parameter and line losses without having the FACTS devices are illustrated in Table 1. As a result of the table, in UPFC maximum loading parameter takes the greatest value than in TCSC and SSSC. Besides in terms of total power losses, it is seen that UPFC is smaller than other devices.

TABLE I
MAXIMUM LOADING PARAMETER AND TOTAL TRANSMISSION LOSSES

	Variable	**MLP**	**Total Active Power Loss**	**Total Active Power Loss**
37-54 Between Transmission Line	Without FACTS	0.97125	0.0851	0.0602
	With TCSC	1.1059	0.0784	0.0587
	With SSSC	1.1111	0.0752	0.0562
	With UPFC	1.1187	0.0692	0.0503
4-5 Between Transmission Line	Without FACTS	0.97125	0.0851	0.0602
	With TCSC	1.1024	0.0816	0.0596
	With SSSC	0.1095	0.0764	0.0573
	With UPFC	1.1156	0.0712	0.0521

VIII. CONCLUSIONS

In this study, In 65 bus system, effects of the points where voltage stability is maximum and the line losses are minimum are investigation by TCSC, SSSC and UPFC which are of FACTS devices. In terms of bus voltage profiles, UPFC is more successful on determination of the optimum place and maximum load parameter and minimizing the line losses than other FACTS. It is concluded that SSSC gives better results than TCSC. It is also seen that in terms of line losses determination of optimum place, UPFC gives best result. It is obviously demonstrated after the study that in both approaches, use of FACTS devices in power systems may be effective.

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