ANALYSIS AND SIMULATION OF SERIES FACTS DEVICES TO MINIMIZE TRANSMISSION LOSS AND GENERATION COST

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ABSTRACT

This paper presents the severity of over load index (SOL) technique to find the optimal location of FACTS controller to achieve optimal power flow solution. The proposed method estimates the SOL index of transmission line to locate the FACTS device. Main objective of optimal power flow is to minimize the overall cost function which includes total active and reactive power production cost under constraints. Among various FACTS devices thyristor controlled phase shifters (TCPST), thyristor controlled series compensator (TCSC) and static synchronous series compensators (SSSC) are considered to control active power flow through transmission line and also to reduce active power loss. Different operating conditions of the power system are considered for finding the optimal location of FACTS controllers. The proposed technique is an effective method for the optimal location of FACTS controllers.

KEYWORDS: *FACTS, TCPST, TCSC, SSSC, OPF*

I. INTRODUCTION

In today's highly complex and interconnected power systems, there is a great need to improve electric power utilization while still maintaining reliability and security. Demand of electric power is continuously rising at a very high rate due to rapid industrial development. To meet this demand it is essential to raise the transmitted power along with the existed transmission facilities. The need for the power flow control in electrical power system is thus evident. Power flow is a function of transmission line impedance, the magnitude of the sending end and receiving end voltages and the phase angle between voltages. By controlling one or a combination of the power flow arrangements, it is possible to control the active, as well as, the reactive power flow in the transmission line [1]. The FACTS devices are capable of changing the system parameters in a fast and effective way. It is known that the benefits brought by FACTS devices include improvement of system stability, enhancement of system reliability, and reduction of operation and transmission investment cost [2]. In previous work, researches concentrated on locating and sizing of different types of FACTS devices in order to maximize the power transfer considering networks with variable loads. The problem was formulated as an optimization problem and was solved using different methods such as using iterative techniques, MATLAB optimization routines or Genetic Algorithm (GA) [3-5]. Optimization problem with the objective of minimizing the generating cost in a network with unchanged loads. The problem is solved using OPF algorithm using NR method. Which is fast and simple compared with conventional technique and also give promising results. Improvements of results with FACTS devices is compared with convention N-R OPF method without FACTS devices. OPF is a very large, non-linear mathematical programming problem, the main purpose of OPF is to determine the optimal operation state of a power system while meeting some specified constraints. Since the OPF solution was introduced by squires [6]. The focus in this paper lies on thyristor controlled phase shifting transformers (TCPST), thyristor controlled series compensators (TCSC) and static synchronous series compensators (SSSC). These facts devices TCPST, TCSC and SSSC by controlling the power flows in the network can help to reduce the flows in heavily loaded lines, to reduce the system loss, reduced cost of production and fulfilled contractual requirements [7]. Location of FACTS devices in the power system are obtained on the basis of static and/or dynamic performance. There are several methods for finding the optimal location of FACTS devices but this paper introduces severity of overload index technique gives optimal location by estimating overload index of each transmission line. The proposed algorithm is tested using the IEEE 5 bus and IEEE 30 bus system and the results are presented.

The description of remaining sections of this paper is as follows. Section 2 introduces OPF without FACTS devices. Modelling of FACTS devices is described in section 3. In section 4 problem formulations is presented. The experimental results on the IEEE5 bus and IEEE30 bus systems are presented in section 5. Finally section 6 summarizes the main conclusion and future scope of the paper.

II. OPF WITHOUT FACTS DEVICES

The objective of active power optimization is to minimize production cost while observing the transmission line and generation active and reactive power limits.

Minimize

$$F_T = \sum_{i=1}^{m} C_i\left(P_{Gi}\right) \tag{1}$$

Subjected to

$$\sum_{i=1}^{m} P_{Gi} - \sum_{k=1}^{n} P_{Dk} - P_L = 0 \tag{2}$$

$$P_L \le P_L^{\max} \tag{3}$$

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} \tag{4}$$

Where n is the number of system buses and number of generating units respectively. $C_i\left(P_{Gi}\right)$ is production cost of the unit at i^{th} bus, F_T is the total production cost of m generators, $P_{Gi}^{\min}$ & $P_{Gi}^{\max}$ are minimum and maximum active power limits of the unit at i^{th} bus. P_{Dk} is the active power load at bus k, P_L is the network active power loss, P_l, $P_1^{\max}$ are the active power flow and its limit on line l.

The augmented lagrangian is, [18]

$$L(P_{Gi}) = F_T(P_{Gi}) + \lambda\left(\sum_{k=1}^{n} P_{Dk} + P_L - \sum_{i=1}^{m} P_{Gi}\right) + \sum_{l=1}^{N_l} \mu_l\left(P_l - P_l^{\max}\right) + \sum_{i=1}^{m}\left[\mu_i^{\max}\left(P_{Gi}^{\max} - P_{Gi}\right) + \mu_i^{\max}\left(P_{Gi} - P_{Gi}^{\max}\right)\right] \tag{5}$$

λ is for power balance equation.

$\mu_i^{\min}$ and $\mu_i^{\max}$ are lower and upper active power limits of unit at i^{th} bus.

μ_l is for active power flow limit on line l.

N_l is the number of transmission line flow violations

III. MODELLING OF FACTS DEVICES

In this paper three facts devices are used for comparing the results these are thyristor controlled phase shifting transformers (TCPST), thyristor controlled series compensators (TCSC) and static synchronous series compensators (SSSC). Modelling of these devices is given in the following sections.[20]

3.1 Modelling of TCPST

TCPST can be modelled by a phase shifting transformer with control parameter ϕ. The power flow equations of the line can be derived as follows [15]& [17]

$$P_k = V_k^2 G - V_k V_m \left[G\,Cos(\theta_k - \theta_m - \phi) + B\,Sin(\theta_k - \theta_m - \phi)\right] \tag{6}$$

$$Q_k = -V_k^2 B - V_k V_m \left[G\,Sin(\theta_k - \theta_m - \phi) - B\,Cos(\theta_k - \theta_m - \phi)\right] \tag{7}$$

$$P_m = V_m^2 G - V_m V_k \left[G\,Cos(\theta_m - \theta_k - \phi) + B\,Sin(\theta_m - \theta_k - \phi)\right] \tag{8}$$

$$Q_m = -V_m^2 B - V_m V_k \left[G\,Sin(\theta_k - \theta_m - \phi) + B\,Cos(\theta_k - \theta_m - \phi)\right] \tag{9}$$

The injected real and reactive power of TCPST at bus and bus are as follows.

$$P_{ks} = -V_i^2 G_{ij} \tan^2\phi - V_k V_l \tan\phi\left[G_{kl}\,Sin\delta_{kl} - B_{kl}\,Cos\,\delta_{kl}\right] \tag{10}$$

$$P_{ls} = -V_k V_l \tan\phi\left[G_{kl}\,Sin\,\delta_{kl} + B_{kl}\,Cos\,\delta_{kl}\right] \tag{11}$$

3.2 Modelling of TCSC

It was derived by examining the voltages and currents in the TCSC circuit under the full range of operating conditions. The basic equation is,

$$Z_{TCSC} = R_{TCSC} + jX_{TCSC} = \frac{V_{TCSC}}{I_{TCSC}} \tag{12}$$

Where, V_{TCSC} is the fundamental frequency voltage across the TCSC module,
I_{TCSC} is the fundamental frequency line current and Z_{TCSC} is the TCSC impedance.
Effective TCSC reactance X_{TCSC} with respect to alpha is,

$$X_{TCSC}(\alpha) = -X_C + C_1\left(2(\pi - \alpha) + Sin(2(\pi - \alpha))\right) - \\ C_2 Cos^2(\pi - \alpha)\left(\omega\left(\tan(\omega(\pi - \alpha))\right) - \tan(\pi - \alpha)\right) \tag{13}$$

3.3 Modelling of SSSC

The SSSC OPF model presented in this section enables very flexible and reliable power system optimization studies to be carried out. The flexibility stems from the generality of the SSSC model and the robustness from the strong convergence exhibited by the OPF solution using Newton's method. The SSSC model may be set to control active powers as well as nodal voltage magnitude, at either the sending or the receiving end bus. The mathematical modelling will be obtained from [8] and that was taken as a reference and implemented in the OPF by using the Lagrangian multiplier concept. A SSSC [9] [10] usually consists of a coupling transformer, an inverter and a capacitor. As shown in Fig. 1 the SSSC is series connected with a transmission line through the coupling transformer.

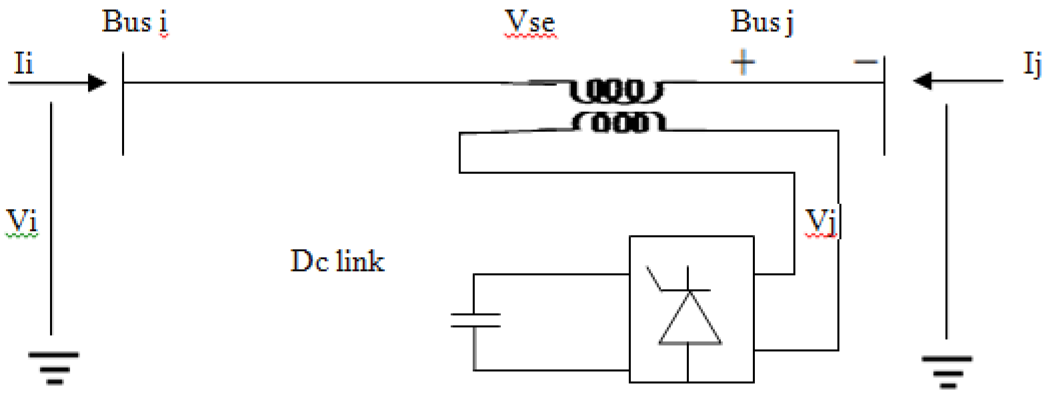

Fig. 1 SSSC basic operating model

It is assumed here that the transmission line is series connected via the SSSC bus *j*. The active and reactive power flows of the SSSC branch *i-j* entering the bus *j* are equal to the sending end active and reactive power flows of the transmission line, respectively. In principle, the SSSC can generate and insert a series voltage, which can be regulated to change the impedance (more precisely reactance) of the transmission line. In this way, the power flow of the transmission line or the voltage of the bus, which the SSSC is connected with, can be controlled.

An equivalent circuit of the SSSC as shown in Fig. 1 can be derived based on the operation principle of the SSSC. In the equivalent, the SSSC is represented by a voltage source V_{se} in series with transformer impedance. In the practical operation of the SSSC, V_{se} can be regulated to control the power flow of line $i - j$ or the voltage at bus i or j [11].

In the equivalent circuit, $V_{se} = V_{se}\angle\theta_{se}$, $V_i = V_i\angle\theta_i$, $V_{se} = V_j\angle\theta_j$ then the bus power flow constraints of the SSSC are,

$$P_{ij} = V_i^2 g_{ii} - V_i V_j \left(g_{ij}\cos\theta_{ij} + b_{ij}\sin\theta_{ij}\right) - V_i V_{se}\left(g_{ij}\cos(\theta_i - \theta_{se}) + b_{ij}\sin(\theta_i - \theta_{se})\right) \quad (14)$$

$$Q_{ij} = -V_i^2 b_{ii} - V_i V_j \left(g_{ij}\sin\theta_{ij} - b_{ij}\cos\theta_{ij}\right) - V_i V_{se}\left(g_{ij}\sin(\theta_i - \theta_{se}) - b_{ij}\cos(\theta_i - \theta_{se})\right) \quad (15)$$

$$P_{ji} = V_j^2 g_{jj} - V_i V_j \left(g_{ij}\cos\theta_{ji} + b_{ij}\sin\theta_{ji}\right) + V_j V_{se}\left(g_{ij}\cos(\theta_j - \theta_{se}) + b_{ij}\sin(\theta_j - \theta_{se})\right) \quad (16)$$

$$Q_{ji} = -V_j^2 b_{jj} - V_i V_j \left(g_{ij}\sin\theta_{ji} - b_{ij}\cos\theta_{ji}\right) + V_j V_{se}\left(g_{ij}\sin(\theta_j - \theta_{se}) - b_{ij}\cos(\theta_j - \theta_{se})\right) \quad (17)$$

where,

$g_{ij} + jb_{ij} = \frac{1}{z_{se}}, g_{ii} = g_{ij}, b_{ii} = b_{ij}, g_{jj} = g_{ij}, b_{jj} = b_{ij}$ The operating constraint of the SSSC (active power exchange via the DC link) is,

$$PE = \mathrm{Re}\left(V_{se} I_{ji}^*\right) = 0 \quad (18)$$

where,

$$Re\left(V_{se} I_{ji}^*\right) = V_i V_{se}\left(g_{ij}\cos(\theta_i - \theta_{se}) - b_{ij}\sin(\theta_i - \theta_{se})\right) V_j V_{se}\left(g_{ij}\sin(\theta_j - \theta_{se}) - b_{ij}\cos(\theta_j - \theta_{se})\right) \quad (19)$$

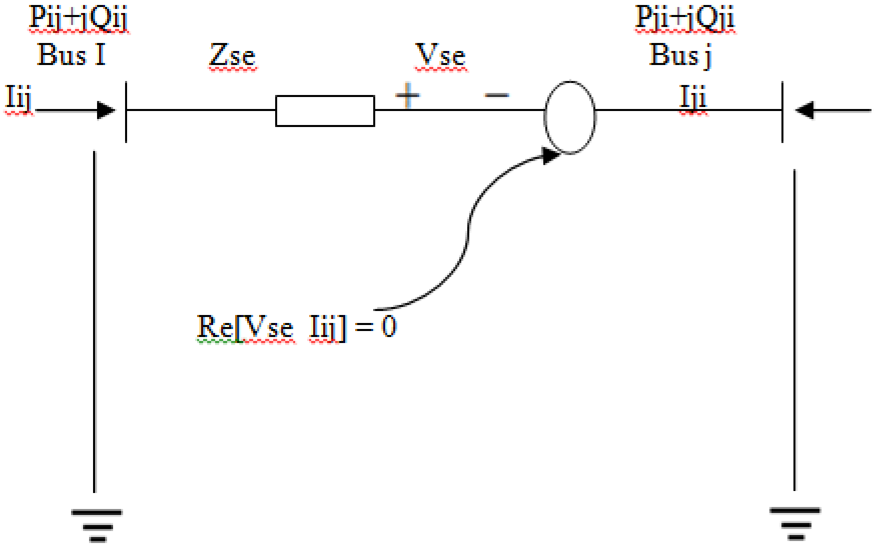

Fig. 2 SSSC Equivalent circuit

IV. OPF FORMULATION WITH SSSC LAGRANGIAN FUNCTION

Based on the above equation the Lagrangian function for the SSSC may be written as,

$$L(x,\lambda) = f(P_g) + \lambda^t h(P_g, V, \theta, \delta_{cr}, V_{cr}) \quad (20)$$

In this expression, $f(P_g)$ is the objective function to be optimized $h(P_g, V, \theta, V_{CR}, \delta_{CR})$; represents the power flow equations; x is the vector of state variables; λ is the vector of Lagrange multipliers for equality constraints; and $P_g, V \, and \, \theta$ are the active power generation, voltage magnitude, and voltage phase angle, respectively. The SSSC control variables are δ_{CR} and V_{CR}. The inequality constraints $g(P_g, V, \theta, V_{CR}, \delta_{CR}) < 0$ are not shown in Eqn. (3.81) because it is added only to $L(x, \lambda)$ when there are variables outside limits.[19]

The Lagrangian function, $L_{km}(x, \lambda)$ corresponding to the power flow mismatch equations at buses k and m, is given by the following equation,

$$L_{km}(x,\lambda) = \lambda_{pk}(P_k + P_{dk} - P_{gk}) + \lambda_{qk}(Q_k + Q_{dk} - Q_{gk}) + \lambda_{pm}(P_m + P_{dm} - P_{gm}) + \lambda_{qm}(Q_m + Q_{dm} - Q_{gm}) \qquad (21)$$

In this expression $P_{dk}, P_{dm}, Q_{dk} \, and \, Q_{dm}$ are the active and reactive power loads at buses *k* and *m*; $P_{gk}, P_{gm}, Q_{gk} \, and \, Q_{gm}$ are the scheduled active power generations at buses *k* and *m*; and $\lambda_{pk}, \lambda_{pm}, \lambda_{qk} \, and \, \lambda_{qm}$ are Lagrange multipliers at buses k and m. The vector of state variables x is $[V \; \delta]^t$, where V and λ include both nodal voltages and SSSC voltage sources.

4.1 SSSC Power Flow Constraints

The power injected at bus m by the SSSC can be formulated as a power flow constraint in the branch connecting buses *m* and *l*. We may write

$$L_{ml}(x,\lambda) = \lambda_{p\,ml}(P_{ml} - P_{specified}) + \lambda_{q\,ml}(Q_{ml} - Q_{specified}) \qquad (22)$$

Where, $\lambda_{P\,ml}$ is the Lagrange multiplier associated with the active power injection at bus *m*; and $P_{specified}$ is the specified active power leaving bus *m*.

In conventional OPF formulations, such constraints are enforced only if power flow limits have been exceeded. However, in this particular application this constraint may remain active throughout the iterative solution [12]. The SSSC Lagrangian function comprising the individual contributions presented above is as follows

$$L_{sssc}(x,\lambda) = L_{km}(x,\lambda) + L_{se}(x,\lambda) + L_{ml}(x,\lambda) \qquad (23)$$

4.2 Optimal setting of SSSC Parameters

Basically, the SSSC has one voltage source inverter (VSI) having a dc storage capacitor. It is connected to the system through a coupling transformer. In this study, the series compensation $\Delta U_{FACTS} = \Delta U_{SSSC}$ is employed [12].

The injected currents at bus *i* and bus *j* can be expressed as follows,

$$\Delta I_{i,send} = \frac{\Delta U_{sssc}}{z_{ij}} \qquad (24)$$

$$\Delta I_{j,send} = -\frac{\Delta U_{sssc}}{z_{ij}} \qquad (25)$$

The cost function for SSSC can be expressed as follows,

$$C_{sssc} = 0.0015 s^2 - 0.5130 s + 133.15 \quad \text{\$/hr} \qquad (26)$$

where, C_{sssc} is the cost function of the SSSC in \$/hr and ‘s’ is the operating range of the FACTS devices in MVAr.

V. SEVERITY OF OVER LOADABILITY INDEX (SOL) COMPUTATION

The location of the FACTS devices in this work is decided based on the severity of the overloading of that particular branch in which the device is incorporated. The process of ranking the branches based on their load ability in the order of their severity involves the following steps.

Step1: Establish the criterion to be considered in formulating the ranking

Step2: For the criterion established in (Step 1), define a scalar mathematical function which has a large value of branch load that which stress the system relative to that criterion, and a small value for those which do not; this function is called a “SOL index.”

The SOL index is such that contingencies resulting in system conditions yielding large valued over load indices are considered more severe than system conditions with smaller over load indices [16]. In the overload ranker, the SOL index is defined as,

$$SOL = \sum_{i=1}^{n} \left(\frac{P_i}{P_{i,\max}} \right)^2 \qquad (27)$$

where,

P_i is the real power flow in line “i”,

$P_{i,\max}$ is the maximum of active power transfer over the i^{th} line and

'n' is the set of monitored lines contributing to SOL.

5.1 Calculation of SOL for IEEE 5 Bus system

Table 1: SOL index of all buses by running the general OPF for IEEE 5 bus system

Bus No./Node No.	SOL index of each bus	Ranking
[3]	**0.5812**	**1**
[4]	0.5310	2
[5]	0.3285	3

As compared the above SOL-indices for the IEEE 5 bus system among the 3 load buses (3, 4, 5) the bus 3 is having the maximum SOL index, it is considered to be the critical bus. Hence line indices will provide accurate information with regard to the stability condition of the lines.

5.2 Calculation of SOL for IEEE 30 Bus system

Table 2: SOL-indices by running the general OPF of maximum loaded buses in IEEE 30 bus system

Branch Number	**SOL indices of different branches**	**Ranking**
[30]	0.7776	2
[24]	0.5672	4
[29]	**0.8873**	**1**
[28]	0.7486	3
[26]	0.5491	5

As we considered the SOL-index table of the IEEE 30 bus system there will be the 5 load buses (24, 26, 28, 29, 30) with the bus (29) is having the maximum load ability, it is considered to be the critical bus. The branch connected to that particular weakest or critical bus will be the optimal location for the FACTS device to be placed. Hence the branch [13]-[14] is chosen to be the optimal location in the IEEE 30 bus case.

VI. SIMULATION RESULTS

The proposed methodology of active power optimal power flow of series FACTS devices as TCPST, TCSC and SSSC for transmission network is implemented using MATLAB on the two test systems viz., IEEE 5-bus and IEEE-30-bus test systems. The cost constants and their typical values for this problem are energy cost (a=60 Rs/hr, b=200 Rs/MW/hr, c=140 Rs/ MW^2/hr). The payback period assumed is five years with depreciation factor (α) as 0.1.

6.1 Optimal power flow for IEEE 5 bus system without and with FACTS devices

The 5-bus test system used to illustrate the use of the conventional power flow Newton– Raphson method and is also used to illustrate the use of the OPF and associated data. The maximum and minimum voltage magnitude limits at all buses are taken to be 0.9p.u. and 1.1 p.u., respectively, except at bus 1 (Slack bus), where the maximum limit is set at 1.5 p.u.

The cost coefficients of the two generating buses are taken to be

$a = 2700\ Rs/Mw^2/hr$

$b = 153\, Rs/Mw/hr$ and,

$c = 0.18\, rs/hr$.

The maximum and minimum generator active power limits are set at 200Mw and10Mw, respectively, whereas the maximum and minimum reactive power limits are set at 300MVAR and -300MVAR, respectively.

Table 3 Comparison of OPF solution without and with FACTS devices for IEEE 5 bus system

Without device	TCPST	TCSC	SSSC
V_{bus}p.u.	V_{bus}p.u.	V_{bus}p.u.	V_{bus}p.u.
1.060	1.06	1.060	1.060
1.100	1.012	1.035	1.049
1.078	1.028	1.042	1.048
1.077	1.027	1.028	1.036
1.072	1.020	1.032	1.049
------	1.009	1.018	1.027

Table 4 Comparison of Active power and Active power generation cost of different cases for IEEE 5 bus system

Case type	P_{loss} (MW)	$P_{Gen,cost}$ (Rs/hr)
Without device	3.55	34,046
TCPST	3.45	33,874
TCSC	3.41	33,558
SSSC	**3.21**	**33,366**

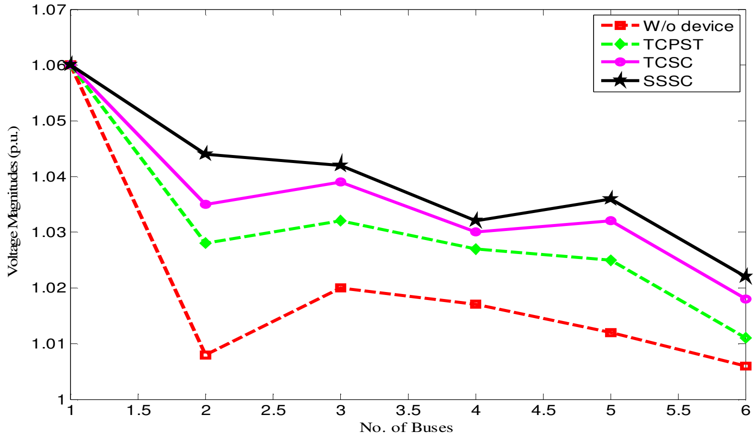

Fig.3 Comparison of without devices and with TCPST, TCSC and SSSC voltages magnitudes at each bus in IEEE 5 Bus system

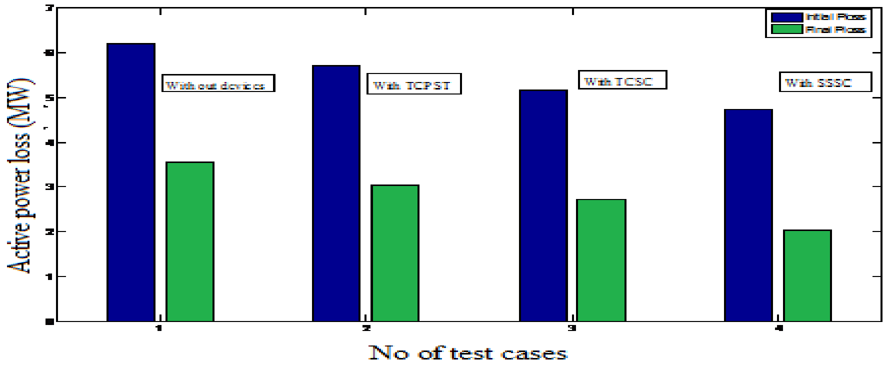

Fig.4 Comparison of Active power loss and % of P_{loss} without and with FACTS devices

6.2 Optimal power flow for IEEE 30 bus system without and with FACTS devices

The IEEE 30-bus test system is used to study the impact of the FACTS devices on the network. The optimal location will be analyzed by using the SOL index from the Table 2 and then FACTS devices are added in series with transmission line (28–29), and the dummy bus (31) is added to enable such a connection to take place.

As compared the voltage magnitudes without and with FACTS devices the voltage profile of the SSSC is improved slightly when compared with TCPST and TCSC, for both the IEEE Test systems. By comparing the SOL-index under normal situation the optimal location of the FACTS device is decided. Hence for the IEEE 30 Bus system (28-29) is the optimally decided branches for the FACTS devices to be incorporated in the electrical power system.

Table 5 The active power and reactive power of different buses for IEEE 30 bus system

Case type	Active power loss (MW)	Reactive power loss (MVAr)
Without Device	18.58	52.73
With TCPST	18.49	46.41
With TCSC	18.37	49.23
With SSSC	18.02	42.45

Table 6 The initial and final costs of active power generation at different buses

Case type	IEEE 5 bus system		IEEE 30 bus system	
	$P_{Gen,\ initial\ cost}$ (Rs/hr)	$P_{Gen,\ final\ cost}$ (Rs/hr)	$P_{Gen,\ initial\ cost}$ (Rs/hr)	$P_{Gen,\ final\ cost}$ (Rs/hr)
Without Device	35,000	34,046	36,900	36,765
With TCPST	35,000	33,874	36,900	35,325
With TCSC	35,000	33,558	36,900	33,795
With SSSC	35,000	33,366	36,900	**33,075**

Furthermore, with SSSC the generation cost is reduced to *680 Rs /hr* in 5 bus system and *3825 Rs/hr*in 30 bus system respectively when compared to TCPST , TCSC and with the base case i.e. 4.66% reduction in the active power generation cost compared to (2.76% , 3.25% and 4.12% for the without FACTS ,with TCPST and TCSC respectively).

Table 7 Comparison of Total Active power generation costs in both the test cases

Case Type device	IEEE 5 bus system		IEEE 30 bus system	
	$P_{loss,Total}$ (MW)	$P_{Gen,cost,Total}$ (Rs/hr)	$P_{loss,Total}$ (MW)	$P_{Gen,cost,Total}$ (Rs/hr)
Without device	3.55	34,046	18.58	36,765
TCPST	3.45	33,874	18.49	35,325
TCSC	3.41	33,558	18.37	33,795
SSSC	**3.21**	**33,366**	**18.02**	**33,075**

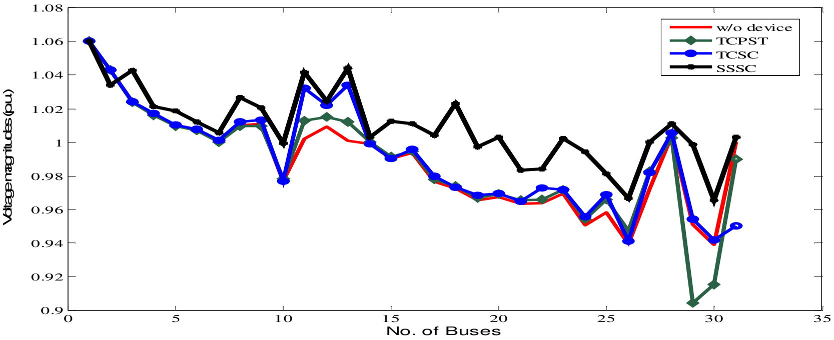

Fig. 5 Comparison of without and with TCPST, TCSC and SSSC voltages at different buses in IEEE 30 Bus system

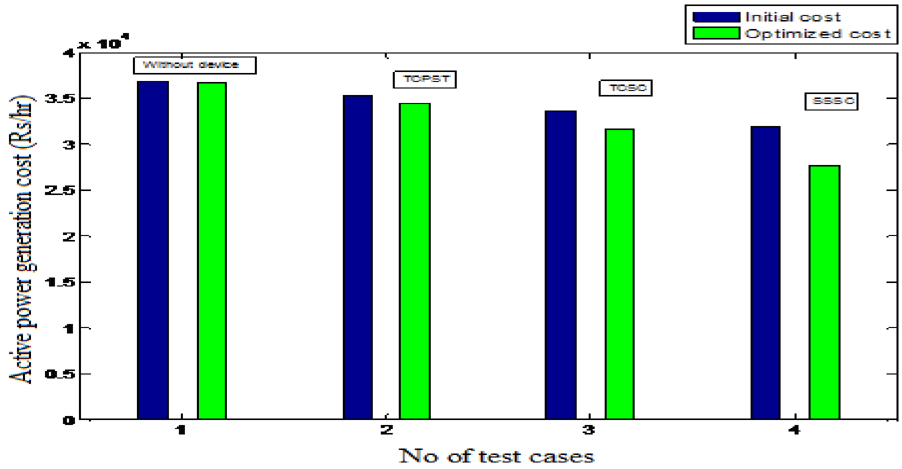

Fig. 6 Comparison of Active power generation cost (Pgi, cost) in case of without device & with TCPST, TCSC and SSSC at different buses in IEEE 30 Bus system

Table 8 Comparison of the costs of different FACTS devices in IEEE 5 bus & IEEE 30 bus system

Type of Device	Cost of the FACTS devices [(Rs/hr) for TCSC & SSSC & (Rs) for TCPST]	
	IEEE 5 bus system	IEEE 30 bus system
TCPST	1,86,075 Rs	3,66,075 Rs
TCSC	6,938.99 Rs/hr	17,600 Rs/hr
SSSC	5,952.47 Rs/hr	13,452 Rs/hr

From Tables (3) and (6) it was clear that the SSSC is improving the overall system performance in both the IEEE test systems when compared with the TCPST, TCSC and base cases. Being having the separate DC link for the SSSC it is capable of generating the reactive power without any external source and hence capable of controlling the reactive power flow of the system like UPFC, instead of controlling only active power as TCSC. The Table 5.18 will gives the costs of the FACTS devices among which the SSSC is possessing the less cost comparable to the other devices. Hence it was concluded that the SSSC is more suitable for the power flow control and optimizing techniques.

VII. CONCLUSIONS

Simulation studies using MATLAB programming code, on IEEE 5 and IEEE 30 bus system are presented to illustrate the methodology and to demonstrate the benefit of the proposed approachIn this paper the optimal power flow analysis with the inclusion of TCPST, TCSC and SSSC has been done. Newton-Raphson method used in polar co-ordinate form is effectively applied to solve the Optimal power flow equations of IEEE 5-Bus & IEEE 30-Bus systems which differ from each other in size & degree of operational complexity.

Themodeling of Series FACTS devices are incorporated into an existing Newton-Raphson load flow algorithm, which is capable of solving large power networks very reliably. It shows that Series FACTS environment can be set to control active power, active power loss and voltage magnitude simultaneously. The Severity of Overloading index is used to find location of the series FACTS devices that they are used in the network.

The proposed algorithms were implemented to find out the proper setting and installation cost of the TCPST, TCSC and SSSC in IEEE-5 bus & IEEE-30 bus test systems. By comparing the results, it is observed that SSSC is more effective than TCSC and TCPST in terms of voltage regulation, power loss reduction, minimization of active power generation cost and improving the active power flow.

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