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A SOL algorithm and simulation of TCPST for optimal power flow solution using NR method

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ABSTRACT

This paper introduces the severity of load (SOL) index technique for finding the optimal location of facts devices to achieve the optimal power flow. Objective function in the OPF, that is to be minimised, are overall cost functions which includes the total active power generation cost function. Among various controllers TCPST is considered and optimal location facts device is determined for improved economic dispatch. The OPF constraints are on generators, transmission lines, and TCPST limits. In this paper TCPST for OPF and the achieved improvements are compared with the case where no facts devices are demonstrated.

***Keywords* – SOL, TCPST, NR, OPF, FACT**

1. INTRODUCTION

In present days with the deregulation of electricity market, the traditional practices of power system have been completely changed. Better utilization of the existing power system resource to increase capabilities by installing FACTS controllers with economic cost becomes essential [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].

A few research works were done [3], [4] on the FACTS controllers for improving static performance of the power system. There is also a great need for studying the impact of FACTS controllers and their impact on the power generation cost are also reported [5]. The objective of this paper is to know the real power allocation of generators and to find the best location of FACTS controllers such that overall system cost which includes the minimization of generation cost of power plants and active power loss. 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], considerable amount of research on different optimization algorithms and solution methods have been done. The main existing techniques for solving the OPF problems are the gradient method, Newton method, linear programming method and decomposition method. Each method has its own advantages and disadvantages, but all of them have their own capabilities for solving the OPF problem [2].

Among the solution methods Newton's method for OPF problem, Newton's method is the most commonly employed. This method requires formulation of Lagrange function combined of objective function with equality and inequality constraints [7]. The flexible AC transmission system is a transmission system which use reliable high speed thyristor based high speed control elements designed based on state of the art developments in power semiconductor devices [8]. The concept of FACTS controllers was first defined by Hingorani in 1988.They are certainly playing an important and major role in the operation and control of modern power system. Facts devices are able to influence and voltages to different degrees depending on the type of device. Typically the devices are divided as shunt connected, series connected and combination of both. The TCPST is series connected device that directly affect the power flows in transmission line to improve power system operation. For OPF control TCPST is used to minimize the total generation fuel cost subject to power balance constraint, real and reactive power generation limits, voltage limits, transmission line limits and FACTS parameter limits. Location of Facts devices in the power system are obtained on the basis of static and dynamic performance [9]. This paper introduces SOL technique for finding the optimal location.

The organization of this paper is as follows. Section 2 introduces OPF without FACTS devices. Modeling of TCPST and problem formulation is described in section 3. The experimental results on the IEEE5 bus and IEEE30 bus systems are presented in section 4. Finally the conclusion and future scope are given.

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2. 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. The problem can be stated as follows.

Minimize $$F_T = \sum_{i=1}^{m} C_i\left(P_{Gi}\right) \quad \text{... (1)}$$

Subjected to $$\sum_{i=1}^{m} P_{Gi} - \sum_{k=1}^{n} P_{Dk} - P_L = 0 \quad \text{... (2)}$$

$$P_L \le P_L^{\max} \quad \text{... (3)}$$

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} \quad \text{... (4)}$$

Where n is the number of system buses and m is the number of generating units respectively. $C_i(P_{Gi})$ 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_l^{max} are the active power flow and its limit on line l.

The augmented lagrangian is,

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

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.

3. MODELING OF TCPST

The structure of a TCPST is given in Fig.1. The shunt connected transformer draws power from the network and provides it to the series connected transformer in order to introduce a voltage VT at the series branch. Compared to conventional phase shifting transformers, the mechanical tap changer is replaced by a thyristor controlled equivalent. The purpose of the TCPST is to control the power flow by shifting the transmission angle.

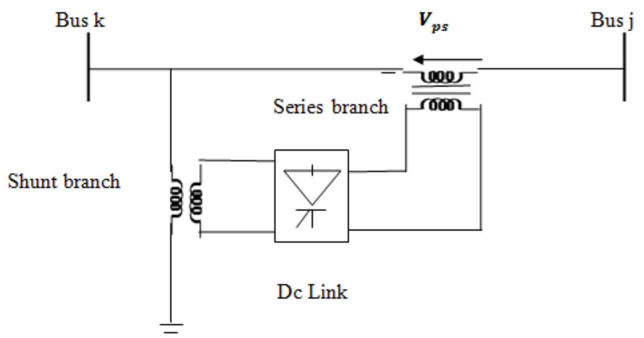

Fig.1 Structure of TCPST

A TCPST model used is given in Fig. 2 where the TCPST corresponds to a variable voltage source with a fixed angle of 90° with respect to the primary voltage. The manipulated variable is the phase shift δ which is determined by the magnitude of the inserted voltage V_{ps}.

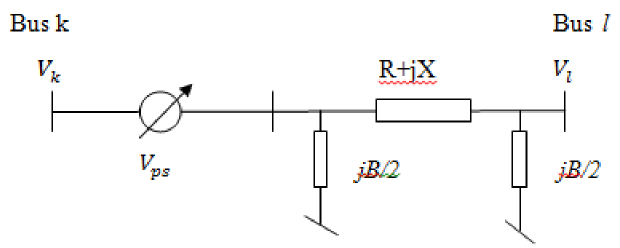

Fig.2 Basic model of TCPST

It is assumed that the device is lossless. Thus, the relationship between the primary and the secondary voltage i.e, where the magnitude of the inserted voltage is determined from the phase shift by,

$$V_k = V_k + V_T \quad \text{... (6)}$$

$$V_k e^{j\theta_k} = V_k e^{j\theta_k} + V_T e^{j\left(\theta_k - 90^0\right)} \quad \text{... (7)}$$

$$V_T = V_K \tan\delta \quad \text{... (8)}$$

The OPF uses Newton's method as its optimization engine, enabling an OPF phase-shifter model that is both flexible and robust towards convergence. It can be set to simulate a wide range of operating modes with ease. The power flow equations as provide the starting point for the derivation of the phase-shifter OPF formulation.

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$$P_k = V_k^2 G - V_k V_m [G Cos(\theta_k - \theta_m - \phi) + B Sin(\theta_k - \theta_m - \phi)] \quad \ldots (9)$$

$$Q_k = -V_k^2 B - V_k V_m [G Sin(\theta_k - \theta_m - \phi) - B Cos(\theta_k - \theta_m - \phi)] \quad \ldots (10)$$

$$P_m = V_m^2 G - V_m V_k [G Cos(\theta_m - \theta_k - \phi) + B Sin(\theta_m - \theta_k - \phi)] \quad \ldots (11)$$

$$Q_m = -V_m^2 B - V_m V_k [G Sin(\theta_k - \theta_m - \phi) + B Cos(\theta_k - \theta_m - \phi)] \quad \ldots (12)$$

Based on the circuit theory, the injection equivalent model of the phase shifter can be obtained. Then by considering the phase shifter into the transmission line the injected powers can be written as,

$$P_{ks} = -V_i^2 G_{ij} \tan^2 \phi - V_k V_l \tan\phi [G_{kl}\, Sin\delta_{kl} - B_{kl}\, Cos\,\delta_{kl}] \quad \ldots (13)$$

$$P_{ls} = -V_k V_l \tan\phi [G_{kl} Sin\delta_{kl} + B_{kl} Cos\delta_{kl}] \quad \ldots (14)$$

Hence to calculate the distribution factors, dc load flow is used. Therefore the above equations can be simplified as,

$$P_{ks} = \tan\phi\, B_{kl}\, Cos\delta_{kl} \quad \ldots (15)$$

$$P_{ks} = -\tan\phi\, B_{kl}\, Cos\,\delta_{kl} \quad \ldots (16)$$

4. OPF formulation with TCPST Lagrangian Function

The main aim of the optimization algorithm described in this chapter is to minimize the active power generation cost in the power system by adjusting suitable controllable parameters. For a phase-shifter model with phase-shifting facilities in the primary winding, the Lagrangian function may be expressed by,

$$L(x,\lambda) = f(P_g) + \lambda^t h(P_g, V, \theta, \phi_t) \quad \ldots (17)$$

In this expression, $f(P_g)$ is the objective function which is to be optimize, term $h(P_g, V, \theta, \phi_t)$ represents the power flow equations; *x* is the vector of state variables, *k* is the vector of Lagrange multipliers for equality constraints; and P_g, V, θ, and ϕ_t are the active power generation, voltage magnitude, voltage phase angle, and phase-shifter angle for tapping position *t*, respectively. The inequality constraints, $h(P_g, V, \theta, \phi_t)$<0, are not shown because they are included only when variables are outside limits. The Lagrangian function of the power flow mismatch equations at buses *k* and *m* is incorporated into the OPF formulation as an equality constraint, given by the following equation

$$L_{km}(x,\lambda) = \lambda_{pk}(P_k + P_{dk} - P_{gk}) + \lambda_{qk}(Q_k + Q_{dk} - Q_{gk}) + \lambda_{pm}(P_m + P_{dm} - P_{gm}) + \lambda_{qm}(Q_m + Q_{dm} - Q_{gm}) \quad \ldots(18)$$

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}, and Q_{gk}, Q_{gm} are the scheduled active and reactive power generations at buses *k* and *m*; and $\lambda_{pk}, \lambda_{pm}, \lambda_{qk}$ and λ_{qm} are Lagrange multipliers for active and reactive powers at buses *k* and *m*. A key function of the phase-shifting transformer is to regulate the amount of active power that flows through it, say P_{km}. In the OPF formulation this operating condition is expressed as an equality constraint, represented by the following Lagrangian function,

$$L_{flow}(x,\lambda) = L_{km}(P_{km} - P_{specified}) \quad \ldots (19)$$

In this expression, $\lambda_{flow-km}$ is the Lagrange multiplier associated with the active power flowing from bus *k* to bus *m*; $P_{specified}$ is the required amount of active power flow through the phase-shifter transformer. The overall Lagrangian function of the phase shifter, encompassing the individual contributions is,

$$L_{ps}(x,\lambda) = \lambda_{flow-km}(P_{km} - P_{specified}) \quad \ldots (20)$$

4.1 Linearized System of Equations

Representation of the phase-shifting transformer in the OPF algorithm requires that matrix W be augmented by one row and one column, with ϕ_t becoming the state variable. Furthermore, if the phase shifter is set to control active power flow then the dimension of matrix W is increased further by one row and one column. Hence, for each phase shifter involved in the OPF solution the dimension of W is increased by up to two rows and columns, depending on operational requirements. If the two-winding transformer has phase-shifting facilities in the primary winding, the linearized system of equations for minimizing the Lagrangian function using Newton's method is

$$\begin{bmatrix} W_{kk} & W_{km} & W_{k\phi} \\ W_{mk} & W_{mm} & W_{m\phi} \\ W_{\phi k} & W_{\phi m} & W_{\phi\phi} \end{bmatrix} \begin{bmatrix} \Delta z_k \\ \Delta z_m \\ \Delta z_\phi \end{bmatrix} = - \begin{bmatrix} g_k \\ g_m \\ g_\phi \end{bmatrix} \quad \ldots (21)$$

In this expression, the structure of matrix and vector terms $W_{kk}, W_{km}, W_{mk}, W_{mm}, W_{\phi k}, W_{\phi m}, W_{k\phi}, W_{m\phi}$ and $W_{\phi\phi}$ is given by Eqns. (22)–(28), respectively.

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$$W_{kk} = \begin{bmatrix} \frac{\partial^2 L}{\partial \theta_k^2} & \frac{\partial^2 L}{\partial \theta_k \partial V_k} & \frac{\partial P_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial \theta_k} \\ \frac{\partial^2 L}{\partial V_k \partial \theta_k} & \frac{\partial^2 L}{\partial \theta_k \partial V_k} & \frac{\partial P_k}{\partial V_k} & \frac{\partial Q_k}{\partial V_k} \\ \frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k}{\partial V_k} & 0 & 0 \\ \frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial V_k} & 0 & 0 \end{bmatrix} \quad \ldots (22)$$

$$W_{mk} = \begin{bmatrix} \frac{\partial^2 L}{\partial \theta_m \partial \theta_k} & \frac{\partial^2 L}{\partial \theta_m \partial V_k} & \frac{\partial P_k}{\partial \theta_m} & \frac{\partial Q_k}{\partial \theta_m} \\ \frac{\partial^2 L}{\partial V_m \partial \theta_k} & \frac{\partial^2 L}{\partial V_m \partial V_k} & \frac{\partial P_k}{\partial V_m} & \frac{\partial Q_k}{\partial V_{mk}} \\ \frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k}{\partial V_k} & 0 & 0 \\ \frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial V_k} & 0 & 0 \end{bmatrix} \quad \ldots (23)$$

$$W_{mk} = \begin{bmatrix} \frac{\partial^2 L}{\partial \theta_m{}^2} & \frac{\partial^2 L}{\partial \theta_m \partial V_m} & \frac{\partial P_m}{\partial \theta_m} & \frac{\partial Q_m}{\partial \theta_m} \\ \frac{\partial^2 L}{\partial V_m \partial \theta_m} & \frac{\partial^2 L}{\partial V_m{}^2} & \frac{\partial P_m}{\partial V_m} & \frac{\partial Q_m}{\partial V_m} \\ \frac{\partial P_m}{\partial \theta_m} & \frac{\partial P_m}{\partial V_m} & 0 & 0 \\ \frac{\partial Q_m}{\partial \theta_m} & \frac{\partial Q_m}{\partial V_m} & 0 & 0 \end{bmatrix} \quad \ldots (24)$$

$$\Delta z_k = \lfloor \Delta \theta_k \quad \Delta V_k \quad \Delta \lambda_{pk} \quad \Delta \lambda_{qk} \rfloor$$
$$\Delta z_m = \lfloor \Delta \theta_m \quad \Delta V_m \quad \Delta \lambda_{pm} \quad \Delta \lambda_{qm} \rfloor$$

$$g_k = [\Delta \theta_m \quad \Delta V_m \quad \Delta \lambda_{pk} \quad \Delta \lambda_{qk}]^t \quad \ldots (25)$$

$$g_m = [\Delta \theta_m \quad \Delta V_m \quad \Delta \lambda_{pm,} \quad \Delta \lambda_{qm}]^t$$

The additional matrix terms in Eqn. (17) reflect the contribution of $\emptyset_t$, the phase shifter state variable. These terms are given explicitly by,

$$W_{k\phi}{}^t = W_{\phi k} = \begin{bmatrix} \frac{\partial^2 L}{\partial \theta_k \partial \phi_t} & \frac{\partial^2 L}{\partial V_k \partial \phi_t} & \frac{\partial P_k}{\partial \phi_t} & \frac{\partial Q_k}{\partial \phi_t} \\ \frac{\partial^2 L}{\partial \theta_k \partial \lambda_\phi} & \frac{\partial V_k}{\partial \lambda_\phi} & 0 & 0 \end{bmatrix} \quad \ldots (26)$$

$$W_{m\phi}{}^t = W_{\phi m} = \begin{bmatrix} \frac{\partial^2 L}{\partial \theta_m \partial \phi_t} & \frac{\partial^2 L}{\partial V_m \partial \phi_t} & \frac{\partial P_m}{\partial \phi_t} & \frac{\partial Q_m}{\partial \phi_t} \\ \frac{\partial^2 L}{\partial \theta_m \partial \lambda_\phi} & \frac{\partial^2 L}{\partial V_m \partial \lambda_\phi} & 0 & 0 \end{bmatrix} \quad \ldots (27)$$

$$W_{\phi\phi} = \begin{bmatrix} \frac{\partial^2 L}{\partial_{\phi t}{}^2} & \frac{\partial^2 L}{\partial_{\phi t} \partial_{\lambda \phi}} \\ \frac{\partial^2 L}{\partial_{\lambda \phi} \partial_{\phi t}} & 0 \end{bmatrix} \quad \ldots (28)$$

$$\Delta Z_\phi = [\Delta \phi_t \quad \Delta \lambda_\phi]^t \quad \ldots (29)$$

$$g_\phi = [\Delta \phi_t \quad \Delta \lambda_\phi]^t \quad \ldots (30)$$

If the phase-shifting mechanism is on the secondary winding rather than the primary winding, the state variable ϕ_u replaces ϕ_t in Eqns. (26) – (30). It is noted that the first and second partial derivatives for the various entries in Eqn. (21) are derived from the Lagrangian function of Eqn. (17), The derivative terms corresponding to inequality constraints are entered into matrix only if limits are enforced as a result of one or more state variables having violated limits.

The procedure described by Eqns. (9) – (25) corresponds to a situation where the phase shifter is set to control active power flowing from buses k to m, which is the phase shifter standard control mode. However, in OPF solutions the phase shifter variables are normally adjusted automatically during the solution process in order to reach the best operating point of the electrical power system. In such a situation, the phase shifter is not set to control a fixed amount of active power flowing from buses k to m, and matrix W is suitably modified to reflect this operating condition.

The initial conditions given to all variables involved in the study impact significantly the convergence pattern. Experience has shown that the phase-shifter model is very robust towards convergence when the phase-shifting angle is initialized at 0^0. State variables are initialized similarly to the power flow problem (i.e.1 p.u. voltage magnitude and 0^0 voltage angle for all buses). The Lagrange multiplier for the power flow constraint, $\lambda_{flow-km}$, is set to zero. These values enable very robust iterative solutions.

4.2 Optimal setting of TCPST Parameters

The voltage angle between the sending and receiving end of the transmission line can be regulated by TCPST. It is modelled as a series compensation voltage $U_{FACTS} = \Delta U_{TCPST}$ which is perpendicular to the bus voltage i.e. $V_i \angle 90^0$. According to the model of the FACTS devices, the rated values (RV) of each FACTS device is converted into the real compensation as follows:
The working range of the TCPST is between the −5 degrees to +5 degrees.

$$\phi_{TCPST} = \text{RV} \times 5(\text{degree}) \quad \ldots (31)$$

The cost of a TCPST is more related to the operating voltage and the current rating of the circuit concerned. Thus, once the TCPST is installed, the cost is fixed and the cost function can be expressed as follows,

$$C_{TCPST} = d * P_{\max} + IC\ (RS) \quad \ldots (32)$$

where,

d is a positive constant representing the capital cost
IC is the installation costs of the TCPST.
P_{max} is the thermal limit of the transmission line where TCPST is to be installed.

The unit for generation cost is *Rs/Hour* and for the investment costs of FACTS devices are *Rs*. They must be unified into *Rs/Hour*. Normally, the FACTS devices will be in-service for many years. However, only a part of its lifetime is employed to regulate the power flow. In this proposed work, 5 years is applied to evaluate the cost function. Therefore the average value of the investment costs is calculated using the following equation

$$C_1(f) = \frac{C(f)}{8760 \times 5} \ Rs/hr \qquad \dots (33)$$

where, C (f) is the total investment costs of FACTS devices

5. 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. In the overload ranker, the SOL index is defined as,

$$SOL = \sum_{i=1}^{n} \left(\frac{Pi}{Pi,\max} \right)^2 \qquad \dots (34)$$

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 [29]-[30] is chosen to be the optimal location in the IEEE 30 bus case.

6. RESULT ANALYSIS

The IEEE *5*-bus test system is taken illustrate the use of the optimal power flow Newton– Raphson method and is also used to illustrate the use of the OPF with TCPST and associated data. Comparison of line flows in NR OPF without facts device and OPF with TCPST are given in Table 3 to Table 6.

6.1 IEEE 5- Bus Systems

Table 3: Nodal parameters for the IEEE 5 -bus system without FACTS devices

Parameters	Bus Number				
	1	2	3	4	5
Voltage magnitudes	1.1096	1.1000	1.0784	1.0779	1.0726
Phase angles	0.00	-1.33	-3.64	-3.83	-4.46
λ_p (Rs/MW/hr)	179.08	177.83	177.37.9	173.33	169.73

Table 4: Nodal voltages in the five-bus network withTCPST

(With active power flow regulation)

Parameter	Bus Number					
	1	2	3	4	5	6
Voltage magnitude (p.u.)	1.109	1.100	1.076	1.079	1.073	1.079
Phase angle (deg)	0.000	-1.193	-4.098	-3.102	-4.097	-2.705
λ_p (Rs/hr)	175.64	178.54	176.44	178.54	175.64	169.84

Table 5: Phase-shifter angles in the five-bus test system

No. of Iterations	Phase angle settings [ϕ_t (deg)]	
	(No active power control)	(Active power control)
0	0.000	0.000
1	-0.325	-1.874
2	-0.363	-2.122
3	-0.346	-2.009
4	-0.346	-2.010

Table 6: Active power generation cost without and with Facts device

Quantity	NR based OPF method Without Facts device	NR based OPF method with TCPST
Active power generation cost (Rs/hr)	34,046.325	33,674.85
Active power loss (MW)	3.55	3.03
Active power generation (MW)	168.04	168.05

6.2 IEEE 30-BUS SYSTEM

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 7: The active power and reactive power for IEEE 30 bus system

Case type	Active power loss (MW)	Reactive power loss (MVAR)
Without FACTS Device	18.58	52.73
With TCPST	18.49	46.41

Table 8: The initial and final costs of active power generation in IEEE 30 bus system

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 FACTS Device	35,000	34,046	36,900	36,765
With TCPST	35,000	33,874	36,900	35,325

From the above sections 6.1 and 6.2 it is observed that the generation cost is reduced to *680 Rs /hr* in IEEE5 bus system and *3825 Rs/hr* in IEEE30 bus system respectively when compared to TCPST, and with the base case i.e. 4.66% reduction in the active power generation cost compared to (2.76%, and 3.25%) without FACTS and with TCPST.

7. CONCLUSION

In this paper SOL technique is effectively and successfully implemented to minimize the operating cost in OPF control with TCPST. The SOL approach achieves better solutions. The thyristor firing angle, a newly introduced state variable in OPF formulations, is combined with nodal voltage magnitudes and angles of the power network in a single frame of reference unified iterative solutions via newton's method. In this firing angle, the thyristor firing angle is regulated in order to achieve an optimal level of compensation under either condition, constrained or unconstrained power flow across the compensated branch. From the above results it is evident that there will be an active power loss reduction by OPF NR method with TCPST will be 14.08 % more compared to NR OPF method and also the active power generation cost decreased by 371.475 Rs/hr by the use of TCPST. The work carried out in this paper can be extended to reduce active power loss and to improve system stability by using various FACTS devices further.

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