OPTIMAL LOCATION OF 'TCPST' FOR LINE FLOW SECURITY ENHANCEMENT USING PSO TECHNIQUE

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***Abstract*— Power system security enhancement is a major concern in the operation of power system. In this paper, the task of security enhancement is formulated as a optimization problem with minimization of fuel cost and minimization of FACTS device investment cost as objectives. Generator active power, generator bus voltage magnitude and the reactance of Thyristor Controlled Phase Shifting Transformer (TCPST) are taken as the decision variables. The probable locations of TCPST are pre-selected based on the values of Line Overload Sensitivity Index (LOSI) calculated for each branch in the system. partical swarm optimization algorithm (PSO) is applied to solve this security optimization problem. In the proposed PSO, the decision variables are represented as floating point numbers in the PSO population. The PSO emphasize non-dominated solutions and simultaneously maintains diversity in the non-dominated solutions. The proposed approach has been evaluated on the IEEE 30-bus and IEEE 6-bus test systems. Simulation results show the effectiveness of the proposed approach for solving the multi-objective security enhancement problem.**

***Keywords*— PSO, TCPST, NR, OPF, FACTS .**

I. 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 r is to know the real power allocation of generators and to find the best location of FACTS controllers such that overall system 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 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.

SCOPF [7] adjusts base case decision variables to minimize the defined objective function subject to base case and contingency state operating constraints. The solution of an SCOPF is useful for both system operation and planning. 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. 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 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 III. The results on the IEEE 6 bus and IEEE 30 bus systems are presented in section VI. Finally the conclusion and future scope are given.

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. The problem can be stated as follows.

Minimize $F_T = \sum_{i=1}^{m} Ci\ (PGi)$ (1)

Subjected to $\sum_{i=1}^{m} PGi - \sum_{k=1}^{n} PDk - P_L = 0$ (2)

$P_L \le P_L^{max}$ (3)

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

Where n is the number of system buses and m is the number of generating units respectively. Ci(PGi) is production cost of the unit at ith bus, FT is the total production cost of m generators, PGi min & PGi max are minimum and maximum active power limits of the unit at ith bus. PDk is the active power load at bus k, PL is the network active power loss, Pl, Plmax are the active power flow and its limit on line l.

III. MODELLING AND PLACEMENT 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.

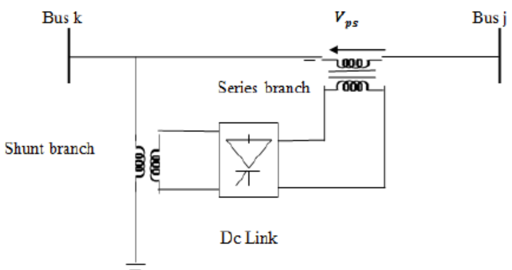

Fig.1 Structure of TCPST

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}.

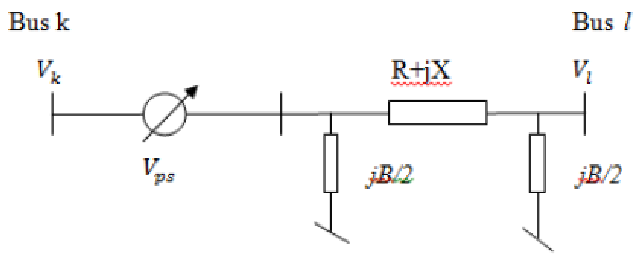

Fig.2 Basic model of TCPST

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,

$V_k = V_k + V_T$ (5)

$V_k\ e^{j} = V_k\ e^{j} + V_T\ e^{j(\theta k-}$ (6)

$V_T = V_k \tan \delta$ (7)

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.

$P_k = V_k^2 G - V_k V_m [\ G \cos(\vartheta_k - \vartheta_m - \Phi) + B\ \sin(\vartheta_k - \vartheta_m -$ (8)

$Q_k = -V_k^2 B - V_k V_m [\ G \sin(\vartheta_k - \vartheta_m - \Phi) - B\ \cos(\vartheta_k - \vartheta_m -$ (9)

$P_m = V_m^2 G - V_m V_k [\ G \cos(\vartheta_m - \vartheta_k - \Phi) + B\ \sin(\vartheta_m - \vartheta_k -$ (10)

$Q_m = -V_m^2 B - V_m V_k [\ G \sin(\vartheta_m - \vartheta_k - \Phi) - B\ \cos(\vartheta_m - \vartheta_k -$ (11)

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,

$P_{ks} = -V_i^2 G_{ij} \tan^2 \Phi - V_k V_l \tan \Phi [G_{kl} \sin \delta_{kl} - B_{kl} \cos \delta_{kl}]$ (12)

$P_{ls} = -V_k V_l \tan \Phi [G_{kl} \sin \delta_{kl} + B_{kl} \cos \delta_{kl}]$ (13)

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

$P_{ks} = \tan \Phi B_{kl} \cos \delta_{kl}$ (14)

$P_{ks} = - \tan \Phi B_{kl} \cos \delta_{kl}$ (15)

IV. Optimal setting of TCPST Parameter

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 −10 degrees to +10 degrees.

$\Phi_{TCPST} = RV \times 10(\text{degree})$ (16)

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,

$C_{TCPST} = d * P_{max} + IC\ (RS)$ (17)

where, *d* is a positive constant representing the capital cost
IC is the installation costs of the TCPST.
Pmax 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

$$C_1(f) = \frac{C(f}{8760} \quad (18)$$

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

V. Particle Swarm Optimization

Particle swarm optimization is a population based evolutionary computing technique that traces its evolution to the emergent motion of a flock of birds searching for food. It scatters random particles i.e. solutions into the problem space. These particles, called swarms, collect information from each other through their respective positions [10, 11]. The particles update their positions using their own experience and the experience of their neighbors. The update mode is termed as the velocity of particles. The position and velocity vectors of the i[th] particle of a *d*-dimensional search space can be represented as $X_i = (x_{i1}, x_{i2}, \ldots\ldots\ldots\ldots x_{id})$ and $V_i = (v_{i1}, v_{i2}, \ldots\ldots\ldots v_{id})$ respectively.

On the basis of the value of the evaluation function, the best previous position of a particle is recorded and represented as $pbest_i = (X_{t1}, X_{t2} \ldots\ldots\ldots X_{td})$. If the *gth* particle is the best among all particles in the group so far, it is represented as $pbest_g = gbest = (X_{t1}, X_{t2}, \ldots\ldots\ldots\ldots X_{td})$. Then, the new velocities and the positions of the particles for the next fitness evaluation are calculated using the following two equations:

$$v_{id}^{k+1} = C[w \times v_{id}^{k} + c_1 \times rand_1 \times (pbest_{id} - x_{id}) + c_2 \times rand_2 \times (gbest_{gd} - x_{id})] \quad (19)$$

$$x_{id}^{k+1} = x_{id} + v_{id}^{k+1} \quad (20)$$

Here *w* is the inertia weight parameter, C is constriction factor, c_1, c_2 are cognitive and social coefficients, and $rand_1$ and $rand_2$ are two separately generated uniformly distributed random numbers in the range [0, 1]. The first part of (19) known as “inertia” or “momentum” and it represents the previous velocity. The second part of (19) is termed as the "cognitive" or “memory” component and represents the personal thinking of each particle. The third part is known as the "social knowledge" component that shows the collaborative effect of the particles, in finding the global optimal solution. The social component always pulls the particles toward the global best particle found so far.

Initially, a population of particles is generated with random positions, and then random velocities are assigned to each particle. The fitness of each particle is then evaluated according to a user defined objective function. At each iteration, the velocity of each particle is calculated according to (19) and the position for the next function evaluation is updated according to (20). Each time if a particle finds a better position than the previously found best position; its location is stored in memory.

VI. Line overload severity index (LOSI) computation

To enhance the security of the system, the TCPST has to be placed at the suitable locations. To determine the best location of TCPST, an index called Line Overload Sensitivity Index (LOSI) is calculated for all the remaining lines. The $LOSI_l$ for branch “l” is defined as the sum of the normalized power flow through branch “l” to all the considered contingencies ‘C’, expressed as:

$$LOSI_l = \sum_{c=1}^{N_c} \left(\frac{S_l^c}{S_l^{max}} \right) \quad (21)$$

where S_l^c = = MVA flow in line ‘l’ during contingency “C”.

The LOSI defined at branch "l" for the base case loading is defined by $LOSI_l^{BL}$. In order to achieve optimal location of TCPST, valid under change in system loading, LOSI indices defined in (20) are also computed at an increased loading and decreased loading scenario. The increased loading scenario pertains to all the loads increased by 5% from their base values and the decreased loading scenario has been simulated with the loads decreased by 5% from their base values. The corresponding LOSI, calculated at each overloaded lines, are termed as $LOSI_l^{IL}$ and $LOSI_l^{DL}$ respectively. The optimal location of TCPST has been decided by an average line overload severity index, computed for every line, as defined in the following:

$$LOSI_l = \left(\frac{LOSI_l^{BL} + LOSI_l^{IL} + LOSI_l^{DL}}{3}\right) \quad (22)$$

The branches are ranked based on their corresponding $LOSI_l$ values. The TCPST are placed on the branches starting from the top of the ranking list and proceeding downward with as many branches as the number of available TCPST.

A. Calculation of LOSI for IEEE 6 Bus system

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

Line No.	LOSI	Ranking
7	**1.9381**	1
6	0.7753	2
3	0.4451	3

As compared the above LOSI -indices for the IEEE 5 bus system among the 3 load buses (7, 6, 3) the bus 7 is having the maximum LOS 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.

B. Calculation of LOSI for IEEE 30 Bus system

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

Line No.	LOSI of different branches	Ranking
18	**0.4249**	1
36	0.4226	2
21	0.4134	3
31	0.4120	4
35	0.4099	5

As we considered the LOS-index table of the IEEE 30 bus system there will be the 5 load buses (18, 36, 21, 31, 35) with the bus (18) 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 [28]-[36] is chosen to be the optimal location in the IEEE 30 bus case.

VII. CONCLUSION

In this paper, the security enhancement task has been formulated as a optimization problem and partical swarm optimization algorithm was applied to solve the same. The location of TCPST was identified based on Line Overload Sensitivity Index. It has considered as optimization criteria, the minimization of fuel cost and installation cost of TCPST. The algorithm has been tested on the standard IEEE 30-bus and IEEE 6-bus systems. The PSO emphasizes non-dominated solutions and simultaneously maintains diversity in the non-dominated solutions. In future, the proposed approach can be applied to solve security-constrained optimal power flow problems with multi-type FACTS devices.

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