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Assessment of Total Transfer Capability Enhancement Using Optimization Technique

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Abstract:- In this expose, a Particle Swarm Optimization (PSO) based method has been suggested to find the optimal location and setting of Thyristor Controlled Series Compensator (TCSC) for simultaneously enhancing the Total Transfer Capability (TTC) and reducing total real power losses of deregulated electricity markets. While solving multi objective OPF, various inequality constraints have been handled by penalty function. The strength of the proposed algorithm has been tested on IEEE 14 bus system. PSO gives accurate results which may be used for online TTC calculation at the energy management centre.

Keywords:- Total Transfer Capability (TTC), Active Power loss Minimization, Particle Swarm Optimization (PSO), Thyristor Controlled Series Compensator (TCSC).

I. INTRODUCTION

This article is prepared in response to a need to better understand the role of the transmission network for effective energy management. Total Transfer Capability (TTC) is defined as the amount of electric power that can be transferred from one area to another over the interconnected transmission network in a reliable manner based on pre-contingency and post-contingency conditions. In recent time, electrical supply systems of many countries have been transformed to competitive structure on the objective of increasing efficiency, reliability, stability and to reduce cost. In this new era, there should be sufficient TTC to fulfill scheduled transactions between the customers and power generators and to provide non-discriminatory open access to market participants. Large increase in power demand, competition and scare natural resources are some factors due to which transmission systems operate very near to their thermal limits. But because of economic, environmental and political reasons it is not preferable to build new transmission lines. So there is an interest in better utilization of existing capacities of power system by installing Flexible A.C. Transmission System (FACTS) device such as Thyristor Controlled Series Compensator. FACTS are the power electronics based converter-inverter circuits which can enhance TTC, voltage stability, load ability, security etc. and can reduce Active power losses or real power loss or simply called transmission loss, production cost of generation, can remove congestion and fulfill transaction requirement rapidly and efficiently. Due to the following two reasons it is necessary to “optimally” locate FACTS devices in order to obtain their full benefits. (1) They are costly devices; (2) They may have negative effects on system stability unless they are optimally placed.

It is the responsibility of the power system operator to quantify the transfer capability and to update available transfer capability (ATC) as real time index for its optimal commercial use maintaining security of the system. Various mathematical and optimization methods have been proposed to maximize TTC/ATC with and without FACTS devices. The parameters for optimisation in this paper include ATC enhancement, voltage profile improvement and active power losses reduction. The Particle Swarm Optimisation (PSO) method [4, 5 and 6] is used in this paper to solve the problem of installation and capacity allocation of FACTS devices in power transmission networks. M.Rashidinejad et al [3] proposed to locate FACTS devices to enhance ATC. So in this article, PSO based algorithm has been suggested to find the best location and setting of TCSC to maximize TTC and to minimize losses of the competitive electricity markets consisting of mutual and multi-party transactions under normal and contingency states.

In this article, we review possible ways for increasing transmission capacity, while in the final part, the emphasis is on the role of transmission capacity in the context of competitive energy management. Two basic questions are addressed, namely, (1) TTC under load Condition and (2) TTC under contingency condition.
This paper is organized as follows: Section 2 describes the modeling of TCSC. Section 3 deals with problem formulation which relates the objective function. A general idea of Mutual and Multi-party Transaction is given in section 4. Particle Swarm Optimization for proposed system is given in section 5.

Implementation steps to Enhance TTC using PSO has been explained in section 6. Results are discussed in section 7.Finally Conclusion are presented in section 8.

II. MODELING OF TCSC

As shown in below figure TCSC has been represented by a variable capacitive/inductive reactance inserted in series with the transmission line. The reactance of the transmission line can be adjusted directly by using TCSC. Let, X_{mn} is the reactance of the transmission line, Xc is the reactance of TCSC and X_{new} is the new reactance of the line after placing TCSC between bus m and n. Mathematically,

$$X_{new} = X_{mn} - X_c \qquad (1)$$

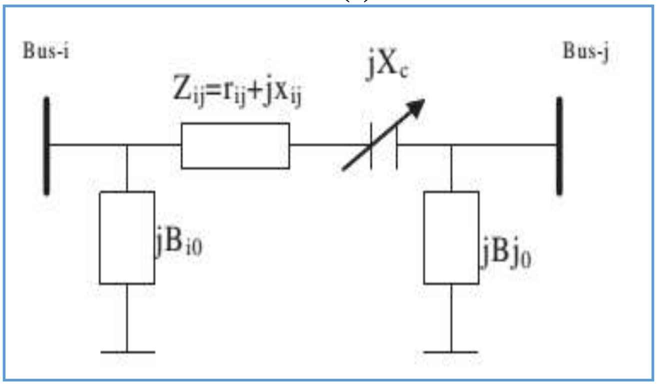


Fig.1. Equivalent circuit of line with TCSC.

The modified power flow equations of the transmission line in the presence of TCSC are given as below:

$$P_{mn} = V_m^2 G_{mn} - V_m V_n \left(G_{mn} cos\delta_{mn} \; B_{mn} sin\delta_{mn}\right) \qquad (2)$$

$$Q_{mn} = V_m^2 (B_m + \frac{B}{2}) - V_m V_n (G_{mn} sin\delta_{mn} \; B_{mn} cos\delta_{mn}) \qquad (3)$$

$$P_{mn} = V_n^2 G_{mn} - V_m V_n (G_{mn} cos\delta_{mn} - B_{mn} sin\delta_{mn}) \qquad (4)$$

$$Q_{mn} = V_n^2 (B_m + \frac{B}{2}) - V_m V_n (G_{mn} sin\delta_{mn} - B_{mn} cos\delta_{mn}) \qquad (5)$$

Where,

$$G_{mn} = \frac{R_{mn}}{R_{mn}^2 + (X_{mn} - X_c)^2}, \; B_{mn} = \frac{-(X_{mn} - X_c)}{R_{mn}^2 + (X_{mn} - X_c)^2} \qquad (6)$$

P_{mn}, Q_{mn} : Active and reactive power flow from bus m to n
P_{nm}, Q_{nm} : Active and reactive power flow from bus n to m
G_{mn} : New line conductance between bus m and n
B_{mn} : New line susceptance between bus m and n
R_{mn} : Line resistance between bus m and n

III. PROBLEM FORMULATION

A multi-objective optimal power flow is used to optimally locate TCSC for maximizing TTC and minimizing total real power loss, subject to satisfy various equality and inequality constraints. The OPF is given in (7).

$$\text{Max}\left\{K_1 \times \sum_{m=1}^{Load\ Sink} P_{Dm} - K_2 \times \sum_{r=(m,n),r\in N_L}^{N_L} (P_{mn} + P_{nm}) - PF\right\} \qquad (7)$$

Subject to the power balance equations (equality constraints)

$$\begin{cases} P_{Gm} - P_{Dm} - - \sum_{n=1}^{N_b} |V_m||V_n||Y_{mn}| \cos(\delta_m - \delta_n - \theta_{mn}) = 0 \\ Q_{Gm} - Q_{Dm} - \sum_{n=1}^{N_b} |V_m||V_n||Y_{mn}| \sin(\delta_m - \delta_n - \theta_{mn}) = 0 \end{cases} \qquad (8)$$

Various operating constraints (inequality constraints)

$$P_{Gm}^{min} \le P_{Gm} \le P_{Gm}^{max} \;, m\forall N_G \qquad (9)$$

$$Q_{Gm}^{min} \le Q_{Gm} \le Q_{Gm}^{max} \;, m\forall N_G \qquad (10)$$

$$|s1| \le S1_{max} \;, l\forall N_L \qquad (11)$$

$$V_m^{min} \le Vm \le V_m^{max} \;, m\forall N_b \qquad (12)$$

$X_C^{min} \leq X_C \leq X_C^{max}$ p.u. (13)
where,
K_1, K_2 : Constants in the range $[10^3, 10^8]$ *LOAD_SINK* : Total number of load buses in sink Area
$\sum_{M=1}^{LoAD\ SINK} PDm$: TTC value
$\sum_{r \in N_L}^{N_L} (P_{mn} + P_{nm}) = P_{Loss}$:Total real power loss of the transmission system
PF : Penalty Function
P_{Gm}, Q_{Gm} : Active and reactive power generation at bus m

P_{Gm}, Q_{Gm}: Active and reactive power demand at bus m

$|Vm| < \delta_m$: Complex voltage at bus m
$|Ymn| < \theta_{mn}$: mn^{th} element of bus admittance matrix
$P_{Gm}^{min}, P_{Gm}^{max}$: Active power generation limits at bus m
$Q_{Gm}^{min}, Q_{Gm}^{max}$: Reactive power generation limits at bus m

S_1^{max} : Thermal limit of lth transmission line
V_m^{min}, V_m^{max} : Voltage magnitude limits at bus m
X_C^{min} : Lower limit of reactance of TCSC
X_C^{min} : Upper limit of reactance of TCSC
N_L : Total number of transmission lines
$N_{\boldsymbol{b}}$: Total number of buses
N_G: Total number of generator buses
Square penalty function is used to handle inequality constraints such as reactive power output of generator buses, voltage magnitude of all buses and transmission lines thermal limits as shown below.

PF=$K_3 \times \sum_{m=1}^{N_G} f(Q_{Gm}) + K_4 \times \sum_{m=1}^{N} f(V_m) + K_5 \times \sum_{m=1}^{N_L} f(S_{lm})$
(14)

$$F(x)= \begin{cases} 0 & if\ x^{min} \leq x \leq x^{max} \\ (x - x^{\max})^2 & if\ x > x^{max} \\ (x^{min} - x)^2 & if\ x < x^{min} \end{cases}$$
(15)
Where,
K_3, K_4, K_5: Penalty coefficients for reactive power output of generator buses (Q_{Gm}), voltage magnitude (V_m) of all buses and transmission line loadingS_{im} respectively. Their values exist in the range [$10^8, 10^{10}$]
x^{min}, x^{max} : Minimum and maximum limits of variable x

IV. MUTUAL AND MULTI-PARTY TRANSACTIONS

A mutual transaction is made directly between a seller and a buyer without any third party intervention. Mathematically, each mutual transaction between a seller at bus m and buyer at bus n satisfies the following power balance relationship:

$P_{Gm} - P_{Dm} = 0$
(16)

A multi-party transaction is a trade arranged by energy brokers and involves more than two parties. It may take place between a group of sellers and a group of buyers at different nodes.

$\sum_{m \in SELLER} P_{Gm}$-$\sum_{m \in BUYER} P_{Dm} = 0$
(17)

P_{Gm} : Active power generation at bus m in a source area
P_{Dn} : Active power demand at bus n in a sink area
SELLER : A group of seller buses which sell power to the buyers
BUYER : A group of buyer buses which buy power from the sellers.

Contingency analysis has been also carried out to study the impact of severe contingencies on the value of feasible TTC.

Feasible TTC=$Min_n\{TTC_{IN}, TTC_{CON}^n\}$
(18)

Where,
TTC_{IN}: Max. power transfer in system intact
condition without considering any contingency
TTC_{CON}^n : Max. power transfer under *nth* contingency.

V. PARTICLE SWARM OPTIMIZATION

PSO is a fast, simple and efficient population-based optimization method which was proposed by Eberhart and Kennedy. It has been motivated by the behavior of organisms such as fish schooling and bird flocking. In PSO, a "Swarm" consists of number of particles which represent the possible solutions. The coordinates of each particle is associated with two vectors, namely the position (x_i) *i x* and velocity vectors(v_i). The size of both vectors is same as that of the problem space dimension. All particles in a swarm fly in the search space to explore optimal solutions. Each particle updates its position based upon its own best position, global best position among particles and its previous velocity vector according to the following equations:

$$V_i^{k+1} = w \times V_i^k + c_1 \times r_1 \times (p_{best\ i} - x_i^k) + c_2 \times r_2 \times (g_{best\ i} - x_i^k)$$
(19)

$$x_i^{k+1} = x_i^k + \chi \times v_i^{k+1}$$
(20)

Where,
v_i^{k+1}:The velocity of i^{th} particle at (K+1) iteration w : Inertia weight of the particle
V_i^k :The velocity of i^{th}particle at k^{th} iteration
c_1, c_2 : Positive constants having values between [0,2.5]
r_1, r_2: Randomly generated numbers between [0, 1]
$p_{best\ i}$: The best position of the i^{th}particle obtained based upon its own experience
$g_{best\ i}$: Global best position of the particle in the population
x_i^{k+1}: The position of i^{th} particle at (K+1) iteration
x_i^k: The position of i^{th}particle at k^{th} iteration
χ: Constriction factor It may help insure convergence. Its low value facilitates fast convergence and little exploration while high value results in slow convergence and much exploration. If no restriction is imposed on the maximum velocity (V_{max}) of the particles then there is likelihood that particles may leave the search space. So velocity of each particle is controlled between (-V_{max}) to (V_{max}).

VI. IMPLEMENTATION STEPS TO ENHANCE TTC USING PSO.

(i) Input the data of lines, generators, buses and loads. Choose population size of particles and convergence criterion. Define type of power transaction.
(ii) Select reactance setting and location of TCSC as control variables.
(iii) Randomly generate population of particles such that their variables exist in their feasible range.
(iv) Randomly install one TCSC in a transmission line and check that TCSC is not employed on the same line more than once in each iteration. Modify the bus admittance matrix.
(v) Run full A.c. Newton-Raphson load flow to get line flows, active power generations, reactive power generations, line losses and voltage magnitude of all buses.
(vi) Calculate the penalty functions of all particles using eqn. (13)
(vii) Calculate the fitness functions of all particles using eqn. (6)
(viii) Find out the "global best" particle having
maximum value of fitness function in the population and "personal best"($p_{best\ i}$)of all particles.
(ix) Generate new population using eqns. (18) and (19).
(x) Depending upon the type of power transaction increase the unit power generations at selected generator buses and increase loads at selected load buses keeping load power factor constant.

(xi) Go to step no. (iv) until maximum number of iterations are completed.
(xii) Fitness value of *best g* particle is the optimized (maximized) value of TTC and minimized value of losses. Coordinates of *best g* particle give optimal setting and location of TCSC respectively.

VII. RESULTS AND DISCUSSIONS

The performance of the proposed algorithm optimization method is tested in the medium size IEEE 14 bus system. The algorithm is implemented using MATLAB environment and a Core 2 Duo, 2.8 MHz, 2GB RAM based PC is for the simulation purpose.

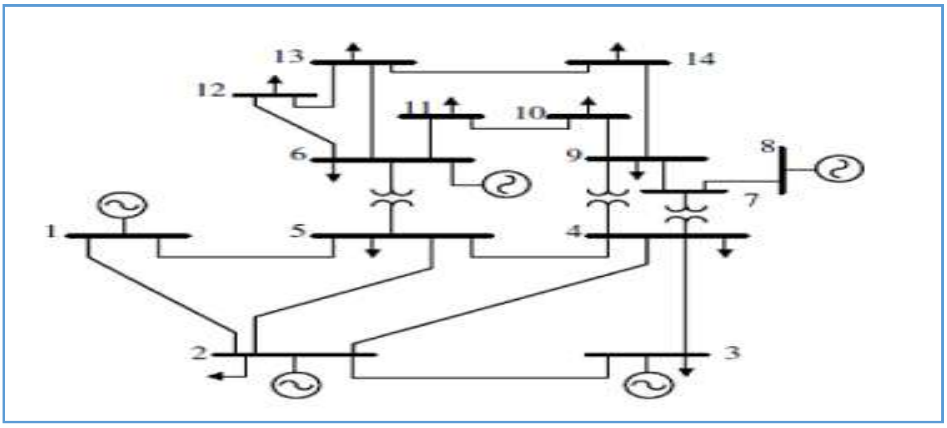


Fig.2. Single line diagram of standard IEEE 14 Bus system

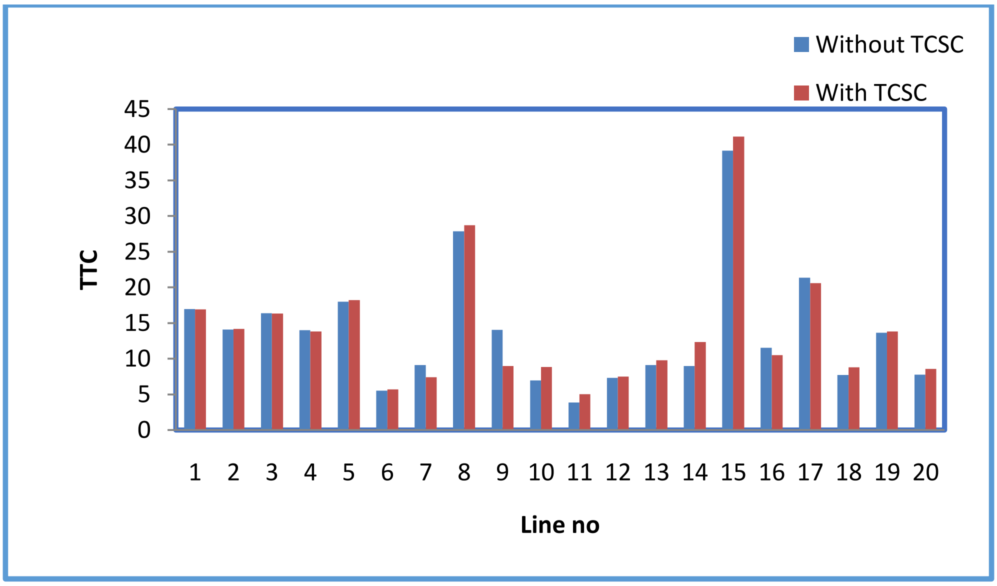
The test system taken has five generating units connected to buses 1,2,3,6 and 8. There are 3 regulating transformers connected between bus numbers 5-6, 4-7 and 4-9. The system is interconnected by 20 transmission lines to attain the objective function i.e. to maximize TTC and thereby minimizing the active power loss which enhances the power flow in the transmission line.

A. Load Condition:

Below given table shows the Total Transfer Capability at load condition with and without using of facts device. For example: Let us consider the 13th line of the table 1 which shows the value 9.122 without TCSC and with TCSC is 9.796.

Table.1. Total Transfer Capability at load condition

Line No	Without TCSC in MVA	With TCSC in MVA
1	16.95	16.901
2	14.067	14.91
3	16.364	16.322
4	13.98	13.810
5	17.999	18.236
6	5.522	5.724
7	9.0999	7.381
8	27.863	28.711
9	14.044	8.993
10	6.951	8.825
11	3.841	5.040
12	7.333	7.506
13	9.122	9.796
14	8.97	12.325
15	39.153	41.143
16	11.515	10.517
17	21.357	20.614
18	7.720	8.777
19	13.648	13.806
20	7.781	8.568

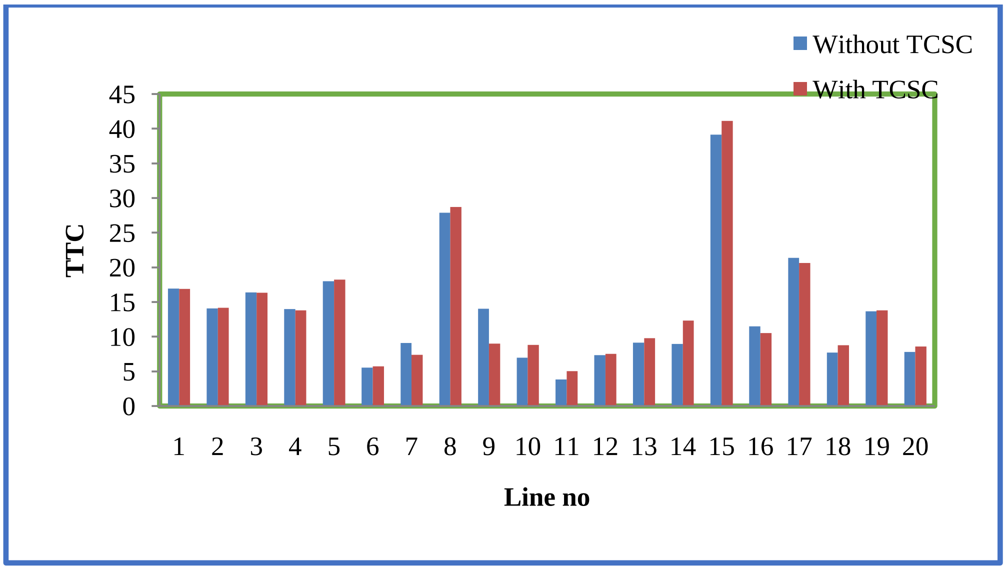


B. Contingency Condition

Following Table shows the Total Transfer Capability at Contingency condition without using the facts device is 35.783 and thereby Enhancement of Total Transfer Capability at Contingency condition after using the facts device is 40.230

Table.2. Total Transfer Capability at Contingency condition

LINE NO	WITHOUT TCSC IN MVA	WITH TCSC IN MVA
1	17.824	16.616
2	13.724	14.351
3	16.064	16.050
4	14.056	13.495
5	18.593	18.341
6	4.442	5.954
7	7.595	5.979
8	28.066	31.041
9	13.591	6.783
10	7.649	10.507
11	12.040	12.040
12	6.738	7.146
13	6.816	8.416
14	7.469	6.737
15	35.783	40.230
16	5.211	5.212
17	23.649	21.919
18	13.088	13.455
19	5.042	6.873



VIII. CONCLUSION

In this article the proposed algorithm is used to find optimal location and setting of TCSC for maximizing TTC. The paper shows step by step procedure for implementation of the Particle Swarm Optimization method to solve the problem of optimal placement of TCSC in a medium size power network. The algorithm is easy to implement and it is able to find multiple optimal solutions to this objective problem. Matlab program were performed on IEEE 14 bus system. Test results indicate that optimally placed TCSC by PSO could significantly increase TTC, under normal and contingency conditions. The paper shows that such outstanding results by enhancing power flow in transmission line which shows that the proposed optimization technique is good in dealing with power system optimization problems. Test results based on the IEEE reliability test system and a utility system illustrate the effectiveness of the TCSC.

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