Touring Ant colony Optimization technique for Optimal Power Flow incorporating Thyristor Controlled Series Compensator

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Abstract **In this work, a study about Touring And Colony Optimization (TACO) for the solution of Optimal Power Flow with the use of controllable FACTS device is done. Its proven that this method can provide an enhanced economic solution with the use of controllable FACTS devices. Thyristor controlled series compensators (TCSC) is considered in this method. In deregulated power system environment it is necessary to maintain specified power in contract transmission line path. Hence the specified power flow control, constraints due to the use of FACTS devices are included in the OPF problem. The sensitivity analysis is carried out for the location of FACTS devices. The proposed method can be considered for solving two sub-problems. The first sub-problem is a power flow control problem by incorporating TCSC in the contract path of power system network and the second sub-problem is the conventional OPF problem. The two sub-problems are simultaneously solved using Touring Ant Colony Optimization (TACO) algorithm. The solutions are compared and tested using a standard IEEE 30-bus system thereby validating feasibility of this approach.**

Keywords: Thyristor Controlled Series Compensator (TCSC), Touring Ant colony Optimization (TACO), Optimal Power Flow (OPF), Flexible AC Transmision Systems (FACTS).

1.INTRODUCTION

Deregulation of the electricity supply system becomes an important issue in many countries. Flexible AC Transmission System (FACTS) [1] devices become more commonly used as the power market becomes more competitive. They may be used to improve the transient responses of power system and can also control the power flow (both active and reactive power). The main advantages of FACTS are the ability in enhancing system flexibility and increasing the loadability. However, FACTS devices are also handicapped due to the high cost of the components.

One of the current main researches on FACTS devices is on the power flow control and economic operation such as optimal power flow (OPF). The OPF optimizes a power system operating objective function (such as the operating cost of thermal resources) while satisfying a set of system operating constraints, including constraints dictated by the electric network. OPF has been widely used in power system operation and planning.

In steady state operation of power system, unwanted loop flow and parallel power flow between utilities are problems in heavily loaded interconnected power systems. These two power flow problems are sometimes beyond the control of generators or it may cost too much with generator regulations. However, with TCSC and/or other control facilities based on power electronics components in network, the unwanted power flow can be easily regulated. Since OPF is a non-linear problem, decouple of the control parameter of the FACTS device is a highly-nonlinear problem so that non traditional technique is used as a methodology to solve.

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 is introduced by Squires [2], considerable amount of research on different optimization algorithms and solution methods have been done, especially in the recent three decades. The main existing techniques for solving the OPF problems include gradient method, Newton method, linear programming (LP), quadratic method, decomposition method, interior point method (IPM) and the latest method is Evolutionary Programming (EP) [3]. However, problems arise with the considerations of FACTS devices in OPF. The controllable parameters of TCSC cannot be added directly to those existing OPF techniques because these parameters will change the admittance matrix.

In some paper proposes an application of Genetic algorithm (GA) to solve the OPF problems with FACTS devices. Genetic algorithm was first proposed by Holland in the early 1970s and put into practical applications in the late 1980s [4]. In power systems GA have been recently applied for optimization of generation expansion planning [5], economic dispatch [6], unit commitment [7], and reactive power planning [8]. GA employs probabilistic transition rules to search the global minima in a error surface. GA is a population based algorithm (Holland, 1975) and evolves a population of solutions to the problem GA usually discovers the promising regions of search space very quickly, however it often needs too many computations to reach a local minima since the probabilistic transition rules are employed and a neighborhoods search mechanism is not used. These disadvantages of above algorithms are not desired in the power system problem.

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In the literature, there are just a few works on the models of TACO proposed for continuous optimization and their engineering applications (Wodrich, 1996; Corne et al., 1999; Hiroyasu et al., 2000). Hiroyasu et al.(2000) have presented the touring ant colony optimizations (TACO) algorithm. This paper proposes an application of touring Ant colony optimization (TACO) to solve the OPF problems with FACTS devices. Ant colony optimization (TACO) algorithm simulates the behaviour of real ant colonies. The main features of the algorithm are distributed computation, positive feedback and constructive greedy search. Therefore, the performance of TACO algorithm is good for local search due to the positive feedback and for global search because of the distribution computation features.

In this paper, a new TACO approach to solve the optimal power flow control problem with FACTS is proposed, where TCSC is used as power flow controllers. The sensitivity analysis is carried to position the TCSC in the test system [9]. TCSC can provide the necessary functional flexibility for optimal power flow control. The total generation fuel cost is used as the objective function and the operation and security limits are considered. Simulation studies are carried out in a modified IEEE 30-bus system to show the effectiveness of the method.

II.STATIC MODELING OF FACTS DEVICES

Static modeling with injected-power is a good model for FACTS devices, because it can handle load flow computation and OPF analysis efficiently.

A. Thyristor Controlled Series Compensator

The effect of TCSC on the network can be seen as a controllable reactance inserted in the related transmission line. The model of the network with TCSC is shown in Fig 2.1. The controllable reactance, x_c, is directly used as the control variable to be implemented in the power flow equation.

The power flow equations of the branch can be derived as follows:

$$P_{ij} = V_i^2 g_{ij} - V_i V_j (g_{ij} \cos\delta_{ij} + b_{ij} \sin\delta_{ij}) \quad (1)$$

$$Q_{ij} = -V_i^2 b_{ij} - V_i V_j (g_{ij} \sin\delta_{ij} - b_{ij} \cos\delta_{ij}) \quad (2)$$

Where $$g_{ij} = \frac{r_{ij}}{r_{ij} + (x_{ij} - x_c)^2}$$

$$b_{ij} = \frac{x_{ij} - x_c}{r_{ij}^2 + (x_{ij} - x_c)}$$

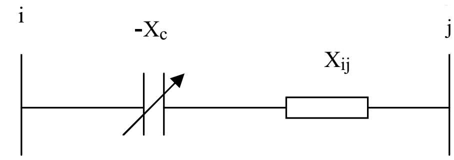

Fig. 2.1 Equivalent circuit of TCSC

Here, the only difference between normal line power flow equation and the TCSC line power flow equation is the controllable reactance x_c

III.PROBLEM FORMULATION

In this study, the optimal power flow problem has the objective of minimizing the total cost of operating the spatially separated generating units subject to the set of equations that characterize the flow of power through the system and all operational and security constraints. The TCSC reactance is included in the OPF problem. The optimal power flow problem in flexible AC transmission systems is therefore expressed as follows:

Objective function

$$\min \sum_{i \in NG} (a_i P_{gi}^2 + b_i P_{gi} + c_i) \quad (3)$$

$$stP_{g\,i} + P_{is}(\phi) - P_d - \sum ViVjYij\,(xc)^* \cos(\theta ij + \delta i - \delta j) = 0 \forall i = N \quad (4)$$

$$stQ_{g\,i} + Q_{is}(\phi) - Q_d - \sum ViVjYij\,(xc)^* Sin(\theta ij + \delta i - \delta j) = 0 \forall i = N \quad (5)$$

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \quad \forall \text{ i} \in \text{NG} \quad (6)$$

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max} \quad \forall \text{ i} \in \text{NG} \quad (7)$$

$$T_{gi}^{\min} \le T_{gi} \le T_{gi}^{\max} \quad \forall \text{ i} \in \text{NT} \quad (8)$$

$$F_{ij}^{\min} \le F_{ij} \le F_{ij}^{\max} \quad \forall \text{ i} \in \text{NB} \quad (9)$$

$$X_{ci}^{\min} \le X_i \le X_{ci}^{\max} \quad \forall \text{ i} \in \text{NP} \quad (10)$$

IV.IMPLEMENTATION OF TACO

A. TACO algorithm

TACO algorithm is the artificial version of the natural optimization process carried out by real ant colonies. If an optimization problem can be expressed in the form of a minimization problem a possible solution to this problem can be considered as a possible way between the nest and food in real ants world. In this case, the value of objective function for a solution corresponds to the length of the way followed by a real ant. Therefore, since the pheromone amount deposited on a natural way depends on its length, the objective function value can be used to determine the pheromone amount of artificial ways in the solution space of the problem.

In TACO algorithm described by Hiroyasu et al. (2000), each solution is represented by a vector of design parameters of which each is coded with a string of binary bits, i.e. a solution is a vector of binary bits. Therefore, artificial ants search for the value of each bit in the string, in other words, they try to decide whether the value of a bit is 0 or 1. In proposed method artificial ants search for the value of each bit in the string, in other words, they try to decide the values between 1and 9.

The concept of TACO algorithm is shown in Fig. 4.1. At the decision stage for the value of a bit, ants use only the pheromone information. Once an ant completes the decision process for the values of all bits in the string, it means that it has produced a solution to the problem.

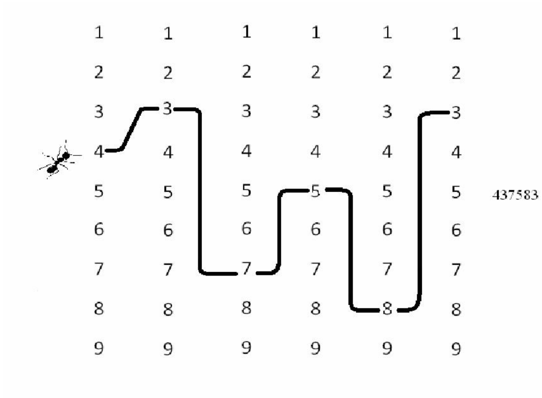

Fig. 4.1. An artificial path (solution) found by an ant.

This solution is evaluated for the problem and a numeric value showing the quality of the solution is calculated by using a function called the evaluation function. An artificial pheromone to be attached to the sub-paths forming the solution is computed using this value. After all ants in the colony have produced their solutions and the pheromone amount belonging to each solution has been calculated, the pheromones of sub paths between the bits are updated. This is carried out by lowering the previous pheromone amounts and depositing the new pheromone amount on the paths. Assume that the probability of being preferred of the sub-path between 1and 9 at a stage is calculated. Then, the following equation is used:

$$P_{ij}(t) = \frac{\tau_{ij}}{\tau_{ij} + \tau_{ii}} \qquad (11)$$

Where, P_{ij} is the probability associated with the sub-path (i-j), and τ_{ii} and τ_{ij} are the artificial pheromones of the sub-paths (i-i, i-j).

Artificial pheromone is computed by the following formula:

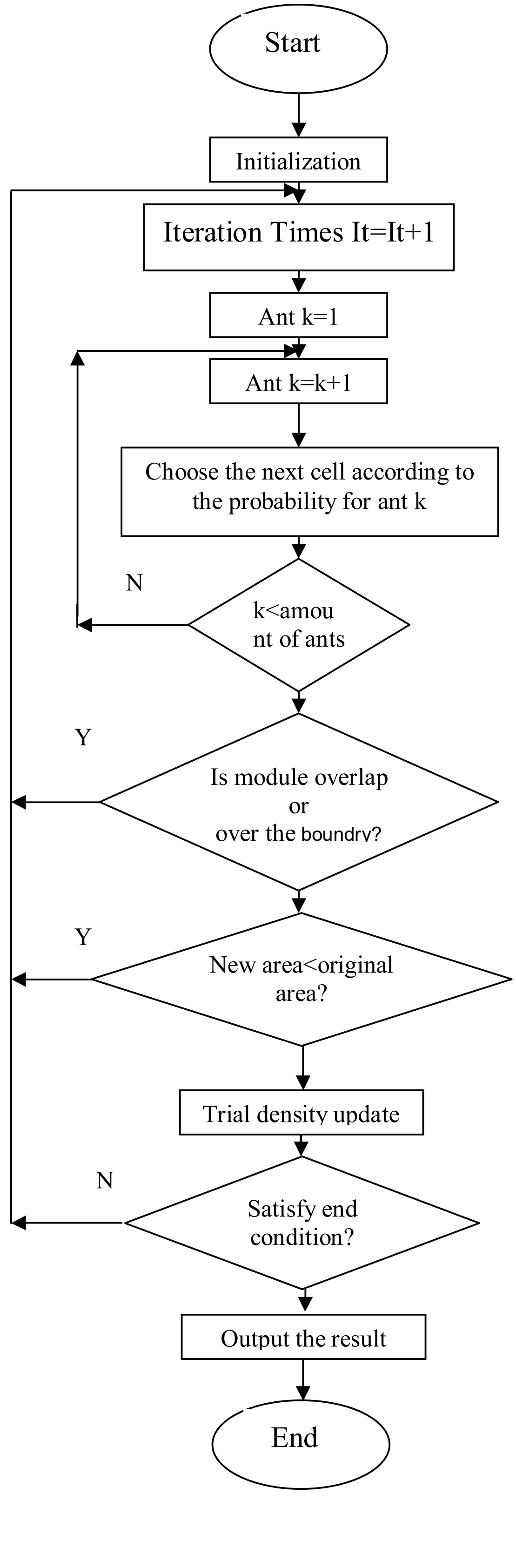

Fig. 4.2. Flow chart for TACO algorithm

$$\Delta\tau^{k}{}_{ij}(t,t+1) = \begin{cases} \dfrac{Q}{F_k} & \text{if the ant k passes the sub-path(i-j).} \\ 0 & \end{cases} \quad (12)$$

Here, $\Delta\tau^{k}_{ij}$ is the pheromone attached to the sub-path (i-j) by the artificial ant k, Q is a positive constant and Fk is the objective function value calculated using the solution found by the ant k. After M ants in the colony complete the search process and produce their solutions, the pheromone amount to be attached to the sub-path (i-j) between the time t and (t+1) is computed by

$$\Delta\tau_{ij}(t,t+1) = \sum_{k=1}^{M} \Delta\tau^{k}{}_{ij}(t,t+1) \quad (13)$$

The pheromone amount of the sub-path (i-j) at the time (t+1) is updated by the following equation:

$$\tau_{ij}(t+1) = \rho\tau ij(t) + \Delta\tau_{ij}(t,t+1) \quad (14)$$

where ρ a coefficient is called the evaporation parameter of which the value is larger than 0 and less than 1. Flow chart for above algorithm is shown in fig. 4.2

V.CASE STUDIES

In this work the standard IEEE 30-bus test system has been used to test the effectiveness of the proposed method. The generation data of the test system are shown in Table I, and the branch impedance, loads and other necessary data can be found in [10]. It has a total of 7 control variables as follows: six unit active power outputs, TCSC constraints and the reactance of the TCSC is between 0 and 0.40 (p.u).

Three cases have been studied; Case 1 is the conventional OPF without FACTS devices and (N-I) security constraints using GA. Case 2 is the conventional OPF with FACTS devices using GA. Case 3 is the conventional OPF with FACTS devices using TACO.

Table I. IEEE 30-bus system generation data

Gen No	Pmin (MW)	Pmax (MW)	Generator co-efficient		
			Alpha	Beta	Gama
1	50	200	0.00375	2	0
2	20	80	0.01750	1.75	0
5	15	50	0.06250	1	0
8	10	35	0.00834	3.25	0
11	10	20	0.02500	3	0
13	12	30	0.02500	3	0

FACTS devices the cost of OPF is 809.8457and Cost of OPF with FACTS using GA and TACO is 819.4017 and 812.2902 respectively. The results show that the generation cost has been reduced in TACO when compare to that of GA, and system the system loss also reduced. This shows the potential of the TACO algorithm. The main optimization results are listed in Table II

Table II Optimization Results

P_{Gi} (MW)	Case 1	Case 2	Case 3
P_{G1} (MW)	194.0000	186.5809	182
P_{G2} (MW)	47.9677	65.9677	51.9677
P_{G5} (MW)	15.0135	11.0135	15.0135
P_{G8} (MW)	10.0096	10.0096	12.0096
P_{G11} (MW)	16.0012	10.0012	8.0012
P_{G13} (MW)	12.0080	12.0080	16.0080
$\sum P_{Gi}$(MW	295	295	295
$\sum$PL	13.283	13.134	13.002
$\sum$cost($/hr)	809.8457	819.4017	812.2902

Two set of test runs are performed, the first using GA and the second using TACO. The FF evolution of the GA and ACO are shown in Fig.5.1 and Fig.5.2 respectively. Convergence speed of OPF with FACTS devices using TACO is much faster when compared to GA. Fig. 5.2 and 5.3 demonstrates the improvement achieved using the new algorithm.

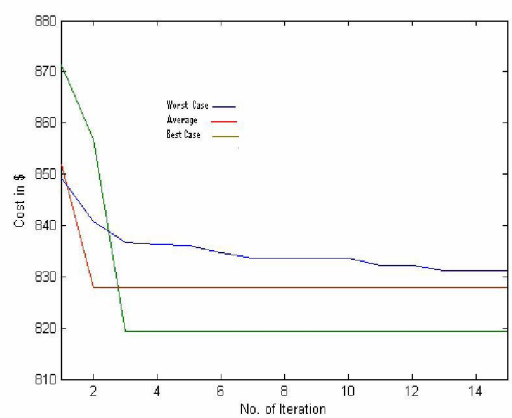

Fig. 5.1 Cost convergence graph using GA

The specified branches flow constraint values are listed in Table III

Table III. IEEE 30-bus system specified line flow data

Line flows	F6
Solution	0.4854
Specified flow	0.2500

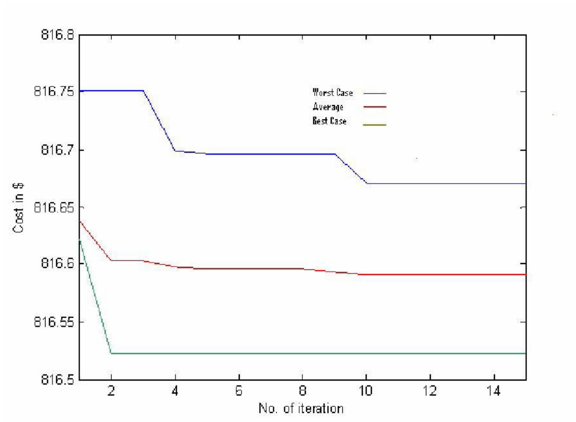

Fig. 5.2 Cost convergence graph using TACO

Along with the conventional OPF, the power through line numbers 6 has been taken as additional constraints. Sensitivity factor of TCSC for line-6 is the most negative than the other lines and hence the most suitable for the TCSC placement. The specified values of power are to be achieved by placing TCSC in line 6. Now the next step is to find the value of TCSC reactance that is needed to maintain the specified power flow.

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These values are found by using GA and TACO method, the TCSC reactance curve is shown in Fig. 5.3 and Fig 5.4. The corresponding power flows are shown on Fig 5.5 and Fig 5.6 respectively. Both the algorithms are converged at the same time but the algorithm TACO gives better result when compare to GA.

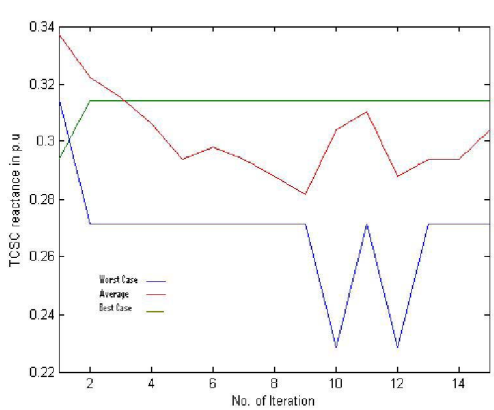

Fig.5.3.Modified IEEE 30 bus system with TCSC value in case 2

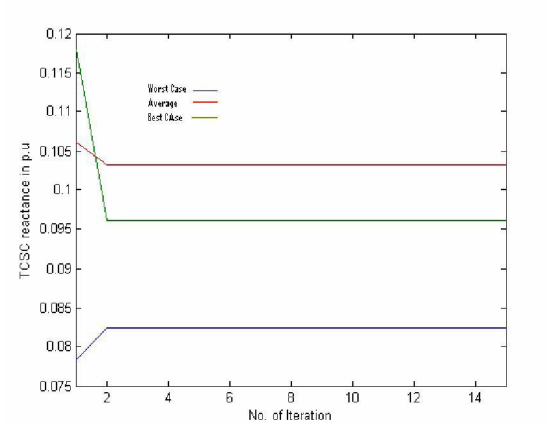

Fig.5.4.Modified IEEE 30 bus system with TCSC value in case 3

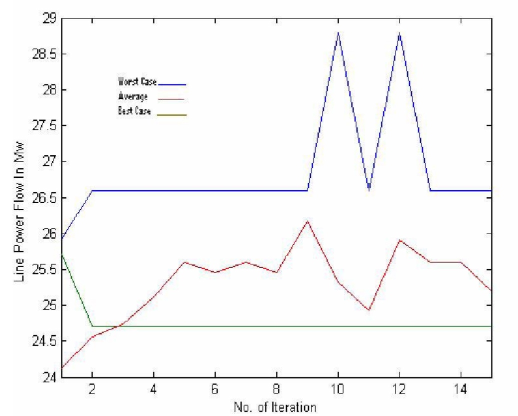

Fig.5.5.Modified IEEE 30 bus system with specified line flows in case 2

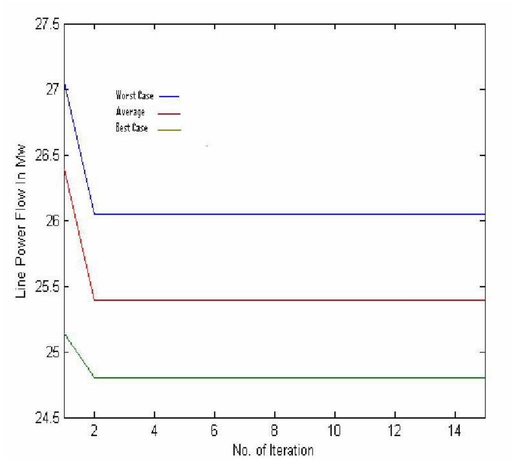

Fig.5.6.Modified IEEE 30 bus system with specified line flows in case 3

If the power flow control constraints are not some specified values but some ranges, it is possible to use the appropriate convergent threshold to achieve this. For example, suppose the power flow control value of one branch is between 0.5 to 0.6 p.u, it can be set the specified branch flow at 0.55 and set the convergent threshold at 0.05 p.u. Thus, when the problem converges, this branch power flow is between 0.5 to 0.6 p.u using this method, and fulfills different power flow control needs.

VI.CONCLUSION

In this paper, a new Touring Ant Colony Optimization method is presented to solve the optimal power flow problem of power system with flexible AC transmission systems (FACTS). The proposed method introduces the injected power model of FACTS devices into a conventional AC optimal power flow problem to exploit the new characteristic of FACTS devices. Case studies on modified IEEE test system show the potential for application of TACO to determine the control parameter of the power flow controls with FACTS. It can be shown that the FACTS device cannot reduce the generation cost (i.e. it is not a cost saving device) compared with normal system OPF. FACTS devices can increase the controllability and feasibility of the system; it can provide wider operating margin and higher voltage stability with higher reserve capacity. As deregulation and contract path is becoming more common, FACTS devices play an important role in the power system.

In this method, TACO effectively finds the optimal setting of the control parameters by using the conventional OPF method as a supplementary black box. It also shows that TACO is suited to deal with non-smooth, non-continuous, non-differentiable and non-convex problem, such as the optimal power flow problem with FACTS.

NOMENCLATURE

N = set of bus indices.
NG= set of generation bus indices.
NT = set of transformer indices.
NB = set of transmission line indices.
NP = set of TCPS indices.
NS = set of TCSC indices.
Y_{ij} and θ_{ij} = magnitude and phase angle of element in admittance matrix.
P_{Gi} and $Q_{Gi=}$ active and reactive power generations at bus i.
P_{di} and Q_{di} = active and reactive power demands at bus i.
V_i and δ_i = voltage magnitude and angle at bus i.
T_i = tapping ratio at transformer i.
I_i = current magnitude at transmission line i.
x_{ci} = reactance of TCSC i.
a_k^c = PI sensitivity factors for TCSC.

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