Synopsis

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Thesis Title: **PARTICLE SWARM OPTIMIZATION IN DEREGULATED ELECTRICAL POWER SYSTEMS**

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Since the last three decades, many electrical power utilities have been forced to change their way of operation and business, from vertically integrated (monopolistic structure) to unbundled (competitive or deregulated) market structure. The main purpose of the deregulation is to introduce competition at wholesale and retail levels in certain part of electrical power sectors. Further, it is expected to provide cheaper electricity, more choice and better service to the consumers. The vertically integrated utilities, which performed all functions of power generation, transmission, distribution and sales, are now unbundled into separate entities which devoted to each function.

Deregulation of the power sector has introduced many new technical challenges and as a result, traditional concepts and practices have been superimposed by an economic market management. Some technical challenges of the open power market are: Total transfer capability, secure bilateral transaction and congestion management. Whereas, some problems which involve economical issues are: Social welfare, active and reactive power spot price and wheeling charges. These problems are much more complex than those of a monopolistic power system.

With the open access to the transmission system by competing generators, the pattern of generations and line flow can change drastically over a few hours. Under such situations, the Independent System Operator requires more direct means of controlling the power flow. Also, large increase in power demand, competition among various market players and scare natural resources are some factors due to which transmission systems operate very near to their thermal and stability limits. But, because of economic, environmental and political reasons it may not be practical to build new transmission lines. So, there is an interest in better utilization of existing capacities of power systems by installing Flexible AC Transmission Systems (FACTS) [1] device like Thyristor Controlled Series Compensator (TCSC). FACTS are the power electronics based converter-inverter devices which can control power flow and other quantities of the power system rapidly, dynamically and efficiently.

Among the FACTS devices, TCSC is very much popular device because it can have a direct control on the power flow in the system without generation rescheduling and topological changes. So the insertion of TCSC in transmission grid may be the best alternative strategy to tackle the mentioned problems. It can enhance Total Transfer Capability (TTC), voltage stability, loadability, security etc. and can reduce active and reactive power losses, cost of generation, remove congestion and fulfill transaction requirement rapidly, dynamically and efficiently. But because of the following reasons, it is necessary to "optimally" locate TCSC in order to obtain its full benefits.

(1) It is a costly device;

(2) It may have adverse effect on system stability unless it is optimally placed [2];

(3) It may reduce profit of some market participants in deregulated power system [3];

It is revealed that with the inclusion of FACTS control variables, the "Optimal placement of FACTS devices (Optimal power flow)" becomes highly nonlinear and non-convex optimization problem. To solve such type of problems, either classical or Artificial Intelligence methods can be used. Eventhough excellent advancements have been incorporated in classical optimization methods, they still suffer with the following drawbacks: In most of the cases, mathematical formulations have to be simplified to get the solutions because of their limited capability to solve real world large scale power system problems. They are weak in handling qualitative constraints. They have poor convergence characteristic and may get stuck at local minima. They can find only a single optimized solution in a single simulation run. They become too slow if the number of variables are large so they are computationally expensive methods for solution of a large power system. To solve such complex optimization problem, various Artificial Intelligence (AI) methods can be used as they are relatively versatile for handling various qualitative constraints. They can find multiple optimal solutions in single simulation run. So they are quite suitable in solving multi-objective optimization problems. In most cases they can find optimal solution. Particle Swarm Optimization (PSO) [4] is the latest entry in the AI methods. It is a fast and simple method which can provide a global solution. PSO has shown its supremacy over other classical and AI methods.

In the deregulated electric power systems, Total Transfer Capability (TTC) analysis is currently a critical issue in planning and operating stages because of increased area interchanges among various utilities. TTC is defined as the amount of electric power that can be transferred over the interconnected transmission network in a reliable manner while meeting all of a specific set of defined pre and post contingency system conditions. So, utilities would have to determine their TTCs to maintain system reliability. TCSC can be used as an alternative to maximize TTC, minimize transmission losses and fulfill contractual requirement by controlling the power flows in the grid. Various methods for TTC determination have been reported in the literature utilizing Continuation power flow [5], repeated power flow method [6], sensitivity based approach to optimally locate FACTS devices to enhance TTC [7], sequential quadratic programming to calculate probabilistic TTC [8], hybrid evolutionary algorithm to optimally place multi-type FACTS devices to maximize TTC [9] and real genetic algorithm to optimally locate two TCSC for enhancing ATC [10]. Method of [5] required effective parametrization of predictor, corrector and step length to obtain global solution so the computational effort required became too large. It used common loading factor to increase generation and load which might result in a conservative TTC. Method of [6] did not optimize generator output power and its voltage. Ying Xiao et al. [11] used predictor corrector primal duel interior point linear programming to enhance ATC using various FACTS devices. However, they did not optimize ratings and locations of FACTS devices. The classical optimization methods [5,6,8] have been used to evaluate TTC. These methods did not give the optimal solution. AI methods [9-10] used to investigate the effect of TCSC on TTC, but those methods were quite time consuming.

Maximization of social welfare function is a main objective of a deregulated power system. It is the summation of consumer surplus, producer surplus and merchandize surplus. FACTS device like TCSC can be used to maximize social welfare. Lin et al. [12] used interior point method for system expansion with UPFC to maximize social welfare and manage congestion. but they did not optimize output power of generators and generator bus voltages. Archarya et al. [3] used sequential quadratic programming to study impact of TCSC on congestion, social welfare and spot price. But they did not optimize TCSC setting, location and its installation cost.

So, from the literature survey it is revealed that OPF problem related to maximization of social welfare has not been yet addressed out, which had also optimized TCSC setting, location and its installation cost.

Transmission pricing has been an important issue on the ongoing debate about power system deregulation. Purpose of pricing is to recover cost of transmission and encourage efficient use of investment. Verma et al. [13] used sensitivity based and sequential quadratic programming approach to study the impact of UPFC on real and reactive power spot prices and wheeling charges. Archarya et al. [3] used sequential quadratic programming to study impact of TCSC on congestion and spot price. Sharma et al. [14] used mixed integer nonlinear programming to locate UPFC to optimize secure bilateral transaction matrix for pool and bilateral electricity markets.

So, from the literature survey it is concluded that concept of spot price is attractive, because it takes into consideration all system constraints and transmission losses. So, it is fair and efficient. As, PSO can not provide Lagrange multipliers which are required for finding spot prices, an interior point method is used to calculate them. But the choice of initial starting points [15] greatly affects the quality of solution of an interior point method. It is also important to study the impact of TCSC on wheeling charges and secure bilateral transactions.

Congestion management is the most basic and the highest priority problem that the system operator has to solve very frequently. In a deregulated electricity market, congestion occurs, when transmission system is unable to accommodate all of its desired transactions due to violation of system operation constraints. Following actions are taken to relieve congestion: (1) active and reactive power rescheduling of generators(OPF based method), (2) action of phase shifting transformers, (3) use of FACTs devices and HVDC lines, (4) line switching, and (5) load shedding. In [16], Relative Electrical Distance (RED) based concept was used for real power rescheduling of generators. But, the generators with same RED would contribute same power to congested line. In this case, the cost was not optimized if both generators had different cost functions. In [17], PSO was used to minimize rescheduling cost of active power. However, the effect of rescheduling cost of reactive power and voltage stability constraints were ignored.

From literature review, it is observed that active power output of all generators were rescheduled to manage congestion. But, it is an uneconomical way to manage congestion, because all generators do not have the same effect (sensitivity) on the power flow of the congested lines. Secondly, the effect of rescheduling of reactive power of generators and voltage stability constraints had been neglected in congestion management OPF formulation.

Hence, the main objectives behind the presented work are:

- To develop Particle Swarm Optimization (PSO) based algorithm for finding the optimal location and setting of TCSC for maximizing Total Transfer Capability (TTC) and minimizing transmission line losses of the deregulated power system which consists of bilateral and multilateral transactions.

- To develop PSO based algorithm for finding the optimal location and setting of TCSC to maximize Social Welfare, minimize total generation cost and installation cost of TCSC while satisfying various constraints.

- To investigate the impact of optimally placed TCSC on transmission pricing (Spot Prices), active power and reactive power wheeling charges and secure bilateral transactions. To suggest an efficient method which can improve convergence characteristic of an Interior point method.

- To develop simple and efficient method for selecting number of participating generators for managing congestion and reactive power generator sensitivity factors (GS^k_{Qgn}) for selecting the participating generators.

- To develop PSO based algorithm to minimize active power rescheduling cost and reactive power rescheduling cost of participating generators considering voltage stability and voltage profile improvement criteria.

The thesis is organized in the following seven chapters:

Chapter 1 introduces the deregulated (restructured) electric power system, working principle of TCSC and some of the technical challenges. It represents the relevant literature survey and sets the motivation behind the research work carried out in this thesis.

In chapter 2, detailed theory of Particle Swarm Optimization (PSO) has been presented. Also, literature review of applications of PSO for solving various power system optimization problems like Economic load dispatch, Reactive power management, Optimal power flow, Power system controller design, Neural network training, Price forecasting, Load forecasting, and other areas of power system has been presented.

Chapter 3 has proposed Particle Swarm Optimization (PSO) based algorithm to find optimal location and setting of TCSC for maximizing TTC and minimizing total real power losses of the competitive electricity markets which consisted of bilateral and multilateral transactions.

Chapter 4 has suggested PSO based algorithm to find the best location and setting of TCSC to maximize Social Welfare, minimize total generation cost and installation cost of TCSC while satisfying various constraints. The results of the proposed method were compared with those of classical method (Nonlinear programming method) and Evolutionary Programming (EP) methods.

Chapter 5 has investigated the impact of optimally placed TCSC on transmission pricing (Spot Prices), active power wheeling charges and reactive power wheeling charges and secure bilateral transactions. The results of the proposed method were compared with that of Primal-Dual Interior Point method.

In chapter 6, Congestion management has been formulated as an optimization problem and solved by PSO. A sensitivity based method has been suggested for selecting number of generators which took part in managing congestion. Then PSO based algorithm has been suggested for minimizing active power rescheduling cost and reactive power rescheduling cost of the selected generators to alleviate congestion considering voltage stability (L-index) and voltage profile improvement criteria.

Chapter 7 presents the main findings of the thesis and makes few suggestions for further research work in this field.

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