CONGESTION MANAGEMENT IN DEREGULATED POWER SYSTEM USING FACTS DEVICES

A DISSERTATION

Submitted in partial fulfilment of the requirements for the award of the degree

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MASTER OF TECHNOLOGY

in

ELECTRICAL ENGINEERING

(With Specialization in Power System Engineering)

By

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CANDIDATE'S DECLARATION

I hereby declare that the work presented in this dissertation entitled **"Congestion management in deregulated power system using FACTS devices"** submitted in partial fulfillment of the requirements for the award of the degree of Master of Technology with specialization in Power System Engineering in the Department of Electrical Engineering, Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out from July 2004 to June 2005 under the guidance of **Dr. N.P.Padhy**, Assistant Professor, Department of Electrical Engineering, Indian Institute of Technology Roorkee, Roorkee and **Dr. R.N.Patel,** lecturer, Department of Electrical Engineering, Indian Institute of Technology Roorkee, Roorkee.

I have not submitted the matter embodied in this report for the award of any other degree or diploma.

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CERTIFICATE

This is to certify that the above statement made by the candidate is true to the best of my knowledge and belief.

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ABSTRACT

From the last two decades the vertically integrated power system is undergoing the deregulation due to which the consumer will ultimately get benefited. However, deregulated power system confronts few technical problems. Congestion in the transmission lines is a critical one of such problems.

Congestion in the transmission lines can be relieved and/or reduced by cost free and non-cost free methods. One of the cost free techniques is installing FACTS devices into the system. FACTS devices have a great flexibility that can control the active power, reactive power and voltage simultaneously. TCSCs and UPFCs are two emerging devices which can relieve the congestion in the transmission lines efficiently.

In this dissertation, an efficient and reliable congestion management algorithm is developed using genetic algorithm. Congestion will be relieved by installing TCSCs and/or UPFCs into the system, but such devices are costlier. Hence it is required to find the optimal locations for FACTS devices. Using genetic algorithm optimal locations will be obtained globally. To validate the performance of the proposed algorithm, IEEE30 bus system with multiple FACTS has been used. The algorithm is found to be robust and independent of number and type of devices.

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CHAPTER-1

INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

Electric power utilities throughout the world are currently undergoing major restructuring process and are adapting the deregulated market operation. Competition has been introduced in the power system around the world based on the idea that it will increase the efficiency of this industrial sector and reduce the cost of electrical energy for all consume Electrical energy is not, a simple commodity unlike other forms of energy; it cannot be easily stored in large quantities. Continuity of supply has been a value that can be much higher than the cost of energy consumed. Overview of the technology of power system competition provides a solid basis upon which workable and durable solutions can be developed for the problems created by the introduction of electricity markets. For integrated operation of such systems, regulating agencies such as pool operator or system operator are created and the open market of electricity is introduced with the help of either separate power exchange or the system/ pool operators themselves. In deregulated environment producers and consumers sell and buy electric energy through transactions. In a market these transactions, done ahead of time and when implemented may cause the electric power network to become congested. The power system deregulation is expected to offer the benefit of lower electricity price through competition, better consumer service and improved system efficiency. However, it poses several technical challenges with respect to its conceptualization and integrated operation. Basic issues of insuring economic, secure and stable operation of the power system, while delivering power at desired quality in terms of voltage magnitude and frequency, have to be addressed carefully in deregulated market which are likely to become more complex as compared to the earlier regulated monopolistic situation.

At the transmission level, primary service is to move the power from production point to the point of consumer. Therefore, establishment of rules for operating the transmission network (technical issues) and for pricing transmission services (economic issues) is the real challenge. This task is highly complex since the technical and economic issues are intermingled with political and legal issues.

The restructuring of the electric power industry has involved paradigm shifts in the real-time control activities of the power grids. Managing dispatch is one of the important control activities in a power system. Optimal power flow (OPF) has perhaps been the most significant technique for obtaining minimum cost generation patterns in a power system with existing transmission and operational constraints. The role of an independent system operator in a competitive market environment would be to facilitate the complete dispatch of the power that gets contracted among the market playe With the trend of an increasing number of bilateral contracts being signed for electricity market trades, the possibility of insufficient resources leading to network congestion may be unavoidable. But, power system elements all over the world have been forced to operate in almost their full capacities due to the environmental and/or economical constraints to build new generation centers and transmission lines. The amount of electric power that can be transmitted between two locations through a transmission network is limited by security constraints. Power flows should not be allowed to increase a limit at which the network to collapse due to angular instability, voltages instability or cascaded outages. The system is said to be congested when such a limit is reached.

In this scenario, congestion management (with an OPF framework) becomes an important issue. Real-time transmission congestion can be defined as the operating condition in which there is not enough transmission capability to implement all the traded transactions simultaneously due to some unexpected contingencies or unexpected loads thrown by consume It (unexpected load) may involve redispatch of generation or load curtailment. Scheduled patterns of generation might results in heavy flows tend to incur greater losses and threaten stability and security and thus, ultimately make certain generation patterns economically undesirable. Hence, there is a need of better utilization of available power system capacities by installing new type of thyristor-based controllers which provide high speed of response. Because of the fast response of these devices, the system becomes more flexible. Hence these devices are called Flexible AC Transmission systems (FACTS) devices. FACTS are the name given to the application of power electronics devices to control line flows and other quantities in the power system.

1.2 OBJECTIVE OF THE WORK

In this work we seek to develop an OPF solution using genetic algorithm. N-R load flow solution incorporating FACTS (TCSC, UPFC) is also developed. FACTS devices assume importance in the context of power system restructuring since they can expand the usage potential of transmission systems by controlling power flows in the network. FACTS devices are operated in a manner so as to ensure that the contractual requirements are fulfilled as far as possible by minimizing line congestion.

In literature various optimization techniques have been used to solve OPF problems. These may be classified as sequential, quadratic, linear, nonlinear, integer and dynamic programming methods, Newton-based methods, interior point methods, etc. But all above methods have limitations like getting local optimal values, requirement of differential equations of objective function. Above limitations can overcome by using heuristic approach methods. Genetic algorithm (GA) is one of the heuristic approach methods and it is used for the OPF framework.

The objective of this work is:

- To solve the OPF using Genetic algorithm and get the generation schedule.
- To get the line flows in all lines with the generation schedule obtained from OPF.
- If one or more line congested then,
    - To select a suitable mathematical model of a TCSC, UPFC.
    - To get the optimal locations for TCSC, UPFC using GA.
- By placing TCSC, UPFC at optimal location perform the load flow solutions using N-R load flow method.

1.3 AUTHOR'S CONTRIBUTION:

The contribution of the author is as follows;

- Developed a program to solve the OPF using GA keeping in view of quadratic cost functions.
- Developed a program to find the optimal location and optimal parameters for TCSC, UPFC using GA.

1.4 LITERATURE REVIEW

1.4.1. Congestion management with OPF

Over the past two decades, many countries have begun to restructure the electric utility industry in favor of the free market. In South America, after the deregulation of power market in the early 1990's there is transformation in the market scenario and gave good results in terms of efficiency, power output and power quality due to competition among generators [1]. Tabors [2] article discusses the merits and demerits of deregulation in UK and Norway and the difference in market structure of two countries.

Power system operation poses greatest challenge in the deregulated power market. An approach to the optimal power dispatch problem in a structure dominated by bilateral and multilateral transactions has been proposed by David and Fang [3] While dispatching the contracted powers if some lines violate the MVA limits, one method to ensure the system security is to enhance the power carrying capacity of lines using FACTS devices, through which congestion is eliminated to some extent [4].

Different methods, for managing the transmission congestion, are implemented around the world. The paper by Christie et al. [5] discusses these various models in detail, like

1. Optimal power flow model found in various implementations in UK, parts of USA
2. The point tariff, price area congestion control model used in the nordpool market area in Norway and Sweden.
3. The transaction based model, which is implemented in the most parts of the US

Each model has its own strengths and flaws. Each maintains system security but differs in its impacts on economics on energy market.

In a market environment where pool and bilateral/multilateral dispatches coexist pool, bilateral and multilateral dispatch coordination is explored and the mathematic models are developed for each case [6]. David and Fang [7] proposed on the prioritization of electricity transactions and a mechanism for coordination between market participants to achieve additional economic advantages.

Harry Singh et al. [8] suggested methods to manage costs associated with the transmission constraints. Those are nodal pricing framework for pool model and cost allocation procedures proposed for the bilateral model.

To optimize the operating cost of thermal resources Bakirtzis et al [9] presented a simple genetic algorithm and enhanced genetic algorithm. Chung et al. [10, 11] presented genetic algorithm and hybrid genetic algorithm methods to solve the OPF incorporating FACT devices. Bhasaputra et al. [12] proposed a hybrid tabu search and simulated annealing approach to minimize the generator fuel cost in OPF control with multi type of FACTS devices.

1.4.2. FACTS Devices

The basic idea about the FACTS devices have been given in the books by Hingorani et al [13], and Song et al. [14]. A Detailed Explanation has been given for all the FACTS devices. Gyugyi [15] gives the concept of unified power flow control (UPFC) and its versatility to control almost all the parameters in the system. Gyugyi et al. [16] presents the control behavior of UPFC and relation between real and reactive power flowing between the lines in which UPFC is connected.

1.4.3. Load flows with Facts devices

The induction of FACTS devices increases the complexity of system and hence the problem arises in the analysis of the system. Acha et al. [17] proposes the Power injection modeling model of the UPFC and TCSC for the load flow studies. In [18] authors presented load flow solutions with embedded FACT devices and in [19] authors presented UPFC injection model in load flow problems.

1.4.3. Optimal locations for FACTS devices

FACTS devices are expensive hence to install them optimally, there are many papers presented in literature. Stephane Gerbex et al. [20] presented genetic algorithm to seek the optimal location of multi-type FACTS devices in power systems. Locations of FACTS devices in power system are obtained on the basis of static and dynamic performance. S.N Singh et al. [21, 22] proposed the injection modeling of FACTS devoices to find the sensitivity analysis to minimize line loss indices. TCSC and TCPAR have been considered as FACTS devices. Verma et al. [24] extended the work proposed in [21] to find injection model of UPFC and find system loss indices to optimally place the UPFC in the system.

1.5 REPORT ORGANIZATION

The first chapter of this dissertation presents the introduction, objective of the work, author's contribution and literature review.

In chapter 2, congestion definition and its effect on the total cost is illustrated with an example. And it also provides an idea of congestion management methodologies.

Chapter 3 presents an overview of genetic algorithm (GA) and acceleration techniques applications.

In chapter 4, the algorithm for optimal power flow solution using GA will be discussed.

In chapter 5, the static model of UPFC and TCSC. And also modified N-R method to incorporate UPFC & TCSC has been presented.

In chapter 6, an algorithm to find the optimal locations for TCSC, UPFC using genetic algorithm is discussed.

Chapter 7 gives the observed results on modified IEEE30 bus system.

Chapter 8 gives conclusions and identifies the scope for future research.

CHAPTER-2

CONGESTION PROBLEM IN DEREGULATED ENVIRONMENT

2.1 INTRODUCTION

In this chapter, we look at the problem of congestion and how it is relieved in regulated and deregulated framework of electricity power markets. A simple example is given for illustrating the line congestion and its effect on the total cost.

2.2 WHAT IS MEANT BY CONGESTION?

Normal condition: The normal condition is when all pool demand and all bilateral and multilateral transactions are dispatched without system security violations. All these transactions will be serviced at their desired value and the Independent System Operator (ISO) only needs to optimize pool dispatch and ancillary services.

The condition where overloads in transmission lines or transformers occur is called congestion. When the producers and consumers of electric energy desire to produce and consume in amounts that would cause the transmission system to operate at or beyond one or more transfer limits, the system is said to be congested. Congestion management, that is, controlling the transmission system so that transfer limits are observed, is perhaps the fundamental transmission management problem. Congestion could prevent system operators from dispatching additional power from a specific generator. Congestion could be caused for various reasons, such as transmission line outages, generator outages, changes in energy demand and uncoordinated transactions. Congestion may result in preventing new contracts, infeasibility in existing and new contracts, additional outages, and monopoly of prices in some regions of power systems and damages to system components. Congestion may be prevented to some extent by means of reservations, rights and congestion pricing.

Congestion is a term that has come to power systems from economics in conjunction with deregulation, although congestion was present in power systems before deregulation. There it was discussed in terms of steady-state security, and the basic objective was to control generator output so that the system remained secure at the lowest cost. When dealing with power flow within its operating area, one entity, the vertically integrated utility, controlled both generation and transmission, gained economically from lower generation costs, and was responsible or the consequences and expected costs when less secure operation resulted in power outages. Conflicts between security and economics could be traded off within one decision-making entity.

2.3 VERTICALLY INTEGRATED OPERATION

The unbundling of the electric power market has led to the evolution of new organizational structures. *Unbundling* implies opening to competition those tasks that are, in a vertically integrated structure, coordinated jointly with the objective of minimizing the total costs of operating the utility. In such a traditional organizational structure, all the control functions, like automatic generation control (AGC), state estimation, generation dispatch, unit commitment, etc., are carried out by an energy management system. Generation is dispatched in a manner that realizes the most economic overall solution. In such an environment, an optimal power flow can perform the dual function of minimizing production costs and of avoiding congestion in a least-cost manner. Congestion management thus involves determining a generation pattern that does not violate the line flow limits. Line flow capacity constraints, when incorporated in the scheduling program, lead to increased marginal costs. This may then be used as an economic signal for rescheduling generation or, in the case of recurring congestion, for installation of new generation/transmission facilities.

2.4 UNBUNDLED OPERATION

In a competitive power market scenario, besides generation, loads, and line flows, contracts between trading entities also comprise the system decision variables. The following pool and bilateral competitive structures for the electricity market have evolved/are evolving:

(1) Single auction power pools, where wholesale sellers (competitive generators) bid to supply power in to a single pool. Load serving entities (LSEs or buyers) then buy wholesale power from that pool at a regulated price and resell it to the retail loads.

(2) Double auction power pools, where the sellers put in their bids in a single pool and the buyers then compete with their offers to buy wholesale power from the pool and then resell it to the retail loads.

(3) In addition to combinations of (1) and (2), bilateral wholesale contracts between the wholesale generators and the LSEs without third-party intervention.

(4) Multilateral contracts, i.e., purchase and sale agreements between several sellers and buyers, possibly with the intervention of third parties such as forward contractors or broke In both (3) and (4) the price-quantity trades are up to the market participants to decide, and not the ISO. The role of the ISO in such a scenario is to maintain system security and carry out congestion management.

The contracts, thus determined by the market conditions, are among the system inputs that drive the power system. The transactions resulting from such contracts may be treated as sets of power injections and extractions at the seller and buyer buses, respectively.

In the deregulated power system the challenge of congestion management for ISO is to create a set of rules that ensure sufficient control over producers and consumers to maintain and acceptable level of power system security and reliability in both the short term and long term while maximizing market efficiency. The rules must be robust, because there will be many aggressive entities seeking to exploit congestion to create market power and increased profits for themselves at the expense of market efficiency. The rules should also be fair in how they affect participant, and they should be transparent, that is, it should be clear to all participants why a particular outcome has occurred. The form of congestion management is dependent on the form of energy market, and congestion management itself cannot be separated from market consideration.

The performance of a market is measured by its social welfare. Social welfare is a combination of the cost of the energy and the benefit of the energy to society as measured by society's willingness to pay for it. If the demand for energy is assumed to be independent of price, that is, if demand has zero price elasticity, then the social welfare is simply the negative of the total amount of money paid for energy. The perfect market has maximum social welfare. Real markets always operate at lower levels of social welfare. The difference in social welfare between a perfect market and a real market is a measure of the efficiency of the real market. The conditions required for perfect competition are:

1. There are a large number of generators, each producing the same product.
2. Each generator attempts to maximize its profits;

3. Each generator is a price taker, it cannot change the market price by changing its bid;
4. Market prices are known to all generators;
5. Transmissions are costless.

When a generator is a price taker, it can be shown that maximizing its profit requires bidding its incremental costs. When a generator bids other than its incremental costs, in an effort to exploit imperfections in the market to increase profits, its behavior is called strategic bidding. If the generator can successfully increase its profits by strategic bidding or by any means other than lowering its costs, it is said to have market power. The obvious example of market power is a non regulated monopoly with zero elasticity where the generator can ask whatever price it wants for electric energy. Market power results in market inefficiency.

There are many possible causes of market power, among them one is congestion. Consider a simple example of a two node system connected by a transmission line, shown in fig 2.1. Let each node have a 100MW constant load. At node A and node B had 200MW generation with an incremental cost of 10$/MWh and 20$/MWh respectively.

If there is no transfer limit between zones, all 200MW of load will be bought from generator A at 10$/MWh, at a cost of 2000$/h as shown in Fig.2.1 (a). If there is a 50MW transfer limit, then 150MW will be bought from A at 10/MWh and the remaining 50MW must be bought from generator B at 20$/MWh, a total cost of 2500$/h. Congestion has created a market inefficiency of 25% of the optimal costs, even without strategic behavior by the generators.

Congestion has also created unlimited market power for generator B. B can increase its bid as much as it wants, because the loads(at node 2) must still buy 50MW from it. Generator B's market power would be limited if there was an additional generator at node B with a lower incremental cost, or if the loads had nonzero price elasticity and reduced their energy purchase as prices increased. In the real power system, cases of both limited and unlimited market power due to congestion can occur. Unlimited market power is probably not socially tolerable.

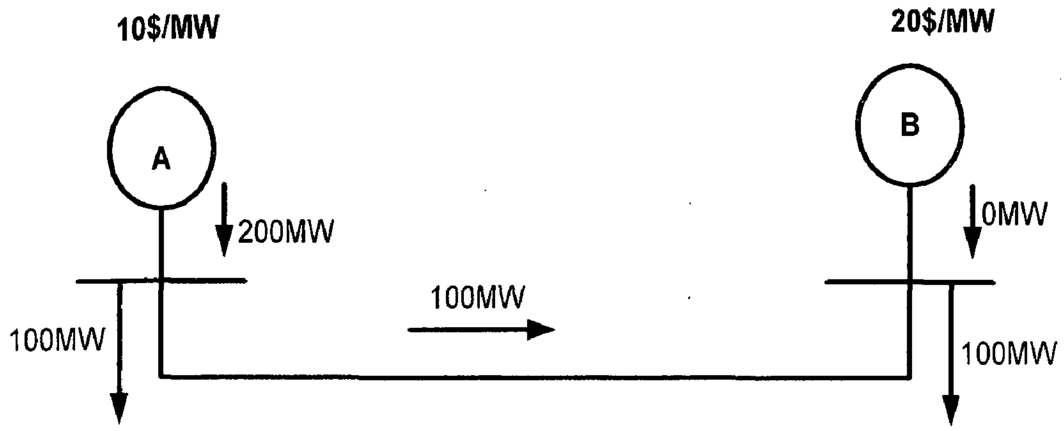

Fig.2.1(a) No congestion

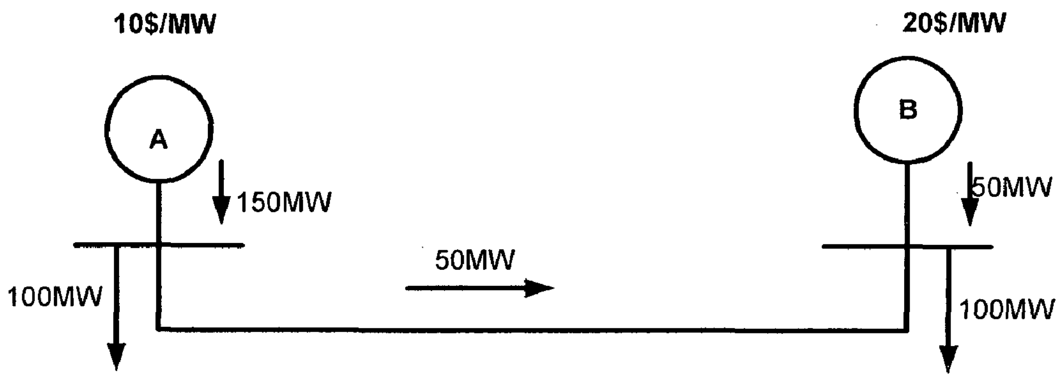

Fig.2.1(b) With 50MW transfer limit congestion

The creation of market inefficiency due to congestion in an otherwise perfect market is not a bad thing, as the cost of market inefficiency can be traded off against the cost of improving the transmission system and thus serves as an economic signal for transmission reinforcement. Even the creation of limited market power can be viewed in this framework. However, unlimited market power, and market power arising from factors other than congestion or the number of generators in a congested zone, such as loopholes in market rules, exploitation of technical parameters, or conflict of interest, does not provide useful economic signals.

2.5 CONGESTION MANAGEMENT METHODOLOGIES

There are two broad paradigms that may be employed for congestion management. These are the *cost-free* means and the *not-cost-free* means. The former include actions like out aging of congested lines or operation of transformer taps, phase shifters, or FACTS devices. These means are termed as *cost-free* only because the marginal costs (and not the capital costs) involved in their usage are nominal. The *non-cost-free* means include:

(1) Rescheduling generation. This leads to generation operation at an equilibrium point away from the one determined by equal incremental costs. Mathematical models of pricing tools may be incorporated in the dispatch framework and the corresponding cost signals obtained. These cost signals may be used for congestion pricing and as indicators to the market participants to rearrange their power injections/extractions such that congestion is avoided.

(2) Prioritization and curtailment of loads/transactions. A parameter termed as *willingness-to-pay-to-avoid-curtailment* is an effective instrument in setting the transaction curtailment strategies which may then be incorporated in the optimal power flow framework.

In this dissertation work congestion is relieved with cost-free method specially using FACTS (TCSC, UPFC) devices. Because of the fast response of these (FACTS) devices, the controlling becomes more flexible. Hence these devices are called Flexible AC Transmission systems (FACTS) devices. Flexible AC Transmission system (FACTS) is the name given to the application of power electronics devices to control flows and other quantities in power system. Facts devices provide new control facilities, both under steady state power flow control and Dynamic state. The possibility of controlling power flow in an electric power system without generation rescheduling or topological changes can solve the problems of planning engineers to much extent and improve the system performance considerably.

CHAPTER-3

CONGESTION MANAGEMENT WITH OPTIMAL POWER FLOW FRAME WORK

3.1 INTRODUCTION

The Optimal Power Flow (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 constrains dictated by the electric network. OPF has been widely used in power system operation and planning. After the electricity sector restructuring, OPF has been used to assess the spatial variation of electricity prices and as a congestion management and pricing tool.

In its most general formulation, the OPF is a nonlinear, non-convex, large-scale, static optimization problem with both continuous and discrete control variables. Even in the absence of non-convex unit operating cost functions, unit prohibited operating zones, and discrete control variables, the OPF problem is non-convex due to the existence of the nonlinear (AC) power flow equality constraints. The presence of discrete control variables, such as switchable shunt devices, transformer tap positions, and phase shifters, further complicates the problem solutions.

The literature on OPF is vast, mathematical programming approaches such as nonlinear programming (NLP), quadratic programming (QP), and linear programming (LP) have been used for the solution of the OPF problem. Some methods, instead of solving the original problem, solve the problem's Karush-Kuhn Tucker (KKT) optimality conditions. For equality-constrained optimization problems, the KKT conditions are a set of nonlinear equations, which can be solved using a Newton-type algorithm. In Newton OPF the inequality constraints are added as quadratic penalty terms to the problem objective function, multiplied by appropriate penalty multiplie Interior point (IP) methods, convert the inequality constraints to equalities by the introduction of nonnegative slack variables. A logarithmic barrier function of the slack variables is then added to the objective function, multiplied by a barrier parameter, which is gradually reduced to zero during the solution process. The unlimited point algorithm uses a transformation of the slack and dual variables of the inequality constraints which converts the OPF problem KKT conditions to a set of nonlinear equations, thus avoiding the heuristic rules for barrier parameter reduction required by IP methods.

OPF programs based on mathematical programming approaches are used daily to solve very large OPF problems. However, they are not guaranteed to converge to the global optimum of the general non-convex OPF problem, although there exists some empirical evidence on the uniqueness of the OPF solution within the domain of interest. To avoid the prohibitive computational requirements of mixed-integer programming, discrete control variables are initially treated as continuous and post-processing discretization logic is subsequently applied. Whereas the effects of discretization on load tap changing transformers are small and usually negligible, the rounding of switchable shunt devices may lead to voltage infeasibility, especially when the discrete VAR steps are large, and requires special logic. The handling of non-convex OPF objective functions, as well as the unit prohibited operating zones, also present problems to mathematical programming OPF approaches.

Recent attempts to overcome the limitation of the classical mathematical programming approaches include the application of simulated annealing-type methods, and genetic algorithms.

3.2 PROBLEM FORMULATION FOR CONGESTION MANAGEMENT

The basic principle for the transmission congestion management could be illustrated with the help of the traditional spot pricing theory. In this framework, the central dispatcher optimally dispatches the generators such that the total social welfare is maximized while satisfying the operation and security related constraints. Specifically, the dispatcher solves the following optimization problem to maximize the social welfare.

$$\min \left(\sum_{i=1}^{N_G} C_{G_i}(P_{G_i}) - \sum_{i=1}^{N_D} B_{D_i}(P_{D_i})\right) \tag{3.1}$$

Subjected to:

$$P_{gi} - P_{di} = \sum_{j=1}^{N_B} |V_i||V_j||Y_{ij}|\cos(\delta_i - \delta_j - \theta_{ij}) \tag{3.2}$$

$$Q_{gi} - Q_{di} = \sum_{j=1}^{N_B} |V_i||V_j||Y_{ij}| \sin(\delta_i - \delta_j - \theta_{ij}) \tag{3.3}$$

$$\begin{aligned} P_{gi,\min} \le P_{gi} \le P_{gi,\max} \\ Q_{gi,\min} \le Q_{gi} \le Q_{gi,\max} \end{aligned} \tag{3.4}$$

$$\begin{aligned} P_{di,\min} \le P_{di} \le P_{di,\max} \\ Q_{di,\min} \le Q_{di} \le Q_{di,\max} \end{aligned} \tag{3.5}$$

$$V_{i,\min} \le V_i \le V_{i,\max} \tag{3.6}$$

$$T_{ij} \ge 0 \tag{3.7}$$

In the objective function $C_{G_i}(P_{G_i})$ is cost function for generating real power P_{Gi} at bus-*i* And $B_{D_i}(P_{D_i})$ is the demand function. T_{ij} is the bilateral transaction between supplier at node i and consumer at node j.

By solving above optimization problem the generation schedule can be obtained and by with this schedule we can find line flows. And then check whether all line flows are within the maximum limits are not, if any (one or more) of line flow exceeds the limit that line is said to be congested and it has to be relieved as quickly as possible. This task will be discussed in following chapte

Above optimization problem can be solved using classical optimization techniques and heuristic search methods. But classical optimization techniques posses their own limitations; heuristic search methods can overcome such limitations. Genetic algorithm is one of them and it is used to solve the above problem which will be discussed in the next chapter.

CHAPTER-4

GENETIC ALGORITHM AND ACCELERATION TECHNIQUES

4.1 INTRODUCTION

Genetic algorithm is a powerful, domain-independent search technique that was inspired by Charles Darwin's "species evolution theory". As the name suggests, it emulates the natural process of evolution to perform an efficient and systematic search of the solution space to progress toward the optimum. It is based mainly on the theory of *natural selection*, which dictates that individuals with certain characteristics or *fitness* are more likely to survive, and hence pass on their characteristics to their offsprings. Genetic algorithms are simulated with the idea of a virtual *population*, which is made up of a collection of *individuals*. The individuals are actually the solutions, encoded as strings. These strings represent points in the search space.

In each iteration, referred to as a *generation*, a new set of strings called *offsprings* are created by *reproduction*. Occasionally new characteristics are injected to the existing individuals to add diversity, and in such cases, the individual is said to have undergone *crossover and mutation*. At the end of each generation, the fitness level of the individuals and the offsprings are evaluated, and those that are deemed to be less fit will be discarded. In turn, the offsprings that has high fitness levels will take their place and represent new solutions.

Genetic algorithms are very different from other search algorithms, and the main characteristics of GA that make them different from other search heuristics are listed below:

They work with coding of parameters: GAs work with a coding of the parameter set, not the parameters themselves. Therefore, one requirement when employing GAs to solve a combinatorial optimization problem is to find an efficient representation of the solution in the form of a chromosome (encoding string).

They search from a set of points: Simulated annealing or tabu search moves from a single point in the search space, using some transition rule, to the next point. This type of point to point movement most often causes trapping in local optima. In contrast, GAs simultaneously works from a rich collection of points (a population of solutions).

Therefore, the probability of getting trapped in the false valleys (in case of minimization problem) is reduced.

They only require objective function values: GAs are not limited by assumptions about the search space (such as continuity, existence of derivatives, etc.), and they do not need or use any auxiliary information. To perform an effective search for better and better structures, they only require objective (cost) function values.

They are non-deterministic: GAs are probabilistic transition rules, not deterministic rules. Mechanism for choice of parents to produce offsprings or for combining of genes in various chromosomes are probabilistic.

They are blind: They are blind in the sense that they do not know when they hit the optimum, and therefore they must be told when to stop.

4.2 WHY GENETIC ALGORITHM?

The real world of search is filled with discontinuities and large multi-modal, noisy search spaces. Traditional methods of search and optimization are too slow in finding a solution in a very complex search space, even when implemented in supercomputers, and are not robust enough since they are local in scope and the optima they seek are the best in a neighborhood of the current point. Genetic algorithm, on the other hand, is a robust and effective search method requiring little information to search effectively in a large or poorly understood search space. Due to the nature that GAs goes through reproduction and mutation, they are able to produce offsprings that have a significant chance of inheriting the best characteristics of both parents, and have a higher fitness value. Thus, making GAs independent of the initial selection of the configurations, and is always able to produce high quality solutions. In addition to it, GAs are computationally simple and easy to implement.

The above-mentioned advantages of genetic algorithm are summarized below in a concise manner:

- GA do not have much mathematical requirements about the optimization problems. Due to their evolutionary nature, genetic algorithms will search for solutions without regard to the specific inner workings of the problem. GAs can handle any kind of objective functions and any kind of constraint (i.e. linear or non-linear) defined on discrete, continuous, or mixed search spaces.

- The nature of evolution operators makes GA very effective at performing global search (in probability). The traditional approaches perform local search by a convergent stepwise procedure, which compares the values of nearby points and moves to the relative optimal points. Global optimization can be found only if the problem possesses certain convexity properties that essentially guarantee that any local optima, is a global optima.
- GA provides us a great flexibility to hybridize with domain-dependent heuristics to make an efficient implementation for a specific problem.

4.3 GENETIC ALGORITHM TERMINOLOGY

Population: It is a group of *individuals*, which may interact together, for example by mating and producing *offsprings*. An initial population constructor or generator is generally required to generate a certain predefined number of solutions within the prescribed limits. The quality of the final solution produced by a GA depends on the size of the population, the limits selected and how the initial population is constructed. The initial population is generally comprises of random solutions that were generated.

Chromosomes: Is the structure that encodes how the organism is to be constructed. Each member of the population may be associated with one or more chromosomes. Chromosomes usually contain information about the solution, which it is to represents. The most common way of encoding chromosomes is usually in a binary string. An example of how a pair of binary chromosomes will look like is shown below, and binary chromosomes would be used for all subsequent illustrations, as they are easier to represent and understand.

- Chromosome 1: 1101100100110110
- Chromosome 2: 1101111000011110

The complete set of chromosomes is called a *genotype*, and the resulting organism is called a *phenotype*. Similarly, the representation of a solution to the optimization problem in the form of an encoded string is termed as a *chromosome*. In most combinatorial optimization problems, a single chromosome is generally sufficient to represent a solution, that is, the genotype and the chromosome are the same. The symbols that make up a chromosome are known as *genes*. The different values a gene can take are called *alleles*.

Fitness: The fitness value of an *individual* (genotype or a chromosome) is a positive number that is a measure of its goodness. It is a value assigned to an individual, which reflects how well the individual solves the task in hand. When the chromosome represents a solution to the combinatorial optimization problem, the fitness value indicates the cost of the solution. In the case of a minimization problem, solutions with lower cost correspond to individuals that are more fit.

Reproduction: Is the creation of new *individuals* from selected parent/s. Common GA reproduction operators are *crossover* and *mutation*. They are derived by analogy from the biological process of evolution. When the crossover operator is applied to a pair of chromosomes, the two individuals selected are called *parents*. Mutation is a genetic operator that is applied to a single chromosome. The resulting individuals produced when genetic operators are applied on the parents are termed as *offsprings*. The selection of the parents is usually done probabilistically in proportion to their fitness level, in hope that the offsprings produced would inherit the best of both parents and attain a higher fitness level. This selection of chromosomes for reproduction is sometimes carried out using the roulette wheel method. The wheel shown in fig 4.1 is divided into sectors of different size.

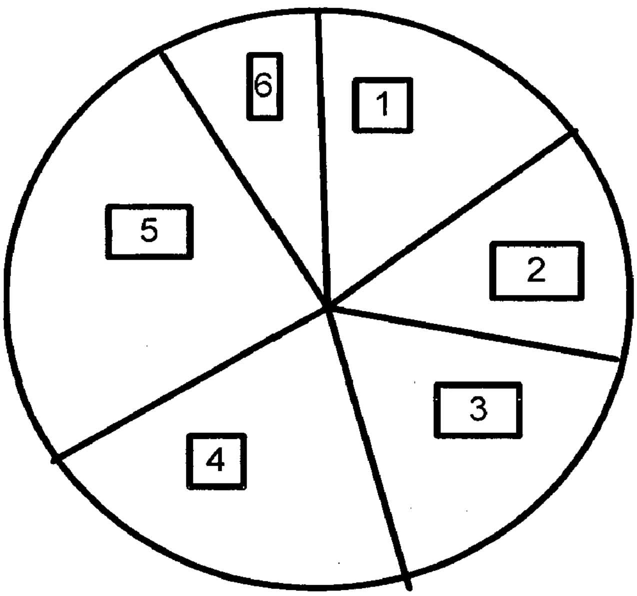

Fig 4.1 Roulette Wheel Selection

The fitness level of the individual in each sector determines the size of the sector. Technically, the higher the fitness levels of the individual, the larger the sector size, in proportion to the rest of the wheel. In concept, to select a parent, the wheel is spun, and whichever individual comes up becomes the selected parent. Therefore, in this method, individuals with lower fitness values also have a finite but lower probability of being selected for reproduction.

Crossover: Is the main genetic operator used for reproduction, and it allows the offsprings to inherit the characteristics of both the parents. The offsprings formed do not always inherit the best of its parents, but children formed with poor fitness generally do not last long. There are several crossover operators, which can be selected depending on the combinatorial optimization problem being solved. Some are more effective than othe The simple crossover method illustrated below uses the "cut-catenate" (single-point crossover operation. It consists of choosing a random cut point and dividing each of the two chromosomes into two parts. The offspring is then generated by catenating the segment of one parent to the left of the cut point with the segment of the second parent to the right of the cut point, as shown below.

- Chromosome 1**: 11011 | 00100110110**
- Chromosome 2: 11011 | 11000011110
- Offspring 1: **11011** | 11000011110
- Offspring 2: 11011 **| 00100110110**

Mutation: Is the occasional random alteration of an offspring from two individuals, by randomly changing allele values of some genes. In the case of binary chromosomes, it corresponds to changing single bit positions. It is not performed on all members of the population, but only probabilistically on some. When used sparingly with reproduction and crossover, mutation protects against premature loss of important notions, in the case when the offspring looses some of the good features of its parent. For instance during crossover, when the offspring inherits the worst feature of its parent, mutation may alter the bad feature/s inherited by the offspring to that that is beneficial, and increases its chances of survival. An example of mutation, shown using binary chromosomes is shown on the following page.

- Original offspring 1: 1101111000011110
- Original offspring 2: 1101100100110110
- Mutated offspring 1: 1100111000011110
- Mutated offspring 2: 1101101100110100

Elitism: Elitism (or an elitist strategy) is a mechanism, which is employed in some Genetic Algorithm to ensure that the chromosomes of the most highly fit member(s) of the population are passed on to the next generation without being altered by genetic operato Using elitism ensures that the maximum fitness of the population can never be reduced from one generation to the next. Elitism usually brings about a more rapid convergence of the population. In some applications elitism improves the chances of locating an optimal individual, while in others it reduces it.

Generation: Is an iteration of the measurement of *fitness* and the creation of a new *population* by means of reproduction operato Because of the addition of offsprings, the size of the population increases. In order to keep the number of the members in a population fixed, a constant number of individuals are selected from this set, which consists of both the individuals of the initial population, and the generated offsprings. Those that possess higher fitness values are selected and those that have lower values are discarded.

4.4 BRIEF OUTLINE OF GENETIC ALGORITHM

The skeletal outline of the genetic algorithm is as illustrated below.

1. **[Start]** Generate random population of n chromosomes.
2. **[Fitness]** Evaluate the fitness $f(x)$ of each chromosome x in the population.
3. **[New population]** Create a new population by repeating following steps until the new population is complete.
   - **[Selection]** Select two parent chromosomes from a population according to their fitness level.
   - **[Crossover]** With a crossover probability cross over the parents to form a new offspring. If no crossover was performed (elitism), offspring is an exact copy of parents.

- **[Mutation]** With a mutation probability mutate new offsprings at each locus.
- **[Accepting]** Place new offspring in a new population depending on their fitness level.

4. **[Replace]** Use new population (parent and offsprings) for a further run of algorithm.
5. **[Test]** If optimum has been achieved, stop and display results.
6. **[Loop]** Else, go to Step 2.

4.5 LIMITATIONS OF GENETIC ALGORITHM

This section presents the limitations of genetic algorithm. As stated earlier in the report in section 4.2, genetic algorithms are blind, as in they do not know it when they hit the optimum, and therefore, they must be told when to stop. This is also the main limit of GA, the stopping criterion, as it is hard to determine if the GA has converged enough. The difficulty is to decide if it is better to observe the mean performance, the best performance, or the number of global iterations and stop when a threshold is reached. Furthermore, it is also difficult to select a method for computing the final solution of the optimization problem. Whether is it better to consider the best chromosome, to use a mean of the best elements arguing that a population is more representative than a stand-alone individual, or is it better to choose a hybrid solution?

4.6 TERMINATION OF THE GA

The stopping criteria in GA will any one of the following two conditions:

(1). the maximum number of generations is achieved.

(2). When the genotype of the population of individuals converges, the convergences of the genotype structure occur when all bit positions in all string are identical. In this case, crossover will have no further effect.

CHAPTER-5

ROLE OF FACT DEVICES IN DEREGULATED POWER SYSTEM

5.1 INRODUCTION

Flexible AC Transmission System (FACTS) is defined by IEEE as: "Alternating current transmission systems incorporating power electronic-based and other static controllers to enhance controllability and increase power transfer capability".

The deregulation process has turned the electric utility inside out. At the heart of restructuring is the need for competition in the trading of electric energy as a commodity. But that by itself is not enough. In addition to an adequate transmission and distribution infrastructure that can accommodate free trading of this commodity, it is also necessary to maintain balance between ever-changing load and generation, stability, voltage and frequency within the defined bounds and cope with various outages.

Since we could not afford to have a fully competitive T&D infrastructure, restructuring of transmission and distribution entities is taking place in a variety of different forms. The key issue for transmission is the rules that motivate or dictate needed investments in transmission. The bottom line is to maximize the value of transmission assets and ensure adequate and timely investment in transmission.

As a result of recent environmental legislation, rights of way issues, increase in construction cost and deregulation policies, there is an increasing recognition of the necessity to utilize existing transmission system assets to the maximum extent possible which can be achieved with the help of FACTS devices. The flexible ac transmission system is the result of related developments in electronic devices designed to overcome the limitations of traditional mechanically controlled power transmission systems. By using reliable, high-speed electronic controllers, the technology offers opportunity for increased efficiency. Some advantages which FACTS devices can offer are;

- Greater control of power, so that it flows on prescribed transmission routes.
- Secure loading of transmission lines to level nearer their thermal limits.
- Greater ability of transfer between controlled areas.
- Prevention of cascading outages.

- Damping of power system oscillations.

The active power transmitted over an ac transmission line is defined by the eqn.5.1

$$P = \frac{V_1 V_2}{X} \sin(\delta_1 - \delta_2) \tag{5.1}$$

Where, V_1 and V_2 are the voltages at the ends of the transmission line. X is the Equivalent impedance of the transmission line, and δ_1 -δ_2 is the phase angle difference between both ends of transmission line. From the eqn.5.1 it is evident that the transmitted power is a function of three parameters: the magnitude of sending end voltage and receiving end voltage, impedance and voltage angle difference. Traditional techniques of reactive power line compensation and voltage adjustment are generally used to alter these parameters to achieve power transmission control. Different type of facts devices can be used to control one or more of these parameters to control the existing power system network. The fast response of FACTS devices improves the controllability of the system and thus makes the system more versatile.

5.2 ROLE OF FACTS DEVICES IN POWER SYSTEM

FACTS devices play an important role in enhancing performances of power system. Some are given below:

(1) FACTS devices by controlling power, can improve the power system performance considerably such as improvement of power quality and security of the supply. FACTS technology can contain cascading outages by limiting the impact of multiple faults, thereby improving the reliability of power supply. Upgrading of transmission lines can increase power quality by increasing voltage and/or current capacity with the help of these devices.

(2) The "free flow" mode of power system operation may be changed into a controlled power flow mode of operation due to powerful controllability of FACTS technology. Where the power flow in one or more transmission lines is controlled in predetermined manner.

(3) FACTS technology can increase secure loading of transmission lines their steady state, short time and dynamic limits. Thus it enhances Transient, voltage and small signal stability of power system.

(4) Due to high capital cost of high voltage transmission, cost considerations are main concerns. Although the price of FACTS devices is high, compared to other methods of solving transmission loading problem, yet FACTS technology is probably the most viable resort because of their ability to effectively control power flows, the power system can be

operated in more optimized situation. As a result, large amount of money may be saved. Also, as people pay more and more attention to the environmental impact of new projects. Thus, it becomes very common for environmental opposition to frustrate attempts to established new transmission routes. Using FACTS technology, however, it is possible to transfer more power over existing routes, thus meeting consumer demand without the construction of new transmission lines. Although FACTS devices themselves need some places to be constructed, compared to the high voltage transmission line, the total environmental improvement is obvious.

(5) The static performance of power system can be improved significantly with these devices leading to losses reduction, Security enhancement, congestion management and available transfer capability enhancement.

5.3 BASIC TYPES OF FACTS CONTROLLERS

In this context, FACTS technology has been rapidly developed in the last ten yea The first FACTS device is Static Var Compensation (SVC) and has been in service for nearly last two decades. It is a shunt device to maintain a healthy voltage profile in system. TCSC, TCSR are series controllers used to control line flows. Three Thyristor Controlled Series Compensation (TCSC) projects have been working successfully in USA since 1991. In general, FACTS controller can be divided into four categories, the general symbols for which is shown in Fig.5.1-Fig.5.4.

- Series Controller
- Shunt Controller
- Combined series-series Controller
- Combined series-shunt controller

Series controllers

The series controller could be variable impedance, such as capacitor, reactor, etc or power electronics based variable source of main frequency, sub synchronous and harmonic frequencies (or a combination) to serve the desired need. In principle, all series controller inject voltage in series with the line. Even variable impedance multiplied by the current flow through it represents an injected series voltage in the line. As long as the voltage is in phase quadrature with the line current, the series controller only supplies or consumes variable reactive power. Any other phase relationship will involve handling of real power as well. Common type or series FACTS controllers, which are generally used, are:

- **Static synchronous series compensator(SSSC)**
- **Interline power flow controllers(IPFC)**
- **Thyristors controlled series capacitor(TCSC)**
- **Thyristor switched series capacitor(TSSC)**
- **Thyristor switched series reactor (TSSR)**
- **Thyristor controlled series reactor(TCSR)**

Shunt controller

As in the case of series controller, the shunt controllers may be variable impedance, variable source, or a combination of these. In principle, all shunt controllers inject current into the system at the point of connection. Even variable shunt impedance connected to line causes a variable current flow and hence represents injection of current into the line .as long as the injected current is in phase quadrature with the line voltage, the shunt controller only supplies or consumes variable reactive power. Any other phase relationship will involve handling of real power as well. The common type of shunt controllers in use are:

- **Static Synchronous Compensator(STATCOM)**
- **Static Synchronous Generator(SSG)**
- **Static VAR Compensator(SVC)**
- **Thyristor Controlled Reactor(TCR)**
- **Thyristor Switched Reactor(TSR)**
- **Thyristor Switched Capacitor(TSC)**
- **Thyristor Controlled Breaking Resistor (TCBR)**

Combined series-series controllers

This could be a combination of separate series controllers, which are controlled in a coordinated manner, in a multi-line system or it could be a unified controller in which series controllers provide independent series reactive compensation for each line but also transfer real power among the lines via the power link. The real power transfer capability of the unified series-series controller, referred to as interlink power flow controller, makes it possible to balance both the real and reactive power flow in the lines and thereby maximize the utilization of the transmission system. Note that the term 'unified' here means that the dc terminals of all controller converters are connected together through real power transfer link.

Combined series-shunt controllers

This could be a combination of separate shunt and series controllers, which are controlled in a coordinated manner or a unified power flow controller with series and shunt elements. In principle, combined shunt and series controllers inject current into the system with the shunt part of the controller. However, when the shunt and series controllers are unified, there can be a real power exchange between the series and shunt controllers via the power link. Common types of these controllers are:

- **Unified Power Flow Controller(UPFC)**
- **Thyristor Controlled Phase Shifting Transformer(TCPST)**
- **Inter-phase Power Controller(IPC)**

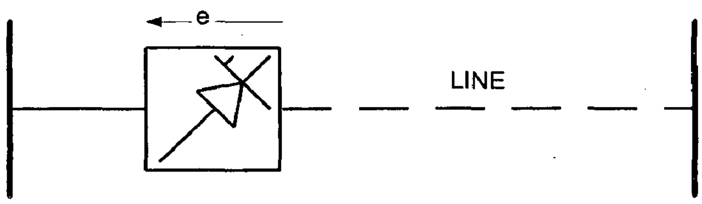

Fig.5.1 Series controllers

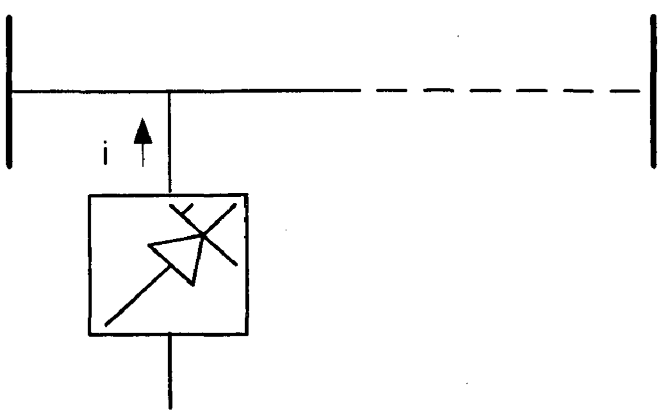

Fig.5.2 Shunt controller

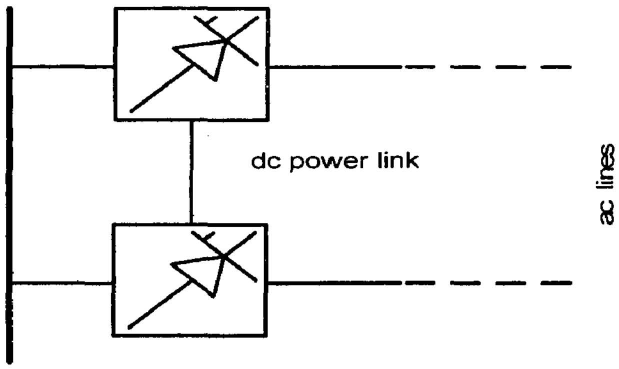

Fig.5.3 Unified series-series controller

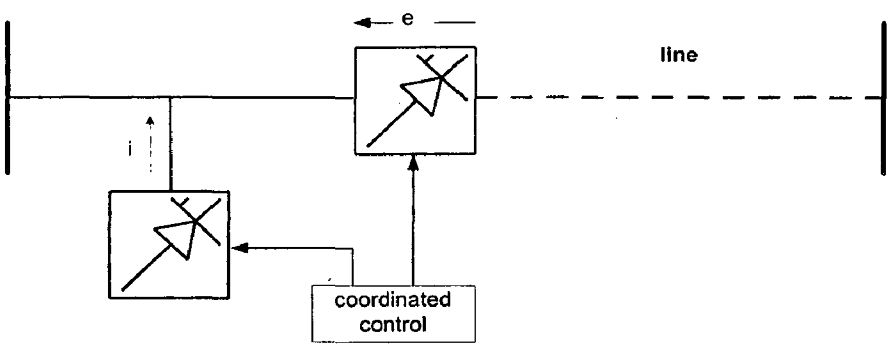

Fig.5.4 Coordinated series and shunt controller

The different FACTs devices are helpful in controlling different parameters effectively. Generally the FACTS devices with both series and shunt controllers are most versatile devices. The implementation of any of the new FACTS controllers is not an easy task. Although they offer substantial advantages for steady state and dynamic operation by controlling the power flow in the transmission line, it brings major challenges in power electronics, device control and protection design which involves huge cost and efforts.

CHAPTER-6

STATIC MODELING OF TCSC AND UPFC

6.1 INTRODUCTION

The thyristor controlled series compensator (TCSC) and unified power flow controller (UPFC) are the most comprehensive devices have emanated so far from the FACTS initiative. In principle at least, the former one offers simple principle which is controlling the line overall inductance and the later one offers new horizons in terms of power system control, with the potential to independently control three power system parameters namely bus voltage, line active and reactive power. The simplest TCSC consist of a converter connected in series with transmission lines in a substation. It controls the active power flow in the line. The simplest UPFC consist of two converters one connected in shunt and one connected in series with transmission lines in a substation. It can control three quantities such as a bus voltage and independent active and reactive power flow of the line. The real power is exchanged among shunt and series converters via a common DC link. From the literature it is found that unified power flow controllers are very powerful and can give flexible and effective power flow control in power system. Their modeling and incorporation in load flow and optimal power flow is very much required.

6.2 THYRISTOR CONTROLLED SERIES CAPACITOR (TCSC)

Series capacitors are used to partially offset the effects of the series inductances of lines. Series compensation results in the improvement of the maximum power transmission capacity of the line. The net effect is a lower load angle for given power transmission level and, therefore, a higher stability margin. The reactive power absorption of a line depends on the transmission current, so when series capacitors are employed, automatically the resulting reactive power compensation is adjusted proportionately. Also, because the series compensation effectively reduces the overall line reactance, it is expected that the net line voltage drop would become less susceptible to the loading conditions

6.2.1 Operation principle of TCSC

TCSC consist of the series compensating capacitor shunted by a thyristor controlled reactor. The basic idea behind the TCSC scheme is to provide a continuously variable capacitor by means of partially canceling the effective compensating capacitance by the TCR. TCR at the fundamental system frequency is continuously variable reactive impedance, controllable by delay angle; the steady state impedance of the TCSC is that of a parallel LC circuit, consisting of fixed capacitive impedance, X_C, and variable inductive impedance, $X_L(\alpha)$. Let consider TCSC as shown in Fig.6.1.

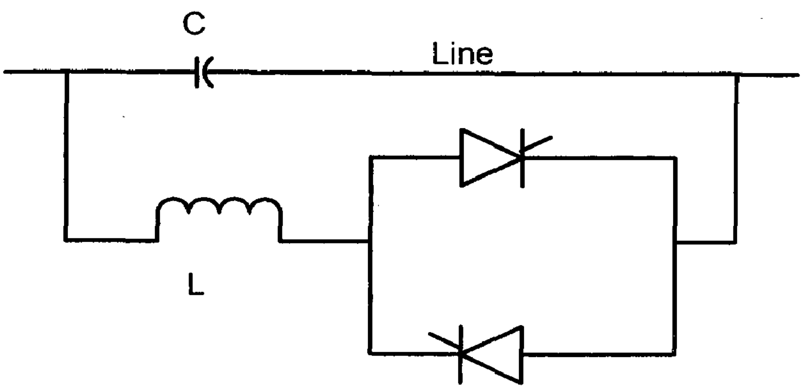

Fig.6.1 Schematic diagram of TCSC

Let the capacitive reactance of capacitor bank

$$X_C = \frac{1}{\varpi_n C} \tag{6.1}$$

And reactance of Thyristor controlled shunt are is give by

$$X_L = \varpi_n L \tag{6.2}$$

$$X_L(\alpha) = \frac{\pi X_L}{\pi - 2\alpha - \sin(\alpha)} \tag{6.3}$$

$$X_{TCSC} = -j\frac{X_C X_L(\alpha)}{X_L(\alpha) - X_C} \tag{6.4}$$

Where

X_L= reactance of the inductor.

α = firing angle of Thyristor

$X_L(\alpha)$=reactance of the thyristor controlled inductor arm.

W_n = Supply frequency.

From eqn.6.4 we see that ,

If $X_L(\alpha)>X_C$, then TCSC shows capacitive characteristics

If $X_L(\alpha)<X_C$, then TCSC shows inductive characteristics

If $X_L(\alpha)=X_C$, then the impedance of the TCSC will be infinite and this is the condition of resonance in parallel inductive and capacitive circuit. Therefore in this region operation of TCSC is not allowed. The TCSC must operate either in capacitive region or in inductive region. Normally it operates in capacitive region.

6.2.2 Modeling of TCSC for power flow studies

Fig. 6.2 shows a simple transmission line represented by its lumped Π- equivalent parameters connected between bus-*i* and bus-*j*.

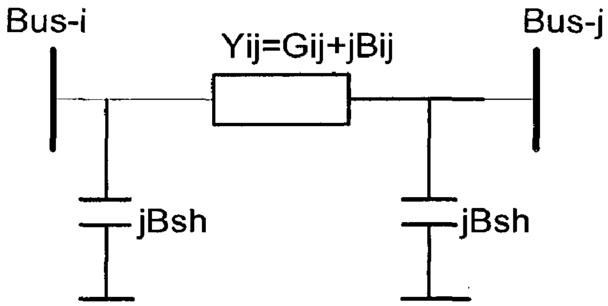

Fig.6.2 Model of transmission line

Let complex voltages at bus-*i* and bus-*j* are $V_i\angle\delta_i$ and $V_j\angle\delta_j$ respectively. The real and reactive power flow from bus-*i* and bus-*j* (P_{ij} and Q_{ij}) can be written as

$$P_{ij} = V_i^2 G_{ij} - V_i V_j [G_{ij}\cos(\delta_{ij}) + B_{ij}\sin(\delta_{ij})] \quad (6.5)$$

$$Q_{ij} = -V_i^2 (B_{ij} + B_{sh}) - V_i V_j [G_{ij}\sin(\delta_{ij}) - B_{ij}\cos(\delta_{ij})] \quad (6.6)$$

Where $\delta_{ij} = \delta_i - \delta_j$. Similarly, the real and reactive power flow form bus-*j* to bus-*i* (P_{ji} and Q_{ji}) is

$$P_{ji} = V_j^2 G_{ij} - V_i V_j [G_{ij}\cos(\delta_{ij}) - B_{ij}\sin(\delta_{ij})] \quad (6.7)$$

$$Q_{ji} = -V_j^2 (B_{ij} + B_{sh}) + V_i V_j [G_{ij}\sin(\delta_{ij}) + B_{ij}\cos(\delta_{ij})] \quad (6.8)$$

The effect of FACTS devices like 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.6.3. During steady state the TCSC can be considered as a static capacitor/reactor offering impedance jX_{TCSC} . The controllable reactance X_{TCSC} is directly used as a control variable to be implemented in the power flow equations.

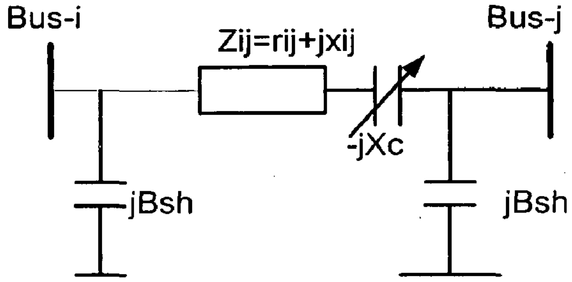

Fig.6.3.Model of transmission line with TCSC

The real power and reactive power flow equation of the branch k flowing from bus i to j can be expressed as

$$P_{ij}^{c} = V_j^2 G_{ij}^{c} - V_i V_j [G_{ij}^{c} \cos(\delta_{ij}) + B_{ij}^{c} \sin(\delta_{ij})] \quad (6.9)$$

$$Q_{ij}^{c} = -V_i^2 (B_{ij}^{c} + B_{sh}) - V_i V_j [G_{ij}^{c} \sin(\delta_{ij}) - B_{ij}^{c} \cos(\delta_{ij})] \quad (6.10)$$

$$P_{ji}^{c} = V_i^2 G_{ij}^{c} - V_i V_j [G_{ij}^{c} \cos(\delta_{ij}) - B_{ij}^{c} \sin(\delta_{ij})] \quad (6.11)$$

$$Q_{ji}^{c} = -V_j^2 (B_{ij}^{c} + B_{sh}) + V_i V_j [G_{ij}^{c} \sin(\delta_{ij}) + B_{ij}^{c} \cos(\delta_{ij})] \quad (6.12)$$

Where $G_{ij}^{c} = \dfrac{r_{ij}}{r_{ij}^2 + (x_{ij} - x_{TCSC})^2}$ and $B_{ij}^{c} = \dfrac{-(x_{ij} - x_{TCSC})}{r_{ij}^2 + (x_{ij} - x_{TCSC})^2}$

The change in the line flow due to series capacitance can be represented as a line without series capacitance with power injected at the receiving and sending ends of the line as shown in Fig.6.4. The real power injections at bus-i (P_{ic}) and bus-j (P_{jc}) can be expressed, using eqn.6.5 to 6.12., as

$$P_{ic} = V_j^2 \Delta G_{ij} - V_i V_j [\Delta G_{ij} \cos(\delta_{ij}) + \Delta B_{ij} \sin(\delta_{ij})] \quad (6.13)$$

$$P_{jc} = V_j^2 \Delta G_{ij} - V_i V_j [\Delta G_{ij} \cos(\delta_{ij}) - \Delta B_{ij} \sin(\delta_{ij})] \quad (6.14)$$

Similarly, the reactive power injections at bus-$i(Q_{ic})$ and bus-j(Q_{jc}) can be expressed as

$$Q_{ic} = -V_i^2 \Delta B_{ij} - V_i V_j [\Delta G_{ij} \sin(\delta_{ij}) - \Delta B_{ij} \cos(\delta_{ij})] \tag{6.15}$$

$$Q_{jc} = -V_j^2 \Delta B_{ij} + V_i V_j [\Delta G_{ij} \sin(\delta_{ij}) + \Delta B_{ij} \cos(\delta_{ij})] \tag{6.16}$$

Where $\Delta G_{ij} = \dfrac{x_{TCSC} r_{ij} (x_{TCSC} - 2x_{ij})}{(r_{ij}^2 + x_{ij}^2)(r_{ij}^2 + (x_{ij} - x_{TCSC})^2)}$ *and* $\Delta B_{ij} = \dfrac{-x_{TCSC}(r_{ij}^2 - x_{ij}^2 + x_{TCSC} x_{ij})}{(r_{ij}^2 + x_{ij}^2)(r_{ij}^2 + (x_{ij} - x_{TCSC})^2)}$

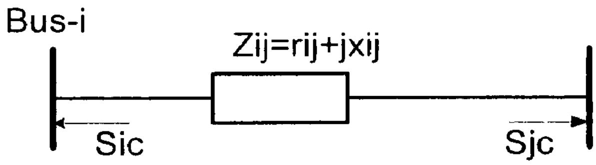

Fig.6.4 Injection model of TCSC

6.3 UNIFIED POWER FLOW CONTROLLER (UPFC)

The UPFC was first proposed by Gyugyi in 1991. It was devised for real-time control and dynamic compensation of ac transmissions system, providing multifunctional flexibility required to solve many of the problems facing the power delivery industry. From conceptual view-point, the UPFC is a generalized synchronous voltage source, represented at the fundamental frequency by voltage phasor V_{s1} with controllable magnitude $(0 \leq V_{s1} \leq V_{s1max})$ and angle $(0 \leq \phi_{s1} \leq 2\pi)$ in series with the transmission line. As far as construction is concerned a UPFC consists of shunt (exciting and series (boosting) transformer, which are connected by two voltage-sourced converters using GTO thyristors valves and a DC circuit. Inverter-2 is used to generate a voltage source at the fundamental frequency with variable amplitude $(0 \leq V_{s1} \leq V_{s1max})$ and phase angle $(0 \leq \phi_{s1} \leq 2\pi)$, which is added to the AC transmission line by the series connected booster transformer. As the series transformer injects series voltage in line, the control of active and reactive power is possible by changing the magnitude and angle of inserted voltage. The real power flows from shunt converter to series converter via a DC link. As both inverters are capable of handling reactive power independently shunt transformer can also inject reactive power on the bus thus helps in maintaining better voltage profile. In this way the inverter output voltage injected in series with the line can be used for direct voltage control, series compensation, phase shifting and their combination and shunt current can be used to maintain good voltage profile. The schematic diagram of UPFC is shown in fig 6.5.

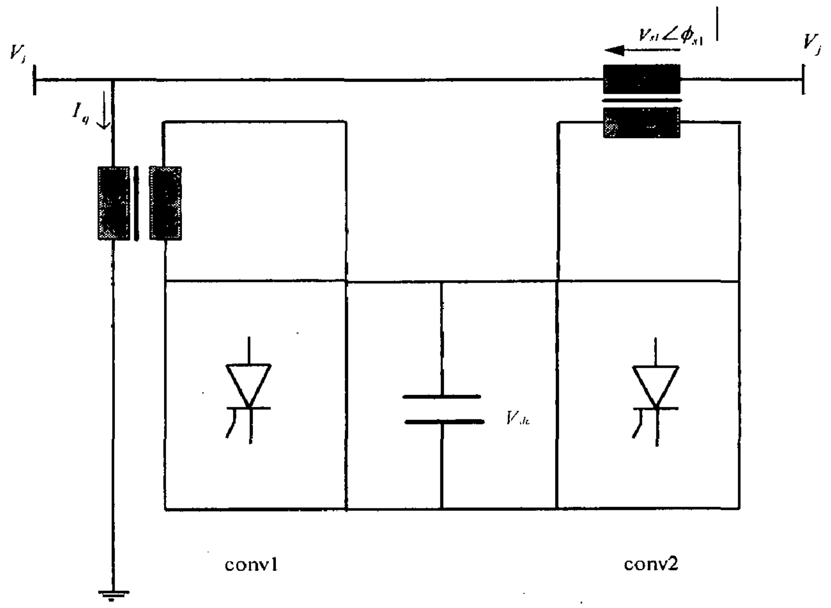

Fig.6.5 The UPFC schematic diagram

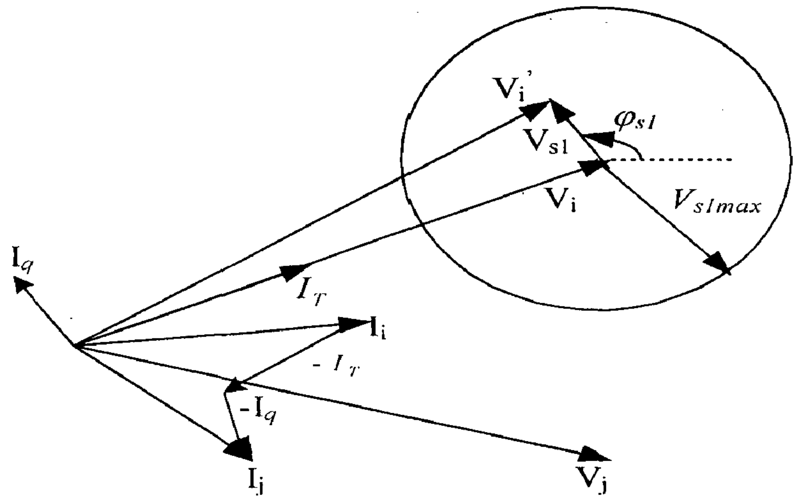

Fig.6.6 Vector- Diagram of UPFC

6.3.1 MODELING OF UPFC FOR POWER FLOW STUDIES

In this section the modeling of unified power flow controller (UPFC) has been presented for static analysis. Let there be n numbers of lines connected at bus-i. The equivalent circuit of UPFC placed at the i^{th} end if the line-k having impedance $r_{ij}+jx_{ij}$ $(=1/(g_{ij}+jb_{ij}))$ connected between bus-i and bus-j. UPFC has three controllable parameters, namely the magnitude and the angle of inserted voltage (V_{s1}, φ_{s1}) in line-k and the magnitude of the current (I_q).The vector diagram of UPFC is shown in Fig.6.6 and circuit diagram is given in Fig.6.7.

Based on the principle of UPFC operation and the circuit diagram, the basic mathematical relations can be written as,

$$I_{ij} = (V_i + V_{s1} - V_j)y_{ij} \qquad (6.17)$$

$$Arg(I_q) = Arg(V_i) \pm \pi/2\,,\ Arg(I_T) = Arg(V_i) \qquad (6.18)$$

$$I_T^* = \frac{Re[V_{s1}I_{ij}^*]}{V_i} \qquad (6.19)$$

The power injection at bus-i can be written as

$$S_i = P_i + jQ_i = V_i I_{ij}^* + V_i(I_T + jI_q)^* + \sum_{\substack{i=1 \\ \neq j}}^{n} V_i I_{in}^* + V_i I_{sh}^* \qquad (6.20)$$

Where, I_{sh} is the shunt current due to line charging.

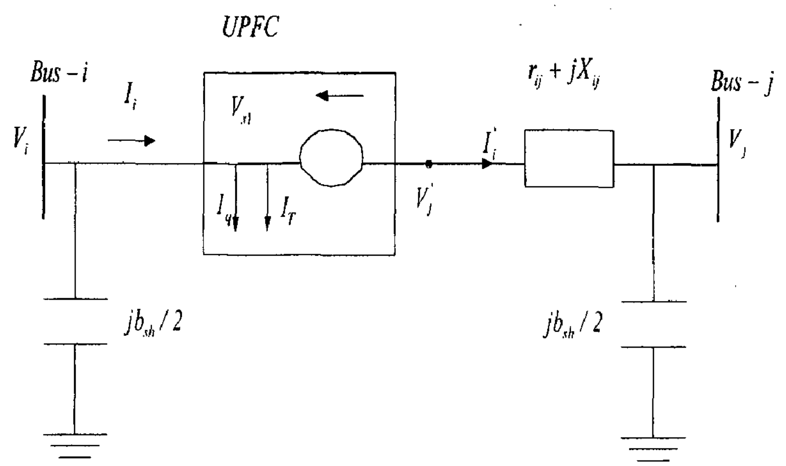

Fig.6.7 Circuit diagram of UPFC

The effect of UPFC can be represented as injected power with the network as shown in Figure 6.7. The injected complex powers S_{ig} (= $P_{ig}+jQ_{ig}$) at bus-i and S_{jg} (= $P_{jg}+jQ_{jg}$) at bus-j can be written as,

$$S_{ig} = S_i^0 - S_i = \left\{V_i V_{s1}^* y_{ij}^* + V_i (I_T + jI_q)^*\right\} \quad (6.21)$$

$$S_{jg} = S_j^0 - S_j = V_j V_{s1}^* y_{ij}^* \quad (6.22)$$

Where, S^0 is the complex power injection when there was no UPFC.

From eqn.6.5, the real and reactive power injections at bus-i can be derived as

$$P_{ig} = -Re\left\{V_i V_{s1}^* y_{ij}^*\right\} - V_i I_T^* \quad (6.23)$$

$$Q_{ig} = -Im\left\{V_i V_{s1}^* y_{ij}^*\right\} + V_i I_q \quad (6.24)$$

$$\begin{aligned} V_i I_T^* &= Re\left\{V_{s1}\angle\varphi_{s1} \times \left(V_i\angle\delta_i + V_{s1}\angle\varphi_{s1} - V_j\angle\delta_j\right)^* \times y_{ij}^*\right\} \\ &= Re\left\{\left(V_{s1}V_i\angle(\varphi_{s1} - \delta_i) + V_{s1}^2 - V_{s1}V_j\angle(\varphi_{s1} - \delta_j)\right) \times (g_{ij} - jb_{ij})\right\} \end{aligned} \quad (6.25)$$

Thus,

$$\begin{aligned} V_i I_T = V_{s1}^2 g_{ij} &+ V_{s1}V_i\left[g_{ij}cos(\varphi_{s1} - \delta_i) + b_{ij}sin(\varphi_{s1} - \delta_i)\right] \\ &- V_{s1}V_j\left[g_{ij}cos(\varphi_{s1} - \delta_j) + b_{ij}sin(\varphi_{s1} - \delta_j)\right] \end{aligned} \quad (6.26)$$

The real and imaginary values of $V_i V_{s1}^* y_{ij}^*$ can be written as,

$$Re\left(V_i V_{s1}^* y_{ij}^*\right) = V_i V_{s1}\left(g_{ij}cos(\delta_i - \varphi_{s1}) + b_{ij}sin(\delta_i - \varphi_{s1})\right) \quad (6.27)$$

$$Im\left(V_i V_{s1}^* y_{ij}^*\right) = V_i V_{s1}\left(g_{ij}sin(\delta_i - \varphi_{s1}) - b_{ij}cos(\delta_i - \varphi_{s1})\right) \quad (6.28)$$

The injected active and reactive powers at bus-i will be

$$P_{ig} = -V_{s1}^2 g_{ij} - 2V_{s1}V_i g_{ij}cos(\varphi_{s1} - \delta_i) + V_{s1}V_j\left[g_{ij}cos(\varphi_{s1} - \delta_j) + b_{ij}sin(\varphi_{s1} - \delta_j)\right] \quad (6.29)$$

$$Q_{ig} = V_i I_q + V_i V_{s1}\left[g_{ij}sin(\varphi_{s1} - \delta_i) + b_{ij}cos(\varphi_{s1} - \delta_i)\right] \quad (6.30)$$

Similarly the real and reactive powers injections at bus-j and bus-h can be derived as

$$P_{jg} = V_j V_{s1}\left(g_{ij}cos(\varphi_{s1} - \delta_j) - b_{ij}sin(\varphi_{s1} - \delta_j)\right) \quad (6.31)$$

$$Q_{jg} = -V_j V_{s1}\left(g_{ij}sin(\varphi_{s1} - \delta_j) + b_{ij}cos(\varphi_{s1} - \delta_j)\right) \quad (6.32)$$

So, A UPFC can be represented as injected power into the network as shown in Fig.6.8. The injected complex powers S_{ig} (= $P_{ig}+jQ_{ig}$) at bus-i, S_{jg} (= $P_{jg}+jQ_{jg}$) at bus-j,

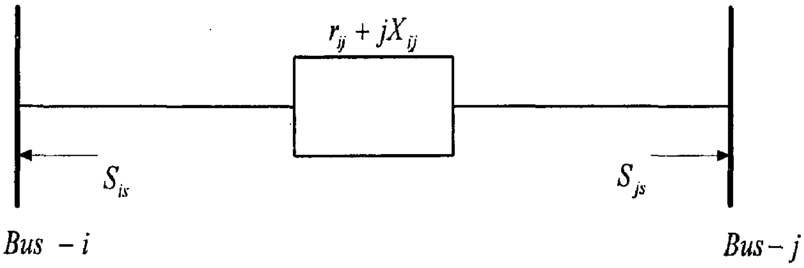

Fig.6.8 Injection model of UPFC

6.4 CANDIDATE LOCATIONS SELECTION

It is very much required to locate FACTS devices optimally in the system for specific objectives. In this work the goal of the optimization is to perform a best utilization of the existing transmission lines. In this respect, the FACTS devices are located in order to maximize the system loadability while observing thermal limits. In other words, we look for increasing as much as possible the power transmitted by the network to the consumers, keeping the power system in a secure state in terms of branch loading.

A configuration of N_F FACTS devices is defined with three parameters:. the location of the devices, their types and their parameter values.

In order to take into account the three aforementioned parameters in the optimization, a particular coding is developed. An individual is represented with three strings of length N_F, where N_F is the number of devices to locate optimally.

The first string corresponds to the location of the devices. It contains the number of the lines where the FACTS are to be located. Each line could appear at maximum once in the string. The order of the lines in the string is not important for a given configuration, but could have its importance when applying the operator of crossover.

The second string is related to the types of the devices. A value is assigned to each type of modeled FACTS device: 1 for TCSC; 2 for UPFC at the midpoint of the line. By this way new other types of FACTS may be easily added.

The last string of the individual represents the parameter values of the devices. It can take N_v discrete values contained between 0 and 1; 0 corresponding to the minimum value that the device can take and 1 to the maximum. According to the model of the FACTS, the real value of the device V_{real} is calculated with the following relation:

$$V_{realF} = V_{\min F} + (V_{\max F} - V_{\min F}) * V_F \qquad (6.33)$$

Where V_{minF} and V_{maxF} are respectively the minimum and the maximum setting value of the device, and V_F is its normalized value.

Fig. 6.9 gives an example three coded strings.

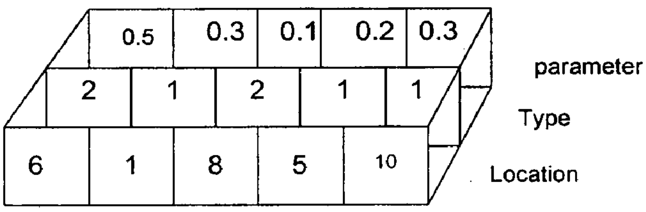

Fig. 6.9. Configuration of 5 FACTS devices

Three TCSCs are located on branches {1, 5, and 10}. Their capacitance values are -K*X_{LI}, where X_{LI} is the reactance of the line I and K is a constant. Two UPFC are located on lines {6, 8}. Their voltage transformations are respectively 0.5 and 0.3.

For a given power system of N_b branches, the initial population is generated from the following parameters:

- N_F the number of FACTS devices to be located optimally.
- the different types of devices to be located.
- N_v the number of possible discrete setting for a device.
- N_i the number of individuals of the population.

The creation of an individual is done in three stages. First, a set of N_F branches of the network are randomly drawn and is put in the first string. As previously mentioned, the order of the branches is not important and different individuals may represent the same configuration of FACTS devices. After drawing the branches where the FACTS devices will be located, the next two steps consist in the attribution of the characteristics of the devices. The second string, referred to the types of the devices, is obtained by randomly drawing numbers among the selected devices. Thus, if we decide to optimally locate only one type of device, this string will contain the same character. Setting values of the devices are finally randomly drawn among the possible. To obtain the entire initial population, these operations are repeated N_i times.

Then, the objective function is computed for every individuals of the population. It represents a mathematical translation of the optimization to realize and does not have to be continuous or derivable. It has to be elaborated so as to favor the reproduction of good individuals without preventing reproduction of interesting othe In our case, the objective function is defined in order to quantify the impact of the FACTS devices on the state of the power system.

The move to a new generation is done from the results obtained for the old generation. A biased roulette wheel is created from the obtained values of the objective function of the current population as represented in Fig.6.10.

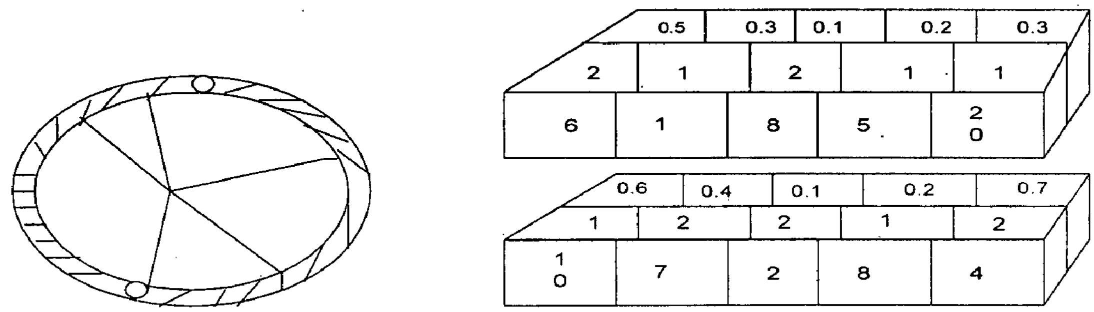

Fig 6.10 Reproduction (a) Draws on the roulettle wheel (b) Selected Individuals

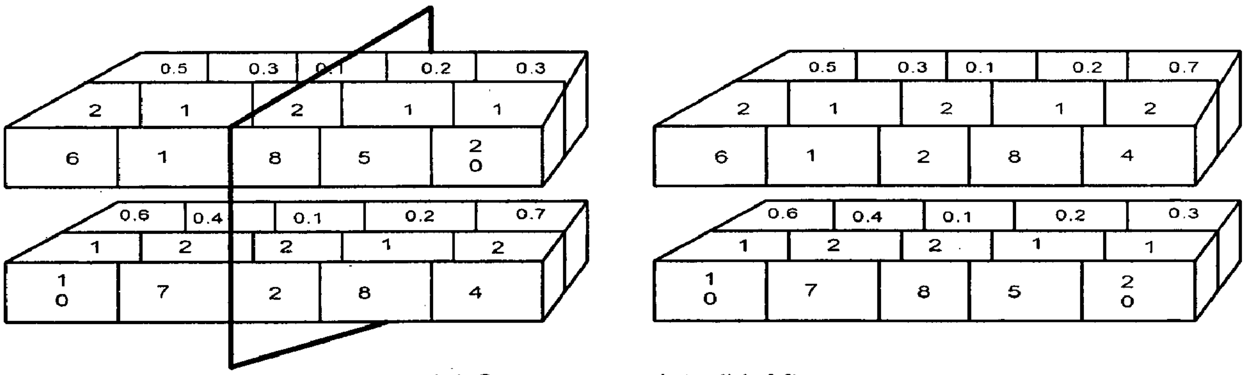

Fig 6.11 Cross over (a) Cross over point (b) After cross over

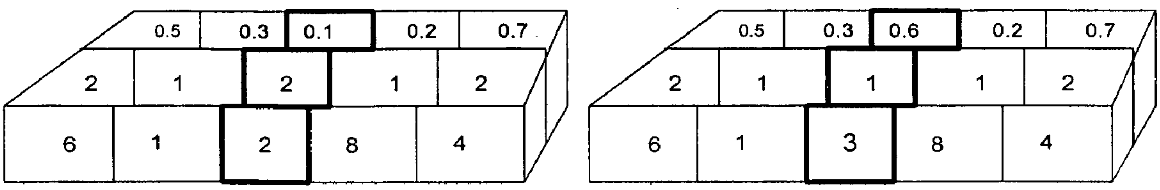

Fig 6.12 Mutation (a) Mutation point (b) After mutation

After that, the operators of reproduction, crossover and mutation are applied successively to generate the offspring.

In turn, two individuals are randomly drawn from the population and reproduced. The probability of drawing an individual is proportional to its part on the biased roulette wheel. Fig.6.10 shows the process of reproduction. The crossover may occur with a probability; generally close to 1. A single-point crossover is applied as shown in Fig.6.11. From the position of crossover point, elements of the three strings of both parents are exchanged.

Mutations are possible independently on all elements of the three strings of an individual. A specific probability is applied for each string: for the first string, for the second and for the last. These probabilities change with the generations. When a mutation occurs on the first string, the one related to the location, a new line among the set of branches having no FACTS is randomly drawn. In the case of mutation on the two other strings, a new value is drawn among the set of possible ones. Examples of mutations are shown in Fig.12.

Operations of selection, crossover and mutation are repeated until the number of desired offsprings is created. The objective function is then calculated for every offsprings and the best individuals among the entire pool, comprising parents and their offsprings, are kept to constitute the new generation. By this way, the objective function of the best individual of the new generation will be the same or higher than the objective function of the best individual of the previous generation. Similarly, the average fitness of the population will be the same or higher than the average fitness of the previous generation. Thus the fitness of the entire population and the fitness of the best individual are increasing for each generation.

Objectives of the Optimization

The objective function is built in order to penalize the configurations of FACTS leading to overloaded transmission lines. Only the technical benefits of the FACTS controllers, in terms of loadability, are taken into account. Other criteria such as costs of installing and maintaining devices are not taken into consideration at this stage of our research.

Therefore, for configuration of FACTS devices, the objective function to maximize is given by,

$$C_{fg} = \Pi^{N_L}{}_{line=1} Ovl_{line} \tag{6.34}$$

Where Ovl_{line} is shown in Fig.6.11

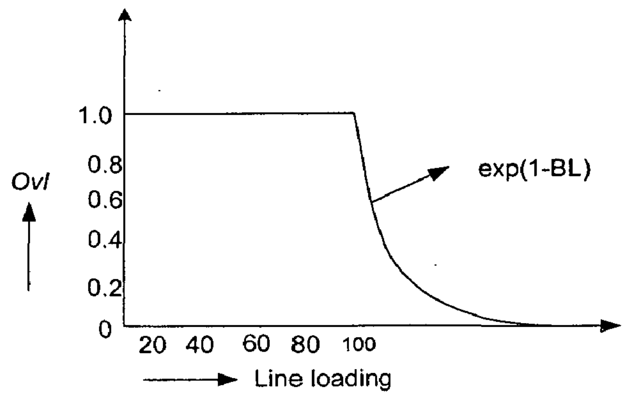

Fig.6.14 Objective function Ovl_{line}

While the branch loading is less than 100%, its value is equal to 1; then it decreases exponentially with the overload. To accelerate the convergence, the product of all objective function is taken.

Flow chart:

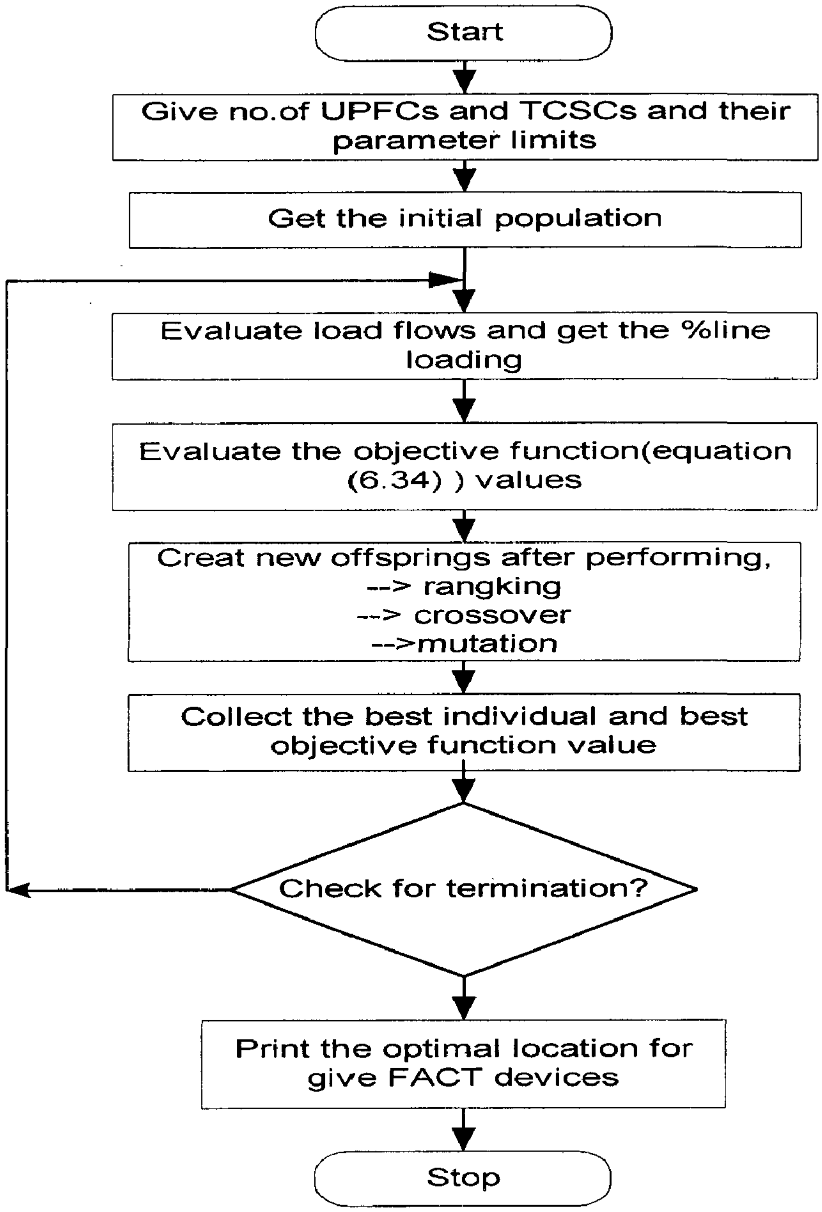

Fig.6.15 Flowchart for optimal locations for FACTS

CHAPTER-7

THE FLOW CHART, RESULTS AND DISCUSSIONS

7.1 INTRODUCTION

After the electricity sector restructuring, OPF has been used to assess the spatial variation of electricity prices and as a congestion management and pricing tool. The Optimal Power Flow (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 constrains dictated by the electric network. OPF has been widely used in power system operation and planning.

One of the OPF goals is a best utilization of the transmission lines. In this respect the FACTS devices are located in order to reduce the line congestion. In other words more attention has been paid to determine optimal generation cost globally. Here in this work only technical benefits of the FACTS controller are taken into account. Other criteria such as costs of installing and maintaining devices are not taken into consideration.

7.2 FLOW CHART

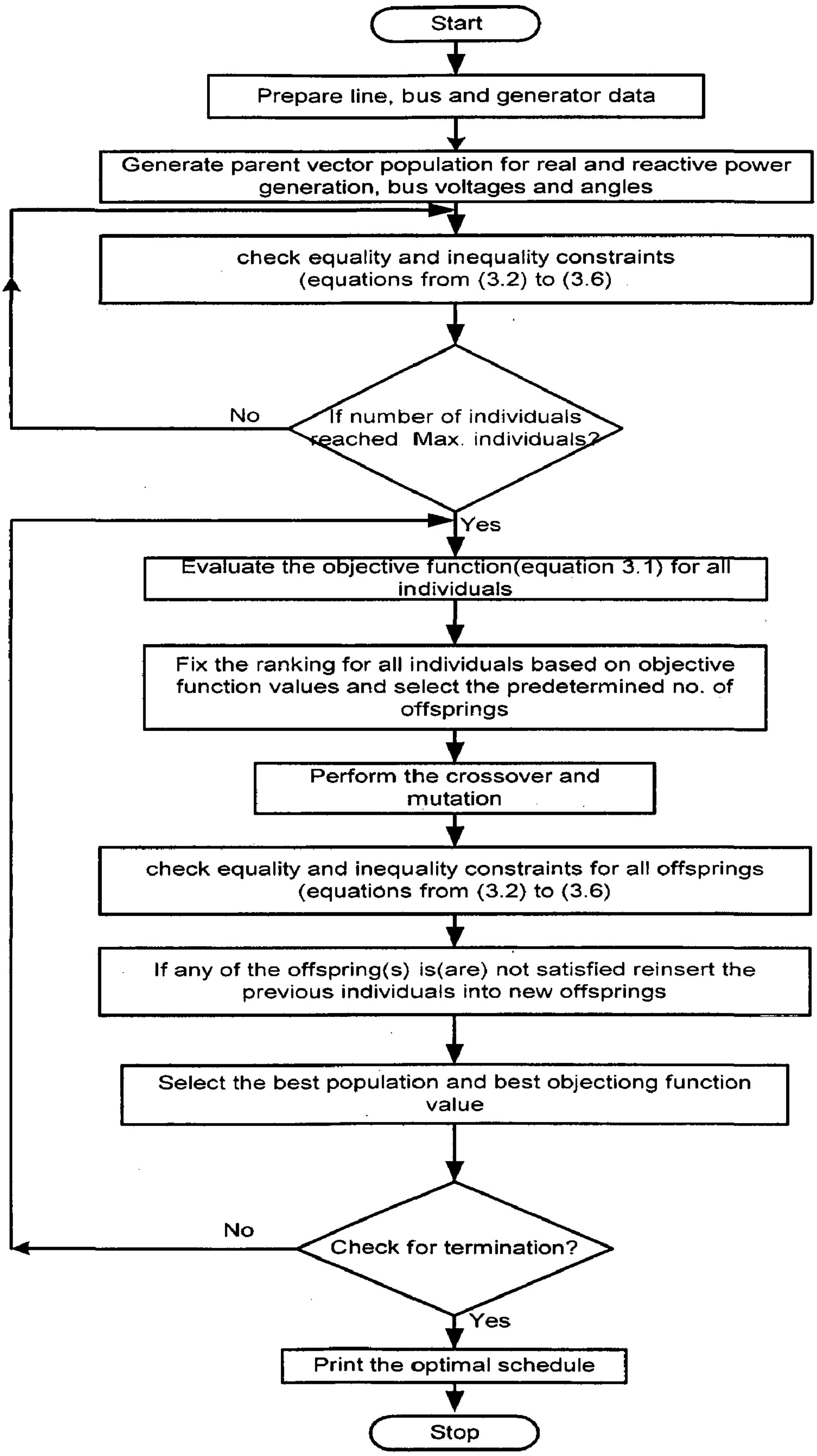

Fig.7.1 Flow chart- OPF using GA

7.3 OBSERVED RESULTS AND DISCUSSIONS

The proposed model has been implemented on IEEE30 bus system. The results obtained have been found satisfactory. The IEEE30 bus test case system data was given in appendix A.

Objective function taken from eqn.3.1 is solved by the genetic algorithm and the optimal schedule is given in table 7.1 and the optimal social welfare is 3068.66$.

Gen No.	Pg (MW)
Generator 1	25.15
Generator 2	35.37
Generator 3	25.31
Generator 4	65.77
Generator 5	45.18
Generator 6	36.69

Table 7.1 Optimal generation schedule without transaction.

Various parameter used in solving OPF using genetic algorithm are given in table 7.2 and the problem optimization is shown in Fig.7.2. In table 7.3 line flows are tabulated from bus injection and to bus injection. In Fig.7.3 line loading is shown.

Population size	200
Mutation rate	0.001
Crossover rate	0.8
Crossover operator	Single point
Selection operator	Roulette wheel
Maximum iterations	50

Table7.2. GA parameters

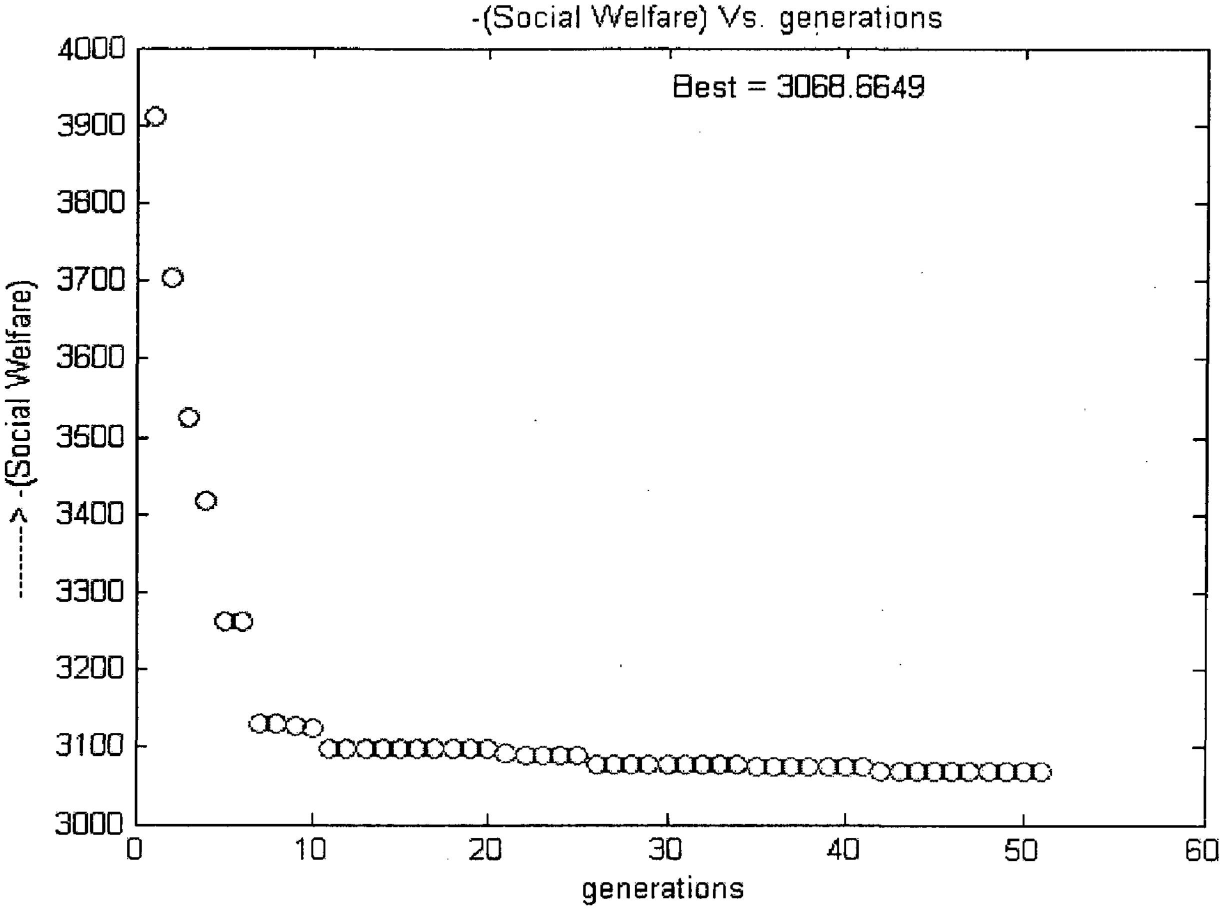

Fig.7.2 –Social welfare Vs. iterations without transaction

From bus	To bus	From bus injection		To bus injection		Line loading
		P(MW)	Q(MVar)	P(MW)	Q(Mvar)	(in %)
1	2	-8.7748	34.5061	13.6742	-36.67	26.8442
1	3	-13.249	10.1518	9.1299	-12.065	18.0913
2	4	-12.071	2.7409	5.4562	-4.6669	10.8668
3	4	-10.984	14.6065	6.762	-14.97	13.4598
2	5	-21.092	20.8133	17.6298	-21.593	34.582
2	6	-14.576	6.1986	4.7384	-8.0942	9.3976
6	4	12.7324	-15.407	2.0353	15.0141	4.0185
5	7	-3.6137	-21.025	-1.0819	20.4405	2.5444
6	7	-18.914	8.1237	23.8819	-8.5427	47.4456
6	8	7.8285	49.7144	-27.221	-48.904	55.1743
6	9	-0.3944	-24.957	-5.6608	26.2323	11.3216
6	10	-6.0083	-12.604	5.3782	13.5815	10.7564
9	11	45.735	2.7817	-45.728	0.9304	91.464
9	10	-31.103	-16.901	39.9119	18.6606	79.8237
4	12	-2.7174	-23.649	6.2011	25.064	12.4022
12	13	48.623	22.0764	-36.623	-19.953	73.246
12	14	-8.4805	-1.6269	7.7094	1.7566	15.2939
12	15	-21.093	-4.1841	17.8385	4.5402	35.3155
12	16	-10.765	-1.2899	6.809	1.3682	13.5436
14	15	-2.3559	-0.1566	1.5135	0.1603	3.0187
16	17	-7.3567	0.4318	3.3165	-0.4143	6.6181
15	18	-7.915	-0.6101	5.6498	0.6664	11.2443
18	19	-4.7692	0.2336	2.4529	-0.2274	4.8996
19	20	4.719	3.6274	-7.0301	-3.5934	14.0942
10	20	-6.8568	-4.1199	9.2301	4.2934	18.3049
10	17	-1.5938	-6.1655	5.6835	6.2143	11.3295
10	21	-15.555	-9.2375	16.7436	9.461	33.2795
10	22	-7.4982	-4.1702	8.2559	4.2749	16.4104
21	22	1.8508	1.739	-0.7561	-1.7383	1.5128
15	23	-7.5954	-1.5904	5.5566	1.6443	11.0597
22	24	-5.6925	-2.5366	7.5581	2.6272	14.9997
23	24	-4.4428	-0.0443	2.3624	0.0562	4.7131
24	25	-1.4935	4.0166	1.2467	-3.9707	2.4409
25	26	-3.4652	-2.2479	3.5	2.3	6.9302
25	27	1.9418	6.2186	-2.18	-6.1454	4.4367
28	27	-14.214	-16.308	14.4821	18.0582	28.9642
27	29	-5.9704	-1.2426	6.0376	1.3699	11.9404
27	30	-6.8109	-1.1442	6.9366	1.3813	13.6212
29	30	-3.6377	-0.4699	3.6634	0.5187	7.2752
8	28	-4.7632	-12.448	8.118	10.5831	15.9954
6	28	-9.7888	-8.5604	6.8429	1.631	13.6628

Table 7.3 Line flows in the lines obtained by load flows using OPF schedule without transaction

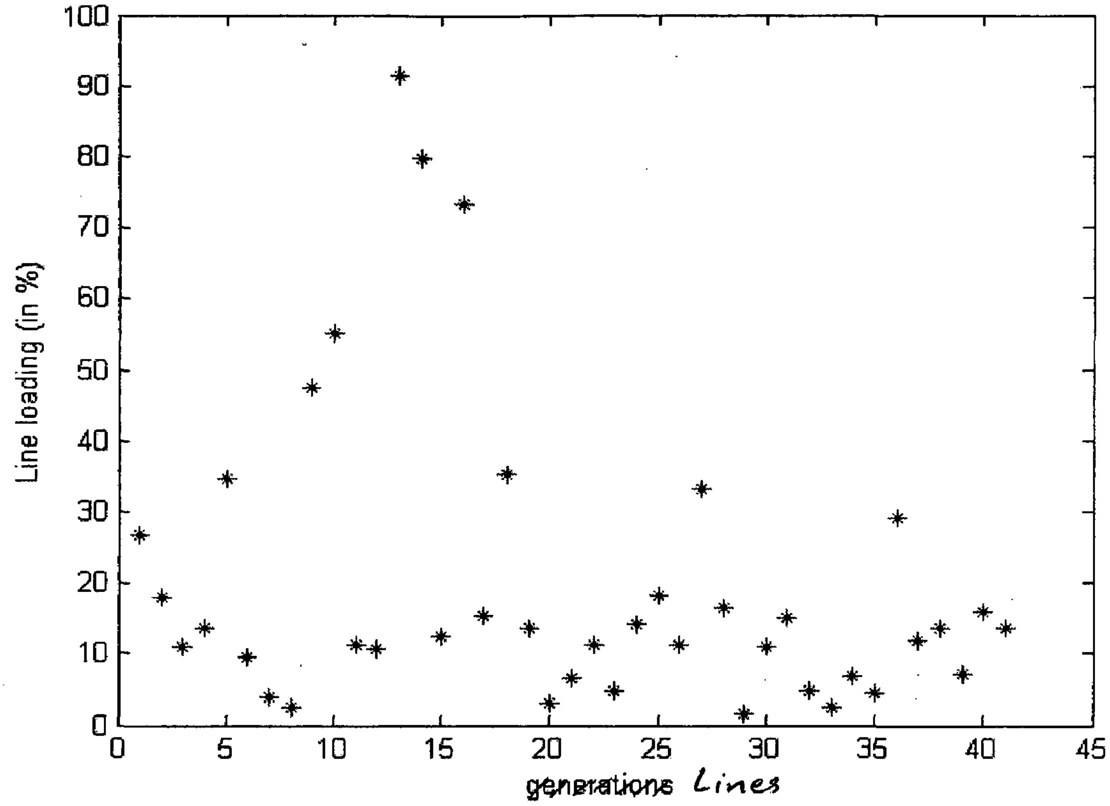

Fig.7.3 Line loading without transaction

Now by assuming new transaction between the supplier at node 13 and the consumer at node 5 optimal social welfare is 3602.38$ and the generation schedule is given table 7.4. The GA parameters are same as given in table 7.2 and the Fig.7.4 shows the social welfare optimization with generations. Table 7.5 gives the line flows and Fig.7.5 shows percentage line loading.

Gen No.	Pg (MW)
Generator 1	35.25
Generator 2	57.94
Generator 3	26.29
Generator 4	48.26
Generator 5	46.04
Generator 6	69.62

Table 7.4 Optimal generation schedule with transaction

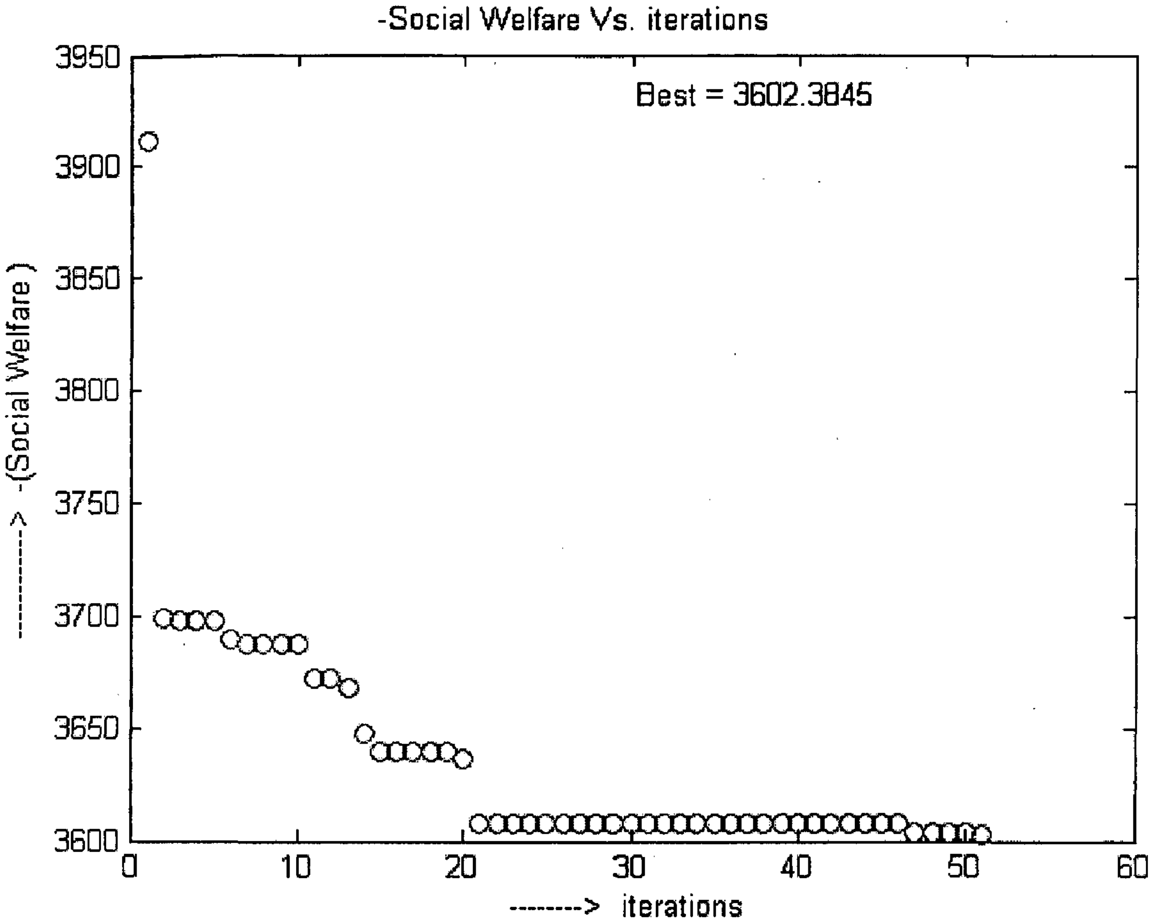

Fig.7.4 –Social welfare Vs. iterations with transaction

From bus	To bus	From bus injection		To bus injection		Line loading
		P(MW)	Q(MVar)	P(MW)	Q(Mvar)	(in %)
1	2	-12.711	34.2586	12.9578	-36.441	25.4239
1	3	-8.2171	11.6323	8.3099	-13.504	16.4342
2	4	-4.5482	4.6051	4.5755	-6.5105	9.0964
3	4	-5.9099	16.0379	5.9464	-16.386	11.8199
2	5	-39.337	27.5942	40.3673	-25.471	78.6754
2	6	-8.1309	8.7687	8.2174	-10.517	16.2618
6	4	16.5966	-17.466	-16.532	17.2085	33.1932
5	7	19.4347	-25.708	-18.978	25.7978	38.8694
6	7	-41.294	14.4885	41.7783	-13.904	82.5881
6	8	6.8509	49.7825	-6.5633	-49.244	13.7019
6	9	17.1301	-25.433	-17.130	27.2726	34.2602
6	10	-0.176	-13.161	0.176	14.0679	0.352
9	11	53.07	3.0365	-53.07	1.9743	66.3375
9	10	-35.554	-18.237	35.5546	19.7349	71.1091
4	12	12.6851	-22.452	-12.685	24.0384	25.3702
12	13	57.763	19.366	-59.393	-13.273	115.655
12	14	-8.9634	-0.98	9.0473	1.1545	17.9268
12	15	-23.136	-2.6433	23.4379	3.2362	46.2739
12	16	-12.482	-0.0414	12.6055	0.3009	24.964
14	15	-2.8473	0.4455	2.8623	-0.4319	5.6946
16	17	-9.1055	1.4991	9.1631	-1.3645	18.2109
15	18	-8.778	0.1348	8.8452	0.002	17.5561
18	19	-5.6452	0.898	5.6619	-0.8643	11.2904
19	20	3.8381	4.2643	-3.8292	-4.2464	7.6762
10	20	-5.9835	-4.8444	6.0292	4.9464	11.967
10	17	0.1767	-7.1292	-0.1631	7.1645	0.3534
10	21	-16.207	-9.1649	16.3067	9.3787	32.4147
10	22	-7.922	-4.1251	7.9697	4.2235	15.844
21	22	1.1933	1.8213	-1.1929	-1.8204	2.3867
15	23	-9.3222	-0.439	9.393	0.5819	18.6445
22	24	-6.7769	-2.4031	6.8248	2.4778	13.5537
23	24	-6.193	1.0181	6.2345	-0.9331	12.386
24	25	-4.3594	5.1553	4.4274	-5.0365	8.7187
25	26	-3.4652	-2.248	3.5	2.3	6.9303
25	27	-0.9622	7.2845	1.0096	-7.1941	1.9244
28	27	-11.395	-17.508	11.3955	19.1192	22.791
27	29	-5.9706	-1.2434	6.0377	1.3702	11.9413
27	30	-6.8111	-1.1452	6.9365	1.3812	13.6223
29	30	-3.6377	-0.4702	3.6635	0.5188	7.2755
8	28	-3.9557	-12.904	4.0525	10.9689	7.9115
6	28	-7.7047	-9.3901	7.7197	2.5002	15.4093

Table 7.5 Line flows in the lines obtained by load flows using OPF schedule with a transaction

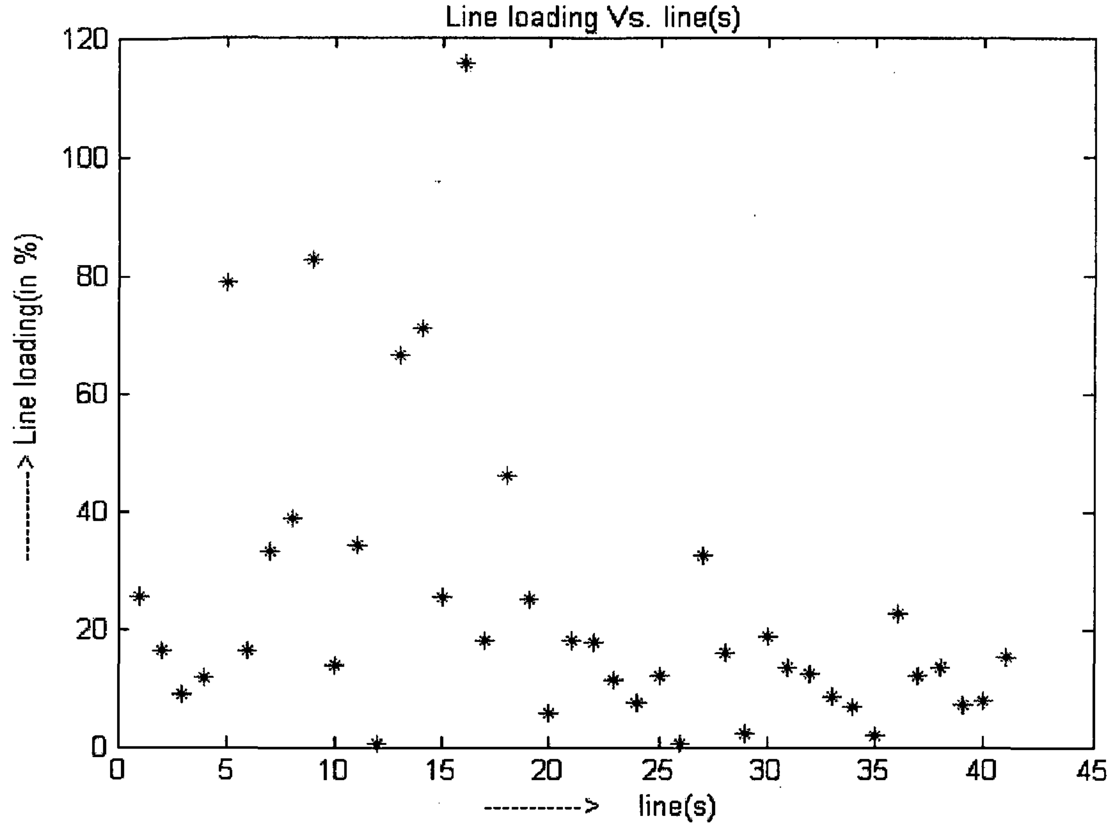

Fig.7.5 Line loading with the optimal schedule with a transaction

In Fig.7.5 observe that line 16 is gets congested. Overloading is get relieved by installing FACTS. To find the optimal location for FACTS devices eqn.6.34 is optimized. By assuming two TCSCs and one UPFC optimal locations and their parameter are given in table 7.6, and Fig.7.6 shows the objective function value. Installing (two TCSCs and one UPFC) at optimal locations line flows are given in table 7.7 and line loading is shown in Fig.7.7. Observe that the percentage line loading in line 16th is reduced in Fig.7.7 as compared in Fig.7.5.

Line No.	Type	Xtcsc	Line No.	Type	Xtcsc	Line No.	Type	Vupfc	Iupfc	Dupfc
15	1	-0.165	40	1	-0.431	23	2	0.4631	0.15	4.3

Table 7.6 Optimal location for two TCSCs and one UPFCs

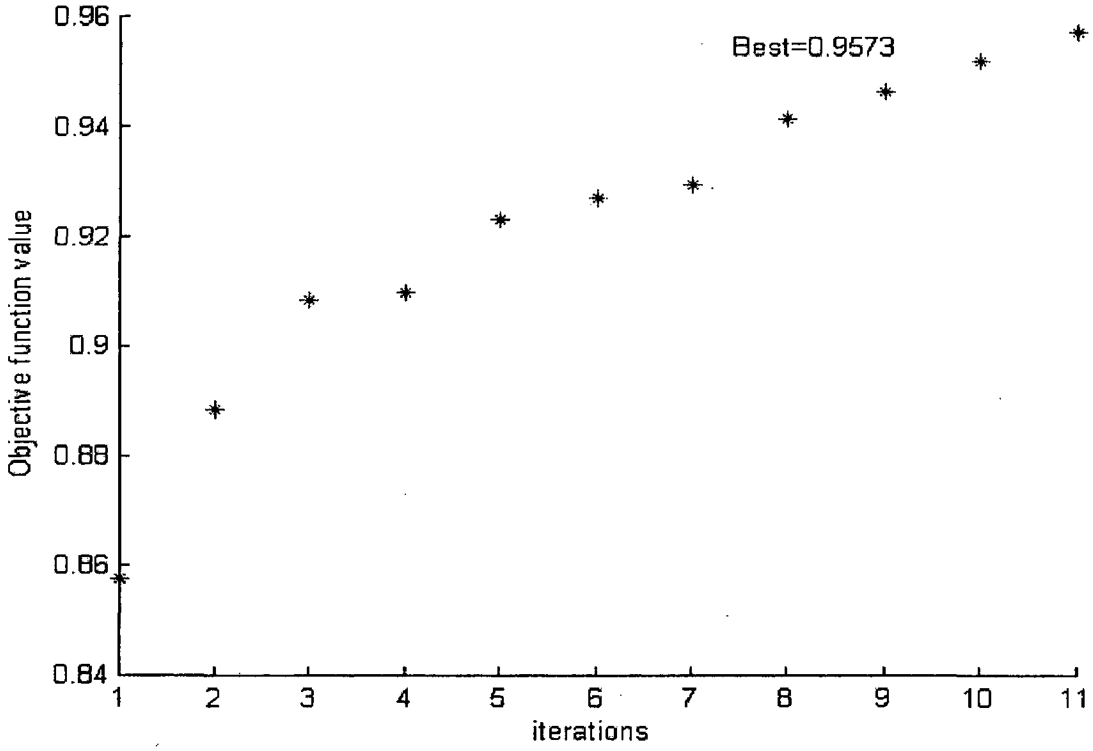

Fig 7.6 Ovl_{line} Vs. iterations with two TCSCs and one UPFC

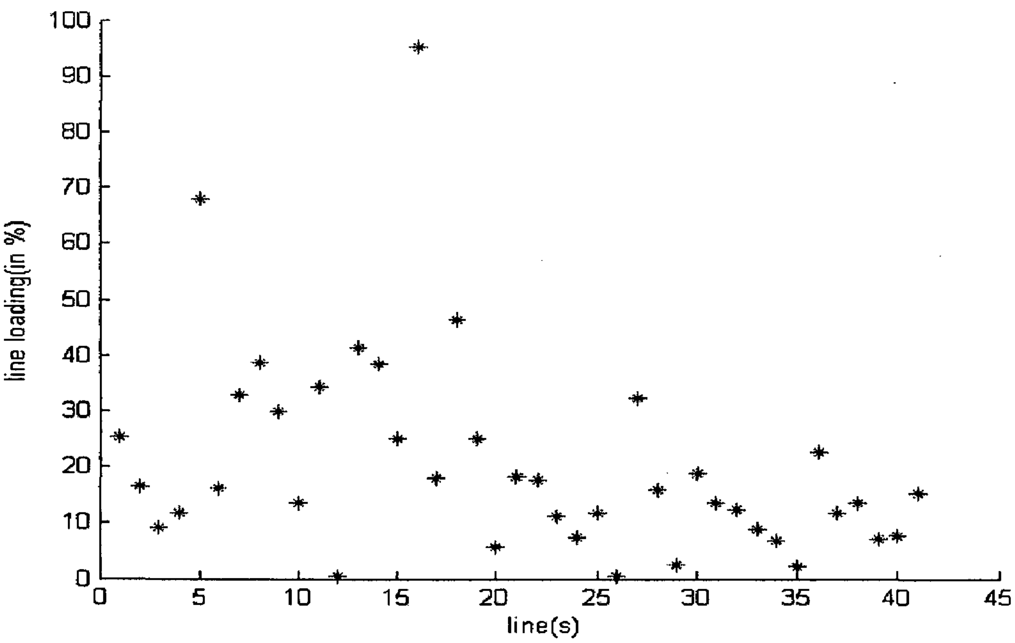

Fig.7.7 Line loading installing two TCSCs and one UPFC.

From bus	To bus	From bus injection		To bus injection		Line loading
		P(MW)	Q(MVar)	P(MW)	Q(Mvar)	(in %)
1	2	-12.703	34.2558	12.9497	-36.438	25.4078
1	3	-8.2489	12.2844	8.3489	-14.124	16.4979
2	4	-4.5504	5.4158	4.5828	-7.3031	9.1008
3	4	-5.9488	16.6558	5.9879	-16.995	11.8977
2	5	-34.038	23.874	34.9292	-22.036	68.0764
2	6	-8.1118	9.3689	8.2046	-11.096	16.2237
6	4	16.4512	-16.606	-16.390	16.337	32.9025
5	7	19.4257	-25.199	-18.980	25.26	38.8513
6	7	-14.942	5.0449	15.1162	-4.8365	29.8842
6	8	6.851	47.2291	-6.5909	-46.787	13.702
6	9	17.2007	-23.377	-17.200	25.0281	34.4014
6	10	-0.1604	-12.380	0.1604	13.1833	0.3207
9	11	33.1543	3.1646	-33.154	0.0136	41.4429
9	10	-19.167	-9.772	19.1671	10.5833	38.3343
4	12	12.5088	-19.668	-12.508	21.0666	25.0175
12	13	47.623	10.6514	-47.173	-5.7599	95.2893
12	14	-9.009	-1.1345	9.0954	1.314	18.0181
12	15	-23.210	-3.2743	23.52	3.8841	46.4208
12	16	-12.552	-0.6803	12.6799	0.9476	25.1056
14	15	-2.8953	0.2859	2.9109	-0.2719	5.7907
16	17	-9.1798	0.8524	9.2381	-0.7164	18.3596
15	18	-8.826	-0.2143	8.8948	0.3545	17.652
18	19	-5.6948	0.5455	5.7117	-0.5113	11.3896
19	20	3.7885	3.9112	-3.7803	-3.8949	7.5769
10	20	-5.9372	-4.4986	5.9804	4.5949	11.8745
10	17	0.2493	-6.4868	-0.2379	6.5164	0.4986
10	21	-16.226	-9.163	16.3266	9.3792	32.4524
10	22	-7.9344	-4.1241	7.9827	4.2237	15.8688
21	22	1.1736	1.8207	-1.1731	-1.8198	2.3471
15	23	-9.4048	-0.8979	9.4783	1.0462	18.8096
22	24	-6.8096	-2.4038	6.8585	2.4799	13.6192
23	24	-6.2782	0.5538	6.3206	-0.4671	12.5565
24	25	-4.4789	4.6872	4.5422	-4.5766	8.9577
25	26	-3.465	-2.2476	3.5	2.3	6.93
25	27	-1.0771	6.8243	1.1192	-6.7438	2.1542
28	27	-11.288	-17.085	11.2885	18.6362	22.5771
27	29	-5.9703	-1.2425	6.0377	1.3699	11.9405
27	30	-6.8107	-1.1442	6.9366	1.3813	13.6214
29	30	-3.6377	-0.4699	3.6635	0.5187	7.2753
8	28	-3.9278	-12.416	4.0174	10.4603	7.8557
6	28	-7.6292	-9.4572	7.6442	2.5807	15.2584

Table 7.7 Line flows with two TCSCs and one UPFC

By assuming one TCSC and two UPFC optimal locations and their parameter are given in table 7.8 and Fig.7.8 shows the objective function value. Installing (one TCSC and two UPFCs) at optimal locations line flows are given in table 7.9 and line loading is shown in Fig.7.9. Once again line loadings are still gets reduced as compared with earlier two cases.

Line No.	Type	Xtcsc	Line No.	Type	Vupfc	Iupfc	Dupfc	Line No.	Type	Vupfc	Iupfc	Dupfc
19	1	0.0558	20	2	0.4884	0.1023	5.67	37	2	0.3397	0.1572	7.8

Table 7.8. Optimal locations for one TCSC and two UPFC

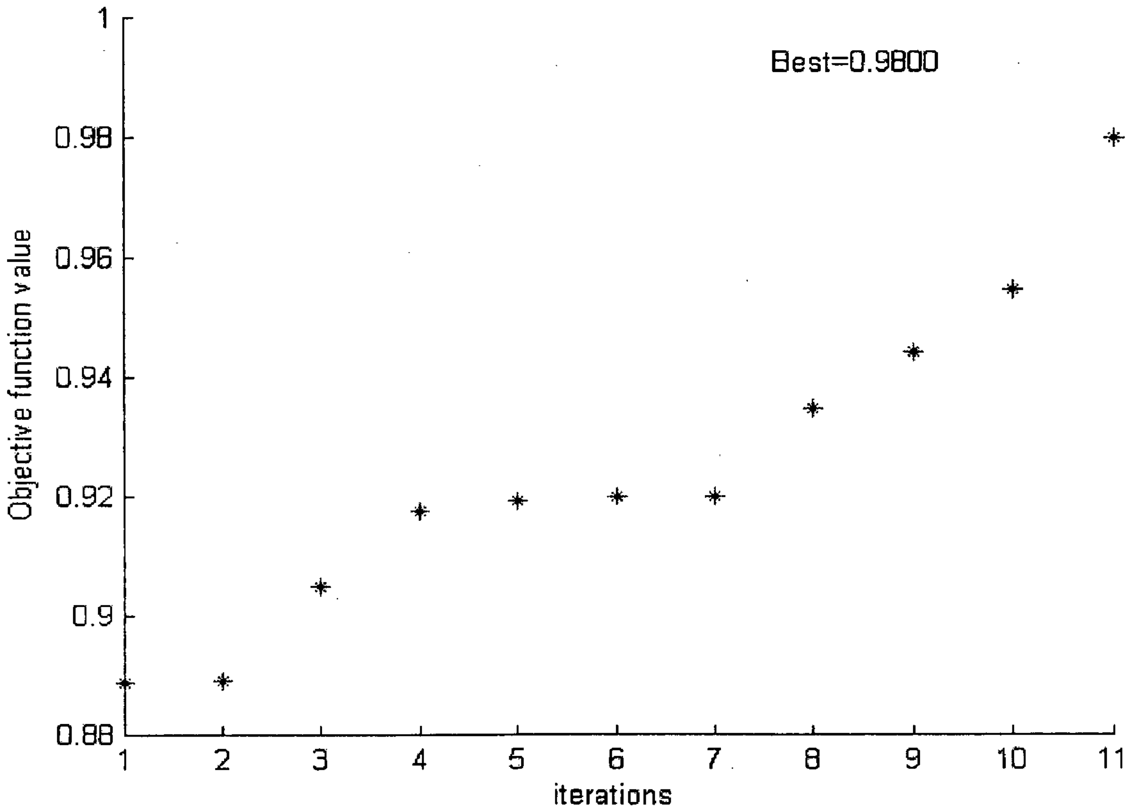

Fig.7.8 Ovl_{line} Vs. iterations

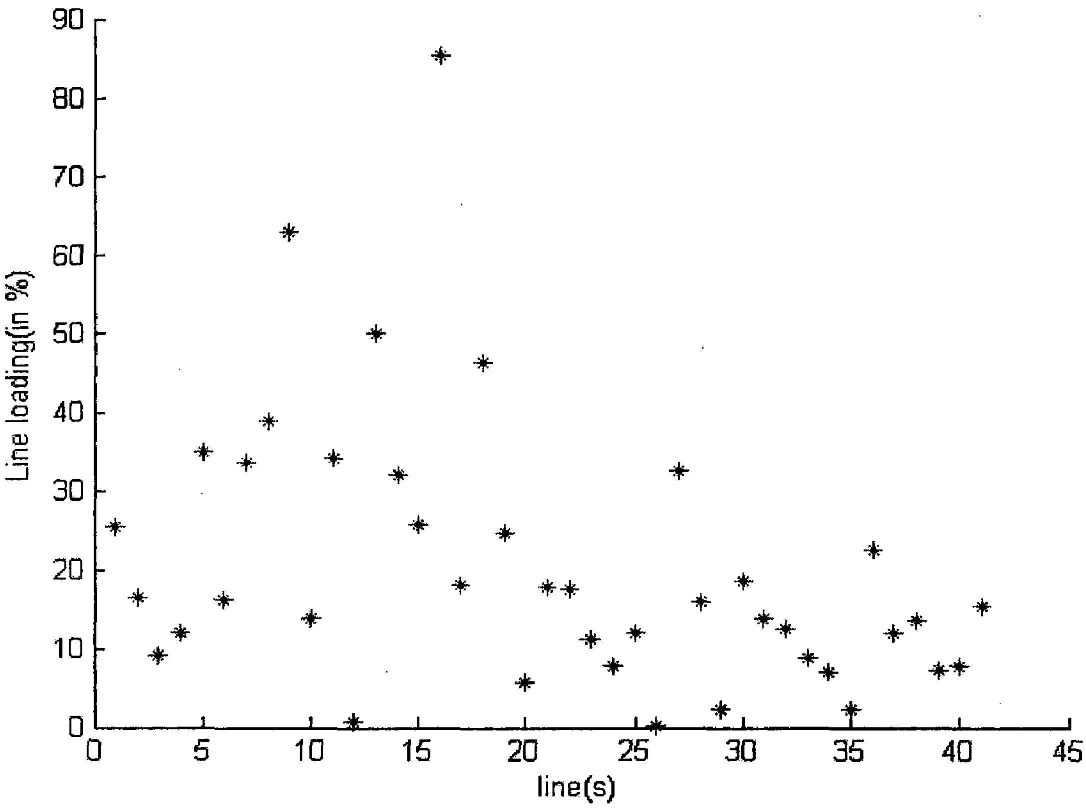

Fig.7.9 Line loading with one TCSC and two UPFCs

From bus	To bus	From bus injection		To bus injection		Line loading
		P(MW)	Q(MVar)	P(MW)	Q(Mvar)	(in %)
1	2	-12.724	34.263	12.9706	-36.445	25.4491
1	3	-8.2251	12.192	8.3238	-14.037	16.4501
2	4	-4.5198	5.2978	4.5513	-7.1882	9.0395
3	4	-5.9238	16.5689	5.9625	-16.910	11.8476
2	5	-17.454	12.2396	17.9112	-11.296	34.9084
2	6	-8.1474	9.3997	8.2408	-11.125	16.2948
6	4	16.7666	-17.213	-16.702	16.956	33.5332
5	7	19.4091	-25.179	-18.965	25.2379	38.8182
6	7	-31.428	10.5976	31.795	-10.16	62.8579
6	8	6.8481	47.1533	-6.5888	-46.714	13.6962
6	9	16.9869	-22.922	-16.986	24.5181	33.9739
6	10	-0.2917	-12.118	0.2917	12.8883	0.5833
9	11	39.8052	3.8024	-39.805	0.0202	49.7565
9	10	-15.928	-7.8501	15.9283	8.5205	31.8567
4	12	12.8513	-21.032	-12.851	22.4837	25.7027
12	13	42.5550	11.583	-41.086	-7.1709	85.144
12	14	-8.9521	-0.9015	9.0364	1.0766	17.9043
12	15	-23.145	-2.3353	23.448	2.932	46.2903
12	16	-12.304	4.5862	12.4422	-4.2242	24.6088
14	15	-2.8363	0.5233	2.8515	-0.5096	5.6726
16	17	-8.9422	-1.1324	8.9985	1.2638	17.8843
15	18	-8.7663	0.4297	8.834	-0.2917	17.5326
18	19	-5.6339	1.1917	5.6511	-1.1571	11.2679
19	20	3.8491	4.557	-3.8394	-4.5375	7.6982
10	20	-5.9909	-5.1292	6.0394	5.2375	11.9818
10	17	0.0039	-4.5217	0.0017	4.5361	0.0077
10	21	-16.257	-9.4978	16.3603	9.719	32.515
10	22	-7.9581	-4.3429	8.0079	4.4455	15.9163
21	22	1.1399	1.4809	-1.1395	-1.4802	2.2797
15	23	-9.3332	-0.352	9.4046	0.4964	18.6663
22	24	-6.8684	-2.9653	6.9209	3.0471	13.7368
23	24	-6.2046	1.1036	6.2468	-1.0172	12.4092
24	25	-4.4676	4.67	4.5305	-4.5602	8.9351
25	26	-3.465	-2.2476	3.5	2.3	6.93
25	27	-1.0654	6.8078	1.1074	-6.7278	2.1309
28	27	-11.3	-17.069	11.3	18.619	22.6001
27	29	-5.9703	-1.2425	6.0377	1.3699	11.9405
27	30	-6.8107	-1.1441	6.9366	1.3813	13.6213
29	30	-3.6377	-0.4699	3.6635	0.5187	7.2753
8	28	-3.9299	-12.400	4.0193	10.4442	7.8598
6	28	-7.6392	-9.4563	7.6542	2.5803	15.2783

Table 7.9 Line flows with one TCSC and two UPFCs

CHAPTER-8

CONCLUSIONS AND FUTURE SCOPE OF THE WORK

CONCLUSIONS

No doubt that the deregulated power systems will posses many advantages over the vertically integrated power systems. But the deregulated power systems are facing some technical problems like congestion management, available transfer capability, security, market power, pricing and economic & environmental issues.

In this work an algorithm for congestion management using OPF has been proposed. The proposed model uses the genetic algorithm to find the global optimal schedule. To relieve the congestion in the lines multiple multi-types of FACTs devices are located optimally using genetic algorithm. The following conclusions have been derived from the proposed model:

* With the above proposal it is possible for ISO to find global optimal schedule with the minimum total generation cost.
* In some transmission lines power flows with the OPF generation schedule are very high. Such extra power flows can be reduced by installing FACTS devices.
* Line loading with two UPFCs and one TCSC is less as compared with the line loading with one UPFC and two TCSCs.
* It has also been observed that proposed algorithm is also suitable for large systems with more number of FACTS devices, and the results so obtained are found to be encouraging.

FUTURE SCOPE OF THE WORK

Research and development is a continuous process. Each end of a research project opens many possibilities for further work. As a consequences of the investigations carried out in this thesis on congestion management, GA, location of FACTS devices following aspects are identified for future research work in this area.

* In this work the suppliers cost curve characteristics are quadratic functions but, by considering non-quadratic cost curves work can be explored.

* Present study has considered the placement of FACTS devices from static point of view. Dynamic consideration of these devices also be explored.
* The objective functions considered to optimally locate the FACTS is only lint loading. It can be further extended by considering other criteria such as costs of installation, real and reactive power losses and voltage constraints.

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APPENDIX A

DATA FOR IEEE-30 BUS SYSTEM (AT 100MVA BASE)

The IEEE-30 bus system in shown in fig A.1. The system data is taken from the [29]. The relevant data are provided in the following tables.

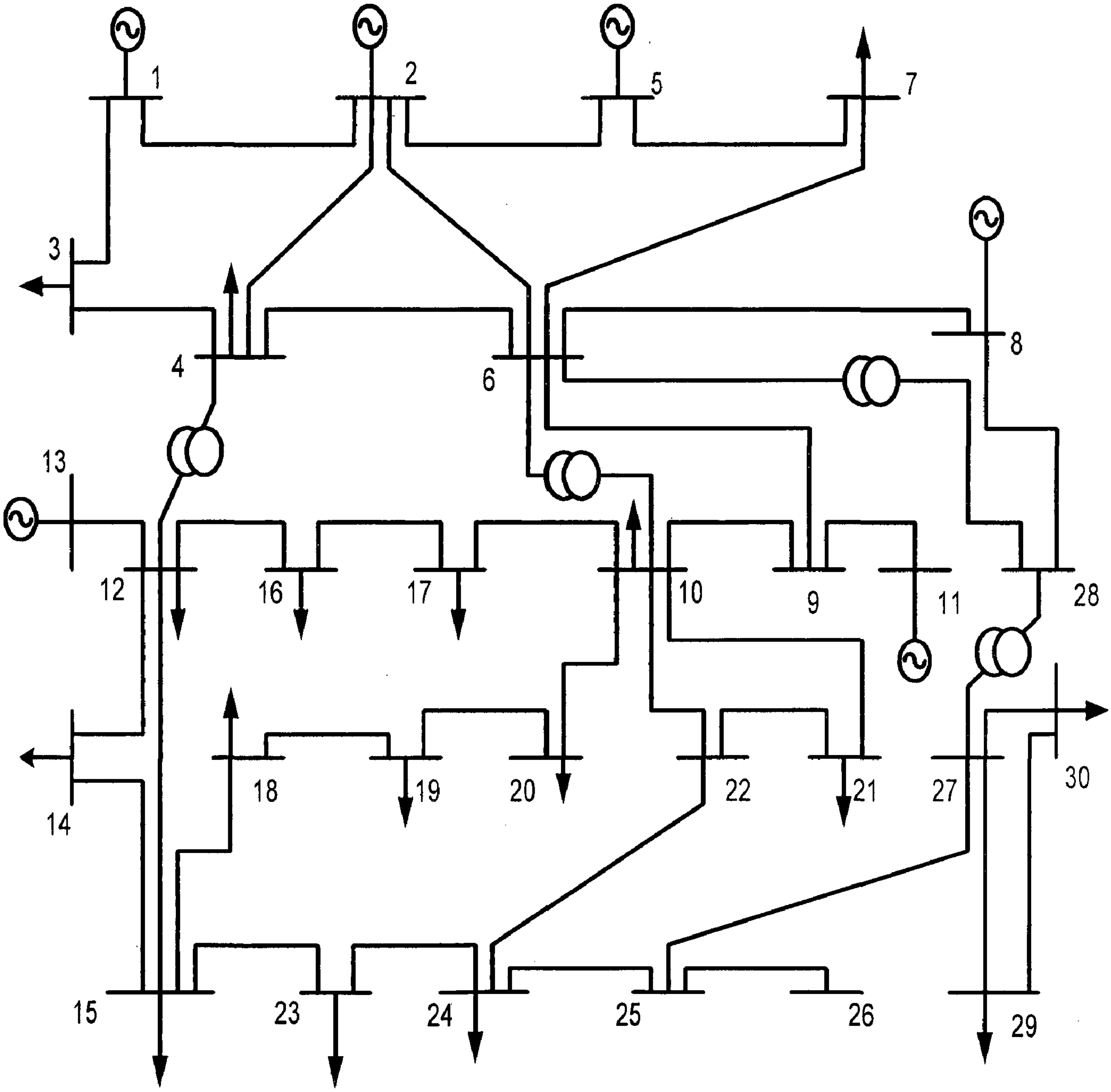

Fig. A.1. IEEE30 bus system.

Bus No.	Real power generation		Reactive power limits		Specified Voltage(p.u.)
	Max(MW)	Min(MW)	Max(MVAR)	Min(MVAR)	
1	50	200	-20	250	1.06
2	20	80	-20	100	1.043
5	15	50	-15	80	1.01
8	10	80	-15	60	1.01
11	10	50	-10	50	1.082
13	12	80	-15	60	1.071

Table A.1 Generator power data

Line No	From Bus	To bus	Series Impedance (p.u)		Taps
			Resistance	Reactance	
11	6	9	0	0.208	0.978
12	6	10	0	0.556	0.969
15	4	12	0	0.256	0.932
36	28	27	0	0.396	0.968

Table A.2 Transformer data

Gen No.	a	b	c
1	0.012	12	150
2	0.0096	9.6	96
3	0.013	13	105
4	0.0094	9.4	94
5	0.001	10	100
6	0.002	9.8	95

Table A.3 supplier cost curve characteristics

Bus No.	Load	
	Real(MW)	Reactive(MVAR)
2	21.7	12.7
3	2.4	1.2
4	7.6	1.6
5	44.2	19
7	22.8	10.9
8	30	30
9	0	0
10	5.8	2
12	11.2	7.5
14	6.2	1.6
15	8.2	2.5
16	3.5	1.8
17	9	5.8
18	3.2	0.9
19	9.5	3.4
20	2.2	0.7
21	17.5	11.2
22	0	0
23	3.2	1.6
24	8.7	6.7
25	0	0
26	3.5	2.3
27	0	0
28	0	0
29	2.4	0.9
30	10.6	1.9

Table A.4 Load bus data

Line No.	From bus	To bus	Resistance(p.u)	Reactance(p.u)	1/2*B	Line limit(MW)
1	1	2	0.0192	0.0575	0.0264	50
2	1	3	0.0452	0.1852	0.0204	50
3	2	4	0.057	0.1737	0.0184	50
4	3	4	0.0132	0.0379	0.0042	50
5	2	5	0.0472	0.1983	0.0209	50
6	2	6	0.0581	0.1763	0.0187	50
7	6	4	0.0119	0.0414	0.0045	50
8	5	7	0.046	0.116	0.0102	50
9	6	7	0.0267	0.082	0.0085	50
10	6	8	0.012	0.042	0.0045	50
11	6	9	0	0.208	0	50
12	6	10	0	0.556	0	50
13	9	11	0	0.208	0	50
14	9	10	0	0.11	0	50
15	4	12	0	0.256	0	50
16	12	13	0	0.14	0	50
17	12	14	0.1231	0.2559	0	50
18	12	15	0.0662	0.1304	0	50
19	12	16	0.0945	0.1987	0	50
20	14	15	0.221	0.1997	0	50
21	16	17	0.0824	0.1923	0	50
22	15	18	0.1073	0.2185	0	50
23	18	19	0.0639	0.1292	0	50
24	19	20	0.034	0.068	0	50
25	10	20	0.0936	0.209	0	50
26	10	17	0.0324	0.0845	0	50
27	10	21	0.0348	0.0749	0	50
28	10	22	0.0727	0.1499	0	50
29	21	22	0.0116	0.0236	0	50
30	15	23	0.1	0.202	0	50
31	22	24	0.115	0.179	0	50
32	23	24	0.132	0.27	0	50
33	24	25	0.1885	0.3292	0	50
34	25	26	0.2544	0.38	0	50
35	25	27	0.1093	0.2087	0	50
36	28	27	0	0.396	0	50
37	27	29	0.2198	0.4153	0	50
38	27	30	0.3202	0.6027	0	50
39	29	30	0.2399	0.4533	0	50
40	8	28	0.0636	0.2	0.0214	50
41	6	28	0.0169	0.0599	0.065	50

Table A.5 Line data