Power Loss Minimization by Optimal Capacitor Allocation and Network Reconfiguration using Modified Cultural Algorithm

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The foregoing thesis, entitled "**Power Loss Minimization by Optimal Capacitor Allocation and Network Reconfiguration using Modified Cultural Algorithm**" is hereby approved by the committee of final examination for evaluation of thesis as a creditable study of an engineering subject carried out and presented by **Vivekananda Haldar** (Registration No. 92344 of 2004–2005) in a manner satisfactory to warrant it's acceptance as a perquisite to the Degree of **Master of Power Engineering**. It is understood that by this approval, the undersigned do not necessarily endorse or approve any statement made, opinion expressed or conclusion drawn therein, but approve the thesis only for the purpose for which it is submitted.

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I hereby declare that this thesis entitled "**Power Loss Minimization by Optimal Capacitor Allocation and Network Reconfiguration using Modified Cultural Algorithm**" contains literature survey and original research work as part of my Degree of Master of Engineering in Power Engineering studies.

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

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Abstract

In a Power System, lesser quantity of power is received by the receiving end than the power sent by the sending end units. This loss of real power is basically due to the resistive line loss of transmission and distribution system. In this thesis, reactive power is minimized to some extent by optimally allocating capacitors locally resulting into minimization of active power loss. Doing reconfiguration of the network the load balancing is achieved which also results in real power loss minimization. A new heuristic soft computing technique called Modified Cultural Algorithm is applied for implementation of these schemes. The basic idea of this method is taken from Cultural Algorithm in which Population Space and Belief Space are two main components. Normative Knowledge, Situation Knowledge, Topographical Knowledge, Domain Knowledge and History Knowledge are the Knowledge sources of the Belief Space. These sources help to influence the Population Space to find out the optimal solution. Situation Knowledge and History Knowledge are only taken as Knowledge sources in the Modified Cultural Algorithm. Concept of Population Pool has been introduced in the formation of Population Space. Best individual of the population is stored in the Belief Space as Belief Space best individual and it is replaced by the new one when it is found to be better than the previous individual value. Taking the characteristic of Belief Space best individual, all the Knowledge sources are manipulated for implementation of Modified Cultural Algorithm. Belief space movements for the loss and cost reduction are shown for understanding the progress towards the optimal point. Two new operators named multiplication and addition have been introduced in the Situation Knowledge influence part. History Knowledge is also modified for the implementation of this algorithm. Five distribution systems and one practical transmission system are taken as test system for implementation of this method. Capacitor installation is done individually at four distribution system. Both network reconfiguration and capacitor allocation is done on 16 bus distribution system and one practical transmission system respectively. New tie line expansion concept is taken for reconfiguration in the transmission system. Only capacitor installation or network reconfiguration does not prove to be beneficial in technical and also in economical respect. This metaheuristic technique has again proved its efficiency in comparison to other heuristic techniques when a combinatorial optimization problem of capacitor allocation and network reconfiguration is considered for loss minimization.

Chapter One

1. Introduction

Network planning is a very important research area in the Power Engineering domain. Especially in the transmission and distribution system, network planning can improve the power quality as well as efficiency of the system. Transmission and Distribution loss is an unwanted phenomenon in the Power system. Generation Company generates power in the power plant. But the utility sector or the receiving end does not get the exact amount of generated power. In the transmission line 3-4% power is lost due to physical constraint of the line and voltage limit. In Indian scenario, Aggregated Transmission and Commercial loss or ATC loss is 30%. This ATC loss actually includes transmission loss, distribution loss and loss due to power theft or pilferage. It is well known that real power loss is inversely proportional to Voltage's Square. If the voltage level of the line is increased, then the real power loss can be reduced to some extent. The real power loss not only depends on the voltage level but also the nature of bus and its loading. However in developing country like India, Ultra High voltage transmission is yet to be achieved due to its high cost. So the alternative methods, which can be applied, are Reactive power compensation or VAR compensation by capacitor allocation and network reconfiguration by switching operation. China has decreased their transmission loss by VAR compensation. In developed country like USA dynamic VAR compensator is a very important thing for reactive power compensation. It is used as a mobile plant. Therefore considering transmission and distribution system, the research domain for the power engineer is now on this network planning and obviously on optimal reactive power compensation for power loss minimization.

1.1. Importance of this work

Now, the power industry is a deregulated industry. But the business has remained as a regulated one. The shareholders and regulatory authorities are giving pressure to the Distribution companies to improve operational efficiency of the system. Power loss is an unavoidable circumstance which affects the utility consumers badly. It is revealed from studies that power losses in distribution networks occur due to joule effect and it is 13% of the generated energy**.** This non-negligible amount of losses directly impacts the financial results and the overall efficiency of Power System. The percentage of real power loss in transmission system is lesser than that of distribution system. But the voltage level of transmission system is much higher than distribution system. So a small percentage reduction of loss in transmission system will be economically beneficial. Therefore, the methods for loss reductions are essential for achieving the financial target of the transmission and distribution companies. Network reconfiguration in the distribution network actually helps to reduce the real power loss of the system. The optimal reconfiguration is done by doing switching operation. Switching operation is nothing but sectionalizing switch removal and tie switch closing in a distribution system. In transmission system, network reconfiguration or transmission line expansion can also be done. Huge amount of loss reduction can be achieved by doing transmission system reconfiguration by tie line expansion. Active power losses can be lesser than the previous modification, done by reconfiguration, placing capacitor in series or in parallel to the system. This capacitor installation provides indirect reactive power to the grid and reduces the magnitude of reactive branch current. Shunt capacitor installation provides additional benefits. It improves the voltage profile, the power factor and the stability of the Power system. Voltage stability of Power System is becoming a serious issue as the load demand of the Power System is increasing day by day. It becomes necessary to find out the degree of voltage stability at the point of maximum loading or where the voltage crosses the limiting margin. It is also crucial because any kind of voltage mismatch can lead to voltage collapse of the total system. The identification of voltage disorder and the maximum loading point in the system is an important work but the necessary and important work is to remove the voltage mismatch and maintain the stability of the system. The reactive power compensation is a way which can improve the voltage stability.

1.2 Outline of the Thesis

In this work, active power loss has been minimized for distribution and transmission system through reactive power compensation by installing shunt capacitors at the buses and also by network reconfiguration operating switches in the distribution system and expanding tie line in the transmission system. Power loss minimization techniques have been described briefly in the chapter two. To find out the optimal configuration for capacitor allocation and network reconfiguration, metaheuristic technique is adopted as optimization tool. Basic idea and overview of optimization and soft computing techniques has been written in brief in chapter three. Application of these computational methods for power loss minimization especially by reactive power compensation is also described in this chapter. The soft computing taken in this work is Cultural Algorithm (CA). It is modified for implementation for this critical and complex problem of Power system. The basic concept of Cultural Algorithm and its implementation in

Power Engineering has been described in chapter four. The next chapter deals with the problem formulation and constraints handling. Problem formulations for capacitor allocation only as well as for both capacitor allocation and network reconfiguration are achieved in chapter five. Description of Modified Cultural Algorithm (MCA) and its implementation technique for network reconfiguration and capacitor allocation is elaborated in the chapter six. Six test systems have been taken to prove the efficiency of the Modified Cultural Algorithm (MCA). Standard 9, 16, 23, 34 and 69 bus distribution systems have been taken for installing shunt capacitors. Network reconfiguration and capacitor allocation has been implemented on the 16 bus distribution system and practical transmission system. Network reconfiguration is done in this practical system by doing tie line expansion rather than doing switching operation. All the results of the studied systems are described in chapter seven with relevant graphs and figures. Efficiency of this MCA is proved by comparative study with the published works. Finally, conclusion is drawn in chapter eight putting a small description for further work. Useful references of the concerned topic of the thesis are given thereafter. Line and load data of the 69 bus system and practical transmission system are stated in Appendix A.

Chapter Two

2. Power Loss Minimization

Active power loss in a Power System means the resistive loss or the line loss. Active power loss can be minimized by employing several techniques. Reactive power compensation by installing shunt capacitor can reduce the loss to some extent. Restructuring of Power System by doing network reconfiguration is another approach for loss minimization. Combination of reactor and shunt capacitor can be useful to minimize the loss. Distributed generation or distributed resources can be used with shunt capacitor for real power loss reduction. Flexible AC transmission system is also helpful in achieving the same reduction. Static synchronous generator with a storage device like battery, flywheel or superconductive magnetic energy storage can also be a good move for this loss reduction problem. Induction generator such as wind turbine couple generator can also be applied as a fixed and variable source for loss minimization. Power electronics controlled i.e., thyristor controlled compensation scheme is again helpful in this regard. But the exact combination or scheme for maximum loss minimization is yet to be achieved.

The Power System is becoming complex and critical day by day. Deregulation in the market has put a pressure to the power companies. So, to have the maximum profit and minimum loss, power companies should think of a good scheme which can give the targeted economical benefit in this competitive market. Power loss minimization by installing capacitor and reconfiguring the network has been economically beneficial in comparison to other techniques. Capacitor installation to the buses is nothing but shunt compensation of reactive power. The concept of shunt compensation as chosen for loss minimization is discussed in the next section 2.1 and benefits of doing optimal capacitor allocation and network reconfiguration in Power System is discussed in section 2.2.

2.1 Compensation in Power System

Compensation in Power System is of two types. One is load compensation and the other is line compensation. Load compensation helps to improve the quality and efficiency of the system in many ways. If surge impedance loading of the line corresponds to the line loading, then a flat voltage profile can be achieved. Compensation device should be chosen keeping the above mentioned idea in mind. If appropriate compensation device is installed in line, then the effective surge impedance will yield virtual natural load concerning the actual load of the line.

This type of compensation is called compensation of surge impedance loading. In the practical system, the demand curve is not smooth. It is varying in every instant of time. So, to have surge impedance loading equal to the natural loading of the line, compensation device should be operated according to the variable load condition. The compensating devices should be the right combination and connection of capacitors and inductors in the lines. Like the previous compensation of surge impedance loading [1], compensation by sectioning of the line is another kind of useful compensation technique. It can be achieved by dividing the line into sections. It is used to avoid under excited operation of alternator or charging current problem. Constant voltage compensators are connected to achieve this compensation at intervals along the line. The smallest section of the line will decide the flow of maximum power and in this way power transfer capability will be increased enhancing the stability of the system. Line length compensation can be achieved by placing capacitors in series with the line. The inductive reactance of the line can be minimized by placing capacitors in series with the line. This reduces the effective length of the line. Series compensation should not be exceeded beyond 80% when the line is 100% compensated. If the limit crosses the margin, then the activity of the line will be changed to a purely resistive one. Series resonance may be resulted even at fundamental frequency. It will create difficulty to control voltages and currents during the abnormal conditions. Even a small disturbance in the terminal alternator rotor angle has the capability to flow huge amount of current. Economical factors and severity of fault current is equally responsible for the location selection of series capacitors. Maximum fault current through the capacitor is the deciding factor for selection of the voltage rating of the capacitor. So, it will be beneficial to use small number of smaller units of capacitors to minimize the sharp change of voltage. This sharp change of voltage can cause different voltages on the two sides of the line. Series or shunt capacitive compensation is necessary for transmitting power over long distances. Flat voltage profile of the network and also stability of the system can be achieved by doing reactive power compensation efficiently. Electrical characteristics of the line can be modified by doing compensation of line which is described below.

- Flat voltage profile can be achieved in all loading conditions. Ferranti effect can also be minimized.
- The chances of under excitation of alternator can be prevented by doing reactive power compensation.
- Power transfer capability and stability of the system can be increased due to reactive power compensation of the system.

Among the entire compensation scheme, shunt compensation is beneficial as reactive power compensation for loss minimization. The cause of it is described in the next section.

2.1.1 Shunt Compensation

Shunt compensation is of two types. These are shunt inductive and shunt capacitive compensation. Shunt compensating reactors are connected at the substation or at the midpoint of the line. It is not uniformly distributed throughout the line. Automatic control of the shunt capacitive compensation helps to maintain the voltage at a constant level. The effect of shunt capacitive compensation is continuously distributed throughout the line. Shunt compensation can control surge impedance loading. Surge impedance loading can be made equal to the actual loading by doing shunt compensation. Normal frequency overvoltage can be prevented by doing shunt compensation. In a double circuit line, shunt compensation can be employed in any one circuit when the other circuit is in breakdown condition. Series compensation is not advantageous compensation. The phenomenon of sub synchronous resonance may occur due to series compensation and it can further proceed to the breakage of shaft between the exciter and the alternator. Shunt compensation is advantageous in comparison to series compensation. The merits of shunt compensation are discussed below.

- There is no danger of sub synchronous resonance in shunt compensation. Natural frequency is super synchronous for shunt compensation. It is not super synchronous only for high degree of shunt compensation and long distance transmission line. So, chances of breakage of generator shaft and exciter are much less.
- Unlike series compensation shunt compensation is done to buses. Shunt compensation requires less amount of reactive power than series compensation for improving same amount of voltage and maintaining stability of the system.
- Shunt compensation is almost protection free. It is not generally damaged by short circuit or any fault condition of the system.

The shunt capacitive compensation is required when the alternator active power output is greater than the surge impedance loading of the line. Huge amount of power can be transmitted by doing shunt compensation. But in the practical system, it requires large amount of capacitors. The alternative methods available for this purpose are higher transmission voltage, use of series capacitors or HVDC etc. But these methods suffer from some limitations. High speed of response of the compensator and the failure of regulating and controlling mechanisms are the limitations. This total system may become unstable due to this. Switched capacitors should be disconnected from such line under light load condition. If it is not done, then it may lead to the ferroresonance of the line. In series compensation, series inductive reactance of the line is cancelled out by the use of series capacitors. Maximum transmittable power, transmission angel of line and the surge impedance can be increased by doing series compensation. It can minimize the series inductive reactance of the line and for the effect of it line charging reactive power absorption will be minimized. The voltage will be reduced in the effect of this compensation. So to maintain the voltage limit, shunt compensation is necessary. The next section described the advantage of shunt compensation for loss reduction and the technique to maintain quality power at stable condition. In the next section importance of shunt capacitor allocation with network reconfiguration is also briefly discussed.

2.2 Optimal Capacitor Allocation and Network Reconfiguration

At present, the Power System is large, complex and critical. Three phase unbalance is a serious issue in distribution feeder. The severity is due to the availability of three types of phases i.e., single, two and three phases in the distribution feeder. The variation of phases is due to industrial, commercial and household customer. Customer demand is responsible for varying the feeder loading and it affects the load forecasting of a particular area. It actually depends on the nature of electricity consumption of that locality and it is totally dependent on the quantity and quality of residents or consumers of that area. Therefore an optimized scheme should be incorporated in the system to have minimum loss with economical benefits. This micro level objective can be approached by doing capacitor allocation at the sensitive load buses with optimum value. Network reconfiguration can be done with capacitor allocation to have more benefits. Reconfiguration of the network balances the conglomerated load. If there is a lump of load at a certain bus, then by shifting the load efficiently to another light load bus can reduce the active power loss. It also stabilizes the system and maintains the nominal voltage at the buses. Though with the prevailing condition of Power System capacitor allocation and network reconfiguration is very much tough and cumbersome approach to reduce the line loss. But it is a useful and less hazardous way to minimize the line loss economically.

However physically it is a well understood fact that capacitor allocation and network reconfiguration is necessary for loss minimization. But it requires a mathematical study for searching the exact configuration i.e., sensitive bus locations and optimal values of capacitor and the optimal switching operation. These days, optimization techniques mainly soft computing techniques are accepted as mathematical tool for searching the best configuration. Soft computing techniques especially Metaheuristic Techniques such as Genetic Algorithm, Particle Swarm Optimization etc. are recently used for searching optimal configurations. Basic overview of optimization technique and application of it for real power loss minimization are described in the next chapter.

Chapter Three

3. Optimization Technique and Soft Computing

Optimization technique is a special branch of mathematics and computer science. Optimization means finding the best one from a set of alternatives. The objective of the optimization problem is either minimization or maximization of a defined function. Actually it means searching of best available value for a certain objective function for a particular domain. The major subfields of optimization are of several types. These are Convex Programming, Integer Programming, Quadratic Programming, Nonlinear Programming, Stochastic Programming, Robust Programming, Combinatorial Optimization, Infinite-dimensional Optimization, Heuristic Algorithms, Constraint Satisfaction, Disjunctive Programming and Trajectory Optimization. The optimization techniques are also designed on dynamic context. Examples are Dynamic Programming, Calculus of Variation, Optimal Control and Mathematical Programming with Equilibrium Constraint. On the basis of characteristics it can be Multi objective, Multimodal and Dimension less problem. The optimization technique is primarily of two types in respect of variables. These are Single Variable Optimization and Multi Variable Optimization. Apart from all these variations of optimization techniques, Heuristic Techniques or Heuristic Algorithm is applied at a higher rate for real world engineering problem. The term soft computing begins from this. It mainly means the metaheuristic technique. Heuristic algorithm is generally applied in such a problem where there is no known method to find out the solution of it. Heuristic means to find and ‘meta’ is a Greek word which means beyond or at a higher level. So, Metaheuristic Methods are higher level searching methods. These are actually applied in Combinatorial Optimization problem. Combinatorial Optimization deals with discrete mathematical object such as a bit of string or permutation which helps to maximize or minimize the metaheuristic’s objective function. Every metaheuristic technique has a generation and mutation operator. It changes the current value with the obtained best value with a state transition rule and finds a neighbor of this best value by doing mutation. In this way it proceeds towards the maximum or minimum according to the objective function. Researchers have been studying soft computing for 58 years. Every year new techniques are coming in the research domain. Some well known soft computing methods are Random Optimization, Local Search, Reactive Search Algorithm, Cuckoo Search, Greedy Algorithm, Genetic Algorithm, Simulated Annealing, Particle Swarm Optimization, Ant Colony Optimization, Tabu Search, Cultural Algorithm, Artificial Bee Colony Algorithm and Random-Restart Hill Climbing Algorithm etc. All these algorithms have been formulated taking the concept of biological science and social science. These soft computing techniques do not give the exact solution of the problem but provides efficient technique to reach a global solution of the real world complex problem. In this Thesis Cultural Algorithm has been taken for finding the optimal configuration for capacitor allocation and network reconfiguration problem. It is discussed in the next chapter. In the next section a useful study of published work regarding loss minimization especially by reactive power compensation is briefly denoted. A few of the above mentioned optimization and soft computing techniques have been used for finding the solution of the problems.

3.1 Different Optimization and Soft Computing Methods applied for Loss Minimization in Power System

Different Techniques are adopted for loss Minimization by capacitor allocation and network reconfiguration. Researchers, scholars, scientists, and practicing engineers have been working for several years in this particular field of Power Engineering. They have been working since 1960 but yet to approach a suitable and ideal scheme for loss minimization in a Power System. Many heuristic and metaheuristic methods are applied to solve the highly constrained problem. Artificial intelligence has also been applied. All these techniques will be discussed in brief in the following sections for optimal capacitor placement and also for network reconfiguration.

3.1.1 Analytical Approach

At the earlier days the capacitor allocation problem was generally solved by analytical method. Chang [2] had mathematically analyzed the shunt capacitor allocation for loss reduction in distribution feeder. Loss reduction by installing capacitors on primary feeders was studied in [3]. It was studied that capacitor installation at the load end would be beneficial rather than placing it in the substation. Size of capacitor bank was limited by voltage, strength of pole on which the capacitor would be placed and the fuse or switch ability. Reliability of the system was also studied in this paper for capacitor placement. Capacitor placement in unbalanced Power System was studied in [4]. Loss and cost minimization was done placing optimal value of capacitor in every phase. Three phase power flow equation was studied considering capacitor limit and harmonic limit. Baran et.al [5] had studied optimal capacitor placement on radial distribution system considering two types of capacitors. One is fixed capacitor and the other one is switched capacitor. The capacitor allocation problem was studied into two segments. Slave problem was defined to find out the capacitor sizing at the particular bus location with the known capacitor type and Master problem was used to find out the sensitive nodes among the entire test feeder. The first one is a non-linear differentiable optimization problem and the last one is an integer programming problem. A method was proposed in [6] for optimum size and location of shunt capacitors for reduction of losses in distribution feeder. The capacitor was allocated on the distribution feeder by doing power factor correction. In this way the power quality had also been improved in this approach. Cost benefit after reactive power compensation had been extensively studied in [7]. In this approach optimal cost benefit was the objective function. The goal was achieved successfully considering the project as a yearly basis.

3.1.2 Genetic Algorithm Approach

Genetic Algorithm (GA) has been successfully implied for reactive power compensation. Genetic Algorithm is applied for a practical case study [8] of Muscat electricity network. GA has a few operators for modifying the old population and creating the new population from the old one. *Crossover*, *Reproduction*, *Selection* and *Mutation* operators are used for the modification. Population is formulated using the concept of binary bits. For GA implementation, the population actually defines the capacitor size and status. In this capacitor allocation problem, capacitor size and status are represented by a string of binary bits. Suppose a capacitor is represented as 10000, and then the first bit of it signifies whether it is on or off. In this approach '1' and '0' are taken for on and off status. The remaining bits represent the capacity of the capacitor. In the above example, the capacitor is on but it is working with minimum capacity level. 11111 represent a capacitor which is working with its full capacity. To represent each type of capacitor, a new string is formulated. It is a concatenation of two strings and it consists of 10 bits. If the string 1111100000 is connected at some node, then it signifies that at the node only one capacitor is working with its full capacity. In this approach, it is assumed that only one capacitor can be placed at one node. The total string represents the capacitor size and also location where to be placed. If a big string consists of 20 strings then it actually consists of 200 bits for the whole system. After formulating the initial population, each chromosome of the population set is tested by the load flow solution method. If the solution results power factor and voltage mismatch from the set range, then this solution is cancelled. Every chromosome is tested by the objective function and fitness value. If the convergence is achieved, then the best chromosome value is selected as the optimal one. Otherwise new population is created by reproduction mechanism and modification of the population is done by crossover and mutation operators. In this way the population progresses towards best solution and finally gives the optimal solution. GA is reliably applied for the large low voltage and medium voltage distribution system in this approach.

Optimal Sizing of fixed capacitor banks is done by GA [9] for distorted interconnected distribution network. The capacitor allocation problem considering capacitor cost, capacitor size, voltage and harmonic constraints is a very difficult and complicated problem. Switchable and fixed capacitors are two options for allocation. Simplifying the analysis, only fixed capacitor value is taken in this paper. For GA implementation, each chromosome is selected as a binary bit of string. After formation of the initial population, fitness function is evaluated for selection of the best chromosome. *Top mate* selection procedure is adopted from Top mate, Roulette rank/cost, Tournament and Random selection procedure. After the completion of selection procedure, Crossover operation is done. *Blending method* is adopted to do the crossover operation. Mutation operator changes one or more bits of the binary string for the formation of new chromosome. *Min-max* method is adopted to mutate the gene in this approach. Finally the simulation is terminated using the *maximum generation* criteria. Crossover and Mutation probability are taken 0.95 and 0.1 respectively. Number of population and number of generations are selected 80 and 50 respectively. Like capacitor allocation, Genetic Algorithm [10] has been applied for network reconfiguration in distribution system. Radiality of the network is maintained in every computation for sectionalizing switch opening and tie switch closing. Only one sectionalizing switch is opened for one tie switch closing. Coding technique is introduced to chalk out the participating branches, loops and tie switches. Bit of '0' and '1' is taken to form chromosome. Initial population is generated randomly. Selection of best individual is done by taking the roulette wheel parent selection technique. This technique chooses the high probable solution for participating in the next generation. The concept of elitism is also included in this GA approach. Crossover, mutation and cloning are the GA operators. They are introduced to find new off spring for the next generation. This stochastic procedure continues on until the iteration number reaches the maximum set value and at the final step the best individual of the population is taken as the optimal solution.

3.1.3 Particle Swarm Optimization Approach

Particle Swarm Optimization (PSO) has been implemented for optimal capacitor placement by Yu et.al [11] considering harmonic distortion. In PSO, a particle represents a potential solution. Every particle moves in the search space and updates its velocity from its own experience and also from its surrounding particle's experience. A particle i is considered as a volume less particle in a D dimensional space. It is represented as $X_i = (x_{i1}x_{i2}, \dots, x_{iD})$. The position and velocity are evaluated by the fitness function. They are associated with the best fitness value at a certain moment. The position is expressed as $P_i = (p_{i1}, p_{i2}, \dots, p_{iD})$ and the best global position is represented as $P_g = (p_{g1}, p_{g2}, \dots, p_{gD})$. Velocity for particle i is expressed as $V_i = (v_{i1}, v_{i2}, \dots, v_{iD})$. The velocity of every particle is updated by an equation. It is described as:

$$v_{id}(t+1) = \omega . v_{id}(\mathrm{t}) + rand(0,c_1).\left(p_{id}(t) - x_{id}(t)\right)$$

$$+rand(0,c_2).\left(p_{gd}(t) - x_{id}(t)\right) \qquad (3.1.3.1)$$

The position of particle is also updated like this:

$$x_{id}(t+1) = x_{id}(\mathrm{t}) + v_{id}(\mathrm{t}+1) \qquad [11] \qquad (3.1.3.2)$$

ω represents the weighting factor. c_1 and c_2 represents two acceleration constants which give an acceleration to the particle to reach towards the best position. The first and the second one help to reach individual best position and overall best position respectively. $rand(0, c_1)$ and $rand(0, c_2)$ are two random functions which create random values in the range $[0, c_1]$ and$[0, c_2]$. Initial population of array of particles is generated taking random position and velocities in a D dimensional space. D is the product of total number of load levels and number of nodes studied in the system. For every load level, AC load flow calculation and harmonic load flow calculations are done. Type of capacitor is tested in every compensation level. After that for every particle cost function which is the objective function is tested and if any constraint value reaches out of the set range, then a penalty function is set to that. After evaluation of the objective function for each particle, the fitness value is compared with the individual best. If the particle fitness value is better than the individual best, then it is set as the individual best and its position is recorded. The minimum fitness value is chosen for the selection of global best among all the particles and the particle of least fitness value is set as the global best. For each particle the velocity and position are updated by (3.1.3.1) and (3.1.3.2). The feasibility of the new particle is confirmed by checking the dimension of the number of capacitors for the system. If iteration number reaches the maximum number of iteration, then the computation procedure is stopped and the best solution or particle is considered as the optimal solution. Otherwise computation procedure continues until the iteration number reaches the maximum iteration number.

PSO [12] is implemented as a swarm intelligence method for capacitor allocation in a radial distribution system. In this approach loss sensitivity factor is considered. How PSO is implemented is described below.

First of all the active power loss is calculated by using the base case distribution load flow. Then solution or candidate buses are identified using the loss sensitivity factor. In the next step, a population of particles is generated. Thereafter particle velocities are generated within the range of $-vmax$ and $vmax$.

$$vmax = (Capmax - Capmin)/N. \quad [12] \tag{3.1.3.4}$$

In (3.1.3.4), $Capmax$ and $Capmin$ defines the maximum and minimum capacitor rating in KVAR and N denotes the number of steps to move the particle from one position to another position. Load flow calculation is done for each particle and active power loss is stored. If a particle's fitness function value is better than the previous one, then the current particle position is considered as the position best. The global position best is selected considering all particles if current global value is better than the previous one, then it is considered as the global best position otherwise the previous global best position remains at that position. Thereafter the velocity is updated using the individual best and global best position as follows:

$$v[i][j]$$

$$= k(w.v[i][j] + c1.rand1.(pbestparticle[i][j] - particle[i][j])$$

$$+c2.rand2.(gbestparticle[j] - particle[i][j])) \; [12] \tag{3.1.3.5}$$

Where, $particle[i]$, $pbestparticle[i]$, $gbestparticle[i]$ and $v[i]$ represents the position of individual i, best position of individual i, best position among the swarm and velocity of individual i respectively. The limits of the velocity are checked. If it violates the set limit, then it is set at proper limits. The position of the particle is updated by adding the modified velocity to it. After the modification of position and velocity, active power loss is calculated for the newly created population. Until the termination criterion is achieved, the above mentioned procedure continues on and finally the program is terminated at the optimal value.

PSO [13] has been applied in distribution system reliability enhancement by placing capacitor optimally. In this paper, the value of maximum capacitor is an integer multiple of smallest capacitor value and the integer is fixed considering the feasibility of capacitor allocation in a real system. The solution procedure is described below. Parameters of PSO such as size of particle, weighting factors, weighting function, maximum number of iterations and other necessary parameters are determined collecting the distribution system data such as load of buses, line data, compensated and uncompensated failure rates and base voltage. Initial particle positions and velocities are randomly selected. $Pbesti$ and $gbest$ related to each particle are evaluated using the reliability based objective function. In order to evaluate the objective function, distribution power flow is studied and the active power loss of the feeder is determined. Reliability factor is calculated using the results of power flow. The values of new velocities and positions are calculated using (3.1.3.6) after evaluation of the objective function.

$$V_i(k+1) = \omega.V_i(k) + C_1.rand1.\left(Pbest - X_i(k)\right) + C_2.rand2.\left(gbest - X_i(k)\right)$$

$$\omega = \left(\frac{\omega_{max} - \omega_{min}}{itermax}\right).iter$$

$$X_i(k+1) = X_i(k) + \Delta t.V_i(k+1) \quad [13] \qquad (3.1.3.6)$$

Position best and global best are updated. The above computation procedure continues until iteration number reaches to the defined maximum number of iteration or if the objective function is not minimized after a certain number of iterations. Since the capacitor placement is not an online study for distribution systems, its computation solution time is not a significant issue. However, in order to avoid excessive computation time for large feeders a compromise between the population and iteration number has to be done to achieve the balanced and acceptable solution.

3.1.4 Ant Colony Optimization Approach

Ant Colony Optimization (ACO) has been implemented by Chang [14] for reconfiguration and capacitor placement to reduce the real power loss of the distribution system. Ant Colony Search Algorithm is based on the behavior of the ants. Ant is a small creature, which finds its food by a searching process. It emits pheromone hormone and by the intensity of that hormone it can easily detect the shortest or the optimal path from their nest to the food source. It finds the path by forming a colony like structure where several ants are involved in it. The hormone pheromone is updated by using state transition rule and local and global pheromone updating rule. State transition rule is shown in (3.1.4.1). It defines the probability with which ant k in node i chooses to move in node j. τ is the pheromone intensity. The inverse of edge distance is defined by η. $J_k(i)$ denotes the set of nodes that remain to be visited by ant k which is on node i. The relative importance between pheromone versus distance is determined by parameter β.

$$p_k(i,j) = \frac{[\tau(i,j)][\eta(i,j)]^{\beta}}{\sum_{m \in J_K(i)}[\tau(i,m)][\eta(i,m)]^{\beta}}, \qquad if\ j \in J_k(i)$$

$$= 0, \qquad otherwise \text{ [14]} \qquad (3.1.4.1)$$

Every ant updates its pheromone intensity by local updating rule (3.1.4.2) and the global updating rule (3.1.4.3).

$$\tau(i,j) = (1-\rho)\tau(i,j) + \rho\tau_0 \qquad (3.1.4.2)$$

$$\tau(i,j) = (1-\sigma)\tau(i,j) + \sigma\delta^{-1} \text{ [14]} \qquad (3.1.4.3)$$

Here a node in the Ant Colony Search represents a different selection of capacitor for a bus in the capacitor allocation problem. The edge distance of the edge connecting the node i and node j represents the cost of the capacitor added at bus j $(j = i + 1)$. A particular bus is bus 1, the edge distance of the edge connecting the S/S bus (i.e., bus = 0) and the bus1 represent the cost of the capacitor added at bus 1. In this approach, the whole procedure is described by taking an example of a 5×5 capacitor placement matrix, shown in Figure 3.1. The column defines the bus and the rows define the capacitor size. There are five buses and each bus has five capacitor sizes.

$$\begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 2 & 2 & 2 & 2 & 2 \\ 3 & 3 & 3 & 3 & 3 \\ 4 & 4 & 4 & 4 & 4 \\ 5 & 5 & 5 & 5 & 5 \end{bmatrix}$$

Figure 3.1 A 5×5 Capacitor Placement Matrix [14]

The path indicated in Figure 3.1 means that the capacitor sizes 3, 2, 3, 1 and 4 have been chosen for the buses 1, 2, 3, 4 and 5 respectively. Each bus has five available capacitor sizes and from each bus to its next bus there are five edges. There are five edge distances and five amounts of pheromone hormones corresponding to these five edges. It is assumed that five ants are moving from bus 1 to bus 5 with five different paths. The first path is indicated as [2 1 2 1 3]. It defines that the path for ant is from node 2 of bus 1 to node 1 of bus2 and proceeding to node 2 of bus 3 then node 1 of bus 4 and finally node 3 of bus 5. This path means that the capacitor sizes 2, 1, 2, 1 and 3 are chosen by the bus 1 to 5. Path distance of this path is assumed as 200. It is the sum of the edge distance of itself. In this problem, path 1 having a path distance of 200 means that capacitor placement [2 1 2 1 3] is 200. The average edge distance for this path is calculated as 200/5 = 40, because every path has five edge distances .The inverse of the average edge distance is determined as $\eta = 1/40$. The distance of the globally best tour is found out from the distance set. $\tau(i,j)$, τo, ρ, σ and β are initially set to 0, 0.1, 0.05, 0.1 and 1 respectively. Local pheromone intensity $\tau(i,j)$ is determined by applying the local updating rule (3.1.4.2). This local $\tau(i,j)$ is then substituted in the global updating rule (3.1.4.3). Finally this global $\tau(i,j)$, η and β are substituted into this state transition rule (3.1.4.1) to determine the probability of these five available capacitor sizes to be selected for installation. The best traversed path among the entire path, achieved by probability calculation, is selected as the global best path for that particular iteration. Similar search procedures is continued to get the final convergent solution of the Ant Colony Search procedure.

ACO has been implemented by Bouri et. al [15] for shunt capacitor allocation in radial distribution system. In this paper medium voltage reactive power planning procedure is adopted. Station capacitor banks are installed on the secondary side of the station transformer with pole mounted capacitors on the downstream distribution feeder. Economical advantages are achieved after capacitor allocation. Transmission and transformer KVA capacity are released. Overall system peak-load losses and annual system energy loss has also been reduced to some extent. The problem is represented as a graph. Edges of the graph are denoted as capacitor value or available capacitor size and allocation. Nodes represent the capacitor 'on' positions or 'off' positions respectively. For implementation of ACO, each ant is considered as a possible solution of the problem. Pheromone hormone is deposited in the path of search and greedy searching method is applied by state transition rule. The rule is implemented stochastically to have a feasible solution. The cost objective function is evaluated for each ant. Local pheromone and global pheromone are updated after the evaluation of the cost objective function. This procedure is continued on until the termination condition is achieved and finally the best feasible solution is taken as the optimal solution for this problem.

Filho et.al [16] has efficiently implemented ACO as a metaheuristic technique for shunt capacitor allocation in radial distribution systems. Two types of information have been used to find the solution of the problem. One is pheromone level information and the other is heuristic level information. Pheromone level represents the desirability of a solution component, which is ant and heuristic level is taken for having the prior information about the problem. Nodes are selected by the ant for adding capacitor with the probabilistic rule. The intensity of pheromone hormone increases as the searching procedure progresses. In this approach, the solution space for capacitor allocation problem is taken as a matrix. Every column of the matrix contains a certain number of nodes which signifies the bus number and the number of row is used to denote the capacitor bank.

3.1.5 Fuzzy Logic Approach

Fuzzy Logic has been successfully implemented by Mekhamer et.al [17] for optimal capacitor allocation in radial distribution system. The Fuzzy set is a generalized Crisp set. In Fuzzy logic, there are few operators. The AND operator, OR operator, Product of Two Fuzzy Sets, The Extension Principle and The Extreme of Fuzzy Function. Actually these operators yield membership functions. The AND operation gives the membership function of intersection. If A and B are two fuzzy sets with membership function $\mu_A(x)$ and $\mu_B(x)$, then the membership function of intersection is given as:

$$\mu_{A\cap B}(x) = \min\left(\mu_A(x), \mu_B(x)\right) \quad x \in X \text{ [17]} \qquad (3.1.5.1)$$

The OR operation gives the membership function of union. It is expressed as:

$$\mu_{A\cup B}(x) = \min\left(\mu_A(x), \mu_B(x)\right) \quad x \in X \qquad (3.1.5.2)$$

Product of two fuzzy sets is expressed as a membership function.

$$\mu_{A.B}(x) = \mu_A(x) * \mu_B(x) \quad x \in X \qquad (3.1.5.3)$$

The Extension Principle is expresses as:

$$\mu_{f(A)}(y) = \max[\mu_i(x_i)] \quad where\ x_i \in U, f(x_i) = y \qquad (3.1.5.4)$$

It is defined that if f maps more than one element of U to the same element y in the set V, then maximum of the membership grades is taken. Extreme Fuzzy Functions define the maximizing set as:

$$\mu_M(x) = \frac{(f(x) - inf.(f))}{(sup.(f) - inf.(f))} \quad [17] \qquad (3.1.5.5)$$

This above fuzzy logic has been applied to the cost function which is the objective function of this capacitor allocation problem. For the implementation of fuzzy logic, two membership functions are formulated. One is for voltage and the other is for power loss. They are described as:

$$\mu_V(i) = \exp\left\{-w\left[\frac{v(i)-1}{v_{max}-v_{max}}\right]^2\right\} \qquad (3.1.5.6)$$

$$\mu_p(i) = \exp\left\{\frac{-wL(i)}{Tloss}\right\} \qquad (3.1.5.7)$$

The AND operator is taken for the decision making purpose. The decision membership function is expressed as:

$$\mu_p(i) = \min\{\mu_V(i), \mu_p(i)\} \quad [17] \qquad (3.1.5.8)$$

Solution procedure is described as follows. Bus voltages and the sectional losses are calculated after studying the load flow program. Membership function for voltage, power loss and decision membership functions are calculated. Candidate node is found out using the lowest membership function. Without violating the capacitor limit, a capacitor is installed at that particular bus and real power loss is calculated doing load flow study. If voltage is not improved, then again membership function should be found out otherwise new capacitor should be placed at the chosen buses. The real power loss and the cost function are again calculated. The procedure continues on until cost function decrement is stopped. The author of this paper has studied 5 methods. The above method is the first one. The best method described in this paper is method 4 and 5. In this method the system has two components. One is the loss due to active current and the other due to reactive current. After performing load flow solution, change in the system losses for every node is found out by selecting suitable capacitor, which causes the maximum power loss change. The value of the capacitor is defined as Q_{ck} which satisfies an equation .The differential equation is described as;

$$\frac{\partial P}{\partial Q_{ck}} = 0 \quad [17] \tag{3.1.5.9}$$

If the available capacitor size is not exactly the accurate one like the chosen value, then nearest capacitor size is taken. After installing the capacitor at the node, load flow calculation is done. If the voltage limit is violated after installation of that capacitor, then next maximum loss change node is considered for capacitor installation. In this way the procedure of optimal capacitor allocation continues on. If cost due to loss and capacitor installation not decreases, then the capacitor value and the sensitive nodes are taken as the optimal solution.

Fuzzy-Genetic Algorithm [18] has been studied for optimal capacitor placement in radial distribution system. Best locations and the optimal size of capacitors are identified using fuzzy set theory. The problem is considered as the maximization problem. In the capacitor placement problem, node voltages and the real power loss indices are taken as the inputs. Capacitor Suitability Index (CSI) is defined in this approach as a suitability index for every node in the total feeder. Best sensitive nodes are chosen considering the higher values. Real power loss indices are the next input to this fuzzy expert system. It is calculated after the load flow solution. The power loss indices are normalized within the range of 0 and 1. Location of the capacitors, the voltage and power loss index at each bus location are represented in Fuzzy membership function. Fuzzy Inferencing and Defuzzification techniques are adopted after the Fuzzy Expert System gets the input from the load flow solution. The MAX_MIN method is used for truncating the membership function of each fired rule at minimum value. A final solution for membership function is obtained in this approach by taking the all union of all the truncated membership functions. The membership functions are all consequent in nature. Capacitor placement suitability membership function of node i for k fired rules is expressed as:

$$\mu_S(i) = maxk[\min[\mu_P(i), \mu_V(i)]] \quad [18] \tag{3.1.5.10}$$

In (3.1.5.10), μ_P and μ_V are the membership functions for the power loss index and voltage respectively. Suitability membership function of a node must be defuzzified to determine the rank of node suitability. Centroid method of defuzzification finds the center of area of the membership function. In this case, Capacitor Suitability Index (CSI) is expressed as:

$$S = \int\{(\mu_S(z)zdz)/(\mu_S(z)dz)\} \quad [18] \tag{3.1.5.11}$$

In (3.1.5.11), S is the cost of objective function, $\mu_S(z)$ is the membership function and z is the height of the membership function. The solution procedure for candidate node selection is described as follows. Total active power loss of base case system is calculated after load flow solution. The power loss reduction and the power loss indices are calculated after this by doing self reactive power compensation. The Power Loss Index and per unit load voltages are taken as inputs to the Fuzzy Expert System (FES). In the next step, Defuzzification is done to the outputs of the Fuzzy Expert System and it gives the ranking of CSI. The highest value of CSI connected to the nodes signifies the optimal solution for the FES. The technique which is applied in this paper is a Fuzzy-Genetic approach. The Genetic Algorithm part is described below. GA is applied for getting the optimum values of capacitors using FES on a radial distribution system. The objective function is maximized keeping the voltages within the set limits. The population is formed considering each string as a list of numbers varying from 0 to 3. The number of capacitor banks at a node is represented by every digit. The total number of digits in a string signifies the total number of candidate buses for selection. Every digit is multiplied with the size of the capacitor for reactive power compensation. Binary representation of a string is not considered to avoid complexity and excess computation time. GA based capacitor sizing procedure is defined briefly in the following section. Population of candidate nodes is generated for sizes of capacitors randomly at the initial stage. Load flow is studied to have voltage at the buses and the active power losses. Fitness function value for each individual is calculated. Roulette Wheel selection method is applied for selection of parent string. Crossover and mutation operation are taken into action for obtaining new strings for next generation. The above procedure is continued on until the difference between the fitness and the average fitness is less than the specified error.

Venkatesh et.al [19] has implemented the Fuzzy Evolutionary method to solve the capacitor allocation problem. Fuzzy model of profit and voltage violation objective are formulated choosing membership function. Fuzzy intersection operator is chosen to form overall fuzzy model of the objective function. The simple product is taken as the intersection operator for this problem. The procedure, adopted, in this paper is described below. A number of solution vectors are generated randomly at the initial period. The overall objective function is evaluated for each individual solution vector. Again a number of solution vectors are generated through a random procedure and evaluated with the same objective function. Now the best individual among the two solution vector sets is chosen. The procedure continues on until the iteration reaches the maximum iteration number. Finally the best individual value is selected from the best solution set. In this approach, data structure of the solution vector is arranged in such a way that the data and structure of the solution can be altered dynamically in each iteration. This helps the searching procedure to become faster.

3.1.6 Heuristic Approach

Heuristics Search Strategies [20] for capacitor placement has been studied in the distribution system. In this approach, cost saving is given more importance than the loss reduction. The computation time and the complexity of the simulation procedure are significantly reduced by this heuristic approach. The test system which is considered for simulation is a balanced three phase network with balance three phase voltages. The effect of harmonics is not considered. Load currents are not dependent on the node voltages. The solution procedure for getting optimal bus location and capacitor values is described in the following section. The peak power loss for the test system is computed and it is checked for each bus to find out the largest effect of reactive power compensation. The sensitive bus or node is selected on the basis of highest impact or change in loss. The capacitor should be placed at that particular node to reduce the real power loss. The capacitor size Q_{ck} is chosen for the sensitive nodes by a certain equation. It is expressed as:

$$\frac{\partial S_k}{\partial Q_{ck}} = 0 \qquad [20] \qquad (3.1.6.1)$$

The value of capacitor is calculated considering the problem as a saving maximization problem. After getting the capacitor value, load flow study is performed for having new values of the load currents. If the voltages of the buses cross the set limit, then the capacitor is removed and the next bus is considered as the sensitive node. The saving is calculated during iteration. There after the next largest real power loss bus is taken as the next sensitive node. The Cost saving is added to get the total saving of the feeder. This computation procedure continues on until the saving reaches a maximum value. The maximum saving value is set at a peak value which defines the optimum level for this problem.

Heuristic Constructive Algorithm has been implemented for capacitor placement on distribution system by Silva et.al [21]. Unit step function is taken to describe the capacitor switching operation. Zero value and unit value would represent the OFF and ON status respectively. The author has taken the sigmoid function as the unit step function. The value of capacitor is represented as a multiplication of sigmoid function with the smallest unit capacitor value. In this heuristic approach, three tasks are considered for solving the capacitor allocation problem. First one is Selection task and the other two are Continuous task and Discrete task respectively. The three tasks are described below. Selection Task helps to find out the number of sensitive buses. Busbar sensitivity index is used to find out the optimal location for capacitor placement. Reactive power is injected indirectly through capacitor allocation in which the voltage are below the minimum limit. This index unit is dollar/volt and it is associated with cost. So naturally with the cost minimization, the voltage level will also improve. Continuous Task defines switch function. Switch sensitivity index is used to get the exact capacitor value for the selected bus location. Discrete Task helps to reach a practical solution. Capacitor values are not continuous in the real world problem. For discrete task, closing switch operation or the ON state is defined by '1' and the OFF state by '0'. The computation procedure continues until the value of objective function reaches above the value of previous one. The iteration procedure is stopped when the termination condition is satisfied.

New Heuristic Strategies have been proposed in [22] for reactive power compensation of radial distribution feeders. The objective of this problem is maximization of cost reduction after reactive power compensation. Two methods are proposed in this approach. These are described below. In the first method, load flow is studied for the original uncompensated feeder at the initial stage. There after loss and cost changes are calculated assuming every node as a candidate node. Cost of the capacitor is initialized as the average cost of the available standards. Then, the node which gives the maximum cost reduction is selected such a way that the capacitor value and loss reduction are positive. Next, the nearest standard value of the evaluated value of capacitor and exact cost is incorporated into the computation. If after doing load flow calculation voltage violation takes place, then this capacitor value is rejected and new node is selected for cost and loss evaluation. The procedure continues on until the cost and loss reduction becomes negative or the new capacitor size is not negative. The second method is same as the previous method only the loss and cost change equations are little different from that of the first method.

3.1.7 Other Soft Computing Approaches

There are other important and useful soft computing methods, apart from the mentioned above, which are used for reactive power compensation and network reconfiguration resulting reduction in active power loss. Su et.al [23] has taken Simulated Annealing (SA) as a soft computing technique for doing loss minimization of distribution system by reconfiguring the network and allocating capacitors at the sensitive buses. The advantage of this soft computing technique is that it can be trusted for achieving a global solution. In this approach, beneficial load transfer is recognized to achieve minimum loss configuration satisfying the voltage constraints. Network of large scale distribution systems has been reconfigured by an Efficient Simulated Annealing Algorithm [24]. Meaningful cooling scheduling and special strategy, required by this technique, helps the searching procedure to reach the optimal solution. Hybrid Differential Evolution [25] has been used for optimal reconfiguration and capacitor placement. Two new schemes have been incorporated into this technique to remove the chances of failure in finding the initial direction for large scale integer problem. Multi direction search and search space reduction are the schemes. These are used before the initialization of the population for improving the search procedure. A new technique Plant Growth Simulation Algorithm has been used by Rao et.al [26] for allocating capacitors optimally in the radial distribution system. External control is not required by this technique and it deals with the limitations and objective function in a separate manner. This avoids the difficulty in getting the boundary factors. Neural Network [27] has been implemented as an Artificial Intelligence tool for controlling capacitor banks and voltage regulators resulting maximum loss minimization in distribution systems. Rao et.al [28] has minimized the real power loss in distribution network by reconfiguring the network using Artificial Bee Colony Algorithm. The hunting behavior of honey bee is mathematically implemented as a swarm intelligence technique. The merit of this algorithm is that external parameters like crossover rate and mutation is not required in this technique like Genetic Algorithm and Differential Evolution. A hybrid technique [29] comprising of Simulated Annealing and Tabu Search has been implemented for network reconfiguration in distribution system. Ant Direction Hybrid Differential Evolution [30] technique has also been implemented as a hybrid technique for large capacitor placement problem.

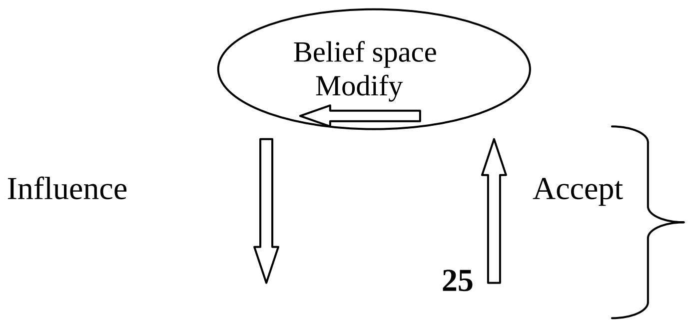
However these soft computing techniques are applied in this problem. But the exact solution or the optimal solution is yet to be achieved for this critical and complex problem. Cultural Algorithm is not applied for this problem hitherto. But it is successfully implemented in other engineering problems and also in the problems of Power Engineering. In this work, Cultural Algorithm (CA) concept is taken as mathematical or soft computing tool for searching the optimal configuration and it has given promising results in comparison to others. Concept of Cultural Algorithm is elaborated in the next chapter.

Chapter Four

4. Cultural Algorithm (CA)

Cultural Algorithm (CA) was first proposed by Robert G. Reynolds [31]. It is an evolutionary algorithm. It describes the evolution of culture in a society. In a society, there are several classes of people. Each class of people has their own culture and norms. The elite class people are denoted as the best individual among all the classes. They are selected on the basis of their knowledge & wealth. The concept or ideas of those people becomes the governing factor of the society. The other classes of people more or less obey those norms and circulate the concepts to their offspring. In this way culture or knowledge progresses from generations to generations making the new generation more up-to-date and fit for the survival.

CA is nothing but the mathematical implementation of the above idea. The elite class people is, the best individual, selected by a performance function or objective function. Knowledge or concept is the Belief Space. Circulation of the concept to the offspring is nothing but the Communication Protocol. In Communication Protocol, there are two functions. One is Accept function and the other function is Influence function. The Accept function helps to update the Belief Space. Influence function guides the population in a certain direction taking knowledge from the Belief Space. Cultural Algorithm concept is shown in Figure 4.1.



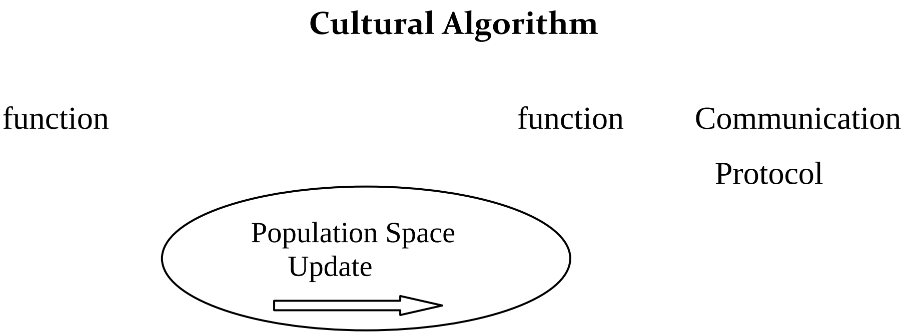


Figure 4.1 Cultural Algorithm Concept

4.1 Description of Algorithm

Cultural Algorithm is described as a dual inheritance system. As mentioned earlier, Population Space and the Belief Space are two main components and Influence functions and Accept functions are two important functions. First one does the evaluation work of each and every individual and the second one determines the best individual among the Population Space to impact the Belief Space. The update function is used to update the Beliefs or Knowledge by using the experience of the elite class individuals. In the next step, the Belief Space Knowledge is used to update the population. New population is created from the old population and the newly created individuals under the influence of Belief Space. Two feedback functions (Accept and Influence) make this total procedure a dual inheritance system of Population Space and Belief Space. The code of Cultural Algorithm which is described in ref [32] is given below.

$\boldsymbol{Begin}$
$t = 0;$
$initialize\ B_t, P_t$
$\boldsymbol{repeat}$
$evaluate\ P_t\ \{obj\ (\ )\}$
$update\ (B_t, accept(P_t))$
$generate\ (P_t, influence\ (B_t))$
$t = t + 1;$
$select\ P_t\ from\ P_{t-1}$
$\boldsymbol{until}\ (termination\ condition\ achieved)$
$\boldsymbol{End}$

B_t and P_t are the Belief Space and Population Space at time$t$.

Jin [33] has studied Cultural Algorithm as Knowledge based system. The total system is configured as a hierarchical architecture to guide the search of Evolutionary Computation. Belief Space which is a main component of this algorithm is described as a tree like hierarchical structure consisting of Belief cells. Every cell has a few characteristics. Each cell has the capability to store Knowledge of corresponding region. The Knowledge which is described in this paper is basically Regional Knowledge and it includes two sub Knowledges. These are

Constraint Knowledge and Normative Knowledge. For updating the Constraint Knowledge, cells are judged based on the count of feasible, infeasible and semi-feasible individuals. Normative Knowledge is updated on the basis of eminent or ordinary cells. Influence function is used to influence the population in Population Space taking idea from Normative and Constraint Knowledge. The search procedure which is taken in this paper is based on some basic rules. The individuals who are in the intersection of eminent and non-infeasible cells, they are considered as very good cells. Off springs are generated from them just doing little perturbation of their values. The next category of individuals which belong to the infeasible cells is moved to the category of non-infeasible cells. The last category of individuals, the category of ordinary cells, is guided to the category of eminent cells. Roulette wheel selection method is applied for selection of cells. Before selection, every cell is weighted. Weight of each cell is defined on the basis of feasibility of cell and it makes the selection procedure easier. If parent is inside an ordinary cell, then the offspring has a higher probability to appear in the eminent cell. Normative Knowledge is used to get the offspring from the parent. The individuals are attracted using an eminent cell which is picked up randomly from the set of eminent cells.

4.2 Knowledge Sources of Cultural Algorithm

Situation Knowledge, Normative Knowledge, Topographical Knowledge, Domain Knowledge and History Knowledge are the five Knowledge sources of Cultural Algorithm. Knowledge source gives the guideline to update the individual of the Population Space. It gives a set of variable ranges. Individual of the population can be adjusted within this variable range. Situation Knowledge is nothing but a set of ideal cases. Situation Knowledge helps individual to reach those ideal ones. Normative Knowledge, is the next Knowledge source, helps the individual to move to the good range. Topographical Knowledge is based on spatial characteristic. It keeps the region based schemata or plans. Domain Knowledge is used to guide the population using its Domain Knowledge. Historical Knowledge keeps the episodic memory. Actually it records important events throughout the iterations. It is termed as Temporal Knowledge. These above mentioned Knowledge sources do the influence work to the Population Space and the best individual of the Population Space updates the Belief Space knowledge. This influence and update procedure is done using a special tool called Communication Protocol. Accept and Influence functions are the main components of this Communication Protocol. Accept function does the selection of best individual’s experiences and update the Knowledge of Belief Space during iteration. It actually takes the experience of the top individuals. Knowledge sources communicate with each other and update their knowledge taking the experiences of the top class individuals. Five Knowledge sources are elaborately described to influence the population in [34]. Parent individual and Offspring individual are expressed as:

$X = < x1, x2, \dots\dots, xn >$

$Y = < y1, y2, \dots\dots, yn >$

Two functions [34] are used for getting offspring from the parent. The functions are $random(\vartheta 1, \vartheta 2)$ and $mutate(\vartheta)$. The first function generates a uniformly random number between the range of $\vartheta 1$ and $\vartheta 2$. The second function generates a Gaussian random number with mean ϑ.

4.2.1 Situation Knowledge

Situation Knowledge contains a set of ideal individuals from the population. Each best individual or the ideal one contains the value of fitness and the value of parameters. How an offspring is generated under the influence of Situation Knowledge is written in a code (as described in ref [34]) below.

$for\ dimension\ i = 1\ to\ n$

$if\ \ Xi < gbi$

$Yi = random(Xi, gbi)$

$else\ if\ \ Xi > gbi$

$Yi = random(gbi, Xi)$

$else$

$Yi = mutate(Xi)$

$endif$

$endfor$

gbi represents the global best individual.

4.2.2 Normative Knowledge

Normative Knowledge is represented in the form of intervals. It contains a range for acceptable variables. Lower limit and upper limit of each individual and the performance value is stored in the data structure. Normative Knowledge is changed by shifting those ranges and modifying performance values. The code [34] for generation of an offspring under the influence of this Knowledge is described below.

$for\ dimension\ i = 1\ to\ n$

$if\ Xi \notin (li, ui)$

$Yi = random\ (li, ui)$

$else$

$Yi = mutate(Xi)$

$endif$

$endfor$

4.2.3 Topographical Knowledge

Topographical Knowledge is termed as regional schemata and it is also represented in the form of data structure. Each cell in the data structure stores the value of lower limit and upper limit for each variable. The initial Knowledge structure contains the sampling of solution in every cell and a list of best cells. The procedure of update is taken place when an individual value is found better than the value of the cell best or if the fitness value is increased with a change of an event. The code described in [34], for this Topographical Knowledge implementation is written below.

$if\ search\ is\ in\ progress/improving$

$if\ Ch\ is\ a\ good\ cell$

$Y = mutate(X)$

$else$

$Pick\ one\ good\ cell\ k,\ 1 \leq k \leq t$

$Y = mutate(Cbk)$

$endif$

$else$

$if\ parent\ X\ is\ better\ than\ Cbh$

$Y = mutate(X)$

$else$

$Select\ one\ cell\ Cs\ from\ the\ top\ level\ cells$

$Y = mutate(Cbs)$

$endif$

$endif$

4.2.4 Domain Knowledge

Domain Knowledge keeps domain ranges and like Situational Knowledge it preserves exemplars from Population Space. It is used for prediction of gradient of incline or decline to locate the resources in the dynamic environment. For implementation of this Knowledge a direction ΔX is defined as $< d1, d2, \ldots\ldots, dn >$. In this expression of direction di values are 1, 0 and -1. '1', '0' and '-1' represent increasing, being the same and decreasing respectively.

The gradient is expressed as:

$$\nabla(\Delta X) = \frac{obj(X+\Delta X) - obj(X)}{\Delta X} \quad [34] \qquad (4.1.8)$$

The code [34] for implementation of this Knowledge is written below.

$if\ max\nabla\ of\ parent\ X > 0$

$//mutate\ X\ in\ the\ steepest\ direction$

$Y = mutate\_in\_direction(X)$

$else$

$//mutate\ global\ best\ in\ global\ best's\ steepest\ direction$

$Y = mutate\_in\_direction(gb)$

$endif$

4.2.5 History Knowledge

History Knowledge records global features. It stores the information of shifts in distance and direction of the optimum value. It is a temporal knowledge or it may be termed as episodic memory. It provides a more global view than the other Knowledges. History Knowledge is used to find out the average change in the parameter values and shift in the direction of the optimum from its previous position. This knowledge is updated with every change event. The update of this Knowledge means the modification of History list and moving averages for each parameter. This Knowledge is implemented as list of a certain temporal points. These episodic points lie in the search path. The code, described in literature [34], for History Knowledge implementation is written below.

$Randomly\ pick\ a\ point\ Pj =< Pj,1, Pj,2, \ldots\ldots, Pj,n >\ \ from\ the\ list$

$if\ parent\ X\ is\ less\ fit\ than\ Pj$

$for\ dimension\ i = 1\ to\ n$

$Yi = random(Xi, Pj, i)$

$//move\ X\ toward\ Pj$

$endfor$

$else$

$for\ dimension\ i = 1\ to\ n$

$Yi = mutate(Xi)$

$endfor$

$endif$

Cultural Algorithm is a well known algorithm in the field of Evolutionary Computation. Several researches have been done to analyze the concept of this algorithm and to implement this algorithm in the real world problem. Few applications of Cultural Algorithm are discussed in the next section.

4.3 Application of Cultural Algorithm

Cultural Algorithm is expressed as a learning process of cultures for solving problems in [32]. It deals with a cone world problem. Normative, Situational, Domain, History and Topographical Knowledge are used to influence the population. Each cell of the whole landscape keeps record of the best individual in its region. In functional landscape composed of cones, this Knowledge helps to direct the search using its idea of cone shape and related parameters. In the landscape problem, this History Knowledge records the significant move or any landscape change. One Knowledge source does the influence work in every generation of population and which source is going to impact the population is selected by the roulette wheel selection method. The population proceeds to the optimal position with the improvement of Knowledge sources. In this search process, some Knowledge sources become successful in the longer run compare to the other sources. CA has been described as a vote-inherit-promote technique for game board implementing data mining problem [35]. In the voting procedure, the individuals in the population are evaluated by the objective function. The Accept function selects the best individual to impact the Belief Space. Modification of the Belief Space is done when inherited Belief is combined with the current Belief. In the last phase, the population is updated under the influence of the Belief Space Knowledge. The cycle is terminated when the convergence criterion is achieved. CA [36] has been used to guide driver learning keeping child vehicle safety as a restraint. Situation Knowledge has been used in this problem to have minimum detrimental effect of an accident. CA has also been used for efficient design validation [37]. Domain Knowledge has been used in this regard. Flexible Job-Shop problem [38] has been solved efficiently again using Cultural Algorithm.

However, Cultural Algorithm has also been successfully implemented in the problem of Power Engineering. It is described in the next section.

4.3.1 Cultural Algorithm applied in Power Engineering

Cultural Algorithm has been applied for a few problems in Power Engineering domain. Economic load dispatch is done by using Improved Differential Evolution Approach based on Cultural Algorithm [39]. Particle Swarm Optimization based Cultural Algorithm [40] is implemented for short term optimal operation of cascaded hydro power stations. Economical dispatch of thermal units has been achieved by applying Artificial Immune Network combined with Normative Knowledge [41]. Electric generator scheduling problem is studied with Multi population Cultural Algorithm [42]. This Cultural Algorithm is successfully implemented for substation planning [43] in the urban area. Actually it is an application of Power System intelligent planning. It is also applied for hydrothermal scheduling [44]. Optimal scheduling configuration has been achieved successfully by applying this soft computing technique. The above mentioned last two applications are described in the following sections.

4.3.1.1 Cultural Algorithm applied in urban network substation optimal planning

Cultural Algorithm is applied geographically for urban network substation optimal planning by Liu et.al [43]. The objective function of this substation planning problem is a cost function. The cost consists of line construction cost, power loss cost and the substation cost. In this approach, three Knowledge sources are taken to update the population. The Knowledge sources are Situation Knowledge, Normative Knowledge and History Knowledge. Geographic Cultural Algorithm implementation procedure is described in the following paragraph.

First of all geographic analysis is done using the GIS space analysis tool. Feasible and infeasible area are divided by this tool and taken as Restrain Knowledge in the Belief Space. Population Space and Belief Space are initialized. Load density function is used to initialize the co-ordinate of the substations. The global best individual is set to zero for the first iteration. The lower and upper bound of each variable is set to infinity and the range is taken as the difference of them. In the next step perturbation vector is generated by selecting three individuals probabilistically from the Population Space. New individuals are generated using the crossover operation. It is done by taking alternatively one individual from population and the other individual from perturbation individual set. Greedy strategy is used to generate child or offspring from the parent. This strategy compares father and child and takes any one of them on the basis of adaptability. If it is found that the child is more acceptable for the problem solution, then the offspring is taken for the next iteration. Otherwise the father is accepted as an individual for the next iteration. The update procedure is done under the influence of Situation Knowledge, Normative Knowledge and History Knowledge. This above procedure is repeated until the total iteration number reaches the preset maximum iteration number or the convergence criterion is satisfied.

4.3.1.2 Cultural Algorithm applied in Generation scheduling of hydrothermal system

Generation scheduling of hydrothermal systems is done using Cultural Algorithm by Yuan et.al [44]. The objective of this problem is to find out the optimal water release from the reservoir and corresponding thermal unit generation such that the fuel cost of the thermal unit is minimized over the complete dispatch period. For the implementation of Cultural Algorithm, the Population Space is initialized using uniform distribution random method. The fuel cost objective function is used to find out the performance score of each individual. Belief Space is initialized in the next step. The lower and upper limits of each variable are store in the Normative Knowledge part of the Belief Space. Initial fitness value for each individual is set to positive infinite value. The Normative Knowledge is subdivided into sub region to handle the constraints of this minimization problem. The type of region is selected on the basis of the count of feasible individual in the region. If both the number of feasible and infeasible individuals is zero, then it is termed as unknown region. If feasible individual number is greater than zero and there is no infeasible individual in the region, then it is termed as feasible region and it is termed infeasible region for the opposite condition. The semi-feasible type is defined for that region in which the number of feasible and infeasible individuals is both greater than zero. New off springs are generated using variation operators under the influence of Belief Space’s Knowledge. Performance score is given to the each new born individual by the objective function. For each individual in the Population Space, competitors are selected randomly. Pair wise competition is conducted between individual and competitor. Individuals which have the maximum number of wins in the competition are selected for the generation of new population. In the next step Belief Space is updated using the Accept function. The above procedure is continued on until the termination condition of this problem is satisfied.

In the next chapter problem formulation for capacitor allocation and network reconfiguration are described briefly.

Chapter Five

5. Problem Formulation and Constraint

Capacitor allocation and network reconfiguration are two individual Power loss minimization scheme. Capacitor allocation objective is to find out the sensitive buses and the value of capacitors for which both real power loss and cost due to power loss and capacitor installation minimizes. Network reconfiguration problem objective is to find out the optimal switching configuration i.e., which sectionalizing switches are to be opened for closing of tie switches such that the real power loss will be minimized. It is done for the distribution system. In this thesis, network reconfiguration is done by doing tie line expansion for the real transmission system and concept of cost has been introduced for tie line expansion. Capacitor allocation problem is formulated first and then problem is formulated for both capacitor allocation and network reconfiguration. In the next section these are described accordingly. Harmonics constraint, power factor constraint and voltage angle constraint has not been taken into consideration to avoid the complexity of the problem. Both the problem formulation in section 5.1 & 5.2 has more or less similar constraints for voltage and capacitor. Only for the problem described in section 5.2, radiality of the distribution network and tie line expansion limit for transmission system are newly introduced. Radiality is a vital thing which should be maintained for doing network reconfiguration especially in the distribution system. So, configuration of the network is done to separate tie switch, sectionalizing switch and common switch for every possible loop in the section 5.3. How this switching combination has been adopted for implantation of MCA is studied in the chapter six. The results after implementation of MCA to the distribution and transmission system have been discussed in chapter seven.

5.1 Problem Formulation for Capacitor Allocation

Shunt capacitor is allocated in the radial distribution feeder to reduce real power loss. Capacitors are allocated to the sensitive nodes or buses for reactive power compensation. The bus voltages and the line losses for the radial feeder are calculated by using the Gauss-Seidel [45] Load flow method. After calculating the line losses, total loss of the feeder is calculated as:

$$PT, loss = \sum_{i=1}^{n} \sum_{j=1}^{n} PLoss(i,j) \qquad (5.1.1)$$

$i = 1,2, \ldots, n$

$j = 1,2, \ldots \ldots, n$

The total number of buses in the distribution network is n. To improve the voltage profile of the radial feeder capacitor value is selected from the possible combination of capacitor sizes. The maximum capacitor size for each bus is limited by an equation:

$$Q_{max}^{C} = LQ_0^{C} \qquad [52] \qquad (5.1.2)$$

Q_0^C is the smallest size of the capacitor combination value. L is an integer.$\{K_1^C, K_2^C, \ldots, K_L^C\}$ is the set [52] of capacitor cost for the set of possible capacitor value $\{Q_0^C, 2Q_0^C, \ldots, LQ_0^C\}$. The objective of the optimization problem is to find the exact bus locations and capacitor values such that the cost for the real power loss and the capacitor installation becomes the least. The expression for cost calculation is:

$$F = K_p(PT, loss) + \sum_{j=1}^{n} K_j^C Q_j^C \qquad [52] \qquad (5.1.3)$$

Our objective is to bring down the cost at minimum by sitting the capacitors at the optimal locations with least values.   Cost has two components. One is variable cost or running cost and the other is fixed cost. K_p is the cost per unit real power loss (\$/KW). K_j^C is the cost per unit capacitor value (\$/KVAr) and j denotes the bus numbers in which the capacitor is to be installed. Voltage constraint is applied in this problem. The bus voltages should lie within the range of V_{min} and V_{max}.

$$V_{min} \leq |V_i| \leq V_{max} \qquad i = 1,2, \ldots, n \qquad (5.1.4)$$

5.2 Problem Formulation for both Capacitor Allocation and Network Reconfiguration

Two cases have been considered in this section. One is a standard 16 bus distribution system and the other is a 132 KV practical transmission system. For the two cases network reconfiguration is done after configuring the system network and imposing suitable constraints. After the network reconfiguration capacitors are installed at the suitable buses economically. Load flow study [45, 46] is done by Gauss Seidel and Fast Decoupled method for radial feeder and transmission system respectively. For the distribution system, every feeder is considered as the radial feeder. Practical transmission system has one radial feeder and the other feeders are interconnected with each other. After the network reconfiguration, capacitors are installed at the selected buses and the total line loss is calculated thereafter. The expression for loss is same as (5.1.1). To improve the voltage profile of the buses capacitor value is selected from the possible combination of capacitor sizes. $\{K_1, K_2, \ldots, K_n\}$ is the set of capacitor cost for the set of possible capacitor value$\{Q_1, Q_2, \ldots, Q_n\}$. The objective of this optimization problem is to find the exact network configuration, bus locations and capacitor values such that the cost for the real power loss, switching operation and the capacitor installation becomes the least. The expression for the cost is:

$$F = K_p(PT, loss) + \sum_{j=1}^{n} K_j \cdot Q_j + \sum_{i=1}^{p} Tie(i).Dist \qquad (5.2.1)$$

Cost has three components. First one is variable cost or running cost and the rest are fixed costs. K_p is the cost per unit real power loss. K_j is the cost per unit reactive power and j denotes the bus number in which the capacitors is to be installed. $Tie(i)$ is the distance in Km for i th tie switch and $Dist$ is the cost of transmission wire in per Km. The total possible tie switch number is p. Voltage constraint is applied in this problem. The bus voltages should lie within the range of V_{min} and V_{max}.

$$V_{min} \leq |V_i| \leq V_{max} \qquad i = 1,2, \ldots, n \qquad (5.2.2)$$

Radiality of the network should be maintained during iteration in distribution system. One sectionalizing switch should be opened for closing of only one tie switch. In transmission system, radiality of the network is not maintained in this approach. The total distance of tie line expansion in transmission system is taken to be limited by maximum affordable distance. The power flow to the every load buses should be maintained after the reconfiguration of the network in both distribution and transmission system. In this work MCA is applied to check every possible combination of capacitors for the load buses of the Power System. This non-traditional algorithm is used to find out the global optimal values satisfying the above-mentioned constraint.

5.3 Configuration of the network

Before network reconfiguration, configuration of the network is done for closing tie switches and opening sectionalizing switches for the radial distribution system and selecting tie switches for transmission system. It is done for the distribution system to identify the common switch in a meshed loop, probable loops and their sectionalizing switches. Configurations for both the networks are shown in Table 5.1 and Table 5.2 respectively.

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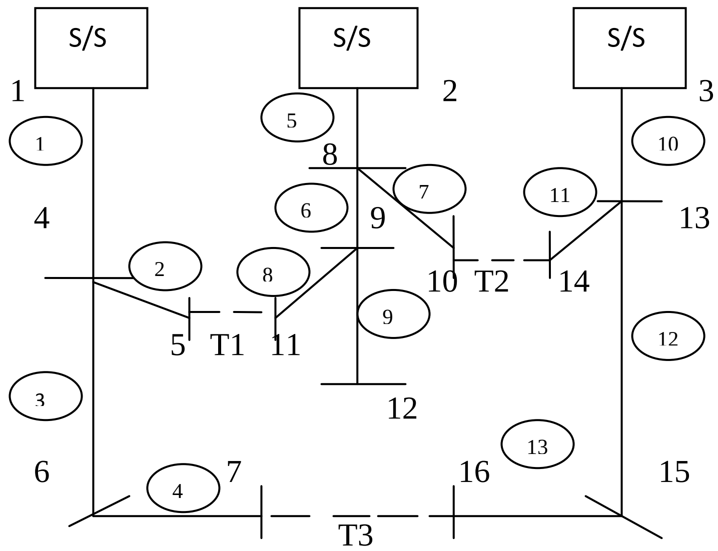

Figure 5.1 IEEE 16 bus System

IEEE 16 bus system, shown in Figure 5.1, is taken from literature [47]. Nomenclature of switches and buses are given differently from the reference mentioned above. In this diagram there are 3 substations, 13 sectionalizing switches and 3 tie switches. Sectionalizing switches are shown inside the circle. First tie switch T1 is between sectionalizing switch 2 and 8. Second tie switch T2 is between sectionalizing switch 7 and 11. The third tie switch is between sectionalizing switch 4 and 13. Now if we check the total network then it can be found that (3!

+1) i.e. 7 possible combinations of loops can be formed. The concept of common switch has been introduced for the meshed loop which contains the branches of two individual loops. The possible combinations of loops and switches are shown in Table 5.1.

Table 5.1 Configuration of the 16 bus radial distribution system

Loop configuration	**Tie switch**	**Sectionalizing switch**	**Common switch**
Loop1	**T1**	**1, 2, 8, 6, 5**	
Loop2	**T2**	**5, 7, 11, 10**	
Loop3	**T3**	**1, 3, 4, 13, 12, 10**	
Loop12	**T1, T2**	**1, 2, 8, 6, 7, 11, 10**	**5**
Loop13	**T1, T3**	**2, 3, 4, 8, 6, 5, 13, 12, 10**	**1**
Loop23	**T2, T3**	**5, 7, 11, 12, 13, 4, 3, 1**	**10**
Loop123	**T1, T2, T3**	**3, 4, 13, 12, 2, 8, 6, 7, 11**	**1, 5, 10**

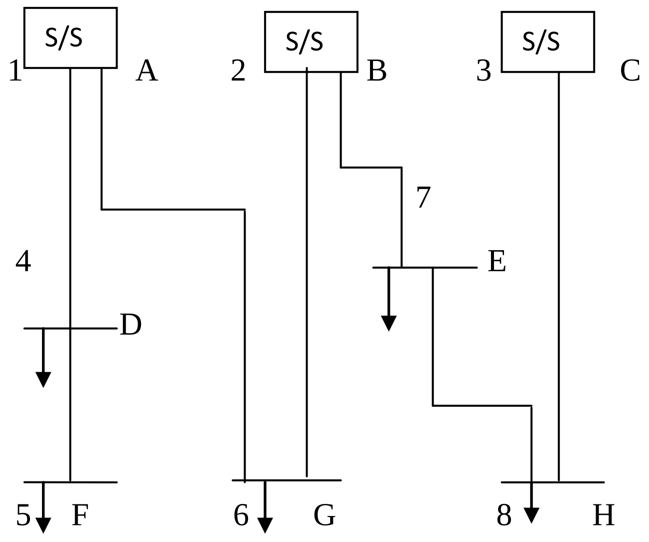

Figure 5.2 Practical Transmission System

In the practical system, shown in Figure 5.2, no concept of looping and common switches is introduced in the configuration of the system to have the best loss and cost minimization model. Only the sectionalizing switches and possible combination of tie switches are tabulated below. Among the all possible combination of tie switches, most feasible one is selected by the MCA. Shunt capacitors are also allocated optimally to the load stations by MCA.

Table 5.2 Configuration of the Practical Transmission System

Sectionalizing switches	**Possible Combination of Tie switches**
1-4, 4-5, 1-6, 2-6, 2-7, 7-8, 3-8	**4-2, 4-7, 6-7, 6-8, 7-3, 6-3, 4-3, 5-3, 1-7, 1-8, 1-5, 5-6, 6-4, 4-8, 5-2, 5-8, 4-7**

For the network reconfiguration of this system, only possible combination of tie switches is considered as the feasible solution space. Sectionalizing switches are not removed from the existing system.

Cultural Algorithm is implemented in a modified form for this above mentioned problems. Description about Modified Cultural Algorithm and its implementation technique are described in the next chapter.

Chapter Six

6. Modified Cultural Algorithm and its Implementation

In this work, the engineering topic is ‘Optimal Capacitor Allocation and Network reconfiguration in a Power System’ for resulting real power loss minimization and the optimization tool or the mathematical tool, adopted, is Cultural Algorithm. Cultural Algorithm has been modified for the implementation of the above scheme. Situation Knowledge and History Knowledge are only used in the Belief Space formulation part as the Knowledge Source. Modified Cultural Algorithm (MCA) and its implementation technique for this problem have been described in the following sections.

6.1 Modified Cultural Algorithm (MCA)

Modified Cultural Algorithm is based on the concept of Cultural Algorithm. But some modifications are done to find the optimal point in the capacitor allocation and network reconfiguration problem, discussed in the previous chapter. In the conventional Cultural Algorithm offspring is formed from the range of global best and parent. Offspring is formed taking global best as the upper limit and parent as the lower limit when parent value is less than the value of global best. If parent is greater than the global best, then the limits are set in opposite order. If parent is equal to the value of global best, then a mutation operator is adopted to find an offspring near about the value of parent. In Modified Cultural Algorithm offspring is also formulated on the basis of global best and parent but the creation procedure of offspring is different in it. During iteration, the Belief Space is updated taking the values from the best individual. In Cultural Algorithm, random and mutation operators are adopted for the Situation Knowledge influence. In Modified Cultural Algorithm, Addition and Multiplication operators are formulated and a random operator is used for the influence of Situation Knowledge. In Cultural Algorithm, History Knowledge influences the population based on random and mutation operator picking a temporal point from the significant search path. In MCA, Situation Knowledge best selected global individual's information is taken for the influence of History Knowledge. This particular information is manipulated for the progress of searching and to find the optimum. Like CA, MCA has also two main parts. One is Population Space and the other is Belief Space. Communication Protocol is the connectivity between the two spaces. Here two cases are considered. One is only optimal capacitor allocation and the other one is network reconfiguration and capacitor allocation. Formation of Population Space, Belief Space best individual and Knowledge Sources of Belief Space and their influences are same in the two cases for capacitor allocation part. So, without repeating the formation of Population Space, Belief Space best individual and Knowledge sources for capacitor allocation in both cases, the formation of these above mentioned ingredients are described only for network reconfiguration and capacitor allocation in the following sections.

6.1.1 Population Space formation

Network reconfiguration and capacitor allocation requires two individual Population Spaces. Each Population Space contains population of solutions for each problem. Both Population Spaces are simultaneously considered as one Population Space for this approach. The Population Space for network reconfiguration is a randomly created tie switch combination and selected sectionalizing switch from the exact loop excluding the common switch for the distribution system reconfiguration. In the transmission system reconfiguration, the Population Space is created only by selecting the possible combination of tie switches in this work. For Capacitor allocation it is the randomly created combination of capacitor values for the system network. Initially a combination of '0' and '1' is created randomly to form the Population Pool. It is developed by the flipping coin concept with a certain probability. For the tie switch selection and sectionalizing switch removal in distribution system, tie switch and sectionalizing switches are selected from the switching operation set or defined loop. Suppose, there are $v1$ rows and

$p1$column in the Population Pool I. Rows and columns define switch set and individual respectively. ‘1’ and ‘0’ define tie switch selected and not selected condition. The first column of Population Pool I is $[\mathbf{0\ 1\ 0\ 1..0\ 1}]$. It defines tie switch 2, 4 and $v1$ is selected for switching operation. Population Space I is formulated by multiplying randomly selected sectionalizing switch from the defined loop for a certain tie switch. Every tie switch defines a loop. For $v1$ tie switch there are $(v1!+1)$ combinations of loops consisting of sectionalizing switches. Sectionalizing switch is selected from selected tie switch loop randomly and multiplied with Population Pool I to have the Population Space I. Every row element of the Population Space I individual is made different by, randomly selecting sectionalizing switches from the switching operation set, excluding the common switch. In this way, Population Space for transmission system reconfiguration can also be formulated by randomly selecting tie switches from the possible combination of tie switches. The procedure is not elaborated here to avoid repetition of same things.

Capacitor values are taken from the capacitor value set to form the final Population Space II. Capacitor value set is defined as $'Capval'$ in (6.1.1.1). Suppose, there are m1 rows and p1 columns in the Population Pool II. The total number of rows denotes the total number of buses of the Power System. Each column signifies each individual of the population. ‘1’ and ‘0’ is denoted as capacitor on position and off position respectively. The first column of the Population Pool II is $[\mathbf{1\ 0\ 1\ 1 \ldots\ldots 0\ 1}]$. It defines that at the bus no1, 3, 4 and $p1$, the capacitor is to be installed. The Population Pool II individual defines the selected locations for the capacitor allocation only. Individual of Population Space II defines both the selected buses and the capacitor values. It is developed by multiplying the randomly chosen $m1$ capacitor values with each individual of the Population Pool II. Suppose randomly chosen $m1$ capacitor values set is $[\boldsymbol{f\ k\ r\ t \ldots\ldots h\ s}]$. After multiplication the first individual of the Population Space II becomes $[\boldsymbol{f\ 0\ r\ t \ldots\ldots 0\ s}]$. It means that at bus no 1, 3, 4 and $p1$ capacitor values of $'f'$ KVAR, $'r'$ KVAR, $'t'$ KVAR and $'s'$ KVAR are placed respectively. Population Space I & II are shown in Figure 6.1 and 6.2 respectively. Now each individual of both Population Spaces is tested by load flow method to calculate the real power loss from (5.1.1) and also to calculate the cost from (5.1.3) or (5.2.1) for distribution or transmission system taking the cost of capacitor. Capacitor cost is taken from the capacitor cost set$'Capcost'$, shown in (6.1.1.2)

Table 6.1 Switching operation set

$Tie\ switch1$ $(loop1)$	$Tie\ switch2$ $(loop2)$	..	..	$Tie\ switch\ v1-1$ $(loop\ v1-1)$	$Tie\ switch\ v1$ $(loopv1)$
$n1, t1, \ldots . c1$	$t1, m1, \ldots . ., j1$	..	..	$k1, n1, \ldots, s1$	$g1, n1, \ldots ., f1$

$$\begin{bmatrix} 00 \ldots \ldots \ldots \ldots 1 \ldots \ldots \ldots . . .1 \\ 11 \ldots \ldots \ldots . . .1 \ldots \ldots \ldots . . .0 \\ 00 \ldots \ldots \ldots \ldots 0 \ldots . \ldots \ldots . .1 \\ 11 \ldots \ldots \ldots \ldots 0 \ldots . \ldots \ldots . .1 \\ \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \\ \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \\ \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \\ 01 \ldots \ldots \ldots \ldots 1 \ldots . \ldots \ldots . .0 \\ 10 \ldots \ldots \ldots \ldots 1 \ldots \ldots \ldots \ldots 1 \end{bmatrix} \Longrightarrow \begin{bmatrix} 00 \ldots \ldots \ldots c1 \ldots \ldots \ldots . . n1 \\ t1m1. \ldots . . . j1 \ldots \ldots \ldots . .0 \\ 00 \ldots \ldots \ldots . .0 \ldots . \ldots \ldots . k1 \\ l1d1 \ldots \ldots . .0 \ldots . \ldots \ldots . e1 \\ \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \\ \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \\ \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \\ 0k1 \ldots \ldots \ldots s1 \ldots . \ldots . . .0 \\ n10 \ldots \ldots \ldots g1 \ldots \ldots \ldots f1 \end{bmatrix}$$

Figure 6.1 Formation of Population Space I from Population Pool I

$$\begin{bmatrix} 10 \ldots \ldots \ldots \ldots 1 \ldots \ldots \ldots \ldots 1 \\ 01 \ldots \ldots \ldots \ldots 1 \ldots \ldots \ldots \ldots 0 \\ 10 \ldots \ldots \ldots \ldots 0 \ldots \ldots \ldots \ldots 1 \\ 10 \ldots \ldots \ldots \ldots 1 \ldots \ldots \ldots \ldots 1 \\ \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \\ \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \\ \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \\ 01 \ldots \ldots \ldots \ldots 1 \ldots \ldots \ldots \ldots 1 \\ 10 \ldots \ldots \ldots \ldots 1 \ldots \ldots \ldots \ldots 1 \end{bmatrix} \Longrightarrow \begin{bmatrix} f0 \ldots \ldots \ldots \ldots 0 \ldots \ldots \ldots \ldots f \\ 0k \ldots \ldots \ldots \ldots k \ldots \ldots \ldots \ldots 0 \\ r0 \ldots \ldots \ldots \ldots 0 \ldots \ldots \ldots \ldots r \\ t0 \ldots \ldots \ldots \ldots t \ldots \ldots \ldots \ldots t \\ \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \\ \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \\ \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \\ 0h \ldots \ldots \ldots \ldots h \ldots \ldots \ldots \ldots h \\ s0 \ldots \ldots \ldots \ldots 0 \ldots \ldots \ldots \ldots s \end{bmatrix}$$

Figure 6.2 Formation of Population Space II from Population Pool II

$$Capval = [a, b, c, \ldots, h, \ldots, w, x, y, z] \tag{6.1.1.1}$$

$$Capcost = [a1, b1, c1, \ldots, h1, \ldots, w1, x1, y1, z1] \tag{6.1.1.2}$$

6.1.2 Belief Space formation

Belief Space is the plan or theory, which helps to speed up the search procedure. During iteration the best individual is selected for the up gradation of the Belief Space. Knowledge or idea is kept in the Belief Space. Initially Knowledge and the Belief Space best individual are set to zero. The Belief Space best individual at initial stage for Population Space I and II are shown in (6.1.2.1) and (6.1.2.2). Table 6.2, Table 6.3, Table 6.4 and Table 6.5 define the Situation Knowledge and History Knowledge influences for Population Space I & II. In this work Situational Knowledge and History Knowledge are adopted to improve the Belief Space Knowledge. Situation Knowledge is formulated by viewing the present scenario or the current population individual. Suppose after nth iteration the best individual is $[0\ j1\ m1\ 0\ t1 \ldots g1](1xv1)$ for reconfiguration of distribution system and $[f\ m\ 0\ w \ldots y\ e](1xm1)$ for capacitor allocation. Then the Situation Knowledge will keep the most sensitive tie switch positions, bus locations and capacitor values of the previous iterations.

History Knowledge is developed by taking the idea of the Situational Knowledge. When there is no significant improvement in the loss and cost reduction of the optimization problem, then Situation Knowledge I's best tie switches, best sectionalizing switches and total number of tie switches are kept in History Knowledge I. Situation Knowledge II's best bus locations, best capacitor values and the total number of locations are kept in the History Knowledge II. In transmission system reconfiguration, Belief Space best individual and History Knowledge concepts are also same. History Knowledge is used for refined search.

$$Belief\ Space\ best\ individual$$
$$for\ switch\ operation\ at\ intial\ stage \qquad (6.1.2.1)$$
$$= [0\ 0\ 0\ 0 \ldots \ldots .0\ 0](1 \times v1)$$

$$Belief\ Space\ best\ individual$$
$$for\ Capacitor\ Allocation\ at\ initial\ stage \qquad (6.1.2.2)$$
$$= [0\ 0\ 0\ 0 \ldots .0\ 0](1 \times m1)$$

Table 6.2 Situational Knowledge I for Population Space I

Best tie switch and corresponding sectionalizing switch						
2	3	5	.	.	.	$v1$
$j1$	$m1$	$t1$	.	.	.	$g1$

Table 6.3 History Knowledge I for Population Space I

Total selected tie switches	*Best tie switches*	*Best sectionalizing switches*
4	$1, 3, 4, v1$	$t1, d1, g1, f1$

Table 6.4 Situational Knowledge II for Population Space II

Best location and capacitor value						
1	2	4	.	.	$m1 - 1$	$m1$
f	m	w	.	.	y	e

Table 6.5 History Knowledge II for Population Space II

$\boldsymbol{Total\ selected\ locations}$	$\boldsymbol{Best\ locations}$	$\boldsymbol{Best\ capacitor\ values}$
$\mathbf{4}$	$\boldsymbol{2, 3, m1 - 2, m1}$	$\boldsymbol{t, r, u, f}$

6.1.3 Communication Protocol

Accept function and Influence function are the two functions of the Communication Protocol. These are discussed below.

6.1.3.1 Accept function

Accept function is applied to update or change the Belief Space's Knowledge. The best individual among the population is selected by the performance function. In this approach only that individual does the improvement work in the Belief Space's Knowledge and replaces the Belief Space best individual.

6.1.3.2 Influence function

Influence function is used to modify the Population Pool and also the Population Space. In this paper the idea that is taken to influence the population in the Population Space by the Belief Space is discussed below.

6.1.3.2.1 Influence of Situation Knowledge

The best-selected tie switches and bus locations from the Situation Knowledge are taken to influence the population. The exact optimal individual tie switches and bus locations may be exactly like the stored locations in the Belief Space. It may be that the sensitive tie switches and bus locations are less or it may be that the sensitive tie switches and bus locations are more. Suppose the sensitive tie switches are 2, 3, 5 and$v1$. The effective factor will be $[\mathbf{0\ 1\ 1\ 0\ 1 \ldots 1}]$ If the sensitive nodes in the Situation Knowledge II are 1, 2, 4, $m1 - 1$and $m1$ for a $m1$ bus

Power System with $p1$ number of individuals in the Population Pool II, the effective factor will be $[\mathbf{1\ 1\ 0\ 1 \ldots 1\ 1}]$. In this MCA implementation approach, 50% of the generated Population Pool is left unchanged in formation of both Population Space I and II. The rest 50% of the Population Pool I & II are manipulated with the effective factor. 50% of that rest Population Pool individual's each row element is multiplied with the effective factor's column element. 12.5% - 20% individuals of that rest population will be totally replaced by the effective factor. 30% - 37.5% individual's each row element will be added with the effective factor each column element. In both distribution and transmission system reconfiguration Situation Knowledge influence is same. Modified Population Pool I & II, after the Situation Knowledge influence, are shown in Figure 6.3 and Figure 6.4 respectively. The resulted individual's each element after multiplication and addition is like this:

Multiplication

$$Offspring = parent \times beliefspace$$

$$Offspring = 0(0 \times 1)\ if\ parent = 0, belief\ space = 1$$
$$= 0(1 \times 0) if\ parent = 1, belief\ space = 0$$
$$= 0(0 \times 0) if\ parent = 0, belief\ space = 0$$
$$= 1(1 \times 1) if\ parent = 1, belief\ space = 1$$

Addition

$$Offspring = parent + beliefspace$$

$$Offspring = 0(0 + 0)\ if\ parent = 0, belief\ space = 0$$
$$= 1(1 + 0) if\ parent = 1, belief\ space = 0$$
$$= 1(0 + 1) if\ parent = 0, belief\ space = 1$$
$$= 1(1 + 1) if\ parent = 1, belief\ space = 1$$

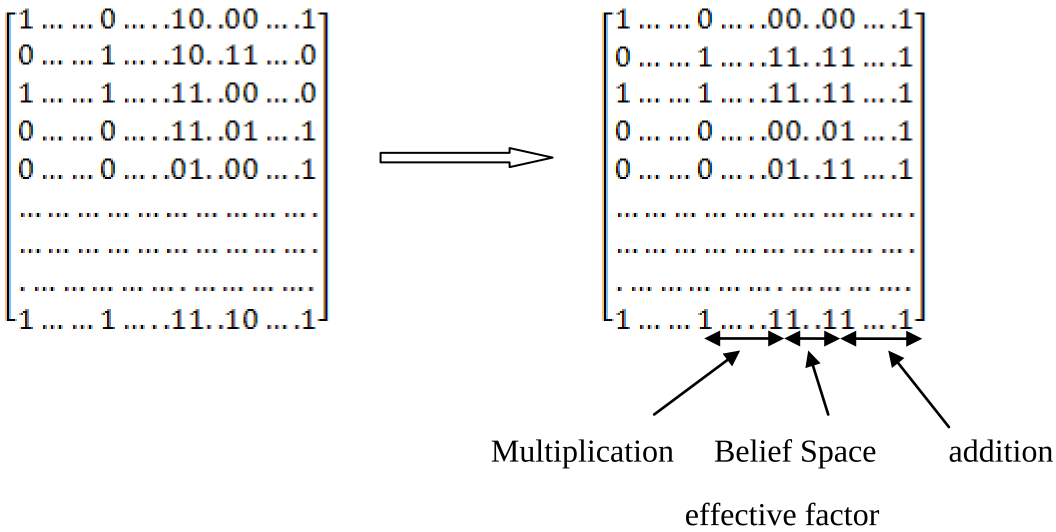

Figure 6.3 Modified Population Space I after the influence of Situation Knowledge I

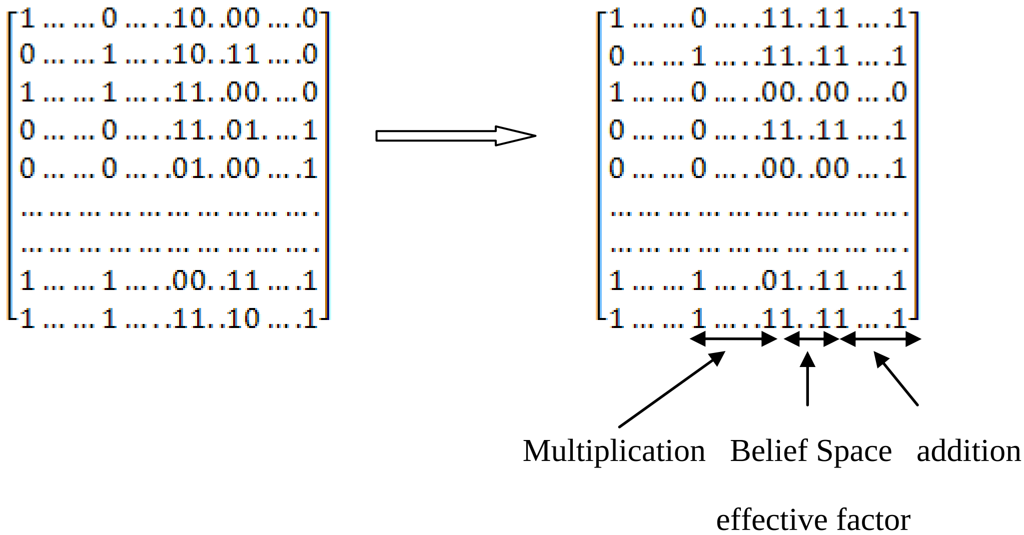

Figure 6.4 Modified Population Pool II after the influence of Situation Knowledge II

Sectionalizing switches are randomly selected from the defined loop considering the concept of common switch for radial distribution feeder. Population Space I is created by taking the chosen sectionalizing switches for removal. Capacitor values are randomly chosen for the selected bus locations from (6.1.1.1) to form the Population Space II.

6.1.3.2.2 Influence of History Knowledge

The information, taken from the History Knowledge of the Belief Space, influences the entire Population Pool. Tie switches and sectionalizing switches for the switching operation and capacitor values and the total number of selected buses are effectively taken into consideration. Suppose the tie switches are 1, 3, 4 and $v1$ and selected capacitor values are $t, r, u,$ and f KVAR respectively. The total number of tie switches and bus locations are equal i.e., 4. Bus locations are 2, 3, $m1 - 2$ and $m1$. The idea, which is established to modify the population, is discussed below. The exact optimal tie switches and capacitor locations may be the same as stored in the Belief Space but the sectionalizing switches and capacitor values are different or optimal capacitor values may be the same as in the Belief Space but the locations are different or the number of tie switches and capacitor locations are same i.e. 4 and 4 but both tie switches and sectionalizing switches are different and for the case of capacitor allocation, both bus locations and capacitor values may be different. Keeping the above-mentioned idea in mind the Population Space is modified for the next iteration for network reconfiguration and capacitor allocation. 50% individuals of the Population Space I have tie switch location exactly shown in the History Knowledge in table 6.5 but the sectionalizing switch is different. The rest 50% of the Population Space I contains 4 tie switch location in each individual but the tie switch and the sectionalizing switch both are different. In transmission system reconfiguration, the concept of sectionalizing switch is not incorporated otherwise the influence strategy is same. One third i.e. from 32%-35% of the Population Space II’s individual locations are same but the capacitor values are different. For the next 32%-35% of Population Space II, capacitor values are exactly equal as t, r, u and f KVAR but the locations are different. The rest 32%-35% of Population Space has 4 sensitive bus locations but the exact bus numbers and capacitor values are different. Modified Population Space I & II after the History Knowledge influence are shown in Figure 6.5.

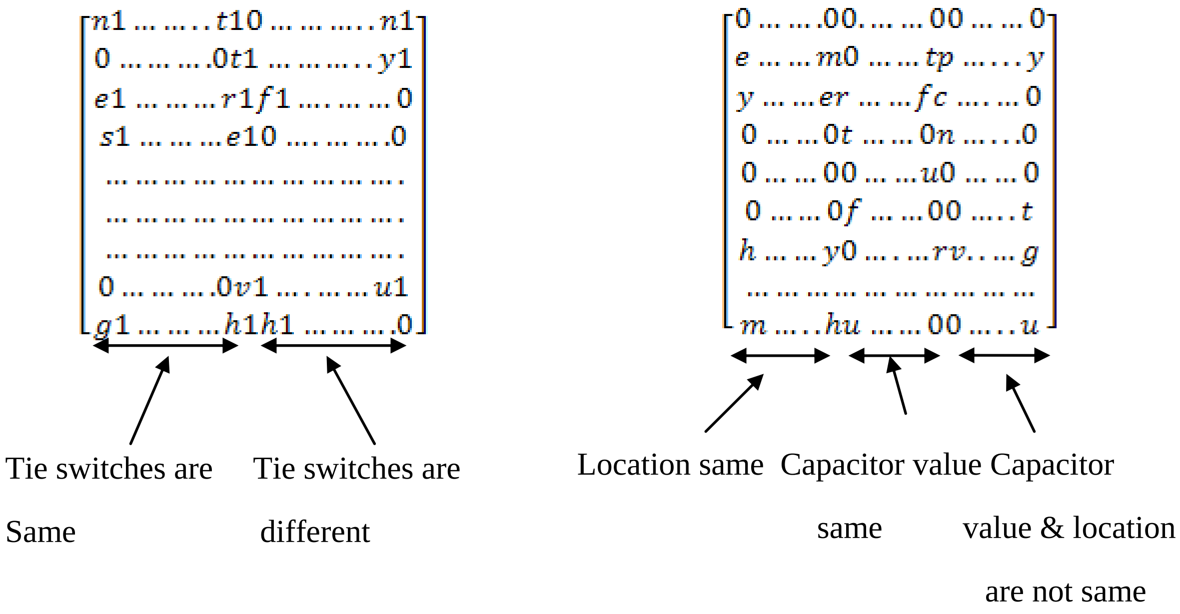

Figure 6.5 Modified Population Space I & II after the influence of History Knowledge I & II

6.4 Proposed Algorithm

The steps, which are adopted for this network reconfiguration and capacitor placement problem, are described below.

1. Read input data i.e., line data and bus data of the Power System network.

2. Calculate the real power loss and the cost without any switching operation and allocating capacitor at the buses of the Power System network.

3. Set the tolerance factor at a higher value than the set value for loss and cost and set maxiter = 0.

4. Initialize the Population Space and Belief Space best individual and Knowledges.

5. Perform the load flow and calculate the loss and cost for every individual of the Population Space.

6. Update the Belief Space individual and Knowledges by seeing the performance of every individual.

7. Modify the Population Pool by using the Situation Knowledge and create the Population Space choosing randomly switches and capacitor values.

8. Repeat steps 5-7 until any one of tolerance factor and maxiter reaches the chosen values.

9. Reset the tolerance factor and maxiter.

10. Perform the History Knowledge influence until tolerance factor or maxiter reaches the chosen values.

11. If termination condition is not satisfied then go to step 3 otherwise stop the iteration and print the best individual’s switches, selected bus locations and capacitor values as the optimal one.

This Proposed algorithm is checked for six test systems which include five distribution systems and one transmission system. The obtained results after implementation of Modified Cultural Algorithm are discussed in the next chapter.

Chapter Seven

7. Results and Discussion

The Modified Cultural Algorithm (MCA) is checked on six test systems. First five test systems are comprised of radial distribution feeder. The last system considered is a practical transmission system. Reactive power compensation by installing capacitor is studied for all the systems. Network reconfiguration and capacitor allocation are studied simultaneously especially for 16 bus distribution system and practical transmission system. New tie line configurations (shown in Table 5.2 in chapter five) are achieved by locating the substations and load stations in Google Earth and the distance between two stations are calculated by using the path distance measuring tool. All the simulations are done by using technical software MATLAB 7.0 with 256 MB RAM, Intel P4 PC configuration. The soft program is developed in house. The input data and the possible capacitor choices for 9-bus and 34-bus are taken from literature [22]. The constant K_p

in (5.1.3) & (5.2.1) is taken as US$ 168/KW to find the cost due to real power loss [22] for 9, 23, 34, 69 bus radial distribution system. The maximum allowable capacitor value for any bus of the distribution system is fixed at 4186 KVAR [22] for the cases of 9, 23 and 34 bus radial distribution system. The voltage constraints, as defined in (5.1.4), are selected as V_{min}= 0.9 p.u and V_{max}= 1.1 p.u for all radial distribution system. In transmission system the voltage limit is set within the range of 0.9 p.u and 1.04 p.u. The tolerance factor, defined in section 6.4 (Proposed Algorithm) is considered as the difference of best individual's loss and cost values from the previous iteration to next iteration. The tolerance factor for loss and cost is set as 0.001 and 10 respectively. The maximum occurrence number of same value for both loss and cost factor is set at 30. The maximum occurrence number is named 'maxiter' in the proposed algorithm.

7.1 9 bus radial distribution system (Test Case I)

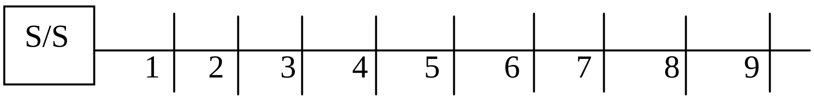

Figure 7.1 9 bus radial distribution system

The first test case is a 9 bus radial distribution system. It is shown in Figure 7.1. There is one source or substation, which is the slack bus and all the other buses are load buses. Without compensation, the real power loss is 783.71 KW and the cost due to loss is US$ 131,675. The lower and upper voltages of this bus without compensation are 0.8375 p.u and 1 p.u. After installing the capacitors at the buses 2, 3, 4, 5, 7 and 9, the real power loss has drastically reduced to 677.5373 KW. The cost has also reduced to US$ 115,756.316. The voltage profile has been improved. The minimum voltage is 0.9003 at bus no 10 after optimal capacitor allocation. The maximum voltage has been increased to 1.007 at bus no 3. Details of these computational results are shown as comparison study with the published works in Table 7.1. Loss comparison with the published works for 9 bus radial distribution system is shown in Figure 7.2. The cost is also compared with the published works given in Figure 7.3. Voltage profile improvement after compensation is shown in Figure 7.4.

Table 7.1 Comparison Study of results for 9 bus radial distribution system

Bus No	No Capacitor placed	Method of ref[48]	Method of ref[20]	Method of ref[49]	Method of ref[17]	Method of ref[22]	MCA Method

	1	Q(KVA) 2	Q(KVA) 3	Q(KVA) 4	Q(KVA) 5	Q(KVA) 6	Q(KVA) 7
1	**0**	**0**	**0**	**0**	**0**	**0**	**0**
2	**0**	**0**	**0**	**3600**	**300**	**3600**	**3300**
3	**0**	**1050**	**1050**	**4050**	**0**	**0**	**2850**
4	**0**	**1050**	**1200**	**450**	**2850**	**4050**	**1950**
5	**0**	**1950**	**1200**	**1200**	**1200**	**1650**	**1200**
6	**0**	**0**	**0**	**0**	**300**	**0**	**0**
7	**0**	**0**	**0**	**0**	**150**	**0**	**300**
8	**0**	**0**	**300**	**150**	**150**	**600**	**0**
9	**0**	**900**	**450**	**600**	**450**	**0**	**450**
Loss (KW)	**783.8**	**704.88**	**686.1**	**681.28**	**684**	**686**	**677.54**
Cost (US$)	**131,675**	**119,420**	**116,149**	**116,320**	**116,111.4**	**117,095**	**115,756.32**
V_{min}	**0.8375**	**0.9028**	**0.88**	**0.9001**	**0.9**	**0.9003**	**0.9003**
V_{max}	**0.9929**	**0.9971**	**0.9963**	**1.007**	**1**	**1.007**	**1.007**

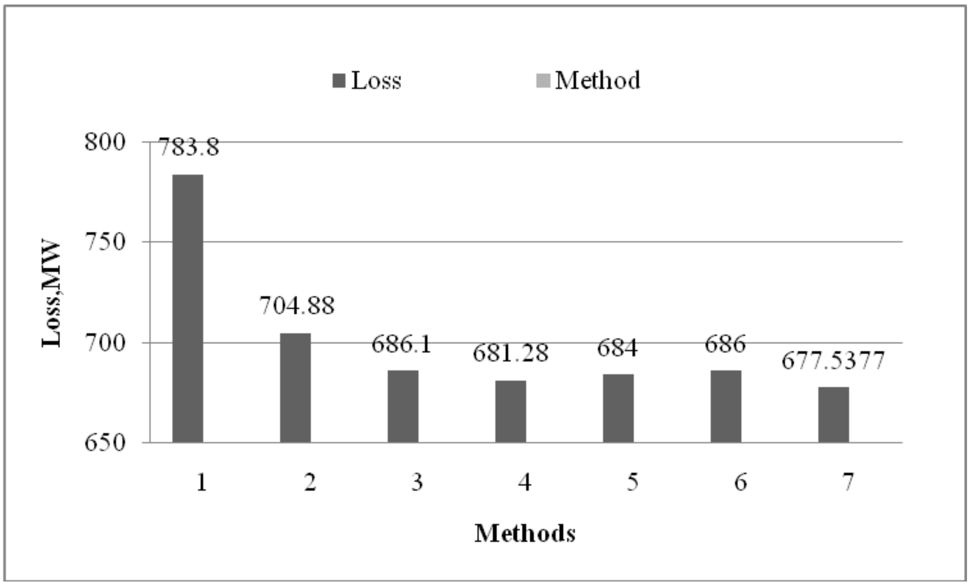

Figure 7.2 Loss comparison for 9 bus radial distribution system

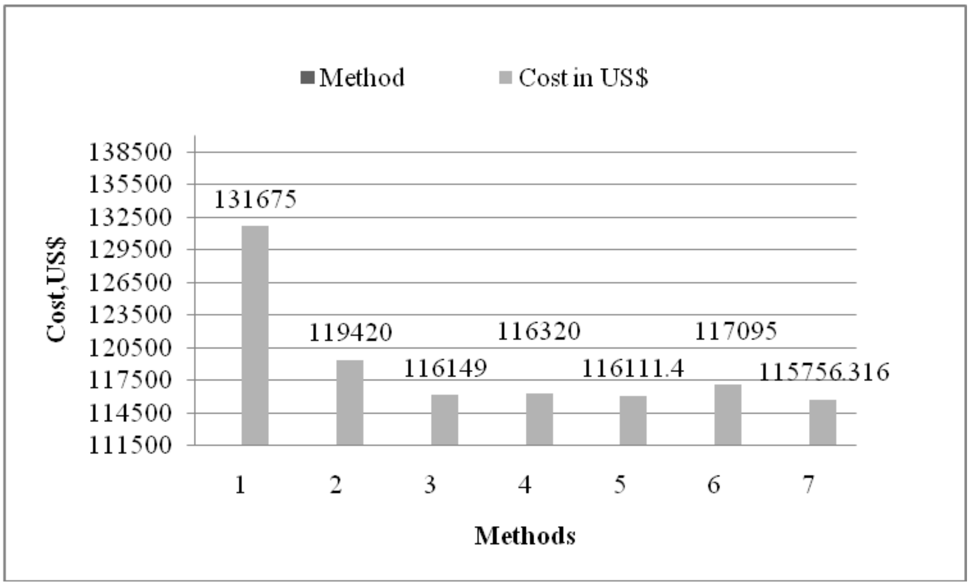

Figure 7.3 Cost comparisons for 9 bus radial distribution system

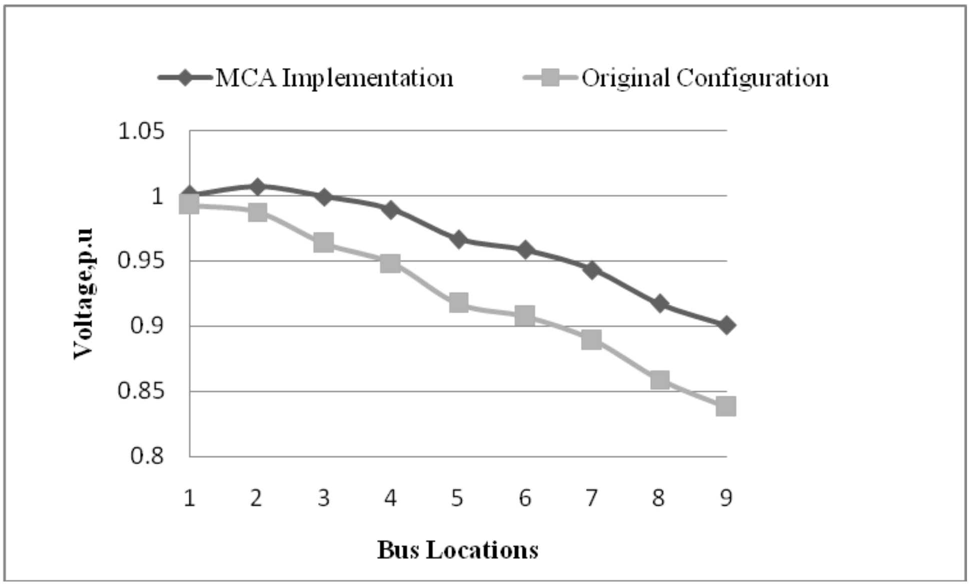

Figure 7.4 Voltage Profile improvement after compensation using MCA in 9 bus radial distribution system

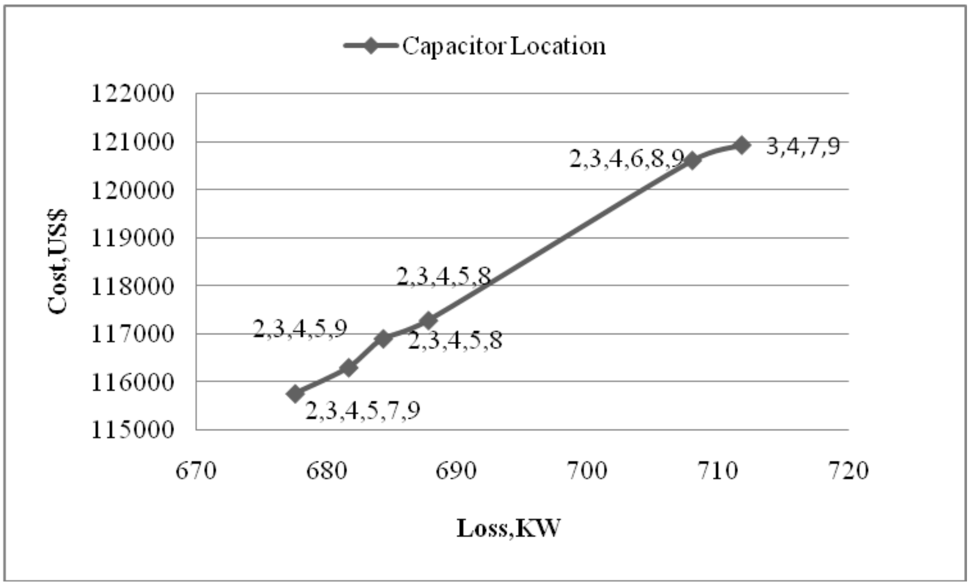

Figure 7.5 Belief Space movement with Loss & Cost for 9 bus radial distribution system

For 9 bus problem Situational Knowledge influence is very strong. It almost helps to reach the solution near the optimal position. History Knowledge influence does the rest work. Belief Space keeps the capacitor positions and the value of the best individual. Through iterations by the influence of Knowledge sources the capacitor locations or the Belief Space locations shifts from one place to another and finally comes to a static optimal locations. It is shown in Figure 7.5. At real power loss of 711.79 KW, Belief Space capacitor locations are 3, 4, 7 and 9. The cost due to capacitor installation is US$ 120930. The capacitor values are 4050, 1500, 450 and 1200 KVAR respectively for the selected bus positions. As the Belief Space moves, the real power loss and the cost due to loss and capacitor installation decrease. The capacitor positions shifts to bus number 2, 3, 4, 6, 8 and 9. With the increase in total capacitor number, decrement of loss to 708.0001 KW and cost to US$ 120610 is observed. The capacitor values at the selected buses are 2250, 2700, 150, 1500, 600 and 750 KVAR. The cost reduces to US$ 117280 for loss of 687.7698 KW and capacitor location changes to 2, 3, 4, 5 and 8. The capacitor values for these selected five locations are 2250, 2100, 2550, 1200 and 1050 KVAR respectively. Belief Space movement further decreases the loss to 684.29 KW and as usual the cost also reduces to US$ 116900. The selected capacitor positions are same as before i.e., 2, 3, 4, 5 and 8 but the capacitor values changes to 3300, 2550, 1950, 1500 and 900 KVAR respectively. In the next movement, the capacitor position changes to 2, 3, 4, 5 and 9 for the loss reduction of 2.65 KW from the previous one and the cost is also reduced by US$ 600. The capacitor values for the selected bus locations are 2550, 2850, 1050, 1950 and 660 KVAR respectively. Finally the movement of Belief Space stops at loss of 677.5377 KW and cost of US$ 115756.316. MCA finally gives the minimum loss and cost configuration at selected bus location 2, 3, 4, 5, 7 and 9. The capacitor values at these selected bus locations are 3300, 2850, 1950, 1200, 300 and 450 KVAR respectively.

7.2 16 bus distribution system (Test Case II)

The second case is a radial distribution system [47] consisting of 16 buses. The system is shown in Figure 5.1 in chapter five. At initial stage, without doing any tie switch operation only capacitors are allocated to do reactive power compensation in this system. The real power loss of the original distribution system is 511 KW. Doing reactive power compensation the real power loss reduces to 487.8 KW. The unit capacitor cost for this system is chosen as US$ 221.9/MVAR taking the average of standards [52] and K_p in (5.2.1) is taken US$ 168000/MW. Switching operation cost in (5.2.1) is not considered in this distribution system. The results after MCA implementation are tabulated in the Table 7.2. The bus locations for installing capacitor are 4, 7, 8, 9 and 10. The capacitor values are 1.5 MVAR, 0.9 MVAR, 1.8 MVAR, 0.6 MVAR and 0.6 MVAR for those selected bus locations. The lowest voltage before capacitor installation was 0.9693 p.u at bus 12 and after capacitor installation optimally using MCA it becomes

0.9734 p.u. The improvement in voltage profile is shown in Figure 7.6. The installation of these capacitor banks reduces the cost from US$ 85848 to US$ 83148.66. The system optimal configuration for both network reconfiguration and capacitor allocation is studied in two ways. These are excluding and including the cost of capacitor from the expression (5.2.1). No switching cost is included in (5.2.1) for this distribution system. In the first case, loss of the distribution network has been reduced from 511 KW to 448 KW. Including the cost of capacitor the loss is minimized to 448.5 KW. Economically optimization of the network keeping the capacitor cost into consideration has changed slightly the capacitor locations and values from the uneconomical way i.e., excluding the capacitor cost. Sensitive bus 13 is changed to bus10 and capacitor values have also been changed from 0.9 MVAR and 0.9 MVAR to 0.6 MVAR and 0.6 MVAR at the last sensitive buses among the selected buses. If only network reconfiguration is done then loss minimizes to 466 KW. Mutual effect of both reconfiguration and loss minimization has cut down the loss and improved the voltage profile. Change in voltage profile after network reconfiguration and capacitor allocation is shown in Figure 7.7. For this distribution network optimal configuration, Situation Knowledge influence is so strong that it requires hardly 20-30 iterations to reach optimal configuration. The capacitor values, selected buses and switch operation are listed in Table 7.3.

Table 7.2 Results after capacitor allocation using MCA in 16 bus radial distribution system

Operations	Original Configuration	MCA Implementation
Selected Bus Locations	**-**	**4, 7, 8, 9 and 10**
Capacitor Values (MVAR)	**-**	**1.5, 0.9, 1.8, 0.6 and 0.6**
Loss (MW)	**511**	**487.8**
Cost (US$)	**85848**	**83148.66**
V_{max} & V_{min} (p.u)	**1.0 & 0.9693**	**1.0 & 0.9734**

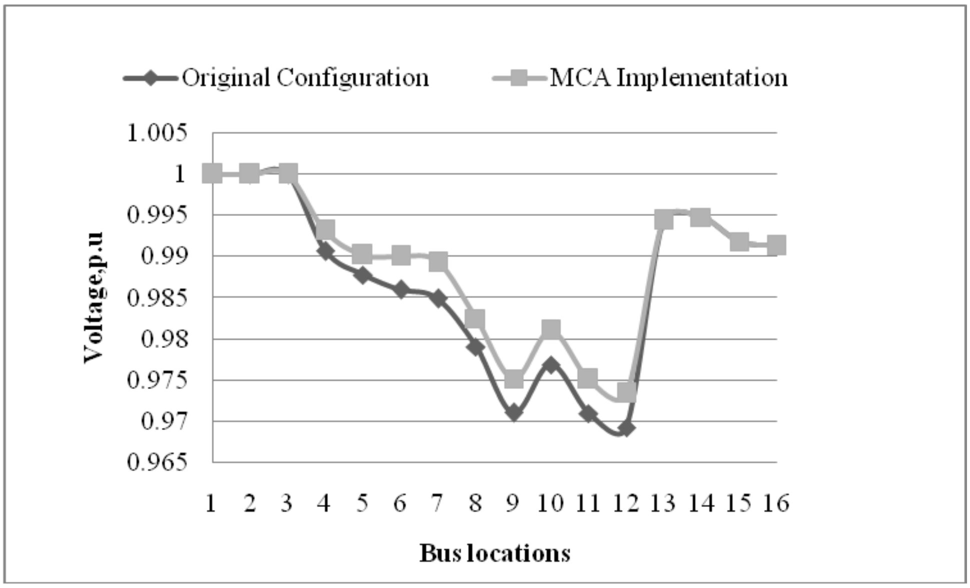

Figure 7.6 Change in voltage profile after capacitor allocation using MCA in 16 bus radial distribution system

Table 7.3 Results after network reconfiguration and capacitor allocation using MCA in 16 bus distribution system

Operations	Original configuration	Excluding Capacitor cost	Including Capacitor Cost
Tie Switch	**-**	**1, 2**	**1, 2**
Sectionalizing Switch	**-**	**8, 7**	**8, 7**
Selected Bus for Capacitor installation	**-**	**4, 7, 8, 9, 13**	**4, 7, 8, 9, 10**
Capacitor values (MVAR)	**-**	**1.5, 0.9, 1.8, 0.9, 0.9**	**1.5, 0.9, 1.8, 0.6, 0.6**
Loss (KW)	**511**	**448**	**448.5**
Cost (US$)	**85848**	**76595.4**	**76546.26**
V_{min}&V_{max}(p.u)	**1 & 0.971**	**1 & 0.9757**	**1 & 0.975**

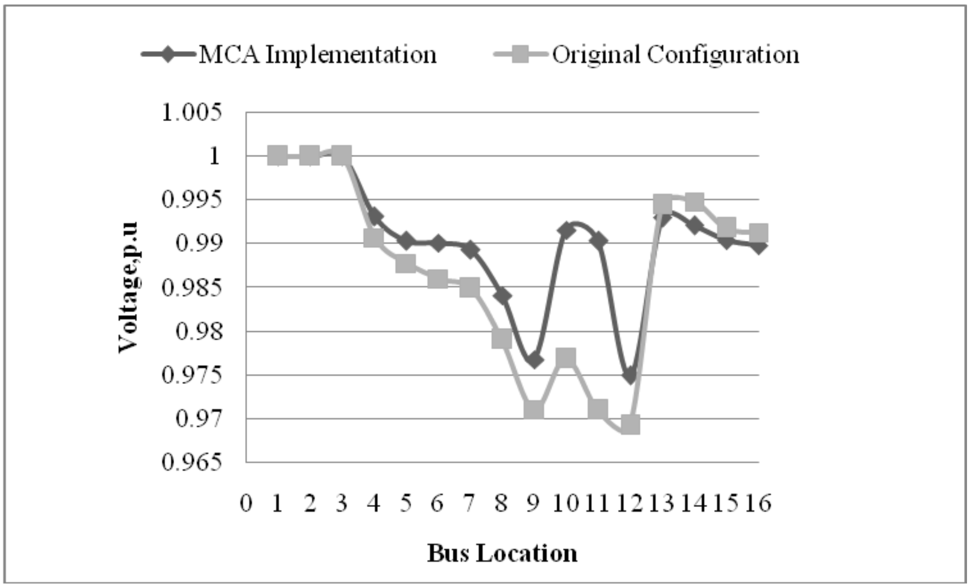

Figure 7.7 Change in voltage profile after network reconfiguration and capacitor allocation using MCA in 16 bus radial distribution system

7.3 23 bus radial system (Test Case III)

The third case is a 23 bus radial distribution system. The system data is taken from ref [22]. It is shown in Figure 7.8. The first bus is the slack bus and the other buses are load buses. The slack bus voltage is 11 KV and it is the base voltage for the feeder. The feeder has no laterals. It is a radial feeder. The system real power loss is 157.187 KW and loss of money for this real power loss is US$ 26407. The maximum and minimum voltages of the system without any capacitor bank at the buses are 1.0 p.u and 0.8934 p.u respectively. After reactive power compensation by installing shunt capacitors using Modified Cultural Algorithm, the active power loss is reduced to 95.1484 KW and due to the reduction in real power loss, the cost is also reduced from US$ 26047 to US$ 16513. The optimal bus locations for capacitor bank installation are 2, 6, 10, and 15. Capacitor Values which are chosen by MCA are 150, 600, 450 and 750 KVAR respectively for those selected buses. The results are shown in Table 7.4. Voltage profile has been improved after reactive power compensation. Improvement in Voltage profile after reactive power compensation is shown in Figure 7.9.

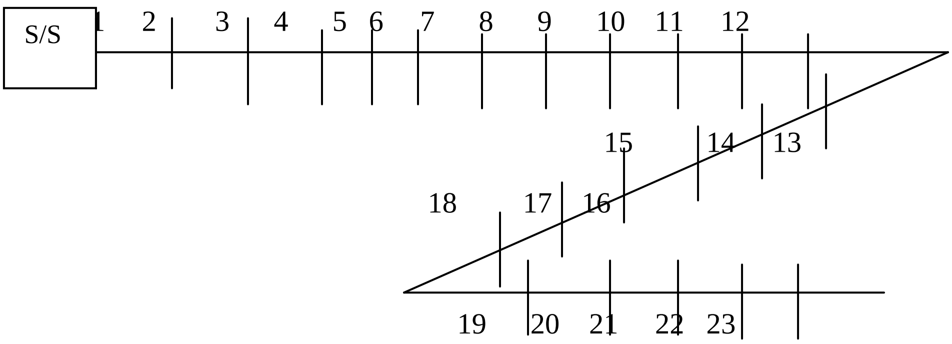

Figure 7.8 23 bus radial distribution system

Table 7.4 Results after capacitor allocation using MCA in 23 bus radial distribution system

Operations	**Original Configuration**	**MCA Implementation**
Selected Bus Locations	**-**	**2, 6, 10 and 15**
Capacitor Values (KVAR)	**-**	**150, 600, 450 and 750**
Loss (KW)	**157.187**	**95.1484**
Cost (US$)	**26407**	**16513**
V_{max}&V_{min} (p.u)	**1.0 & 0.8934**	**1.0 & 0.9523**

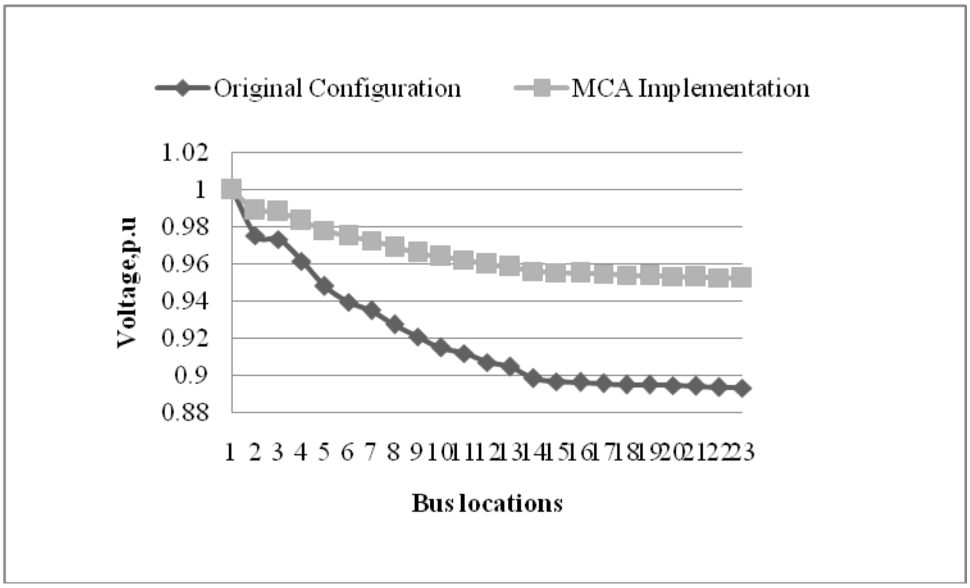

Figure 7.9 Change in voltage profile after capacitor allocation using MCA in 23 bus radial distribution system

7.4 34 bus radial distribution system (Test Case IV)

This system is a 34 bus radial distribution system [22] and it consists of 34 buses. It is shown in Figure 7.10. All the buses are load buses except one slack bus. Without compensation the real power loss and the cost due to loss are 221.5 KW and US$ 37212 respectively. After selecting suitable locations and capacitor values by Modified Cultural Algorithm, the loss has been reduced to 160.88 KW. Due to reduction in loss, the cost has also been minimized to US$ 27646.21. The voltage profile has also been improved. The lowest voltage after capacitor allocation is 0.9511 p.u. The comparison study with ref [22] is shown in Table 7.5. The loss and cost reduction after implementation of MCA are 27.3% and 25.7% respectively. The result is quite satisfactory in comparison with the reference method [22] which yields loss and cost reduction of 25.28% and 24.08% respectively.

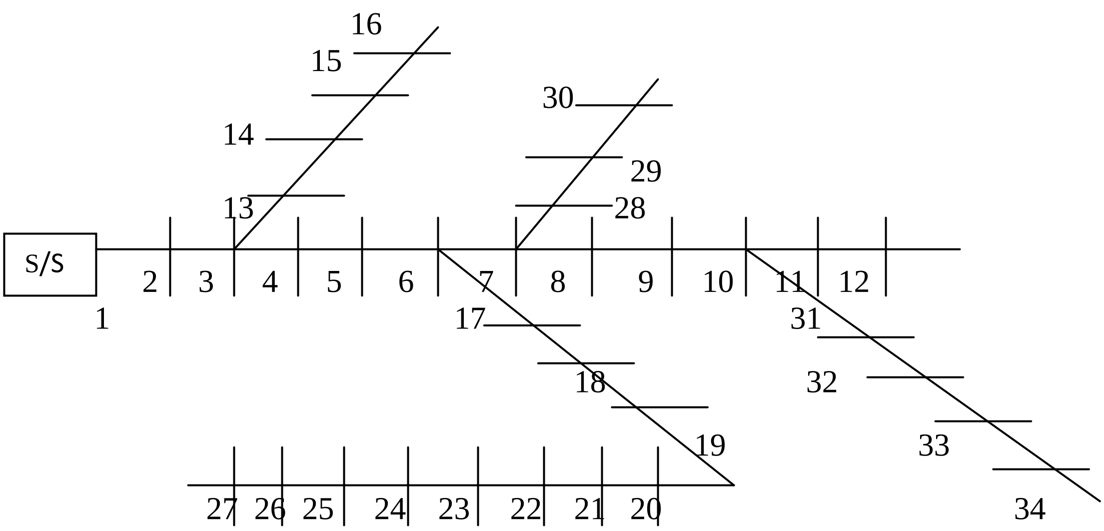

Figure 7.10 34 bus radial distribution system

Table 7.5 Comparison Study of Results for 34 bus radial distribution system

Methods	No Capacitor Placed	Method of ref [22]	Proposed MCA method
Total Capacitor placed in MVAR	0	2.1	2.7
Loss in KW	221.5	165.5	160.8849
Cost in US$	37212	28250	27646.21
V_{min} (p.u)	0.9417	0.9510	0.9511
V_{max} (p.u)	1	1	1

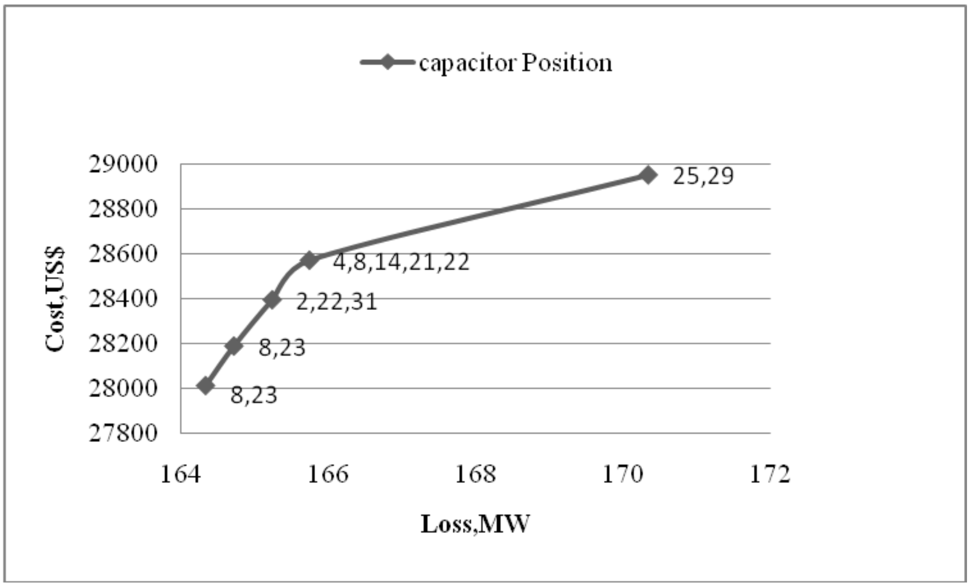

Figure 7.11 Belief Space movement for 34 bus radial distribution system

The Belief Space of the Modified Cultural Algorithm modifies the Population Space and creates new offspring. With the increment of iteration number, Belief Space capacitor position and capacitor values change and do reduction in loss and cost. It is shown in Figure 7.11. The selected bus locations are 25 and 29 at loss of 170.3409 KW and cost of US$ 28953. Capacitor values for those bus locations are 1200 and 600 KVAR. Belief Space moves from this position to another position for resulting reduction in loss and cost. The sensitive bus locations change to

4, 8, 14, 21 and 22 for selected capacitor values of 750, 900, 150, 750 and 150 KVAR respectively. The loss and cost reduces to 165.739 KW and US$ 28573 respectively for this move. Further movement of Belief Space reduces the total number of selected bus locations to 3. For bus location 2, 22 and 31, capacitor values 1200, 1500 and 600 KVAR are selected. Again the real power loss reduces to 165.2332 KW and cost also reduces to US$ 28397. For doing further decrement in loss and cost, Belief Space capacitor location changes to 8 and 23. Capacitor value 1050 and 1350 KVAR are selected for these bus locations. Loss and cost reduce to 164.7124 KW and US$ 28191 respectively. Finally the real power loss reduces to 164.328 KW and the cost minimizes to US$ 28015. At this position, the capacitor locations are same but the values of capacitors are changed from the previous position. Capacitor value of 1200 KVAR is selected for the each bus locations i.e. 8 and 23 respectively.

7.5 69 bus radial distribution system (Test Case V)

This is a 69 bus [50, 51] radial distribution system, consisting of one slack bus and 68 load buses. The line and bus data is shown in Appendix A in Table A.4. It is shown in Figure 7.12. It has one main feeder and 7 laterals. The value of unit capacitor is 200 KVAR and its cost is US$ 4/KVAR. The maximum allowable capacitor value is 600 KVAR. The cost of real power loss is US$ 0.06 /KWh. The load flow study is done for 6760 hr with 1 p.u load. After implementation of the MCA, the loss and cost have been drastically decreased from 225 KW to 145.2169 KW and from US$ 91,260 to US$ 66,099.97 respectively. The lowest voltage of the total system has been improved by 2.51% after placing the capacitors in 5 places. The results are shown in Table 7.6. For 69 bus radial distribution system, Situational Knowledge and History Knowledge influence both act equally to reach the optimal solution. The capacitor locations are shifted through iterations by the Belief Space movement for resulting minimization of real power loss and cost.

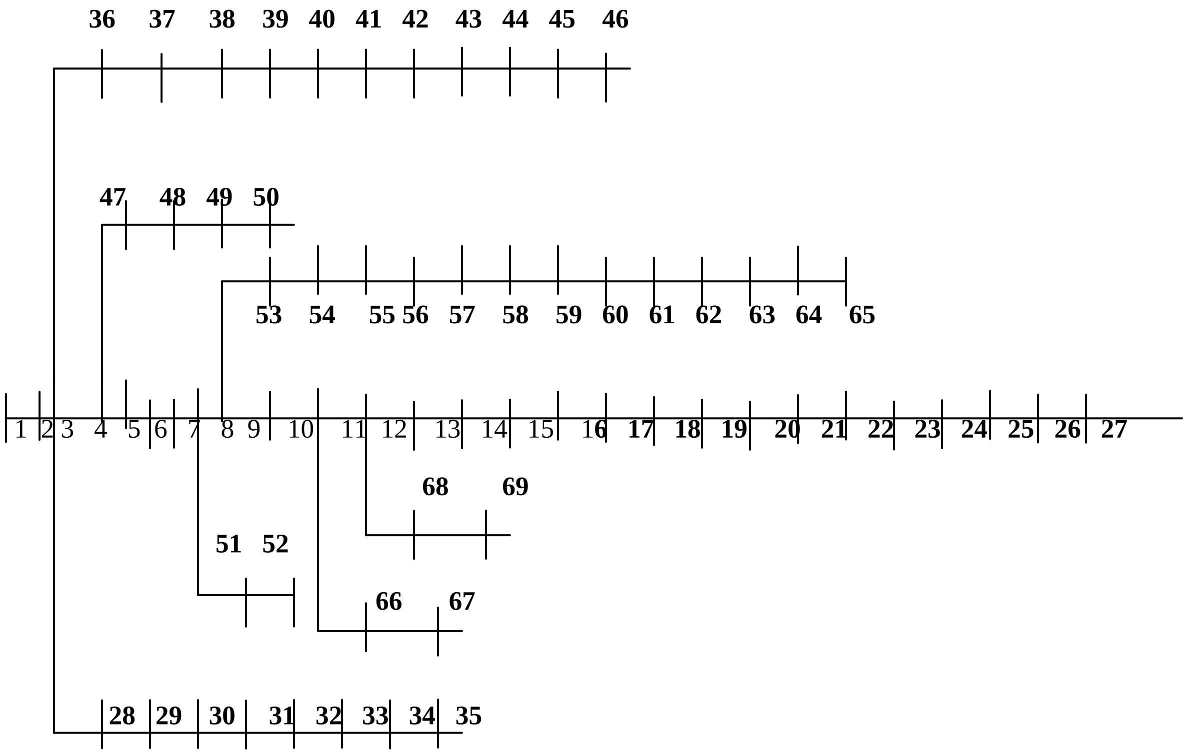

Figure 7.12 69 bus radial distribution system

Table 7.6 Results after capacitor allocation in 69 bus radial distribution system using MCA

Methods	**Without Capacitor**		**Proposed Method (MCA)**	
Total Capacitor placed in KVAR	**Bus No**	**Capacitor Value in KVAR**	**Bus No**	**Capacitor value in KVAR**
	1	**0**	**11**	**400**
	2	**0**	**14**	**200**
	3	**0**	**61**	**600**
	.	**.**	**62**	**400**
	.	**.**	**65**	**200**
	69	**0**		
Total Losses in KW	**225**		**145.2169**	
Total Cost in US$	**91,260**		**66,099.97**	
% Loss saving	**0**		**35.49**	
% Cost Saving	**0**		**27.56**	
V_{min} & V_{max} in p.u	**0.9091 & 1.0**		**0.9320 & 1.0**	

7.6 Practical Transmission System (Test Case VI)

This test case is a 132KV practical transmission system (shown in Figure 5.2). Buses 1, 2, 3 are 220/132KV Substation .The first one is considered as slack bus. Other buses are considered as voltage controlled bus. All other stations are 132/33KV Substations and they are considered as load buses. From Substation A to Station D and F is a radial feeder. Substation A and Substation B are interconnected via load station G. Substation B, Load Station E, load Station H and Substation C form a closed loop. This system is not a radial system like those previous distribution systems, discussed in the earlier sections. The capacitor values are taken 10, 12.5, 25, 32.5, 40, 50, 30 and 20 MVAR for doing reactive power compensation. The p.u resistance, p.u reactance and p.u half susceptance values are taken 0.000931 Ω/Km, 0.002216 Ω/Km and 0.000255 Ω/Km respectively as positive sequence parameter considering the system as stable and balance. Cost of unit capacitor and value of K_p in (5.2.1) are taken same as described in section 7.2 (16 bus distribution system). Total distance of possible tie switch combination is 531.1Km and 35% of this length i.e., 185.88 Km is set as the maximum affordable transmission distance for feasible switch selection. Transmission line costing $Dist$ in (5.2.1) is taken as US$100/Km. All the single line in the system signifies double circuit network except the line from bus 7 to bus 8. Fast decoupled load flow method [45, 46] is used for power flow calculation. Reactive power compensation is done first in the practical system using MCA. The active power loss reduces from 9.8153 MW to 9.53 MW as a result of reactive power compensation and the cost due to real power loss reduction and capacitor installation decreases from US$ 1648970.4 to US$ 1623784.75. The voltage profile has been improved after capacitor placement. It is shown in Figure 7.13. The minimum voltage of the system has been increased from 0.9793 p.u to 0.9878 p.u. Total capacitor value of 102.5 MVAR is placed in the transmission system. Four buses are selected for installation of 32.5, 10, 20 and 40 MVAR of capacitor. The selected bus locations are 4, 5, 6 and 8. The transmission real power loss has been further reduced by doing simultaneously network reconfiguration and capacitor allocation. This time, the real power loss has been decreased by 5.87 MW. The cost has also been reduced from US$ 1648970.4 to US$ 674654. The results after MCA implementation is listed in Table 7.11. The minimum voltage has also been improved from 0.9793 p.u to 0.9924 p.u after both reconfiguration and capacitor allocation. The network reconfiguration for this practical system is done by selecting new tie switches 5,9,10 and 11. Capacitor values of 12.5 MVAR, 20 MVAR and 20 MVAR are placed at the bus location 4, 6 and 8 respectively. If only network reconfiguration is approached, then the real power loss will reduce to 4.02 MW for selection of same tie switches and value of minimum voltage will increase from 0.9793 p.u to 0.9909 p.u. This value of minimum voltage is less than that of the reconfigured and compensated system. The voltage profile after both reconfiguration and capacitor allocation is studied with original configuration in Figure 7.14. Belief Space movement for switching operation and capacitor allocation with the loss reduction are shown in Figure 7.15 and Figure 7.16 respectively. Economically loss minimization for the transmission network has given mutual importance to both the Belief Spaces i.e., network reconfiguration Belief Space and capacitor allocation Belief Space. The Belief Spaces values are complementary to each other. Individually the network reconfiguration or capacitor allocation Belief Space will not give the exact loss and cost values. Both the network switching data and the capacitor bus locations and installed MVAR will ultimately give the exact loss and cost for the system, taken in this work. Belief Space for network reconfiguration moves from tie switch 9 to 5, 9, 10 and 11.The loss also diminishes with the movement from 5.31 MW to 3.95 MW. Belief Space movement for switching operation is more or less confined in 4 switches. The best switches moves from switch 5, 9 to switch 5, 9 and 11 for loss reduction of 0.44 MW. 0.53 MW of real power loss reduction causes to move the Belief Space switches to switch 9, 10. At last the MCA finds the minimum loss at switch 5, 9, 10 and 11 reducing 0.27 MW of real power from the previous value. Belief Space for capacitor allocation also moves from certain bus locations to other bus locations for loss minimization and the capacitor value also changes. At bus locations 2, 4, 5 and 8, the capacitor values are 40 MVAR, 12.5 MVAR, 12.5 MVAR and 40 MVAR. The optimum locations, found out in this system are 4, 6 and 8. The capacitor values in these locations are 12.5 MVAR, 20 MVAR and 20 MVAR. The Belief Space moves gradually to the minimum one. At the early stage of iteration, the sensitive bus locations are 2, 4, 5 and 8, then the locations moves to 2, 5, and 8 at 4.87 MW of loss. After it, the sensitive bus locations move to 2, 3, 4 and 7 at 4.75 MW of loss. But the movement is not stopped as the influence of the Knowledge sources is not done sufficiently. The locations again moves to 4, 5 and 8 at loss of 4.22 MW and ultimately the journey stops at locations 4, 6 and 8 at loss of 3.95 MW. Capacitor values 40 MVAR, 20 MVAR, 32.5 MVAR, 30 MVAR and 10 MVAR are mainly selected by the Knowledge sources. At loss of 5.31 MW, the total installed capacitor value is 92.5 MVAR. As the Belief Space moves, the total MVAR installed at buses changes to 55 MVAR at 4.87 MW of loss. Then it increases to 145 MVAR at 4.75 MW of loss. At 4.22 MW of loss the total capacitor value diminishes to 42.5 MVAR and ultimately it stops at 52.5 MVAR for loss of 3.95 MW. Capacitor allocation approach is same as the distribution system studied above. Original bus data and line data of the network are given in Table A.1 and A.2 and new line configuration is shown in Table A.3 in the Appendix A.

Table 7.7 Results after capacitor allocation using MCA in Practical Transmission System

Operations	Original Configuration	MCA implementation
Bus No	**Capacitor Value (MVAR)**	**Capacitor Value (MVAR)**
1	0	0
2	0	0
3	0	0
4	0	32.5
5	0	10
6	0	20
7	0	0
8	0	40
Loss (MW)	9.8153	9.53
Cost (MW)	1648970.4	1623784.75

V_{min} (p.u)	**0.9793**	**0.9878**
V_{max} (p.u)	**1**	**1**

Table 7.8 Results after network reconfiguration and capacitor allocation using MCA in Practical Transmission System

Configurations without sectionalizing switch removal	**Original configuration**	**Only network reconfiguration**	**Both reconfiguration and capacitor allocation**
Tie switch selection	**-**	**5, 9, 10, 11**	**5, 9, 10, 11**
Bus no	**Capacitor (MVAR)**	**Capacitor (MVAR)**	**Capacitor (MVAR)**
1	**-**	**-**	**0**
2	**-**	**-**	**0**
3	**-**	**-**	**0**
4	**-**	**-**	**12.5**
5	**-**	**-**	**0**
6	**-**	**-**	**20**
7	**-**	**-**	**0**
8	**-**	**-**	**20**
Length(Km)	**-**	**118.94**	**118.94**
Cost(US$)	**1648970.4**	**687254**	**674654**
Loss(MW)	**9.8153**	**4.02**	**3.945**
V_{max}&V_{min}(p.u)	**1.0 & 0.9793**	**1 & 0.9909**	**1 & 0.9924**

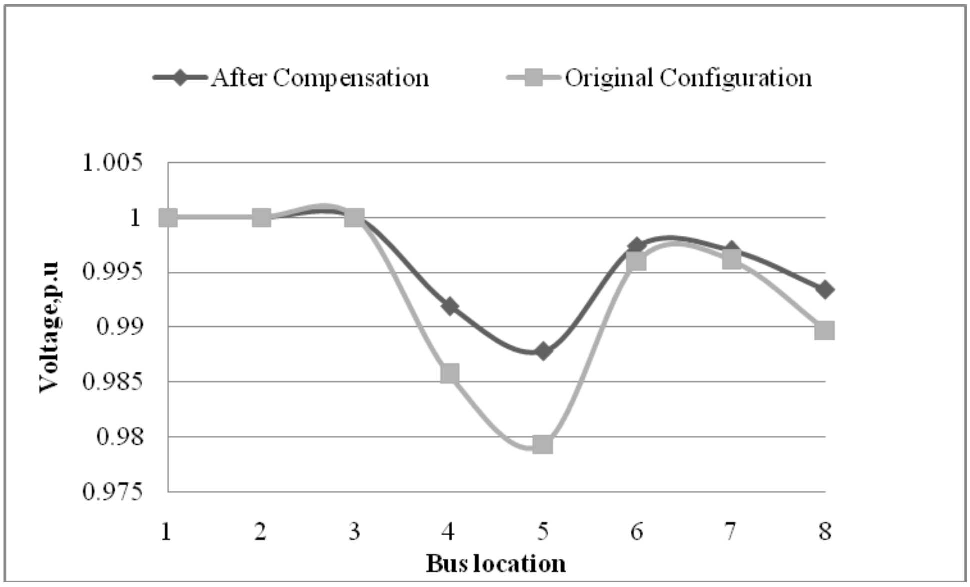

Figure 7.13 Change in voltage profile after capacitor allocation with original configuration using MCA in Practical Transmission System

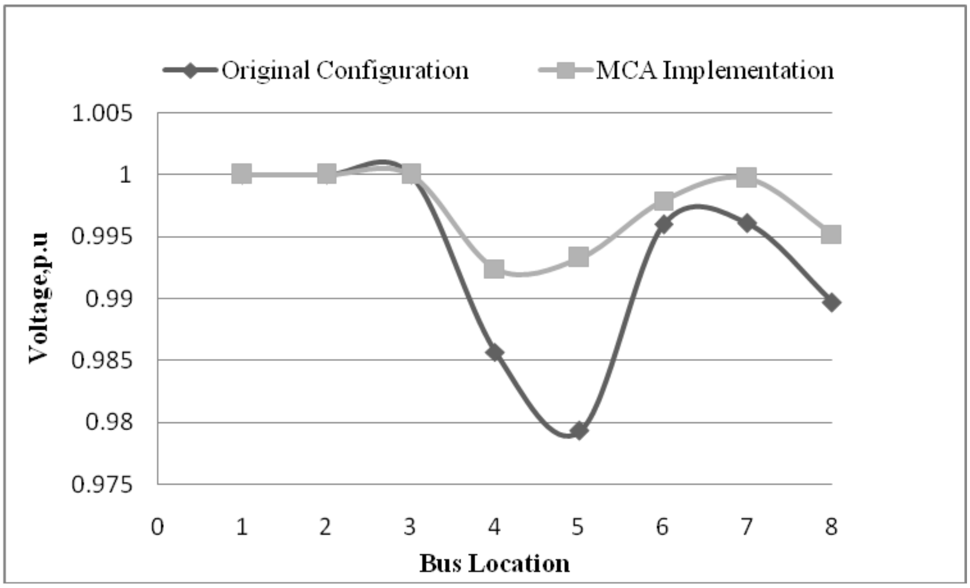

Figure 7.14 Change in voltage profile after network reconfiguration and capacitor allocation with original configuration using MCA in Practical Transmission System

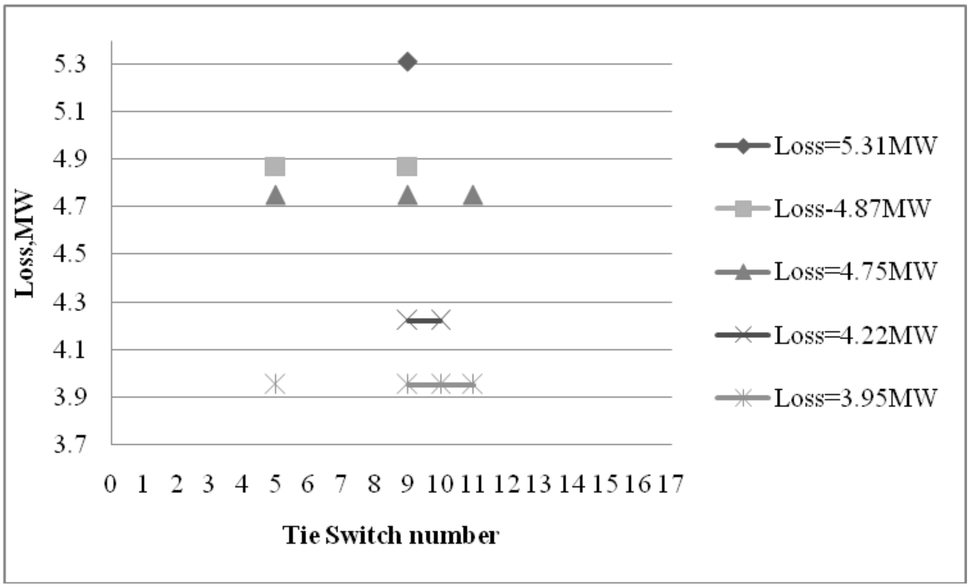

Figure 7.15 Belief Space movement for switching operation in Practical Transmission System

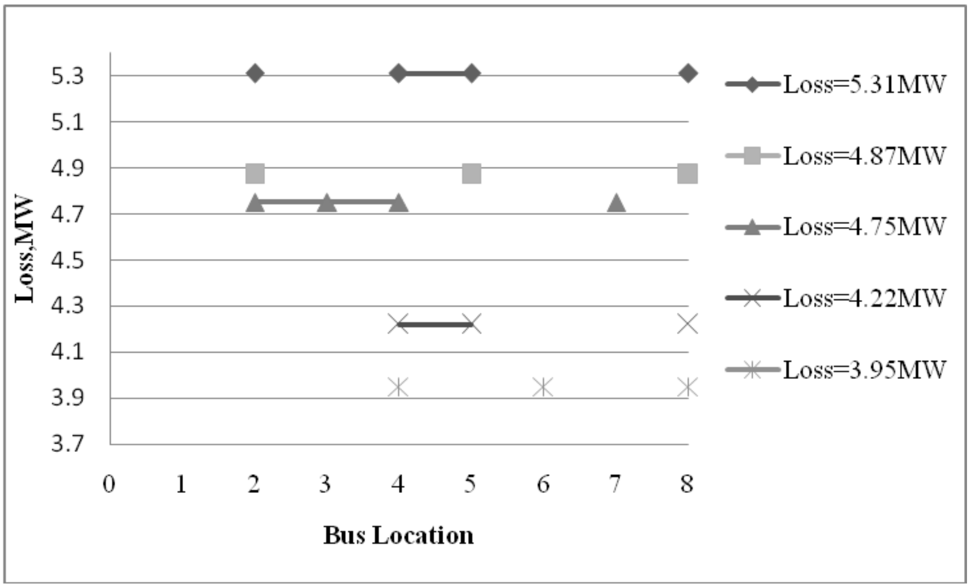

Figure 7.16 Belief Space movement for capacitor allocation in practical Transmission System

In the next chapter an overall summary of the work is described briefly drawing conclusion and putting an idea for further study in this particular field of Power Engineering.

Chapter Eight

8. Conclusion and Scope of Future Work

In this work, capacitor allocation and network reconfiguration are taken as two schemes for minimization of real power loss through reactive power compensation and load balancing. Soft computing technique actually metaheuristic technique like Cultural Algorithm has been taken for searching optimal values and configuration for achieving the target. Cultural Algorithm has been modified and implemented satisfactorily with promising results. This Modified Cultural Algorithm outperforms other techniques in comparison. Conclusion is drawn in the next section. Some probable view of future research on this topic is described in section 8.2.

8.1 Conclusion

Optimal capacitor placement and network reconfiguration in Power System is not an easy job. Several iterations and computation time will be required achieving a fruitful solution. Local optima and the global optima is a very important thing to consider. Optimization methods, which are conventional, have a tendency to stick to the local optimal point and it is very hard to get rid of that. The implementation logic of a new heuristic technique called MCA developed in house is almost free from this criticality. It has cut short the computation time and it helps to accelerate the procedure of computation. The effectiveness and superiority of this non-conventional technique has been established by comparing it with the other published works. Only two Knowledge sources have been taken in the Influence function. More Knowledge sources can also be taken into action to check their effectiveness. Consideration of both the bus location and capacitor value at a time has helped a lot to reach the optimum point quickly. It actually deals with a huge possible combination of solutions i.e., capacitor values and locations and also switch combinations. Concept of Belief Space with the information of all the individuals from all iterations has made the searching process quite easier. Only network reconfiguration or only capacitor allocation is not economical as well as beneficial for the system improvement. It needs both reconfiguration and capacitor allocation in a very efficient manner to have the maximum improvement of the system. However reconfiguration is done for the 16 bus system and practical transmission system. It is done with capacitor installation in the proposed real system considering the present system undisturbed. This is done to have no voltage collapse or mismatch. It will be a challenging task to reconfigure the transmission network by removing the existing sectionalizing switches. So it can be concluded from this study that Modified Cultural Algorithm is helpful and useful for getting optimal solution from such a combinatorial optimization problem of capacitor allocation and network reconfiguration in the Power System.

8.2 Scope of Future Work

Implementation of Distributed energy resources with shunt capacitor can be a good approach for loss minimization. Transmission expansion with application of superconductive magnetic energy storage as a static synchronous generator can minimize the active power loss making the daily load curve flat. Transformer tap changing option with capacitor allocation and distributed generation may be done for the same reduction of real power loss. Actually a suitable and optimal combination of the above mentioned scheme should be studied for the extension of the work. The Modified Cultural Algorithm only includes two Knowledge sources. It can be studied with the five Knowledge sources of Cultural Algorithm. A study of making hybrid optimization technique with MCA will be a good research for fine tuning of the soft computing technique. Particle Swarm Optimization, Differential evolution, Simulated Annealing and other metaheuristic techniques can be useful for making hybrid optimization technique with Modified Cultural Algorithm. Transmission reconfiguration which has been done in this research work is only based on the line or cable cost. The cost of transmission tower and land can be incorporated as an extended study of it. Transmission expansion considering geographical location may be a good study for doing the economical improvement of the system.

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Appendix A

Table A.1 Bus Data of Practical Transmission System

Bus no	Pd(load) (MW)	Qd(load) (MW)	Voltage (KV)	Type of bus
1	-	-	132	Slack
2	-	-	132	PV
3	-	-	132	PV
4	87.4	37.23	-	PQ
5	36.8	15.676	-	PQ
6	64.4	27.434	-	PQ
7	32.2	13.717	-	PQ
8	124.2	52.90	-	PQ

Table A.2 Line Data of Practical Transmission System

From Bus	To Bus	Length in Km
1	4	22.5
4	5	35
1	6	15.5
2	6	36
2	7	10
7	8	15
3	8	22.7

Table A.3 New line configuration of Practical Transmission System

Tie switch	From Bus	To bus	Distance in Km
1	4	2	16.2
2	4	7	43.46
3	6	7	34.24
4	6	8	34.45
5	7	3	7.50
6	6	3	41.28
7	4	3	24.83
8	5	3	50.59
9	1	7	34.56
10	1	8	34.93
11	1	5	41.95
12	5	6	32.79
13	6	4	16.53
14	4	8	17.84
15	5	2	37.58
16	5	8	45.42
17	4	7	16.73

Table A.4 69 bus Line and Bus Data

From bus	To bus	R (ohm)	X (ohm)	P(Kw)	Q(KVAr)
1	2	0.0005	0.0012	0	0
2	3	0.0005	0.0012	0	0
3	4	0.0015	0.0036	0	0
4	5	0.0251	0.0294	0	0
5	6	0.3660	0.1864	2.6	2.2
6	7	0.3811	0.1941	40.4	30
7	8	0.0922	0.0470	75	54
8	9	0.0493	0.0251	30	22
9	10	0.8190	0.2707	28	19
10	11	0.1872	0.0691	145	104
11	12	0.7114	0.2351	145	104
12	13	1.03	0.34	8	5.5
13	14	1.044	0.3450	8	5.5
14	15	1.058	0.3496	0	0
15	16	0.1966	0.065	45.5	30
16	17	0.3744	0.1238	60	35
17	18	0.0047	0.0016	60	35
18	19	0.3276	0.1083	0	0
19	20	0.2106	0.0696	1	0.6
20	21	0.3416	0.1129	114	81
21	22	0.0140	0.0046	5.5	3.5
22	23	0.1591	0.0526	0	0

23	24	0.3463	0.1145	28	20
24	25	0.7488	0.2475	0	0
25	26	0.3089	0.1021	14	10
26	27	0.1732	0.0572	14	10
3	28	0.0044	0.0108	26	18.6
28	29	0.064	0.1565	26	18.6
29	30	0.3978	0.1315	0	0
30	31	0.0702	0.0232	0	0
31	32	0.351	0.1160	0	0
32	33	0.839	0.2861	14	10
33	34	1.708	0.5646	19.5	14
34	35	1.474	0.4873	6	4
3	36	0.0044	0.0108	26	18.55
36	37	0.064	0.1565	26	18.55
37	38	0.1053	0.1230	0	0
38	39	0.0304	0.0355	24	17
39	40	0.0018	0.0021	24	17
40	41	0.7283	0.8509	1.2	1
41	42	0.310	0.3623	0	0
42	43	0.041	0.0478	6	4.3
43	44	0.0092	0.0116	0	0
44	45	0.1089	0.1373	39.22	26.3
45	46	0.0009	0.0012	39.22	26.3
4	47	0.0034	0.0084	0	0
47	48	0.0851	0.2083	79	56.4
48	49	0.2898	0.7091	384.7	274.5

49	**50**	**0.0822**	**0.2011**	**384.7**	**274.5**
8	**51**	**0.0928**	**0.0473**	**40.5**	**28.3**
51	**52**	**0.3319**	**0.1114**	**3.6**	**2.7**
9	**53**	**0.1740**	**0.0886**	**4.35**	**3.5**
53	**54**	**0.203**	**0.1034**	**26.4**	**19**
54	**55**	**0.2842**	**0.1447**	**24**	**17.2**
55	**56**	**0.2813**	**0.1443**	**0**	**0**
56	**57**	**1.59**	**0.5337**	**0**	**0**
57	**58**	**0.7837**	**0.2630**	**0**	**0**
58	**59**	**0.3042**	**0.1006**	**100**	**72**
59	**60**	**0.3861**	**0.1172**	**0**	**0**
60	**61**	**0.5075**	**0.2585**	**1244**	**888**
61	**62**	**0.0974**	**0.0496**	**32**	**23**
62	**63**	**0.1450**	**0.0738**	**0**	**0**
63	**64**	**0.7105**	**0.3619**	**227**	**162**
64	**65**	**1.041**	**0.5302**	**59**	**42**
11	**66**	**0.2012**	**0.0611**	**18**	**13**
66	**67**	**0.0047**	**0.0014**	**18**	**13**
12	**68**	**0.7394**	**0.2444**	**28**	**20**
68	**69**	**0.0047**	**0.0016**	**28**	**20**