An Efficient Method for Selection of Optimal Conductors in Planning of Radial Distribution Network

Thesis submitted in partial fulfillment of the requirements for the award of degree of

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in
Power Systems & Electric Drives

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Certificate

I hereby certify that the work which is being presented in the thesis entitled, **"An Efficient Method for Selection of Optimal Conductors in Planning of Radial Distribution Network"**, in partial fulfillment of the requirements for the award of degree of **Master of Engineering** in **Power Systems & Electric Drives** submitted in Electrical & Instrumentation Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Ms. Aabha**, Lecturer, EIED.

The matter presented in this thesis has not been submitted for the award of any other degree of this or any other university.

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

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ABSTRACT

Distribution system is one from which the power is distributed to various users through feeders, distributors and service mains. Feeders are conductors of large current carrying capacity, carrying the current in bulk to the feeding points. Conductor is often the biggest contributor to distribution system losses. Economic conductor sizing is therefore of major importance. If a conductor is loaded up to or near its thermal rating, the losses will be increased. Therefore, line conductors are loaded below their thermal limit. The power loss is significantly high in distribution systems because of lower voltages and higher currents, when compared to that in high voltage transmission systems. Studies have indicated that as much as 13% of total power generated is consumed as I^2R losses in distribution level. Reduction of total loss in distribution systems is very essential to improve the overall efficiency of power delivery.

In this thesis work, an attempt has been made for selecting optimal size of branch conductor of radial distribution feeders based on PSO (Particle Swarm Optimization) . The capital investment in laying distribution network lines accounts for a considerable fraction of total capital, investment. The problem is posed as an optimization problem with an objective to minimize the overall cost of annual energy losses and depreciation on the cost of conductors. The conductor, which is determined by this method will maintain acceptable voltage levels of the radial distribution system. Besides, it gives maximum saving in the capital cost of conducting material and cost of energy losses. The proposed method also shows that only proper selection of optimum branch conductors reduces losses instead of using uniform conductors. The effectiveness of the proposed method is demonstrated through an example.

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CHAPTER -1

INTRODUCTION

The distribution system constitutes a significant part of a total power system. A distribution system is one from which the power is distributed to various users through feeders distributors and service mains. Feeders are conductors of large current carrying capacity, carrying the current in bulk to the feeding points. Power losses in the lines account for the major portion of the distribution system losses. These power losses mainly depends on the type of conductor and its resistance, size and length. To meet the present growing domestic, industrial and commercial load day by day, effective planning of radial distribution network is required. Increasing costs of energy and costs of generating capacity are encouraging the electric utility to spend capital to improve the efficiency of the distribution system. The objective of distribution system planning is to assure that the growing demand for electricity, in terms of increasing growth rates and high load densities, can be satisfied in an optimum way by additional distribution systems.

1.1 Distribution Systems

An electric distribution system, or distribution plant as it is sometimes called, is all of that part of an electric power system between the bulk power source or sources and the consumers service switches. The effectiveness with which a distribution system fulfills this function is measured in terms of voltage regulation, service continuity, flexibility, efficiency, and cost. The cost of distribution is an important factor in the delivered cost of electric power. The bulk power sources are located in or near the load area to be served by the distribution system and may be either generating stations or power substations supplied over transmission lines. Distribution systems can, in general, be divided into six parts, namely, subtransmission circuits, distribution substations, distribution or primary feeders, distribution transformers, secondary circuits or secondaries, and consumers service connections and meters or consumers services.

Figure 1.1 is a schematic diagram of a typical distribution system showing these parts.

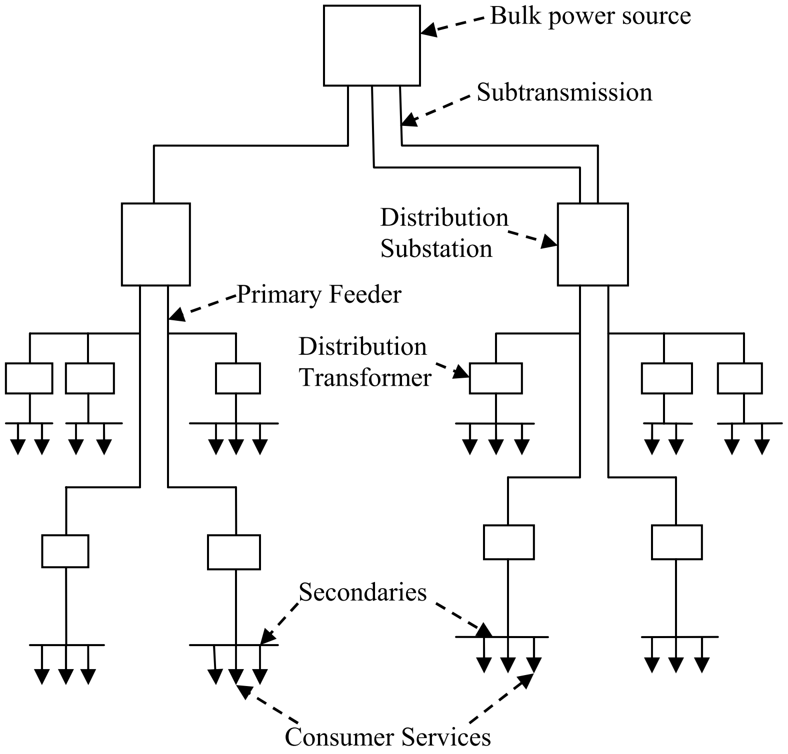

Fig. 1.1 Typical Distribution system

1.1.1 Subtransmission Circuits

The subtransmission circuits extend from the bulk power source or sources to the various distribution substations located in the load area. They may be radial circuits connected to a bulk power source at only one end or loop and ring circuits connected to one or more bulk power sources at both ends. The subtransmission circuits consist of underground cable, aerial cable, or overhead open-wire conductors carried on poles, or some combination of them. The subtransmission voltage is usually between 11 and 33 kv.

1.1.2 Distribution Substation

Each distribution substation normally serves its own load area, which is a subdivision of the area served by the distribution system. At the distribution substation the subtransmission voltage is reduced for general distribution throughout the area. The substation consists of one or more power-transformer banks together with the necessary voltage regulating equipment, buses, and switchgear.

1.1.3 Primary Feeders

The area served by the distribution substation is also subdivided and each subdivision is supplied by a distribution or primary feeder. The three-phase primary feeder is usually run out from the low voltage bus of the substation to its load center where it branches into three phase sub feeders and single-phase laterals.

1.1.4 Distribution transformers

Distribution transformers are ordinarily connected to each primary feeder and its subfeeders and laterals. These transformers serve to step down from the distribution voltage to the utilization voltage. Each transformer or bank of transformers supplies a consumer or group of consumers over its secondary circuit. Each consumer is connected to the secondary circuit through his service leads and meter. The secondaries and service connections may be either cable or open-wire circuits.

1.2 Classification of Distribution Systems

A distribution system may be classified according to:

(i) Nature of current: According to nature of current, distribution system may be classified as (a) d.c. distribution system and (b) a.c. distribution system. Now-a-days a.c. system is universally adopted for distribution of electric power as it is simpler and more economical than direct current method.

(ii) Type of construction: According to type of construction, distribution system may be classified as (a) overhead system and (b) underground system. The overhead system is generally employed for distribution as it is 5 to 10 times cheaper than the equivalent underground system. In general, the underground system is used at places where overhead construction is impracticable or prohibited by the local laws.

(iii) Scheme of connection: According to scheme of connection, the distribution system may be classified as (a) radial system, (b) ring main system and (c) inter-connected system. Each scheme has its own advantages and disadvantages.

1.3 Connection Scheme of Distribution System

There are three fundamentally different ways to lay out a power distribution system used by electric utilities, each of which has variations in its own design:

1. Radial Feeder System

Most power distribution systems are designed to be radial, to have only one path between each customer and the substation. The power flows exclusively away from the substation and out to the customer along a single path, which, if interrupted, results in complete loss of power to the customer. Radial design is by far the most widely used form of distribution design. Its predominance is due to two overwhelming advantages: it is much less costly than the other two alternatives and it is much simpler in planning, design, and operation.

In most radial plans, both the feeder and the secondary systems are designed and operated radially. Each radial feeder serves a definite service area. Many radial feeder systems are laid out and constructed as networks, but operated radially by opening switches at certain points throughout the physical network configuration so that the resulting configuration is electrically radial. Each service transformer in these systems feeds power into a small radial system around it, basically a single electrical path from each service transformer to the customers nearby. Regardless of whether it uses single-phase laterals or not, the biggest advantages of the radial system configuration, in addition to its lower cost, is the simplicity of analysis and predictability of performance. Because there is only one path between each customer and the substation, the direction of power flow is absolutely certain and thus voltage profiles can be determined with a good degree of accuracy without resorting to exotic calculation methods, equipment capacity requirements can be ascertained exactly; fault levels can be predicted with a reasonable degree of accuracy; and protective device: breaker, relays and fuses can be coordinated in an absolutely assured manner, without resorting to network methods of analysis.

On the debit side, radial feeder systems are less reliable than loop or network system because there is only one path between the substation and the customer. Thus, if any element along this path fails, a loss of power delivery results.

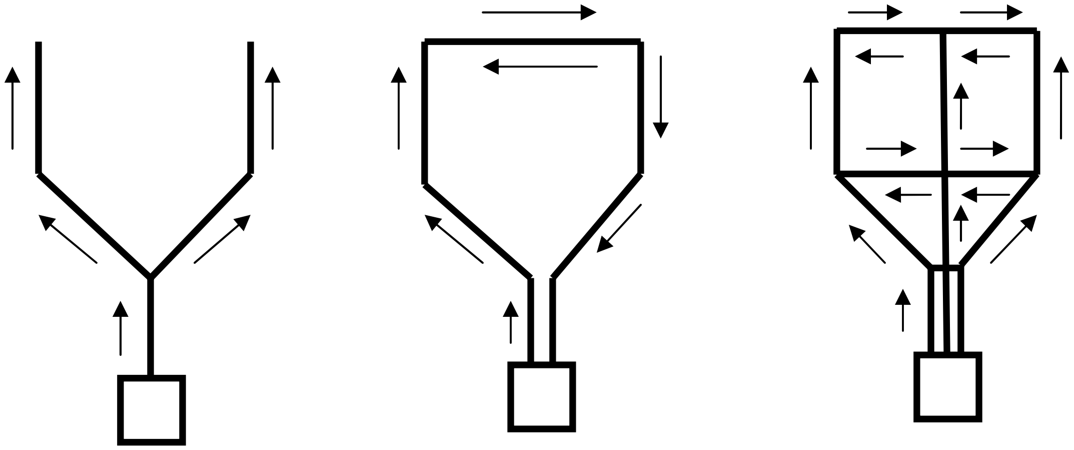

Fig. 1.2 Connection scheme of distribution system

2. Loop Feeder System

A loop system has two paths between the power sources (substations, service transformers) and each customer. Equipment is sized and each loop is designed so that service can be maintained regardless of where an open point might be on the loop. Because of this requirement, whether operated radially (with one open point in each loop) or with closed loops, the basic equipment capacity requirements of the loop feeder design do not change.

In terms of complexity, a loop feeder system is only slightly more omplicated than a radial system - power usually flows out from both sides toward the middle, and in all cases can take only one of two routes. Voltage drop, sizing, and protection engineering are only slightly more complicated than for radial systems. But if designed thus, and if the protection (relay-breakers and sectionalizers) is also built to proper design standards, the loop system is more reliable than radial systems. Service will not be interrupted to the majority of customers whenever a segment is outaged, because there is no "downstream" portion of any loop.

The major disadvantage of loop systems is a higher capacity cost than purely radial distribution. A loop must be designed to meet all power and voltage drop requirements when fed from either end. It needs extra capacity on each end, and the conductor must be large enough to handle the power and voltage drop needs of the entire feeder if fed from either end.

3. Distribution Network

Distribution networks are the most complicated, but most reliable, and in very rare cases also the most economical method of distributing electric power. A network involves multiple paths between all points in the network. Networks provide continuity of service (reliability) far beyond that of radial and loop designs: if a failure occurs in one line, power instantly and automatically re-routes itself through other pathways.

Most distribution networks are underground systems, simply because they are employed mostly in high density areas, where overhead space is not available. Rarely is the primary voltage level a network, because that proves very expensive and often will not work well. Instead, a "distribution network" almost always involves "interlaced" radial feeders and a network secondary system - a grid of electrically strong (i.e., larger than needed to just feed customers in the immediate area when everything is functioning) conductor connecting all the customers together at utilization voltage. In this type of design, the secondary grid is fed from radial feeders through service transformers, basically the same way secondary is fed in radial or loop systems. The feeders are radial, but laid out in an interlaced manner – none has a sole service area, but instead they overlap.

The interconnected system has the following advantages:

- It increases the service reliability.
- Any area fed from one generating station during peak load hours can be fed from the other generating station. This reduces reserve power capacity and increases efficiency of the system.

Networks have one major disadvantage. They are much more complicated than other forms of distribution, and thus much more difficult to analyze and operate.

1.4 Requirement of a Distribution System

A considerable amount of effort is necessary to maintain an electric power supply within the requirements of various types of consumers. Some of the requirements of a good distribution system are: proper voltage, availability of power on demand, and reliability.

(i) Proper Voltage: One important requirement of a distribution system is that voltage variations at consumers terminals should be as low as possible. The changes in voltage are generally caused due to the variation of load on the system. Low voltage causes loss of revenue, inefficient lighting and possible burning out of motors. High voltage causes lamps to burn out permanently and may cause failure of other appliances. Therefore, a good distribution system should ensure that the voltage variations at consumers' terminals are within permissible limits. The limit of voltage variations is ±10% of the rated value at the consumers terminals. Thus, if the declared voltage is 230 V, then the highest voltage of the consumer should not exceed 244 V while the lowest voltage of the consumer should not be less than 216 V.

(ii) Availability of Power Demand: Power must be available to the consumers in any amount that they may require from time to time. For example, motors may be started or shut down, lights may be turned on or off, without advance warning to the electric supply company. As electrical energy cannot be stored, therefore, the distribution system must be capable of supplying load demands of the consumers. This necessitates that operating staff must continuously study load patterns to predict in advance those major load changes that follow the known schedules.

(iii) Reliability: Modern industry is almost dependent on electric power for its operation. Homes and office buildings are lighted, heated, cooled and ventilated by electric power. This calls for reliable service. Unfortunately electric power, like everything else that is man-made, can never be absolutely reliable. However, the reliability can be improved to a considerable extent by (a) inter-connected system, (b) reliable automatic control system and (c) providing additional reserve facilities.

1.5 Design Considerations in Distribution System

Good voltage regulation of a distribution network is probably the most important factor responsible for delivering good service to the consumers. For this purpose, design of feeders and distributors requires careful consideration:

(i) Feeders: A feeder is designed from the point of view of its current carrying capacity while the voltage drop consideration is relatively not important. It is because voltage drop in a feeder can be compensated by means of voltage regulating equipment at the sub-station.

(ii) Distributors: A distributor is designed from the point of view of the voltage drop in it. It is because a distributor supplies power to the consumers and there is a statutory limit of voltage variations at the consumer terminal (± 10% of rated value). The size and length of the distributor should be such that voltage at the consumer's terminals is within the permissible limits.

1.6 Overhead Versus Underground System

The distribution system can be overhead or underground. Overhead lines are generally mounted on wooden, concrete or steel poles which are arranged to carry distribution transformers in addition to the conductors. The choice between overhead and underground system depends upon a number of widely differing factors.

1. **Public Safety:** The underground system is more safe than overhead system because all distribution wiring is placed underground and there are little chances of any hazard.

2. **Initial Cost:** The underground system is more expensive due to the high cost of trenching, conduits, cables, manholes, and other special equipments. The initial cost of an underground system may be five to ten times than that of an overhead system.

3. **Flexibility:** The overhead system is much more flexible than the underground system. In the latter case, manholes, duct lines etc., are permanently placed once installed and the load expansion can only be met by laying new lines. However on an overhead system, poles, wires, transformer etc., can be easily shifted to meet the change in load conditions.

4. **Faults:** The chances of fault in underground system are very rare as the cables are laid underground and are generally provided with better insulation.

5. **Appearance:** The general appearance of an underground system is better as all the distribution lines are visible. This factor is exerting considerable public pressure on electric supply companies to switch over to underground system.

6. **Fault location and repairs:** In general, there are little chances of fault in an underground system. However, if a fault does occur, it is difficult to locate and repair the system. On an overhead system, the conductors are visible and easily accessible so that fault locations and repairs can easily be made.

7. **Current carrying capacity and voltage drop:** An overhead distribution conductor has a considerably higher current carrying capacity than an underground cable conductor of the same material and cross-section. On the other hand, underground cable conductor has much lower inductive reactance than that of an overhead conductor because of closer spacing of conductor.

8. Useful Life: The useful life of underground system is much longer than that of an overhead system. An overhead system may have a useful life of 25 years, whereas an underground system may have a useful life of more than 50 years.

9. Maintenance cost: The maintenance cost of underground system is very low as compared with that of overhead system because of less chances of fault and service interruptions from wind, ice, lightning as well as from traffic hazards.

10. Interference with communication circuits: An overhead system causes electromagnetic interference with telephone lines. The power line currents are superimposed on speech currents, resulting in the potential of the communication channel being raised to an undesirable level. However, there is no such interference with the underground system.

1.7 Size of Feeder's Conductor

The conductor size of a feeder is governed by the current carrying capacity, voltage drop, and overall economy. The current carrying capacity of a conductor depends on the conductor losses and surroundings. For determining the voltage drop, it is necessary to calculate the inductive reactance of the feeder. After calculating the inductive reactance, the voltage drop of conductor can be calculated. If the voltage drop comes out to be higher than it is necessary to select another conductor size to reduce the voltage drop.

The value of conductor size obtained above should be checked for overall economy. By the application of Kelvin's law, the most economical conductor size can be calculated. According to Kelvin's law the most economical cross-section is that which makes the annual value of interest and depreciation of the conductor equal to the annual cost of the energy wasted in the conductor. The maximum current on the feeder is not remains always but it occurs certain times. At all the other time the value of current is less than the maximum value. And it is necessary to have a factor for this calculation. This factor is known as loss factor which is defined as:

Loss Factor = average power loss/loss at peak load

If the load is constant through out the time than loss factor is one. In actual practice load varies time to time. If the actual load pattern is known then loss factor can be easily calculated. An approximate value of loss factor can be found from the following equation:

$$\text{Loss Factor} = (0.3 \times \text{Load Factor}) + 0.7\,(\text{Load Factor})^2$$

where , Load Factor = average load / peak load

1.8 Literature Review

References [1-3] are available books on electric distribution system, where the basic fundamentals of distribution system [1-2], its modeling and analysis [3] can be seen.H. L. Willis [2] concentrates more on planning side.

Ponnavaikko and Rao in ref. [4] have proposed a new technique for distribution system planning through optimal conductor gradation. He suggested a model to represent feeder cost, energy cost and voltage regulation as a function of cross- section of the conductor. They have obtained the optimum cross-section of branch conductors by dynamic programming approach. However, their method is only suitable for main feeder and it cannot handle lateral branches.

Tram and Wall [5] proposed an algorithm for optimal selection of conductors of radial distribution feeder. Researchers developed a fast algorithm to help the distribution engineer select proper conductors for his feeder expansion plans is presented. The optimal conductor type is determined for each feeder segment to maintain an acceptable voltage profile along the entire feeder, minimizing capital investments and the cost of feeder losses. Lateral branches as well as regulators along the feeder are considered. In this paper, computer implementation of the algorithm is described. Its use in conjunction with an optimization model for configuring feeder networks to derive an overall distribution expansion plan is also discussed.

Z.Wang [6] presents a new approach to the optimization problem of conductor size selection in planning radial distribution systems which is formulated as an integer programming problem. However, it is difficult to solve such a large scale problem accurately and provides an approximate optimal solution.

Sujit Mandal [7] presented a systematic approach for selection of an optimal conductor set. Several financial and engineering factors are considered in his method. His main intention was to arrive at a solution, which will be the most economical when both capital and operating costs are considered. Wall *et al.* [8] have considered a few small systems to determine the best conductors for different feeder segments of these systems.

W.C. Kiran & R.B. Adler [9] in 1982 suggested a dynamic model for the development of primary and secondary circuits supplying a residential area. Main features of his model is, that it can support optimal conductor sizing associated with capital requirement and energy losses, as area load evolves. These revenue requirements are responsive to change in area load (positive or negative) arising with change in the number of residences and change in load as per residence, year by year.

Funkhouser and Huber [10] worked on a method for determining economical aluminum conductor steel reinforced (ACSR) conductor sizes for distribution systems in 1955. In their some of important discussions are, three conductors (2/0, 266 MCM, 397 MCM) could be standardized and used in combination for the most economical circuit design for the loads to be carried by a 13-kV distribution system. They also studied the effect of voltage regulation on the conductor selection process. This method is based on the assumption of uniform load distribution for the feeders.

Leppert and Allen [11] suggested that conductor selection is not only based on simple engineering considerations such as current capacity and voltage drop but also on various other considerations, e.g. load growth and wholesale power cost escalations. Anders et al. published their work in 1993 [12] where they analyzed the parameters that affect the economic selection of cable sizes. They did a sensitivity analysis of the different parameters as to how they affect the overall economics of the system.

M. Sreedhar *et al.* [13] presents a novel method based on fuzzy logic approach for design of radial distribution systems, which selects the optimal size of branch conductor. A fuzzy based satisfaction parameter is proposed which handles voltage deviation index, power quality index and cost function.

Ranjan R *et al.* [17] developed voltage deviation index (VDI) as power quality index and then propose a simple computer algorithm for the optimal branch selection based on evolutionary programming. The proposed method incorporates the voltage constraints, maximum current carrying capacity of each feeder and minimization of proposed VDI simultaneously.

1.9 Objective of the Thesis Work

In this thesis work, the main aim is to develop an algorithm for optimal selection of branch conductor. Load flow method presented by Das *et al*.[14] is used to calculate voltage at each bus and real and reactive power losses. Particle Swarm Optimization (PSO) technique is used with an objective to minimize the overall cost of annual energy losses and depreciation on the cost of conductors. The proposed method also maintain acceptable voltage levels of the radial distribution system.

1.10 Organization of the Thesis Work

Chapter 1 presents the introduction of the distribution system, connection schemes of distribution system, size of feeder conductor, literature survey, aim of the thesis work .

Chapter 2 gives the overview of the Particle Swarm Optimization technique (PSO).

Chapter 3 presents the assumptions made ,load flow method applied, PSO based proposed algorithm for optimal conductor selection.

Chapter 4 shows the overall conclusion and future scope of the thesis work.

CHAPTER – 2

PARTICLE SWARM OPTIMIZATION TECHNIQUE

2.1 Overview

PSO is a heuristic technique inspired by the collective intelligence of swarms of biological populations. It is an evolutionary computation technique developed by Eberhart and Kennedy in 1995 inspired by the social behaviour of bird flocking or fish schooling[16]. It is a very simple concept and can be implemented in a few lines of computer code. It requires only primitive mathematical operators, so is computationally inexpensive in terms of both memory requirements and speed.

It is a population based search algorithm where each individual is referred to as particle and represents a candidate solution. Each particle in PSO flies through the search space with an adaptable velocity that is dynamically modified according to its own flying experience and also the flying experience of the other particles. In PSO each particles strive to improve themselves by imitating traits from their successful peers. Further, each particle has a memory and hence it is capable of remembering the best position in the search space ever visited by it. The position corresponding to the best fitness is known as Pbest and the overall best out of all the particles in the population is called Gbest .Each individual corresponds to a candidate solution to the problem. Individuals in a swarm approach to the optimum through its present velocity, previous experience, and the experience of its neighbours.

The particles of the swarm are assumed to travel the problem search space in a discrete rather than continuous time steps. At each time step (iteration) the velocity of each particle is modified using its current velocity and its distance from Pbest and Gbest. The velocity (accelerating) of each particle changes toward its Pbest and Gbest (global version). Acceleration is weighted by a random term, with separate random numbers being generated for acceleration towards Pbest and Gbest.

Each agent tries to modify its position using the following information:

- The current positions (X, Y)
- The current velocities (VX, VY)
- The distance between the current position and Pbest
- The distance between the current position and Gbest

This modification can be represented by the concept of velocity (modified value for the current positions). Velocity of each agent can be modified by the following equation:

$$V_i^{k+1} = \omega V_i^k + c_1 \mathrm{rand}_1 \times \left(\mathrm{Pbest}_i^k - X_i^k\right) + c_2 \mathrm{rand}_2 \times \left(\mathrm{Gbest}^k - X_i^k\right) \ldots\ldots\ldots (1)$$

Where ,

V_i^k : Velocity of individual i at iteration k.
ω : Weight parameter.
c_1, c_2 : Weight factors.
rand_1, rand_2 : Random numbers between 0 and 1.
X_i^k : Position of individual i at iteration k.
Pbest_i^k : Best position of individual i until iteration k.
Gbest_i^k : Best position of the group until iteration k.

The following weighting function is usually utilized:

$$\omega = \omega_{max} - \frac{\omega_{max} - \omega_{min}}{\mathrm{Iter}_{max}} \times \mathrm{Iter} \qquad \ldots\ldots\ldots\ldots\ldots (2)$$

Where,

ω_{max} , ω_{min} : Initial, final weights,
Iter_{max} : Maximum iteration number,
Iter : Current iteration number.

PSO using (1), (2) is called inertia weights approach (IWA).

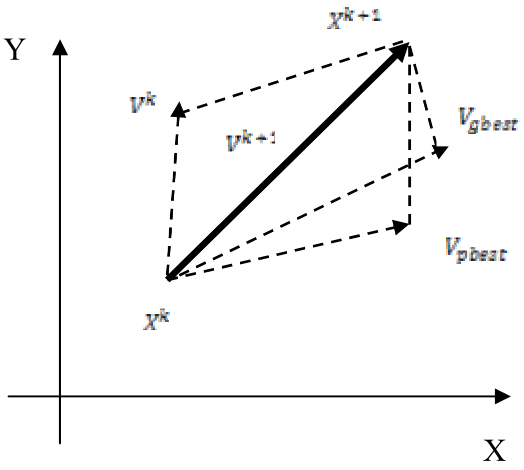

Figure 2.1 Concept of modification of a searching point by PSO

Where,

X^k : current searching point,
X^{k+1} : modified searching point,
V^k : current velocity,
V^{k+1} : modified velocity,
V_{pbest} : velocity based on pbest,
V_{gbest} : velocity based on gbest.

The current position (searching point in the solution space) can be modified by the following equation:

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad \dots\dots\dots\dots\dots (3)$$

Figure 2.1 shows a concept of modification of a searching point by PSO. Each agent changes its current position using the integration of vectors as shown in Fig 2.1.

The general flowchart of PSO with IWA can be described as follows:

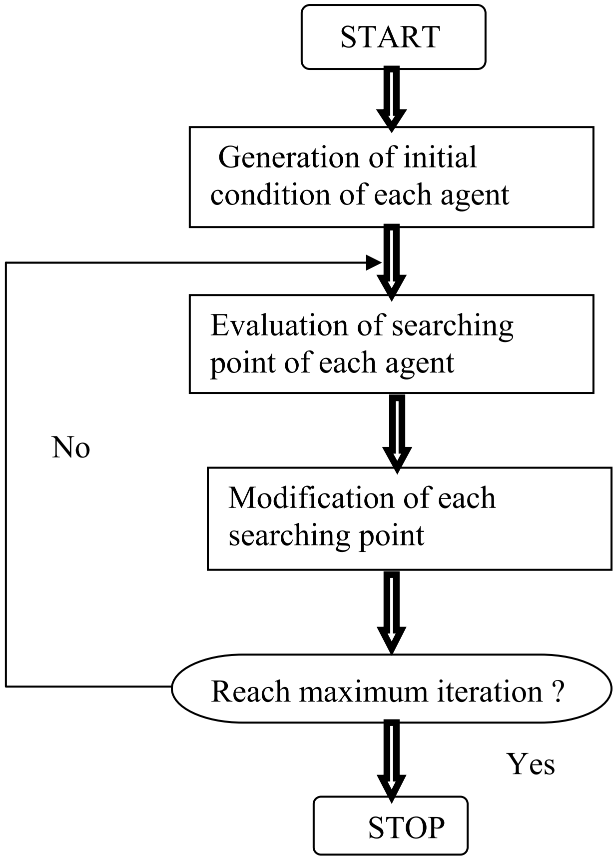

Figure 2.2 A general flowchart of PSO

Step 1. Generation of initial condition of each agent: Initial searching points (X_i^0) and velocities (V_i^0) of each agent are usually generated randomly within the allowable range. The current searching point is set to Pbest for each agent. The best evaluated value of Pbest is set to Gbest, and the agent number with the best value is stored.

Step 2. Evaluation of searching point of each agent: The objective function value is calculated for each agent. If the value is better than the current Pbest of the agent, the Pbest value is replaced by the current value. If the best value of Pbest is better than the current Gbest, Gbest is replaced by the best value and the agent number with the best value is stored.

Step 3. Modification of each searching point: The current searching point of each agent is changed using (1), (2) and (3).

Step 4. Checking the exit condition. The current iteration number reaches the predetermined maximum iteration number, then exits. Otherwise, the process proceeds to step 2.

2.2 Discrete PSO

The original PSO described above treats nonlinear optimization problems with continuous variables. However, practical engineering problems are often formulated as combinatorial optimization problems. Kennedy and Eberhart developed a discrete binary version of PSO for these problems [16]. They proposed a model wherein the probability of an agent's deciding yes or no, true or false, or making some other decision is a function of personal and social factors as follows:

$$P(X = 1) = f\left(X_i^k, V_i^k, Pbest_i, Gbest\right) \quad \ldots\ldots\ldots\ldots(4)$$

The parameter V, an agent's tendency to make one or the other choice, will determine a probability threshold. If V is higher, the agent is more likely to choose 1, and lower values favor 0 choice. Such a threshold requires staying in the range [0, 1]. One of the functions accomplishing this feature is the sigmoid function, which is usually utilized in artificial neural networks.

$$sig\left(V_i^k\right) = \frac{1}{1 + \exp\left(-V_i^k\right)} \quad \ldots\ldots\ldots\ldots\ldots(5)$$

The agent's tendency should be adjusted for success of the agent and the group. In order to accomplish this, a formula for each V_i^k that will be some function of the difference between the agent's current position and the best positions found so far by itself and by the group should be developed. Namely, like the basic continuous version, the formula for the binary version of PSO can be described as follows:

$$\mathrm{V}_i^{k+1} = \mathrm{V}_i^{k} + \mathrm{rand}_1 \times (\mathrm{Pbest}_i - \mathrm{X}_i^{k}) + \mathrm{rand}_2 \times (\mathrm{Gbest} - \mathrm{X}_i^{k}) \ldots\ldots\ldots\ldots (6)$$

$\rho_i^{k+1} < sig(\mathrm{V}_i^{k+1})$ then $\mathrm{X}_i^{k+1} = 1;$

else $\mathrm{X}_i^{k+1} = 0;$

where, rand is a positive random number drawn from a uniform distribution with a predefined upper limit, and ρ_i^{k+1} is a vector of random numbers of [0.0, 1.0]. These formulas are iterated repeatedly over each dimension of each agent.

CHAPTER -3

OPTIMAL CONDUCTOR SELECTION

Selection of conductors for design and upgrading of distribution systems is an important part of the planning process. After taking all the factors into consideration, utilities select four or five conductors to meet their requirement [2]. This selection is done mainly based on engineering judgment. Historical factors also play role in the selection process, i.e., if a company has been using a particular size of conductor, they would like to continue to use that size unless there are compelling reasons not to do so.

In this thesis , Discrete Particle Swarm Optimization (DPSO) algorithm is proposed for selecting the optimal type of conductor for radial distribution systems. The conductor, which is determined by this method, will satisfy the maximum current carrying capacity and maintain acceptable voltage levels of the radial distribution systems. In addition, it gives the maximum saving in capital cost of conducting material and cost of energy loss.

3.1 Assumptions

A balanced three-phase radial network is assumed and can be represented by its equivalent single-line diagram. Line shunt capacitance is negligible at the distribution voltage levels.

3.2 Load flow method

The vector based distribution load flow method [14] is used to calculate voltage at each bus and total real and reactive power losses. In any radial distribution system, the electrical equivalent of a typical branch, which is connected between node 1 and 2 having a resistance r(1) and inductive reactance x(1) is shown in Fig. 3.1.

From Fig. 3.1, current flowing through branch-1 is given by:

$$I(1) = \frac{|V(1)|\angle\delta(1) - |V(2)|\angle\delta(2)}{R(1) + jX(1)} \qquad \dots\dots\dots\dots\dots(1)$$

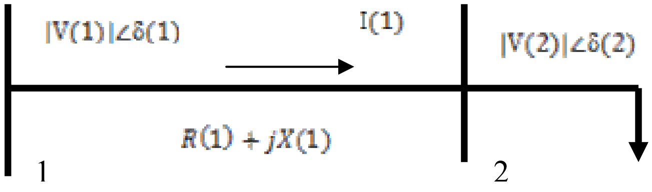

Fig. 3.1 Single line diagram of a typical branch

$$P(2) - jQ(2) = |V(2)|\angle\delta(2) * I(1) \qquad \dots\dots.\dots\dots(2)$$

From eqns. (1) and (2) we have

$$\begin{aligned}|V(2)| = \Big[&\{(P(2)R(1) + Q(2)X(1) - 0.5|V(1)|^2)^2 \\ &- (R^2(1) + X^2(1))(P^2(2) + Q^2(2))\}^{1/2} \\ &- (P(2)R(1) + Q(2)X(1) - 0.5|V(1)|^2)\Big]^{1/2} \qquad \dots\dots\dots\dots\dots(3)\end{aligned}$$

Equation (3) can be written in generalized form :

$$\begin{aligned}|V(i+1)| = \Big[&\{(P(i+1)R(i) + Q(i+1)X(i) - 0.5|V(i)|^2)^2 \\ &- (R^2(i) + X^2(i))(P^2(i+1) + Q^2(i+1))\}^{1/2} \\ &- (P(i+1)R(i) + Q(i+1)X(i) - 0.5|V(i)|^2)\Big]^{1/2} \qquad \dots\dots\dots\dots\dots(4)\end{aligned}$$

where,

node no., i = 1,2,….,NB

branch no.,j = 1,2,….,NB-1

NB = total no. of nodes

P(i + 1) = total real power load fed through node i + 1

Q(i + 1) = total reactive power load fed through node

R(j) = resistance of jth branch

X(j) = reactance of jth branch

From fig. 1, the total real and reactive power load fed through node 2 are given by:

$$P(2) = \sum_{i=2}^{NB} PL(i) + \sum_{i=2}^{NB-1} LP(i)$$

…………….(5)

$$Q(2) = \sum_{i=2}^{NB} QL(i) + \sum_{i=2}^{NB-1} LQ(i)$$

Where,

PL(i) = real power load of ith node

QL(i) = reactive power load of ith node

LP(j) = real power loss of branch j

LQ(j) = reactive power loss of branch j

The real and reactive power losses in branch 1 are :

$$LP(1) = \frac{R(1) * [P^2(2) + Q^2(2)]}{|V(2)|^2}$$

…………….(6)

$$LQ(1) = \frac{X(1) * [P^2(2) + Q^2(2)]}{|V(2)|^2}$$

Eqn. (5) can be written in generalized form as:

$$P(i+1) = \sum_{j=i+1}^{NB} PL(j) + \sum_{j=i+1}^{NB-1} LP(j)$$

for i= 1,2,….,NB-2

……………(7)

$$Q(i+1) = \sum_{j=i+1}^{NB} QL(j) + \sum_{j=i+1}^{NB-1} LQ(j)$$

for i = 1,2,…NB-2

For the last node,

P(NB) = PL(NB) and Q(NB) = QL(NB) ……………(8)

Eqn. (6) can be written in generalized form as :

$$LP(i) = \frac{R(i) * [P^2(i+1) + Q^2(i+1)]}{|V(i+1)|^2}$$

…………(9)

$$LQ(i) = \frac{X(i) * [P^2(i+1) + Q^2(i+1)]}{|V(i+1)|^2}$$

Flowchart for the algorithm of radial distribution network is shown below:

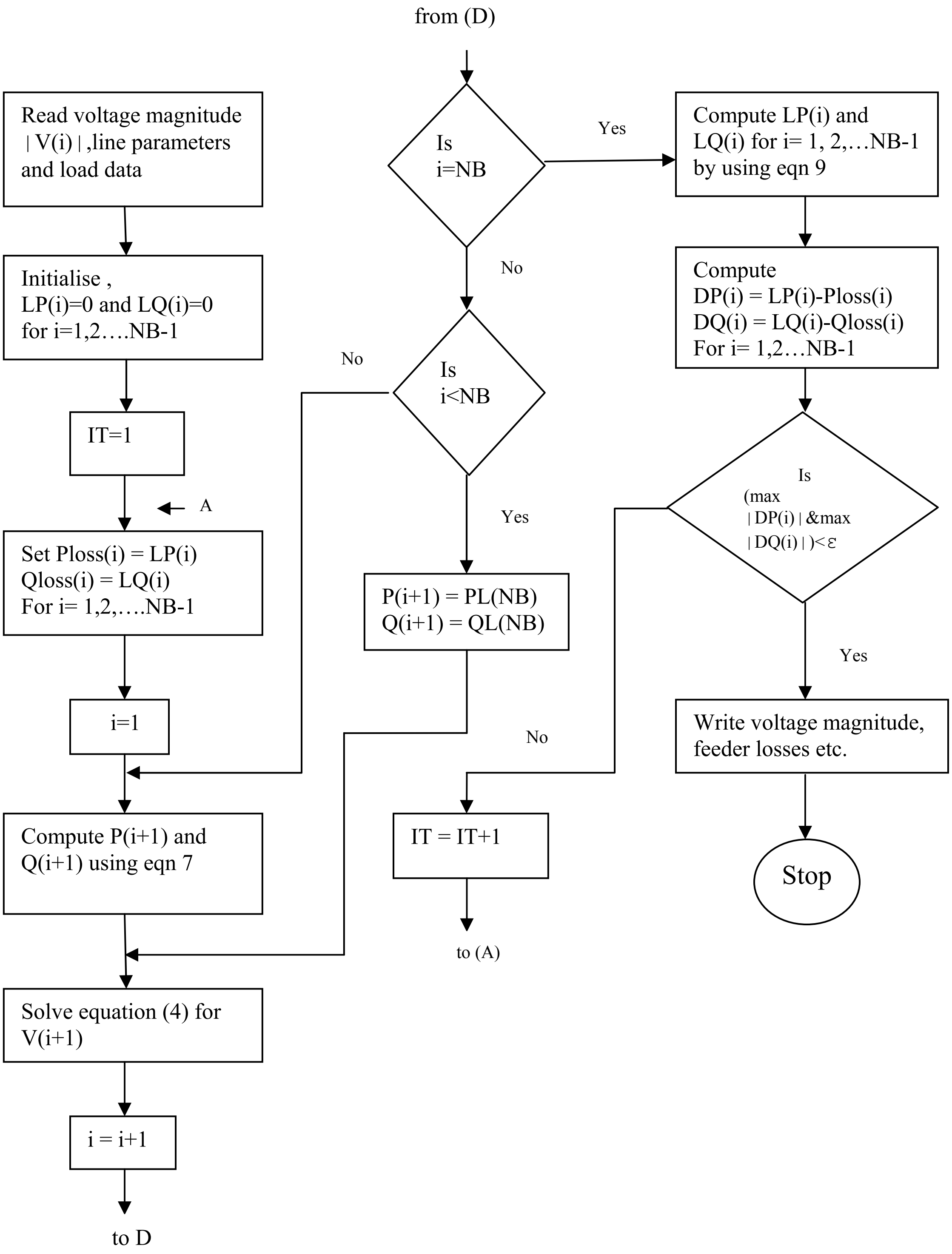

Fig. 3.2 Flowchart for algorithm of radial distribution network

3.3 Implementation of PSO for optimal conductor selection

In this section, the optimal size of the conductor in each branch of the radial distribution system is calculated using PSO. The different steps for implementation of PSO are explained in the following section.

3.3.1 Performance of discrete particle swarm optimization using inertia weights

The following describes the position and velocity update equations with weight factors included:

$$V_i = W \times V_i + C_1 \times rand_1 \times (Pbest_i - X_i) + C_2 \times rand_2 \times (Gbest_i - X_i) \quad \text{.........(10)}$$

$$X_i \rightarrow X_i + V_i \quad \text{..........(11)}$$

where C_1 and C_2 are positive constants and called cognitive and social parameters.

Eq. (10) calculates a new velocity for each particle (potential solution) based on its previous velocity, the particle's location at which the best fitness so far has been achieved, and the population global (or local neighborhood, in the neighborhood version of the algorithm) location at which the best fitness so far has been achieved.

Eq. (11) updates each particle's position in solution hyperspace. The two random numbers are independently generated. The use of the inertia weight, which typically decreases linearly from about 0.9 to 0.4 during a run, has provided improved performance in a number of applications.

3.3.2 Parameter selection in particle swarm optimization

Unlike many other computational intelligence techniques, the particle swarm optimizer has few parameters to tune. Many attempts have been made to improve the performance of originally developed PSO. Many parameters have been added to the originally developed PSO to modify or to improve the performance of the technique. A quick statistical experiment is used to fine tune these parameters for the class of constrained optimization problem considered. Before going to the actual steps, various parameters of PSO with respect to the case are to be selected. In this case, types of conductors are selected as parameters. These values are system dependent. Hence, the PSO parameter values will vary from system to system. These parameters are encoded using suitable techniques.

3.3.3 Swarm size, P

The swarm size or the number of individuals inside the population is determined by the integer parameter ‘P’. For very small values of P the possibility of being trapped in local optima is very likely. Larger population will increase the computation time requirements.

3.4 Objective Function[5]

In any radial distribution system, the optimal choice of the size of conductor in each branch of the system, which minimizes the sum of depreciation on capital investment and cost of energy losses, is important. The problem of choice of the optimal size of conductor for each feeder segment is presented as an optimization problem using discrete particle swarm optimization technique. The objective is to select optimal conductor in each branch of the system, which minimizes the sum of depreciation on capital investment and cost of energy losses.

The objective function for optimal selection of conductor for branch j with k type conductor is:

$$\min F(j, k) = CL(j, k) + CC(j, k) \qquad \text{……..(12)}$$

(i) Cost of energy losses (CL):

The annual cost for the loss in branch j with k type conductor is,

$$CL(j,k) = \text{Peak loss}(j,k) \times [K_p + K_e \times Lsf \times 8760] \qquad \text{……….(13)}$$

Where,

K_p = Annual demand cost due to power loss(Rs./kW)

K_e = Annual cost due to energy loss(Rs./kWh)

Lsf = Loss factor

Peak loss(j, k) = Real power loss of branch j under peak load conditions with k type conductor

(ii) Depreciation on capital investment (CC):

The annual capital cost for branch j with k type conductor is,

$$CC(j,k) = \alpha \times [cost(k) \times len(j)] \times A_k \qquad \ldots\ldots\ldots(14)$$

where,

α = Interest and depreciation factor

Cost(k) = Cost of k-type conductor(Rs./km)

Len(j) = Length of branch j(km)

A_k = Area of k-type conductor

3.5 Evaluation of fitness function

The evaluation of fitness function is a procedure to determine the fitness of each string in the population. Since the DPSO proceeds in the direction of evolving best-fit strings and the fitness value is the only information available to the DPSO, the performance of the algorithm is highly sensitive to the fitness values.The fitness function f, which has been chosen in this problem, is

$$f = \frac{1}{F(j,k)} \qquad \ldots\ldots\ldots\ldots\ldots(15)$$

3.6 Constraints:

a) The feeder voltage at every node of the feeder must be above the acceptable voltage level, i.e., min $|V(i)| \geq V_{min}$ for all i.

b) Current flowing through branch-j with k-type conductor should be less than the maximum current carrying capacity of k-type conductor.

3.7 Algorithm for optimal type of conductor selection

The detailed algorithm to determine optimal size of the conductor is given below:

Step 1. Read the system data.

Step 2. Perform load flow.

Step 3. Initialize population with random position and velocity vectors.

Step 4. Set the iteration count to ‘1’.

Step 5. Calculate the objective function using Eq. (12).

Step 6. Calculate the fitness value for each particles position(p) using Eq. (15).

Step 7. If fitness(p) is better than fitness(Pbest) then Pbest = p.

Step 8. Set best of Pbest’s as Gbest.

Step 9. Update particles velocity and position using eqn (10) and (11).

Step 10. Increment iteration count. If iteration count < max. count, goto Step 4. Else go to Step11.

Step 11. Print the total real power loss, reactive power loss, and voltages.

3.8 Example

A 16-node rural distribution feeder in India is considered as an example [17] to illustrate the above proposed algorithm. This feeder is heavily loaded during agriculture season. The basic objective is to reconductor some of the branches of this radial distribution system.

Presently in India utilities are using three or four types of conductors for rural distribution network. Data for this feeder is given in Appendix B and Appendix C. First base case load flow study is carried out and then for optimization of branch conductor, four different types of conductors are used. The conductors data is available in Appendix A. Limit of minimum voltage is taken as V=0.90 pu. Results of conductor optimization are presented in Table 1, and Table 2 gives the comparison of results. Fig 3.2 shows the single line diagram containing 16-node for a balanced radial distribution network.

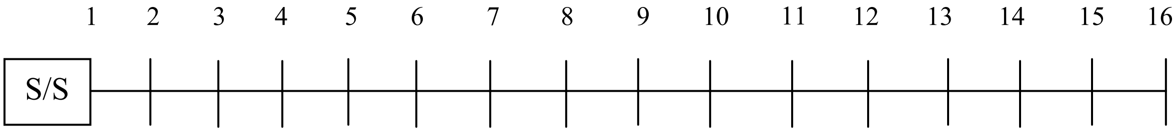

Figure 3.3 Single line diagram for a balanced radial distribution network (existing)

TABLE 3.1

Voltage Magnitude for 16-node distribution system

(Existing network)

Node No.	Voltage Magnitude (pu)
1	1.0000
2	0.9919
3	0.9858
4	0.9775
5	0.9678
6	0.9595
7	0.9542
8	0.9468
9	0.9348
10	0.9258
11	0.9171
12	0.9099
13	0.8992
14	0.8948
15	0.8879
16	0.8867

TABLE 3.2

Branch Losses (Existing network)

Branch No.	Real Power Loss (kW)	Reactive Power Loss (kVAR)
1	5.5794	5.4604
2	3.8804	3.7976
3	4.9731	4.8670
4	5.5456	5.4274
5	4.7466	3.2043
6	2.7601	1.8632
7	3.5471	2.3945
8	5.5777	3.7653
9	4.3927	1.8313
10	3.8100	1.5884
11	2.3646	0.9858
12	3.5820	1.0142
13	1.1274	0.3192
14	1.2324	0.3489
15	0.0721	0.0204

TABLE 3.3

Conductors in the feeder after modifications

Branch No.	Existing Feeder	Modifications
	From	To
5	Rabbit	Raccon
6	Rabbit	Raccon
7	Rabbit	Raccon
8	Rabbit	Raccon
9	Weasel	Raccon
10	Weasel	Rabbit
11	Weasel	Raccon
12	Squirrel	Raccon
13	Squirrel	Weasel
14	Squirrel	Rabbit

TABLE 3.4

Voltage magnitude for 16-node distribution system

(After conductor modification)

Node No.	Voltage Magnitude (pu)
1	1.0000
2	0.9920
3	0.9860
4	0.9779
5	0.9683
6	0.9619
7	0.9579
8	0.9522
9	0.9430
10	0.9382
11	0.9323
12	0.9285
13	0.9244
14	0.9213
15	0.9180
16	0.9168

TABLE 3.5

Branch losses (After conductor modifications)

Branch No.	**Real Power Loss (kW)**	**Reactive Power Loss (kVAR)**
1	5.4462	5.3300
2	3.7799	3.6993
3	4.8346	4.7315
4	5.3784	5.2637
5	3.0799	3.0123
6	1.7828	1.7447
7	2.2827	2.2340
8	3.5824	3.5060
9	1.6790	1.6432
10	2.1595	1.4578
11	0.8946	0.8755
12	0.8951	0.8760
13	0.7002	0.2919
14	0.4561	0.3079
15	0.0675	0.0191

TABLE 3.6

Comparison of results

<table>
<tr><th></th><th>Before Applying PSO</th><th>After Applying PSO</th></tr>
<tr><td>Minimum Voltage</td><td>0.8867</td><td>0.9168</td></tr>
<tr><td>Real Power Loss(kW)</td><td>53.1912</td><td>37.0168</td></tr>
<tr><td>Reactive Power Loss(kVAR)</td><td>36.8877</td><td>34.9929</td></tr>
<tr><td colspan="3">After conductor modification:
Net reduction in real power loss = 16.1744 kW
Net reduction in reactive power loss = 1.8948 kVAR</td></tr>
</table>

CHAPTER-4

CONCLUSION AND FUTURE SCOPE OF WORK

4.1 Conclusions

It is very challenging to select an optimal set of conductors for designing a distribution system. In this thesis work, an algorithm has been proposed for selecting the optimal branch conductor using discrete particle swarm optimization algorithm. The proposed method selects the optimal branch conductor by minimizing the sum of cost of energy losses and depreciation cost of feeder conductor. In addition the algorithm keeps the maximum current carrying capacity and minimum voltage within prescribed limit. The proposed algorithm has been implemented on 16-node radial distribution systems in India.

4.2 Future Scope of Work

After carrying thesis work in optimal conductor selection for Radial distribution systems, the presented work can be extended in the area by:

- Weather conditions
- Sag & Tension

as conductor parameters depend upon these things.

REFERENCES

[1] Anthony J. Pansini, Electrical Distribution Engineering, The Fairmont Press,2007.

[2] H. L. Willis, Power Distribution Planning Reference Book. New York: Marcel Dekker, 1997.

[3] W. H. kersting, Distribution System Modelling and Analysis. New York: CRC, 2000.

[4] M. Ponnavaikko and K.S.P. Rao (1982), “An approach to optimal distribution system planning through conductor gradation”, IEEE Transactions on PAS:1735-1742.

[5] H.N. Tram, D.L. Wall (1988) “Optimal conductor selection in radial distribution systems” IEEE Transactions on PAS, 3: 200-206.

[6] Z Wang, et al., “A Practical Approach to the Conductor Size Selection in Planning Radial Distribution Systems ”, IEEE Transactions on Power delivery, Vol. 15, No. 1,January 2000.

[7] Mandal S,Pahwa A “Optimal Selection of Conductors for Distribution Feeders”, IEEE Transactions on Power systems, Vol. 17, No. 1, February 2002.

[8] D.Wall, G.Thompson, J.Green. “An optimization model for planning radial distribution network” IEEE Transactions on Power Apparatus and Systems,1979,98:1061-1065.

[9] W.C. Kiran , R.B. Adler (1982) “A distribution system cost model and its application to optimal conductor sizing” IEEE Transactions on PAS, 101:1439-1442.

[10] A.W. Funkhouser and R. P. Huber, “A method for determining economical ACSR conductor sizes for distribution systems”, *AIEE Trans. Power Apparat. Syst.*, vol. PAS-74, pp. 479–484, June 1955.

[11] S. Leppert, A. Allen. “Conductor life cycle cost analysis” Proc. Rural Electric Power Conf, 1995, C2.1–2.8.

[12] G. Anders, et al. “Parameters affecting economic selection of cable sizes”, IEEE Trans. on Power Delivery, 1993,8(3): 1661–1667.

[13] M.Sreedhar,et al., “A Novel Method for Optimal Conductor Selection of Radial Distribution Feeders Using Fuzzy Evolutionary Programming” ,International Journal of Electrical Power Engineering 2(1): 6-10,2008.

[14] Das.D, H.S Nagi and DP Kothari, “Novel method for solving Radial Distribution System” ,IEE Proc. Gener.Trans.Distrib,1994,141:291-298.

[15] Kennedy J, Eberhart R., “Particle swarm optimization” Proceedings of IEEE International Conference on Neural Networks (ICNN’95) Perth, Australia: IEEE Press; 1995.Vol. IV p. 1942–1948.

[16] Kennedy J, Eberhart R. “A discrete binary version of the particle swarm optimization algorithm”,Proceedings of the 1997 Conference on Systems, Man, and Cybernetics (SMC’97).IEEE Press; 1997. pp. 4104–4109.

[17] Ranjan R, et al., “Optimal Conductor Selection Of Radial Distribution Feeders Using Evolutionary Programming” ,Conference on Convergent Technologies for asia pacific region, Vol. 1, pp. 456-459,oct 2003.

[18] Sivangaraju and Vishwanantha Rao, “Optimal conductor selection in radial distribution system using discrete particle swarm optimization”, World journal of modelling and simulation,Vol. 5,pp 96-104.

Appendix A

Table A.1 Data for Conductors[17]

Type of Conductor	Area of cross section (mm^2)	Resistance (Ω/km)	Reactance (Ω/km)	Maximum current carrying capacity (amp)	Cost of Conductors (Rs/km)
Squirrel	12.90	1.3760	0.3896	115	1260
Weasel	19.35	0.9108	0.3797	150	1420
Rabbit	32.26	0.5441	0.3673	208	1785
Raccon	48.39	0.3657	0.3579	270	2285
Other Data : Ke = Rs. 0.50/KWh, Kp= Rs. 2500/kW , Lsf = 0.20 , α= 0.10					

Appendix B

B.1 Line Data for example[17]

Branch (j)	Type of Conductors (k)	Sending end node m1	Receiving end node m2	Length Len(j)
1	Raccon	1	2	2.00
2	Raccon	2	3	1.60
3	Raccon	3	4	2.30
4	Raccon	4	5	2.90
5	Rabbit	5	6	2.20
6	Rabbit	6	7	1.57
7	Rabbit	7	8	2.40
8	Rabbit	8	9	4.00
9	Weasel	9	10	2.30
10	Weasel	10	11	2.50
11	Weasel	11	12	2.70
12	Squirrel	12	13	3.20
13	Squirrel	13	14	1.70
14	Squirrel	14	15	3.80
15	Squirrel	15	16	2.00

Appendix C

C.1 Load Data for example[17]

Node No.	Real Power Load (kW)	Reactive Power Load (kVAr)
1	0.00	0.00
2	48.75	43.00
3	37.50	33.00
4	37.50	33.00
5	75.00	66.10
6	48.75	43.00
7	37.50	33.00
8	12.00	10.60
9	37.50	33.00
10	37.50	33.00
11	75.00	66.10
12	18.75	16.50
13	48.75	43.00
14	48.75	43.00
15	75.00	66.10
16	37.50	33.00