A New Method for Optimal Conductor Selection of Radial Distribution Network

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

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in
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CERTIFICATE

I hereby certify that the work which is being presented in the thesis entitled, **"A New Method for Optimal Conductor Selection 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 *Dr. Smarajit Ghosh, Prof. & Head, 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 the best of my knowledge.

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V. K. Shailesh Kumar Ch.

Dedicated to My Parents

ABSTRACT

The optimum planning of power distribution networks is one of the most important research fields for electrical engineers. That is because of the close proximity of these networks to the ultimate consumers. Normally in distribution system operational costs are high because of their losses. The ultimate aim of this thesis work is to plan distribution networks which satisfy the growing demand for electricity, fulfill specific technical operational constraints and which are also characterized by the minimum overall cost.

In this thesis work a simple and efficient method for optimal conductor selection of radial distribution networks. The proposed method also shows that only proper selection of optimum branch conductors reduces losses instead of using uniform conductors. The usefulness of the proposed method is demonstrated by two examples, 16 node, 31 node radial distribution network.

CONTENTS

2 Optimal Conductor Selection

Appendix

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

NB	Total number of Nodes
LN1	Total number of Branches
jj	Branch number i.e., jj = 1,2,3,……LN1
m1	IS(jj) be the sending node of branch jj
m2	IR(jj) be the receiving end node of branch jj
V(m1)	voltage of sending end node of branch jj
V(m2)	voltage of receiving end node of branch jj
R(jj)	resistance of branch jj
X(jj)	reactance of branch jj
Z(jj)	impedance of branch jj
LP(jj)	Real power loss of branch jj
LQ(jj)	reactive power loss of branch jj
DVMAX	Maximum voltage difference
TPL	total real power load
TQL	total reactive power load
V(1,k)	Substation voltage (constant for all k)
V(2,k)	Voltage of node 2 with k-type conductor of banch-1, k=1,2,….,NTYPE
I(1,k)	Current of branch-1 with k-type conductor of branch-1, k=1,2,…,NTYPE
Z(1,k)	Impedance of branch-1 with k-type conductor of branch-1, k=1,2,…,NTYPE
NTYPE	Total number of conductors
Kp	Annual demand cost of losses (Rs/kW)
KE	Energy cost of losses (Rs/kW)
T	8670 hrs
Lsf	Loss factor
COST	Cost of k-type conductor (Rs / km), k = 1,2,…..,NTYPE
LEN(jj)	Length of branch-jj
A	Carrying charge rate of feeders

CHAPTER 1

INTRODUCTION TO DISTRIBUTION SYSTEMS

1.1 Introduction

Although there is no “typical” electric power system, a diagram including the several components that are usually to be found in the makeup of such a system is shown in Figure 1.1; particular attention should be paid to those elements which will make up the component under discussion, the distribution system.

While the energy flow is obviously from the power generating plant to the consumer, it may be more informative for our purposes to reverse the direction of observation and consider events from the consumer back to the generating source.

Energy is consumed by users at a nominal utilization voltage that may range generally (in the United States) from 110 to 125 V, and from 220 to 250 V, for some large commercial and industrial users, the nominal figures are 277 V and 480 V. It flows through a metering device that determines the billing for the consumer, but which may also serve to obtain data useful later for planning, design, and operating purposes. The metering equipment usually includes a means of disconnecting the consumer from the incoming supply should this become necessary for any reason.

The energy flows through conductors to the meter from the secondary mains (if any); these conductors are referred to as the consumer’s *service,* or sometimes also as the *service drop.*

Several services are connected to the secondary mains; the secondary mains now serve as a path to the several services from the distribution transformers which supply them.

At the transformer, the voltage of the energy being delivered is reduced to the utilization voltage values mentioned earlier from higher *primary* line voltages that may range from 2200 V to as high as 46,000 V. The transformer is protected from overloads and faults by fuses or so-called weak links on the high-voltage side; the latter also usually include circuit-breaking devices on the low-voltage side. These operate to disconnect the transformer in the event of overloads or faults. The circuit

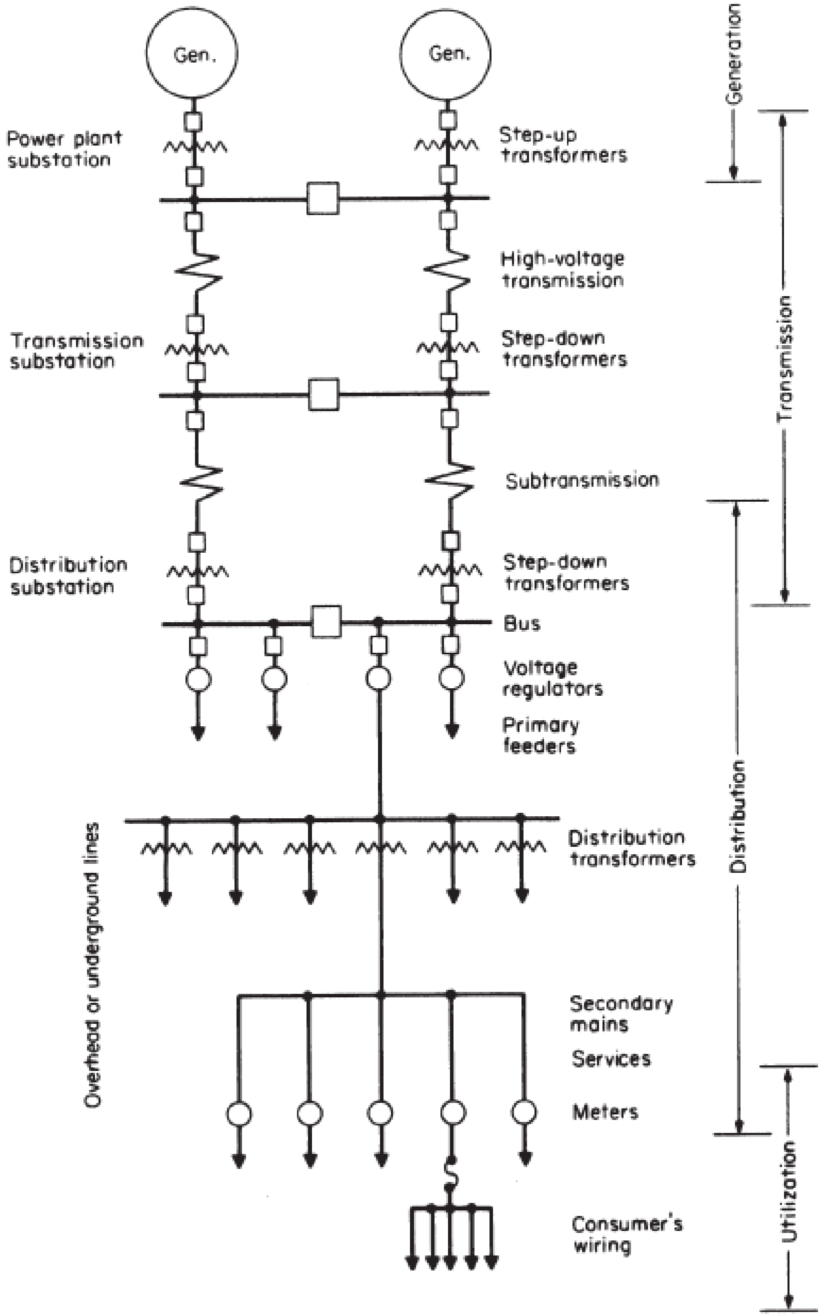


Figure 1.1 Typical electric system showing operational divisions.

breakers (where they exist) on the secondary, or low-voltage, side operate only if the condition is caused by faults or overloads in the secondary mains, services, or consumers' premises; the primary fuse or weak link in addition operates in the event of a failure within the transformer itself.

If the transformer is situated on an overhead system, it is also protected from lightning or line voltage surges by a surge arrester, which drains the voltage surge to ground before it can do damage to the trans - former.

The transformer is connected to the primary circuit, which may be a lateral or spur consisting of one phase of the usual three-phase primary main. This is done usually through a *line* or *sectionalizing fuse,* whose function is to disconnect the lateral from the main in the event of fault or overload in the lateral. The lateral conductors carry the sum of the energy components flowing through each of the transformers, which represent not only the energy used by the consumers connected thereto, but also the energy lost in the lines and transformers to that point.

The three-phase main may consist of several three-phase branches connected together, sometimes through other line or sectionalizing fuses, but sometimes also through switches. Each of the branches may have several single-phase laterals connected to it through line or sectionalizing fuses.

Where single-phase or three-phase overhead lines run for any considerable distance without distribution transformer installations connected to them, surge arresters may be installed on the lines for protection, as described earlier.

Some three-phase laterals may sometimes also be connected to the three-phase main through *circuit reclosers.* The recloser acts to disconnect the lateral from the main should a fault occur on the lateral, much as a line or sectionalizing fuse. However, it acts to reconnect the lateral to the main, reenergizing it one or more times after a time delay in a predetermined sequence before remaining open permanently. This is done so that a fault which may be only of a temporary nature, such as a tree limb falling on the line, will not cause a prolonged interruption of service to the consumers connected to the lateral.

The three-phase mains emanate from a *distribution substation,* sup - plied from a *bus* in that station. The three-phase mains, usually referred to as a *circuit* or *feeder,* are connected to the bus through a protective circuit breaker and sometimes a voltage regulator. The voltage regulator is usually a modified form of transformer and serves to maintain outgoing voltage within a predetermined band or range on the circuit or feeder as its load varies. It is sometimes placed electrically in the substation circuit so that it regulates the voltage of the entire bus rather than a single outgoing circuit or feeder, and sometimes along the route of a feeder for partial feeder regulation. The circuit breaker in the feeder acts to disconnect that feeder from the bus in the event of overload or fault on the outgoing or distribution feeder.

1.2 Subtransmission System

The substation bus usually supplies several distribution feeders and carries the sum of the energy supplied to each of the distribution feeders connected to it. In turn, the bus is supplied through one or more transformers and associated circuit breaker protection. These substation transformers step down the voltage of their supply circuit, usually called the *subtransmission* system, which operates at voltages usually from 23,000 to 138,000 V.

The subtransmission systems may supply several distribution substations and may act as *tie feeders* between two or more substations that are either of the *bulk power or transmission* type or of the distribution type. They may also be tapped to supply some distribution load, usually through a circuit breaker, for a single consumer, generally an industrial plant or a commercial consumer having a substantially large load.

The transmission or bulk power substation serves much the same purposes as a distribution substation, except that, as the name implies, it handles much greater amounts of energy: the sum of the energy individually supplied to the subtransmission lines and associated distribution substations and losses. Voltages at the transmission substations are reduced to outgoing subtransmission line voltages from transmission voltages that may range from 69,000 to upwards of 750,000 V.

The transmission lines usually emanate from another substation associated with a power generating plant. This last substation operates in much the same manner as other substations, but serves to step up to transmission line voltage values the voltages produced by the generators. Because of material and insulation limitations, generator voltages may range from a few thousand volts for older and smaller units to some 20,000 volts for more recent, larger ones. Both buses and transformers in these substations are protected by circuit breakers, surge arresters, and other protective devices.

In all the systems described, conductors should be large enough that the energy loss in them will not be excessive, nor the loss in voltage so great that normal nominal voltage ranges at the consumer's services cannot be maintained.

In some instances, voltage regulators and capacitors are installed at strategic points on overhead primary circuits as a means of compensating for voltage drops or losses, and incidentally help in holding down energy losses in the conductors.

In many of the distribution system arrangements, some of the several elements between the generating plant and the consumer may not be necessary. In a relatively small area, such as a small town, that is served by a power plant situated in or very near the service area, the distribution feeder may emanate directly from the power plant bus, and all other elements may be eliminated, as indicated in Figure 1.2 This is perhaps one extreme; in many other instances only some of the other elements may not be necessary; e.g., a similar small area somewhat distant from the generating plant may find it necessary to install a distribution substation supplied by a transmission line of appropriate voltage only.

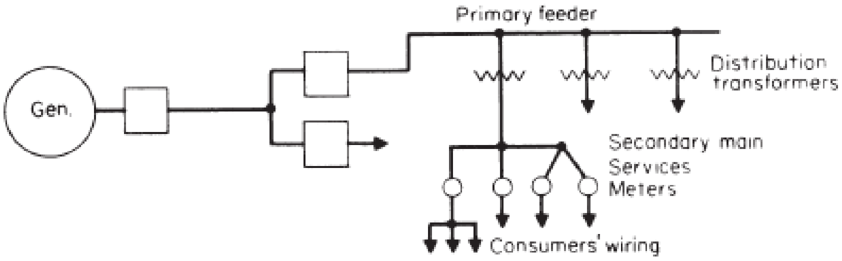


Figure 1.2 "Abbreviated" electric system

In the case of areas of high load density and rather severe service reliability requirements, the distribution system becomes more complex and more expensive. The several secondary mains to which the consumers' services are connected may all be connected into a mesh or network. The transformers supplying these secondary mains or net - work are supplied from several different primary feeders, so that if one or more of these feeders is out of service for any reason, the secondary network is supplied from the remaining ones and service to the consumers is not interrupted. To prevent a feeding-back from the energized secondary network through the transformers connected to feeders out of service (thereby energizing the primary and creating unsafe conditions), automatically operated circuit breakers, called *network protectors,* are connected between the secondary network and the secondary of the transformers; these open when the direction of energy flow is reversed.

The two examples cited here are perhaps the two extremes in the design of distribution systems, the first the simplest, the latter the most complex. There are many variations in between these, and the basic ones will be described in their appropriate places.

Only distribution systems, however, will be the subject of further description and discussion in this book. In general, these include the distribution substation, primary feeders, transformers, secondary mains, services, and other elements between the substation and the consumers' points of service.

1.3 Distribution System Considerations

In determining the design of distribution systems, three broad classifications of choices need to be considered:

1. The type of electric system: dc or ac, and if ac, single-phase or polyphase.
2. The type of delivery system: radial, loop, or network. Radial systems include duplicate and throwover systems.
3. The type of construction: overhead or underground.

1.3.1 DESIRED FEATURES

Electrical energy may be distributed over two or more wires. The principal features desired are safety; smooth and even flow of power, as far as is practical; and economy.

1.3.2 Safety

The safety factor usually requires a voltage low enough to be safe when the electric energy is utilized by the ordinary consumer.

1.3.4 Smooth and Even Flow of Power

A steady, uniform, nonfluctuating flow of power is highly desirable, both for lighting and for the operation of motors for power purposes. Although a direct current system fills these requirements admirably, it is limited in the distance over which it can economically supply power at utilization voltage. Alternating current systems deliver power in a fluctuating manner following the cyclic variations of the voltage generated. Such fluctuations of power are not objectionable for heating, lighting, and small motors, but are not entirely satisfactory for the operation of some devices such as large motors, which must deliver mechanical power steadily and therefore require a steady input of electric power. This may be done by supplying electricity to the motors by two or three circuits, each supplying a portion of the power, whose fluctuations are purposely made not to occur at the same time, thereby decreasing or damping out the effect of the fluctuations. These two or three separate alternating current circuits (each often referred to as a single-phase circuit) are combined into one polyphase (two- or three-phase) circuit. The voltages for polyphase circuits or systems are supplied from polyphase generators.

1.3.4 Economy

The third factor requires the minimum use of conductors for delivery of electric energy. This usually calls for the use of higher voltages where conditions permit and the elimination of some conductors by providing a common return path for two or more circuits.

1.4 Various Type Of Distribution Systems

1. Dc Two – Wire System.
2. Dc Three- Wire System.
3. Single Phase AC.
4. 3 Phase 4 Wire AC

Electrical power is transmitted by high voltage transmission lines from sending end substation to receiving end substation. At the receiving end substation the voltage is stepped down to a lower value (say 66Kv or 33Kv or 11Kv). The secondary transmission system transfer power from this receiving end substation to secondary substation. A secondary substation consists of two or more power transformers together with voltage regulating equipments, buses and switchgear. At the secondary substation voltage is stepped down to 11Kv. The portion of the power network between a secondary substation and consumers is known as distribution system. The distribution system can be classified into primary and secondary system. Some large consumers are given high voltage supply from the receiving end substations or secondary substation.

The area served by a secondary substation can be subdivided into a number of sub- areas. Each sub area has its primary and secondary distribution system. The primary distribution system consists of main feeders and laterals. The main feeder runs from the low voltage bus of the secondary substation and acts as the main source of supply to sub- feeders, laterals or direct connected distribution transformers. The lateral is supplied by the main feeder and extends through the load area with connection to distribution transformers. The distribution transformers are located at convenient places in the load area. They may be located in specially constructed enclosures or may be pole mounted. The distribution transformers for a large buildings may be located within the building itself. At the distribution transformer the voltage is stepped down to 400v and power is fed into the secondary distribution systems. The secondary distribution system consists of distributors which are laid along the road sides. The service connections to consumers are tapped off from the distributors. The main feeders, laterals and distributors may consist of overhead lines or cables or both. The distributors are 3 phase 4 wire circuits, the neutral wire being necessary to supply the single phase loads. Most of the residential and commercial consumers are given single phase supply. Some large residential and commercial consumers get 3 phase supply. The service connections of consumers are known as service mains.

1.5 Direct Current Systems

Direct current systems usually consist of two or three wires. Al- though such distribution systems are no longer employed, except in very special instances, older ones now exist and will continue to exist for some time. Direct current systems are essentially the same as single- phase ac systems of two or three wires; the same discussion for those systems also applies to dc systems.

1.6 Alternating Current Single-Phase Systems

1.6.1 Two-wire Systems

The simplest and oldest circuit consists of two conductors between which a relatively constant voltage is maintained, with the load connected between the two conductors; refer to Figure 1.3. In almost all cases, one conductor is grounded. The grounding of one conductor, usually called the *neutral,* is basically a safety measure. Should the live conductor come in contact accidentally with the neutral conductor, the voltage of the live conductor will be dissipated throughout a relatively large body of earth and thereby rendered harmless. In calculating power ($I^2 R$) losses in the conductors, the resistance of the conductors must be considered. In the case of the neutral conductor, because the ground, in parallel with the conductor, reduces the effective resistance, the “return” current will divide between the conductor and ground in inverse proportion to their resistances.

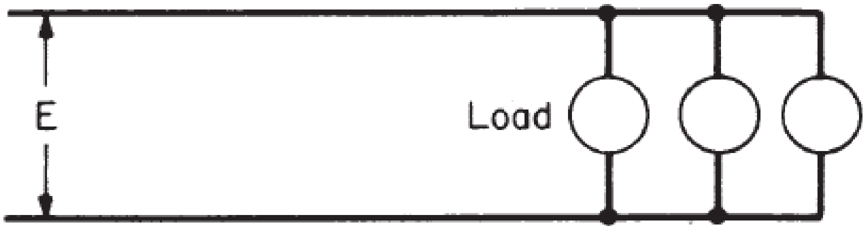


Figure 1.3 AC single-phase two- wire system.

Thus the I^2R loss in the neutral conductor will be lower than that in the live conductor; the I^2R loss in the earth may, for practical purposes, be disregarded. In calculating voltage drop in the circuits, both the resistance and reactance of the two conductors must be considered. (In dc circuits, reactance does not exist during normal flow of current.) This combination of reactance and resistance, known as impedance, is measured in ohms. Because the current in the grounded neutral conductor may be less than the current in the live conductor, the voltage drop in the neutral conductor may also be less.

1.6.2 Three-wire Systems

Essentially the three-wire system is a combination of two two-wire systems with a single wire serving as the neutral of each of the two-wire systems. At a given instant, if one of the live conductors is E volts (say 120 V) "above" the neutral, the other live conductor will be E volts (120 V) "below" the neutral, and the voltage between the two live (or outside) conductors will be $2E$ (240 V). (Figure 1.4). If the load is balanced between the two (two-wire) systems, the common neutral conductor carries no current and the system acts as a two-wire system at twice the voltage of the component system; each unit of load (such as a lamp) of one component system is in series with a similar unit of the other system. If the load is not balanced, the neutral conductor carries a current equal to the difference between the currents in the outside conductors. Here again, the neutral conductor is usually connected to ground.

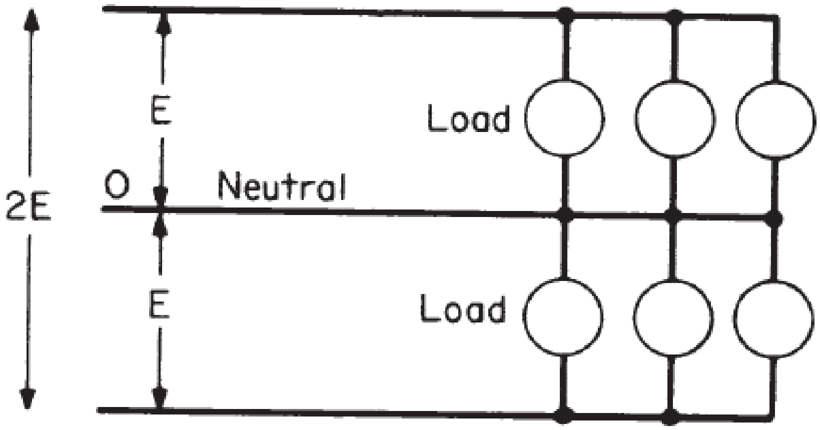


Figure 1.4 AC single-phase three-wire system.

For a balanced system, power loss and voltage drop are determined in the same way as for a two-wire circuit consisting of the outside conductors; the neutral is neglected.

Where the loads on the two portions of the three-wire circuit are unbalanced, voltages at the utilization or receiving ends may be different. These are shown schematically in Figure 1.5. Let the distance between the dashed lines represent the voltage. There will be a voltage drop, with reference to the neutral, in each of the conductors 1 and 2. The neutral conductor will carry the difference in currents, that is, $I_2 - I_1$, or I_n. This current in the neutral conductor will produce a voltage drop in that conductor, as indicated in Figure 1.5. The result will be a much larger drop in voltage between conductor 2 and neutral than between conductor 1 and neutral. If the unbalance is so large that I_n is greater than I_1, the receiving end voltage $E\mathrm{R}_1$ will be greater than the sending end voltage $E\mathrm{S}_1$, and there will be an actual rise in voltage across that side.

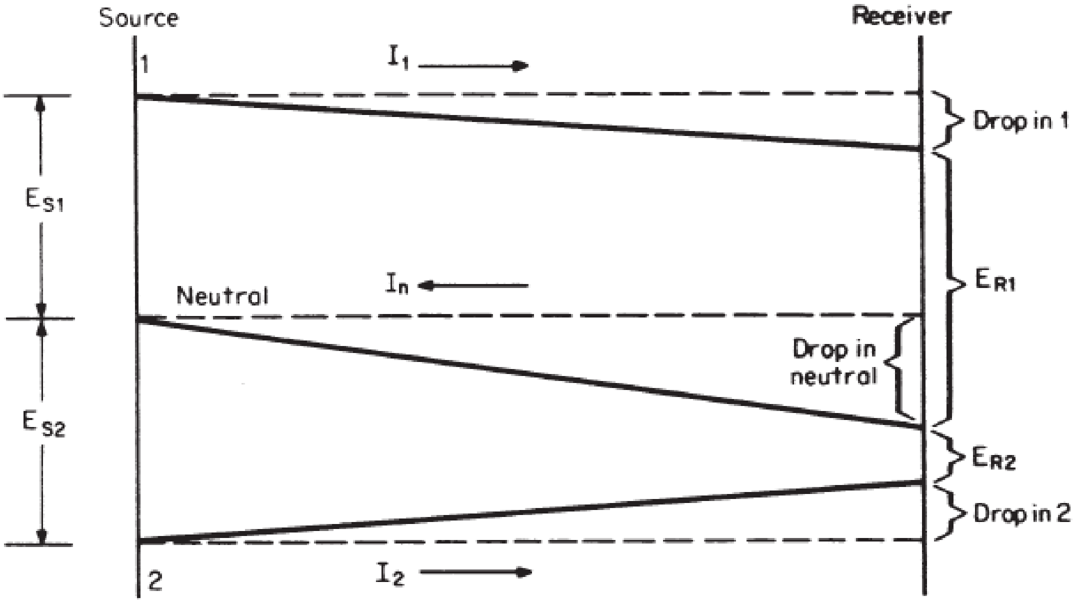


Figure 1.5 Unbalanced load single-phase three-wire system.

The limiting case occurs when $I_1 = 0$ and $I_n = I^2$. In that case, all the load is carried on side 2; the rise in voltage on side 1 will be half as much as the drop in voltage on the loaded side 2. However, if an equal load is now added to side 1, the loads in both parts of the circuit will be balanced and I_n will equal 0. The drop in voltage between conductor 2 and the neutral will be reduced to half that obtained with the load on side 2 only, although the load now supplied is doubled.

Voltage drops in the conductors will depend on the currents flowing in them and their impedances. The power loss in each conductor (I^2R) will depend on the current flowing in it and its resistance. In all of this discussion, the size of the neutral has been assumed to be the same as the live or outside conductors.

1.6.3 Series Systems

The series type of circuit is used chiefly for street lighting and, although being rapidly replaced by multiple-circuit lighting, nevertheless still exists in substantial numbers. It consists of a single-conductor loop in which the current is maintained at a constant value, the loads connected in series; see Figure 1.6. The voltage between the conductors at the source or at any other point depends on the amount of load connected beyond that point. The voltage at the source is equal to the vectorial sum of the voltages across the various loads and the voltage drop in the conductor.

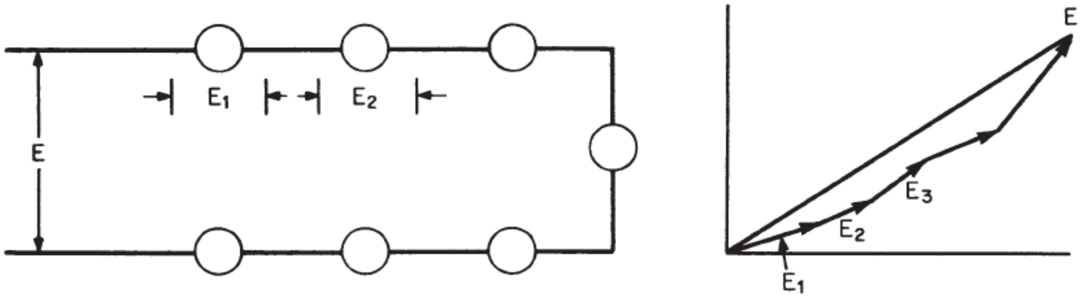


Figure 1.6 AC single-phase series system and voltage vector diagram.

The voltage drop in each section of the conductor depends on the current flowing in it (which is constant in value) and the impedance of that section of the conductor.

The power supplied the circuit equals the sum of the power for the individual units of load and the line losses. Power loss in each section of the conductor will depend on the current (squared) and the resistance of that section of the conductor.

1.7 OVER HEAD 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.

1.8 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. W. H. Kersting [3] provides the best regarding analysis, where as H. L. Willis [2] concentrates more on planning side.

Funkhouser and Huber worked on a method for determining economical aluminum conductor steel reinforced (ACSR) conductor sizes for distribution systems [4] 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.

Distribution losses account for the bulk of system losses and the capital investment for distribution networks is a considerable fraction of total capital investment. Therefore, a considerable attention has been focused on optimal distribution system planning over the last few years.

W. G. Krin & R. B. Adler [6] 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.

The distribution feeders have been assumed to be uniform cross-section in the methods of Refs. [4-6]. The most important characteristic of distribution networks is that they are radial and load carried by different feeder segments are different.

The work done by Wall *et al.* [7] was published in 1988 in which the researchers considered a rather simple system to determine the best conductors for different feeder segments of these systems. 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. But most important characteristic of distribution networks is that they are radial and load carried by different feeder segments are different.

Ponnavaikko and Rao in ref. [8] have proposed a model (PPR model) for optimal conductor selection of radial distribution networks. Their model is flexible and can handle the variations of load growth rate, load factor, cost of energy etc. over a plan period. The PPR model considers the conductor-grading problem as an optimization of minimizing the sum of feeder cost and presents the worth of feeder energy loss costs. The main drawback of this method of ref. [8] is that it cannot handle lateral branches. Tram and Wall in Ref. [7] have developed a computer algorithm for optimum selection of conductors of radial distribution networks. They have also explored the possibility of utilizing a regulator instead of reconductoring the feeder segments to resolve the voltage problems. Ponnavaikko and Rao in ref. [9] have proposed a new technique for distribution system planning through optimal conductor gradation. 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. Nagendra Rao in Ref. [11] have also proposed a technique for obtaining optimal branch conductor cross-section. However, main drawback of this method is that it cannot handle lateral branches.

However, the methods of Refs. [6-9] available in the literature are not based on any load flow techniques which is important for optimizing the branch conductors of radial distribution networks. Also it is very important to consider voltage constraint and maximum current carrying capacity for each type of conductor.

Chiang et al. [12] have used the method of simulated annealing to obtain the optimum values of shunt capacitors for radial distribution networks. Sunshararanjan and Pahwa [13] have used genetic algorithms for obtaining the optimum values of shunt capacitors. They have [13] treated the capacitors as constant reactive power load and no method is suggested to reduce CPU time. Genetic algorithm based solution is capable of determining a nearest global solution with lesser computational burden than the simulated annealing method [13].

Sujit Mandal [14] 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.

G. Salis & A. Safigianni [15-17] contributed lot of their work on Primary and secondary distribution system analysis and planning Primarily their method is based on economic criteria leads to a network configuration close to the optimum solution, so that the network has a minimum cost for capital and losses and fulfills the following technical constraints, thermal and economic capacity,

1.9 Structure of the thesis

Chapter 1 Introduction to distribution systems is given where various basics have been introduced. Types of existing distribution system models have also been discussed. Literature review done by researchers till date is presented, a through analysis has been done on the existing methods. Followed by organization of this thesis and aim of the present work

Chapter 2 In this chapter various assumptions, modified load flow algorithm is first explained, followed by constraints concerned to optimal conductor selection. Later on algorithm for optimal conductor selection and is demonstrated by two examples, 16 node, 31 node radial distribution network.

Chapter 3 Basing on the observations during the mathematical process conclusions are made, and future scope is presented where certainly where the new method needs to improve.

1.10 Aim of thesis

In this thesis work, the main aim was to develop a computer algorithm for optimal branch conductor selection of radial distribution feeders based on an efficient load flow technique developed in Ref. [18]. The proposed method has the capability to consider lateral branches. It also considers voltage constraint and maximum current carrying capacity of each conductor.

CHAPTER 2

OPTIMAL CONDUCTOR SELECTION

2.1 Assumption:

It is assumed that the three-phase radial networks are balanced and can be represented by their equivalent single-line diagram.

2.2 Modified load flow algorithm:

A modified version of the load-flow in Ref. [18] is suggested to optimize the branch conductor.

Figure 2.1 shows the single line diagram. Table 2.1 shows the branch number, sending-end and receiving-end. Consider branch 1, the receiving-end node voltage of branch 1 can be written as

$$V(2,k) = V(1,k) - I(1,k) \times Z(1,k) \quad (2.1)$$

Similarly for branch 2,

$$V(3,k) = V(2,k) - I(2,k) \times Z(2,k) \quad (2.2)$$

Substation voltage V(1,k) is known. If we can calculate I(1,k) for k=1,2,…….,NTYPE, i.e., current of branch-1 for different type of conductors, we can easily calculate V(2,k) for k = 1,2,…….., NTYPE from equation 2.1.

Once V(2,k) is known, we can easily calculate V(3,k) for k=1,2,……,NTYPE from equation-2 if the current through branch 2 i.e., I(2,k) is known for k=1,2,….,NTYPE. Similarly, voltage at nodes 4,5,…….,NB can be easily calculated for k=1,2,……..,NTYPE.

Therefore, a generalized equation of sending-end and receiving-end voltage, branch current and branch impedance is given below:

$$V(m2,k) = V(m1,k) - I(jj,k) \times Z(jj,k) \quad (2.3)$$

Equation 2.3 can be evaluated for jj=1,2,….., LN1(=NB-1) with different type of conductors. For developing the optimal branch conductor algorithm, charging currents are neglected.

Now current through branch 1 is equal to sum of the load currents of all nodes beyond branch-1. The "ident" software of Ref. [18] has been used to determine nodes beyond all branches. The general expression of branch current for branch-jj having k-type conductor is given by

$$I(jj,k) = \sum_{k=1}^{N(jj)} IL\{IE(jj,k),k\} \tag{2.4}$$

The load current of node i is as follows:

$$IL(i,k) = \frac{PL(i) - jQL(i)}{V^{*}(i,k)} \tag{2.5}$$

where i = 2,3,….NB and k=1,2…..,NTYPE

Equation (2.5) clearly shows that as node voltages are different for different type of conductors, load currents are also different for different type of conductors.

Real and Reactive power losses of branch-jj with k-type conductor are given by:

$$LP(jj,k) = |I(jj,k)|^2 \, R(jj,k) \tag{2.6}$$

$$LQ(jj,k) = |I(jj,k)|^2 \, X(jj,k) \tag{2.7}$$

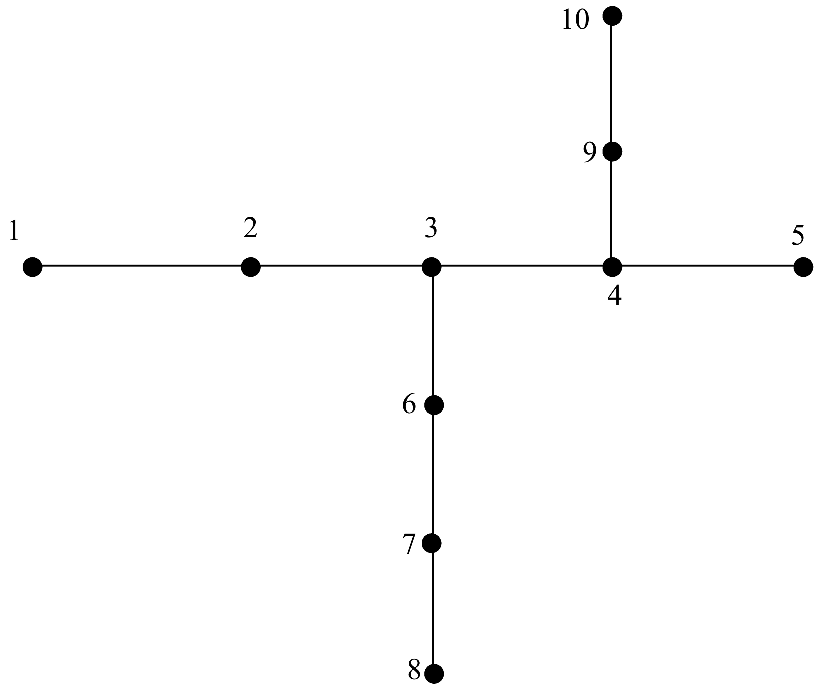


Figure 2.1: Single line diagram for a balanced radial distribution network

Table 2.1 Branch number, sending-end and receiving-end nodes of Figure 2.1

Branch Number	Sending-end	Receiving-end
1	1	2
2	2	3
3	3	4
4	4	5
5	3	6
6	6	7
7	7	8
8	4	9
9	9	10

2.3 Objective Function:

The basic problem is the selection of conductor for each branch of a radial distribution feeder, which will minimize the sum of cost of capital investment and the cost of losses while maintaining an acceptable voltage.

The annual cost for loss in branch-jj with k-type conductor can be calculated by

$$L(jj,k) = K_p * LP(jj,k) + Lsf * LP(jj,k) * T * K_E \tag{2.8}$$

In Equation (2.8), the loss factor is used because LP(jj,k) is the peak real power loss of branch-jj with k-type conductor and Lsf*LP(jj,k) gives the average real power loss of branch-jj with k-type conductor.

The annual cost of capital for branch-jj with k-type conductor is given by

$$CC(jj,k) = \alpha *COST(k)*LEN(jj) \tag{2.9}$$

The objective function for branch-jj with k-type conductor can be written as

$$F(jj,k) = L(jj,k) + C(jj,k) \tag{2.10}$$

In this thesis work the optimal conductor selection is obtained by branch-wise techniques.

2.4 Constraints:

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

ii) Maximum current carrying capacity: Current flowing through branch-jj with k-type conductor should be less than the maximum current carrying capacity of k-type conductor.

2.5 Algorithm for Optimal Conductor Selection:

Step 1 : Read real system data and assume a flat voltage start

Step 2 : Identify the nodes beyond all the branches using algorithm of Ref. [18]

Step 3 : IT=1 and DVMAX = 0.0

Step 4 : Calculate the load current using equation 2.5

Step 5 : jj=1

Step 6 : m1 = IR(jj)

Step 7 : m2 = IS(jj)

Step 8 : k = 1

Step 9 : Compute I(jj,k) and V(m2,k) using equation 2.4 and equation 2.3 respectively.

Step 10 : Set

VV(k)=|V(m2,k)| and CII(k)=|I(jj,k)|

Step 11 : Compute LP(jj,k) using equation 2.6

Step 12 : Compute L(jj,k) and CC(jj,k) using equation 2.8 and equation 2.9 respectively.

Step 13 : Compute F(jj,k) using equation-2.10

Step 14 : Set FN(k) = F(jj,k)

Step 15 : k = k + 1

Step 16 : If (k ≤ NTYPE) go to step-9 otherwise go to step 17

Step 17 : Arrange FN(k) in an ascending order for k = 1,2,…….,NTYPE and store different k for ascending order of FN(k) in KS(j).

Step 18 : J6 = 1

Step 19 : M33 = KS(J6)

Step 20 : If {VV(M33) > V_{min} and CII(M33) ≤ CMAX(M33)}

Go to step 23 otherwise go to step 21

Step 21 : J6 = J6+1

Step 22 : If (J6 ≤ NTYPE) go to step 19

Otherwise go to step 21

Step 23 : Compute receiving-end voltage using equation 2.3

Step 24 : Calculate absolute change in voltage at node m2 i.e.,

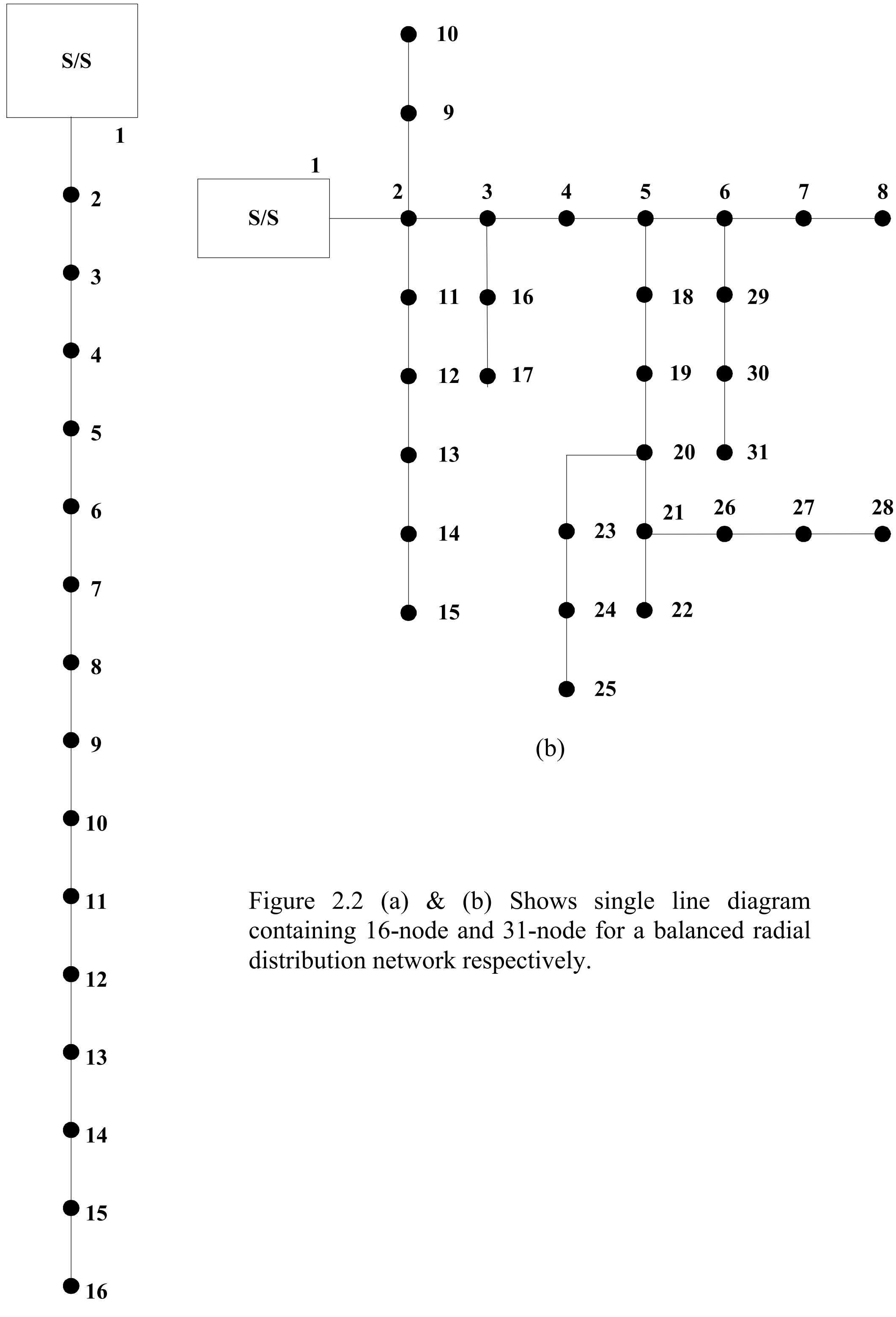
DV(m2) = ABS (|V(m2)|-VV(m2)

```
Step 25  :  If(DV(m2) > DVMAX)
             DVMAX = DV(m2)
Step 26  :  TYPE(jj) = M33
Step 27  :  jj = jj + 1
Step 28  :  If (jj ≤ LN1) go to step 7
             Otherwise go to step 29.
Step 29  :  If (DVMAX < ε) go to step 31 , otherwise go to step 30
Step 30  :  If (IT ≤ ITMAX) go to step 6
             Otherwise print diagnostics and go to step 32
Step 31  :  Solution has converged, write voltages, power losses, types of
            conductor for each branch, feeder losses etc.
Step 32  :  Stop
```

2.6 Examples:

In this section, effectiveness of the proposed method is demonstrated by two examples, 16 node, and 31 node radial distribution network.

In first case an existing rural distribution feeder is considered. The feeder is heavily loaded during agricultural season. The basic objective is to examine whether branch conductors of this feeder are properly selected or not. Data of the conductors are given in Appendix A (Table A.1). Line data and Load data for example 1 are given in Appendix B (Table B.1).



(b)

(a)

Figure 2.2 (a) & (b) Shows single line diagram containing 16-node and 31-node for a balanced radial distribution network respectively.

Table 2.2 Line Data for Example-1 (Figure 2.2 (a))

Branch no.	Sending-end (m1)	Receiving-end (m2)
1	1	2
2	2	3
3	3	4
4	4	5
5	5	6
6	6	7
7	7	8
8	8	9
9	9	10
10	10	11
11	11	12
12	12	13
13	13	14
14	14	15
15	15	16

Table 2.3 Line Data for Example-2 (Figure 2.2 (b))

Branch No.	**Sending-end node m1=IS(jj)**	**Receiving-end node m2=IR(jj)**
1	1	2
2	2	3
3	3	4
4	4	5
5	5	6
6	6	7
7	7	8
8	2	9
9	9	10
10	2	11
11	11	12
12	12	13
13	13	14
14	12	15
15	3	16
16	16	17
17	5	18
18	18	19
19	19	20
20	20	21
21	21	22
22	20	23
23	23	24
24	24	25
25	21	26
26	26	27
27	27	28
28	6	29
29	29	30
30	30	31

First a base case load flow is carried out using the data given in Appendix B (Table B.1). **The real and reactive power losses** are **53.47 kW and 37.17 kVAr** respectively. Minimum voltage at node 16 is **|V(16)| = 0.88670 p.u.**

For the optimization of branch conductors four different type of conductors are used (Appendix A, Table A.1). Line and Load data in Appendix B (Table B.1) is used for the purpose of comparison. Limit of minimum voltage is taken as 0.90 p.u. Modification of branch conductors is depicted in Table 2.4.

Table 2.4 Modification of branch conductors, Example 1

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

After modification of branch conductors, the real and reactive power losses are **37.36kW and 35.15 kVAr** respectively. Minimum voltage occurs at node 16 is $|V(16)|=0.91533$ p.u.

Therefore, reduction of the real power and reactive power losses are **16.11 kW and 2.02 kVAr** respectively and also improvement of voltage.

In second case another radial feeder is considered. This radial feeder is planned for supplying power to rural areas. Basic objective of this practical problem is to find out the optimal branch conductors using the proposed conductor optimization algorithm. Line and load data of this feeder are given in **Appendix C** (Table C.1).

In India during agricultural season, rural distribution feeders are heavily loaded and power factor of the loads is very poor because of agricultural motor pump sets. Power factor of the rural loads vary between 0.6 and 0.8 Ref. [18]. For this example, power factor of the load is taken as 0.75. Minimum voltage limit (V_{min}) is taken as $\mathbf{V_{min}= 0.95}$. Optimization results of this feeder are depicted in Table 2.5.

Table 2.5 Optimal branch conductor of Example 2

Branch Number	Type of Conductor
1,2,3,4 and 17	Raccon
5,8 and 19	Rabbit
10,11 and 20	Weasel
6 to 9, 12 to 16 and 21 to 30	Squirrel

Total real power loss =23.405 kW and reactive power loss = 19.032 kVAr and minimum voltage $|V_{28}|$ = 0.96954.

CHAPTER 3

Conclusions and Future Scope of Work

3.1 Conclusions

In this thesis work, a method has been presented for optimal branch conductors of radial distribution feeders based on a load flow technique [18]. The proposed method selects optimal branch conductors by minimizing an objective function, which is the sum of feeder loss cost, and the feeder cost. In addition, the proposed method keeps the minimum voltage within the prescribed limit and the current flowing through each branch is less than the maximum current carrying capacity of the corresponding branch conductor. Effectiveness of the proposed method has been demonstrated by two examples, 16 node, 31 node radial distribution network.

3.2 Future Scope of Work

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

1. Day conditions
2. Sag & Tension

as conductor parameters depend on these things.

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Appendix A

Table A.1 Data for Conductors

Type of Conductor	Area of Cross – section (mm^2)	Resistance (Ω/Km)	Reactance (Ω/Km)	Maximum current carrying capacity (Amps)	Cost of Conuctors (Rs/Km)
Squirrel	12.90	1.3760	0.3896	70.0	2889.0
Weasel	19.35	0.9108	0.3797	100.00	4338.0
Rabbit	32.36	0.5441	0.3673	148.0	7306.0
Raccon	48.39	0.3657	0.3579	200.0	10950.0
K_E = Rs 1.00per kWh, K_P = Rs 4000 per kW, Lsf = 0.20					

Appendix B

Table B.1 Load Data for Example-1

Branch no.	Type of conductor	Length (Km) LEN(jj)	Load at m2	
			KW	**KVAr**
1	Raccon	2.00	48.75	43.00
2	-do-	1.60	37.50	33.00
3	-do-	2.30	33.00	75.00
4	-do-	2.90	75.00	66.10
5	Rabbit	2.20	48.75	43.00
6	-do-	1.57	37.50	33.00
7	-do-	2.40	12.00	10.60
8	-do-	4.00	37.50	33.00
9	Weasel	2.30	37.50	33.00
10	-do-	2.50	75.00	66.10
11	-do-	2.70	18.75	16.50
12	Squirrel	3.20	48.75	43.00
13	-do-	1.70	48.75	43.00
14	-do-	3.80	75.00	66.10
15	-do	2.00	37.50	66.10
Load KVA at node 1 is 0.0				

APPENDIX C

Table C.1 Load Data for Example-2

Branch No.	**Length (Km) LEN(jj)**	**KVA Load at m2**
1	1.00	16.00
2	1.30	50.00
3	1.60	50.00
4	2.90	100.00
5	3.20	250.00
6	1.50	25.00
7	3.40	100.00
8	2.50	50.00
9	2.20	50.00
10	1.40	16.00
11	2.33	25.00
12	4.00	65.00
13	3.50	65.00
14	1.00	16.00
15	2.90	50.00
16	2.20	25.00
17	1.67	25.00
18	2.45	25.00
19	1.46	16.00
20	1.50	65.00
21	1.70	65.00
22	1.80	50.00
23	2.90	25.00
24	1.10	25.00
25	1.90	16.00
26	2.00	25.00
27	2.00	25.00
28	1.50	16.00
29	2.70	50.00
30	1.15	25.00

APPENDIX D

Curriculum Vitae

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CAREER OBJECTIVE:

Intend to build a career with leading company with a team of committed & dedicated people, which will use my full potential.

PERSONAL PROFILE:

Name : V. K. Shailesh Kumar Ch.
Date Of Birth : 25-08-1985
Sex : Male
Father's Name : Ch. Satyanand Rao
Languages Known : English, Hindi, & Telugu
Nationality : Indian

EDUCATION:

S.No	Qualifying Exam	Name of the Institution	Academic Year	Percent Obtained
1.	Post Graduation (Power Systems and Electrical Drives)	Thapar University, India	2006-2008	7.44 (C.G.P.A)
2.	Bachelor in Technology (Electrical & Electronics Engineering)	Jawaharlal Technological University, Hyderabad, India	2002-2006	71.01 % (Distinction)
3.	High School (11th – 12th)	Vikas Vidyalayam Jr. College, Visakhapatnam, India	2000-2002	82.6 %
4.	Schooling (S.S.C.)	Ramakrishna Residential Public School, Visakhapatnam, India	1999-2000	77.66 %

SOFTWARE EXPOSURE:

Programming Language: C, Matlab (Ver. 7.x), CYMDIST

Presented Science Project:

- Low Noise Audio Amplifier
  At Electronex-2003 (05-07 December, 2003)
  Conducted By Pydah Degree College,
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Presented Technical Papers On:

International conference:

- Advanced Control Systems "Fuzzy Logic Control"
  Awarded 2nd Prize in Cybernetics Session
  At INTERNATIONAL CONFERENCE on Systemics, Cybernetics and Informatics.
  Under the aegis of Pentagram Research Center, India
  January 06-09,2005

National conference:

- "High Voltage Direct Current Transmission"
  At ELECTRICA-04 (25-26th February, 2004)
  Conducted by College of Engineering-GITAM,
  Visakhapatnam, Andhra Pradesh, India.
- An Overall Idea On "Solar Electric Systems"
  At ELECTRICA-03 (06-07th March, 2003)
  Conducted by College of Engineering-GITAM,
  Visakhapatnam, Andhra Pradesh, India.

Attended Workshop:

- "Energy Conservation"
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  On 28th August 2003 at Rajahmundry, Andhra Pradesh, India.

Junior Research Fellow:

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