OPTIMISATION OF FEEDER SIZES IN A DISTRIBUTION NETWORK

A DISSERTATION

submitted in partial fulfilment of the
requirements for the award of the degree
of
MASTER OF ENGINEERING
in
ELECTRICAL ENGINEERING
(Power System Engineering)

By

SURESH SINGH

DEPARTMENT OF ELECTRICAL ENGINEERING
UNIVERSITY OF ROORKEE
ROORKEE-247 667 (INDIA)
April, 1986.

DEDICATED

TO

MY PARENTS

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled "OPTIMISATION OF FEEDER SIZES IN A DISTRIBUTION NETWORK" in partial fulfilment of the requirements for the degree of MASTER OF ENGINEERING in ELECTRICAL ENGINEERING with specialisation in POWER SYSTEM ENGINEERING submitted in the Department of Electrical Engineering, UNIVERSITY OF ROORKEE, ROORKEE is an authentic record of my own work carried out during a period of about 8 months, from August 8, 1985 to March 31, 1986 under the supervision of Sri Vinay Pant, Lecturer, Electrical Engineering Department, UNIVERSITY OF ROORKEE, ROORKEE (INDIA).

The matter embodied in this dissertation has not been submitted for the award of any other degree or diploma.

Dated: April 11, 1986 (SURESH SINGH)

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

(VINAY PANT)

Dated:
April 11, 1986

Lecturer,
Department of Electrical Engg.
University of Roorkee,
Roorkee (INDIA)

ACKNOWLEDGEMENT

This work is the culmination of one and a half year POST-GRADUATE programme in ELECTRICAL ENGINEERING at UNIVERSITY OF ROORKEE, ROORKEE. This represents not just effort of the past 8 months but also the help, guidance and support received during this entire duration of the MASTER OF ENGINEERING course, from all my teachers, my mentors, my friends and above all my parents.

I am deeply grateful to Dr. M.P. Dave, Prof. ELECTRICAL ENGINEERING DEPARTMENT and Sri Vinay Pant, Lecturer, ELECTRICAL ENGINEERING DEPARTMENT, U.O.R., Roorkee for their encouragement and incalculable help. In spite of a very busy schedule, they were always available for discussions. Without them to guide me and many excellent suggestions given, the completion of this Thesis was not possible. It was a pleasure and privilege to have worked with them, during the period of this work.

I am also grateful to Dr. P. Mukhopadhyay, Prof. & Head, ELECTRICAL ENGINEERING DEPARTMENT, U.O.R., ROORKEE for providing all facilities needed.

The help rendered by Dr. J.D. Sharma, Prof. ELECTRICAL ENGINEERING DEPARTMENT, U.O.R. ROORKEE is also gratefully acknowledged.

Finally, it is a pleasure to thank Sri O.P. Dhama, Mr. Anil Kumar and Mr. Arvind Raghuvanshi, who made significant contributions to this work.

S Singh

(SURESH SINGH)

ROORKEE

DATE April 11, 1986

ABSTRACT

This dissertation work describes the optimization of feeder sizes in a distribution network through optimal grading of the conductor cross-sections along the feeder main and an efficient optimization procedure for parameter optimization.

The distribution system planning problem has been high lighted in the introductory chapter. A brief review of the available literature on these two aspects of distribution system planning has been given in Chapter-II.

The third chapter deals with the conductor gradation problem. In this chapter mathematical models to represent feeder voltage drop, feeder cost and energy loss cost are described as a function of conductor cross-section. The effect of growth factors such as increase in the cost of energy with time and growth in load factor have been described. By using these models a cost function, representing an over-all cost of the feeder (consisting of capital investment and the present worth of the energy loss cost) during the feeder life is defined. Minimization of the cost function is done, subject to a voltage drop constraint. This model is applicable to any type of radial feeder. The results of the application of these models to a system are also included in this chapter.

For parameter optimization, mathematical models to represent the various cost components, loss coefficients, substation feed area and feeder service area in terms of the variable system parameters are given in Chapter-IV. Two objective functions- one to represent the system cost as a function of substation feed area and the other to represent the substation cost as a function of the feeder

service area are defined. The objective functions are minimized using two level optimization process to obtain the optimal substation feed area and feeder service area for a given conductor size and load density. The optimized substation feed area and feeder service area determine the optimal voltage regulation, number of substations, number of feeder ofper substation, feeder loading, feeder main length and conductor size. The optimized parameters for a test system have been obtained and are included in this chapter.

The Chapter-V is the concluding chapter, in which the results obtained, have been discussed. The details of the computer programs and their flow charts are given in Appendix A and D.

LIST OF SYMBOLS

LF	Load factor
LF_u	Ultimate load factor
LF_p	Present load factor
LLF	Loss load factor
LLF_k	Loss load factor in the K^{th} year
KV	Circuit voltage in Kilo Volts
Q	Power factor angle
V	Percentage coltage regulation of a radial distribution feeder
L	Feeder main length in Km
L_s	Length of the lateral feeder in Km
ℓ	Spacing between the laterals in a uniformly loaded feeder in Km
D	Connected load density in KW/sq.Km.
Pf	Power factor
DF	Load diversity factor at the feeder mains
DF_s	Load diversity factor at the laterals
a_s	Substation feed area in Sq.Km.
a_f	feeder service area in Sq.Km.
n_s	Number of substations in the study area
n_f	Number of feeders per substation
Z	Zig-zag factor of the feeder main
UF	Utilization factor of the transformers in substations
C_f	Feeder main cost in Rupees per Km.
C_f'	Lateral feeder cost in Rupees per Km.
A	Area of the study system in Sq.Km.
C_{e_k}	Cost of energy at the K^{th} year
U	Annual discount rate in p.u.
NLS	Expected life of transformer (years)
NLF	Expected life of feeders (years)
N_t	Number of transformers in a substation

KVA_t	Capacity of a single transformer
R_s	Radius of the circular feed-area of secondary distribution substation
a'	Fixed part of transformer core loss in KW
b'	Variable part of transformer core loss in KW/KVA capacity of transformer
c'	Fixed part of transformer full load copper loss in KW
d'	Variable part of transformer full load copper loss in KW/KVA capacity of the Transformer
e	Substation fixed cost component in Rs
h	Substation variable cost capacity component in Rs/KVA
f	Substation variable cost-feeder bay component in Rs/KVA

CONTENTS

CHAPTER-I

INTRODUCTION

CHAPTER-I

INTRODUCTION:

The Distribution networks fed from the distribution substations (transformer stations), supply energy to the small (domestic) or medium sized (small industrial and commercial) customers. The whole network between substation and the consumer's service point, is known as Distribution Network. The Primary and Secondary distribution networks in a distribution network are distinguished on the basis of voltage. The secondary distribution system consists of secondary distribution feeders, feading the secondary distribution substations which transform the voltage from a HT level to an LT level and feeding the LT consumers. The primary distribution system consists of the primary distribution feeders, feeding the HT consumers, the secondary distribution substations and primary distribution substations that transform the voltage from a subtransmission or transmission level to a primary distribution level. Distribution network is a significant part of a power system.

The circuit adequacy, service quality and economy are the three main objectives of the distribution network planning. The prime concern is given to the system economy, which includes both the fixed cost (Capital investment) and variable cost (Cost of energy losses). A proper distribution system planning must provide an economical network with a minimum number of outages implying maximum reliability because most of the interruptions of the consumers belong to the distribution network.

To meet the increase in future load demand proper system expansion is needed. Hapazard expansion results in problems like fluctuations in voltage, low voltage problems and supply interruption to the consumers. The design of distribution equipment to be added in the present distribution network should result in minimum changes in the network configuration. To achieve an overall system economy it is must to choose the optimal substation feed-area and feeder service area also. A large substation feed area will require lesser number of substations, hence resulting in lower capital investment. But the feeder cost and cost of energy losses will increase due to increase in the lengths and number of feeders for feeding the desired power. On the other hand if we have small substation feed area then the situation is reversed. The capital investment will increase but the cost of energy loss will decrease. Hence the best choice lies in between these two extremes. In order to render a specified quality service to residential customers, the distribution planning engineer must know (a) The most economical design of distribution transformers and secondaries (b) The optimum combination of subtransmission and primary feeder voltages to employ in system expansion (c) The optimum load carrying capability ratings of the primary feeder circuits, distribution substations, subtransmission circuits and bulk power substations to supply system load areas and (d) The point or points in the distribution system which are most practicable and economic to regulate system voltages. In order to provide an adequate and reliable service to the consumers optimal approach in planning is used. But the optimal distribution network planning is complicated system. The planner faced with a number of technical and economical problems.

The choice of distribution substation location and rating is of primary concern in distribution system planning. The number and location of substations depends on several factors such as load density, geographical limitations, environmental considerations, rights of way availability etc. However, it is unlikely that all distribution substations will become overloaded at the same time, and even if they did, a decision must be made as to which substation must be expanded. The distribution planner is required to determine the load magnitude and it's geographic location. The distribution substations must be located and sized in such a way as to minimize the feeder losses and construction losses.

The optimal route of a distribution feeder radiating from a substation of a given location and feeding a number of loads with known demands and locations, is achieved through optimization of the lengths of feeders and branches.

In a distribution network the feeders are mostly radial. The loading in the feeder sections of a feeder main is always in decending order from the substation to the far-end. The radial feeders permits the choice of multiple conductor configuration, subject to the availability of the standard conductor sizes. This is known as conductor gradation and optimal conductor gradation helps in improving system economy.

The measure of the circuit adequacy is the feeder voltage regulation, voltage regulation also influences the service quality and system economy to a great extent. It is necessary to make a trade-off between the capital investment and recurring expenditure to choose an optimal value of voltage regulation for distribution network, because if a planner design feeders with lower voltage regulations then it leads to increased capital investment but reduced distribution losses and so resulting in less annual recurring expenditure. On the other hand, for higher values of voltage regulation, it results in less capital investment and more annual recurring expenditure due to higher losses and also calls for maintaining higher levels of voltage at the substations. Voltage regulation is the function of circuit voltage, load, loading pattern, power factor, conductor size and circuit length. The optimization of these distribution network parameters will result in an optimal choice of voltage regulation.

Electric distribution losses constitute a substantial percentage of the total system losses. In a distribution feeder, losses occur due to the following reasons (a) line losses on phase conductors (b) line losses on ground wires (c) transformer core and leakage losses (d) excess losses due to lack of co-ordination of VAR elements (e) Excess losses due to load characteristics and (f) excess losses due to load imbalance on phases. The distribution lines results in a high percentage energy losses due to the use of low distribution voltages and the inherent high resistance characteristic the reactive power control is normally provided by addition of shunt capacitors in the system. Economic benefits of capacitor application to distribution feeders include (a) Reduced KVA input to feeder (b) reduced I^2R demand and energy losses (c) Reduced I^2X losses (d) Reduced regulation costs and (e) increase revenue as a result of increased voltage levels. The power feeder keeps on swinging between 0.6 (during peak load) and 0.9 (during light load) shunt capacitors are commonly applied on primary feeders for voltage control to provide a feeder voltage within the prescribed maximum and minimum allowable values at light load and peak load conditions. The optimum size and location of the capacitors can be determined on the basis of maximum savings in energy loss and power loss reductions.

The optimality of the distribution network continues to change with time as the load density grows. It is due to the change in load factor, loading conditions and the cost of components. To obtain the realistic results. The planner has to take into consideration this growing trend also.

The present work deals with the two aspects of Distribution System planning, namely; conductor gradation and parameter optimization. A brief review of the available methods for solving these two problems is given in the following chapter.

CHAPTER-2

LITERATURE-REVIEW

CHAPTER - II

LITERATURE REVIEW

2.1 REVIEW OF METHODS FOR CONDUCTOR SIZE SELECTION

A.W. Funkhouser and R.P. Huber [4] studied the problem of conductor gradation as early as in 1955, through an enumeration procedure. For the selection of the conductor sizes for use in a distribution system, an economic comparison of the various sizes is made in two ways. Firstly, the economical sizes for any value of load is determined, secondly, the most economical arrangement of these sizes for a growing uniformly distributed load is determined. A check of voltage regulation is made to ensure that the sizes selected are adequate from this stand point. Certain simplifying assumptions are made, in making up the cost comparison studies for this purpose, viz, the cost of poles and hardware is left out, span lengths are limited by existing pole-line spacing and service drop requirements. The economic study involves the determination of the annual costs of investment and cost of losses per circuit per mile for each size of conductor and for a range of loads upto the maximum allowable load per circuit. The accumulated annual cost is evaluated by adding these two costs, this accumulated cost then forms the basis of economic comparison between the various conductor sizes combinations selected for the system.

K.S. Hindi and A. Brameller [5] studied the problem of conductor gradation in seventies through linear programming and integer programming methods without considering the effect of the growth factors. They developed two methods to design a tapered low voltage radial distribution network. The first method is for tapering between nodes and is based on a transshipment model, while the second one is for tapering at nodes and is based on a zero-one integer model. The first ıod has proved to be computationally very efficient, while second method solved by a special purpose branch and ıd program proved less efficient.

W.G. Kirn et. al. [6] studied the results of an ·ication of a distribution system cost model to the optimal luctor sizing in the primary and secondary portions of the ·ribution system. This model was used to demonstrate a ·cy for sizing the conductors of the different portions of distribution circuit (Primary feeder, Main and laterals ·ell as secondary main and service connection). This model used to analyse the penalties associated with optimal ·uctor sizing policies based on incorrect projections of rate and nature of the future circuit load development, h is attributed to the growth of existing loads and the th due to the addition of new consumers.

M. Ponnavaikko and K.S. Prakasa Rao [7] proposed a edure for optimal conductor gradation. They developed a l which represents feeder cost, energy loss cost and age regulation as a function of conductor cross-section an objective function in terms of annual costs for mizing the conductor cross-sections. The load growth in re years of the plan period has been taken into account. developed method is capable of handling any type of uctor loading i.e. it is valid for uniform and non- orm loading of the feeders. This problem has been ulated as a dynamic programming problem, because of it's onably less computational efforts in comparison to eration technique used by Funkhouser et. al. [4] . The ctive cost function is minimized with respect to the able conductor cross-sections subjected to the voltage constraint. This model is realistic and flexible enough to handle the variations in the load growth rate, load factor, cost of energy etc. over the plan period.

P.S. Nagendra Rao [8] presented a novel method for determining optimal conductor cross-sections for radial distribution feeders, by proposing a direct solution procedure for conductor grading, thereby eliminating the complexity of dynamic programming approach used by M. Ponnavaikko et. al. [7] . The proposed solution technique is extremely simple, involving very few computation and needs lesser computer storage. This method used mathematical models developed by M. Ponnavaikko et.al. [7] . This method eliminates (i) The bulk of the computation, (ii) The need for large computer storage and (iii) The need for complex computer programming. This method is also capable of adjusting the conductor sizes if the sizes selected from the economic point of view violate the voltage drop constraint. This is achieved by calculating penalty functions and minimizing it till the constraint is satisfied. The details of this method are given in Chapter - III.

2.2 REVIEW OF METHODS FOR PARAMETER OPTIMIZATION OF DISTRIBUTION SYSTEM:

The isolated planning and hapazard growth causes highly uneconomical investments and poses serious problems to the overall economy. This situation in the distribution system management accentuated the need for an optimal design of distribution system.

A brief outlines of various methods available for optimal system design are given in the subsequent paragraphs.

W.J. Denton et.al [10] presented methods for distribution system planning which take load growth into account in such a way that exact locations and magnitudes of future loads need not be known to arrive at an economic system for serving the loads when they develop. To accomplish this they devised hypothetical equivalent distribution systems for quickly analysing the service quality and the economic feasibility of distribution system growth plans applicable to the system load areas of the actual system being studied.

R.F. Lawrence et.al [11-12] developed a method of finding the most economical distribution transformer and secondary conductor size combination. The method of solution is to select a range of transformer ratings, secondary conductor sizes and the number of connected customers and then trying all the possible combinations of these variables. The most economical design is that combination, having the lowest cost within operating and service quality limits. They have made certain assumptions in the development of these models such as, all connected customers have the same maximum demand and power factor, loads are balanced, such that no loss or voltage drop occurs in the neutral conductor. Under steady state conditions, customers take off points are equally spaced along the secondary and the transformer is connected to the centre of the secondary runs so that an equal number of customers are served in each direction from the transformer. They also developed a model to give the optimum load carrying capability and ratings of the primary feeder circuits and distribution substations. Their work also includes the development of an optimization procedure to tobtain a system that has minimum cost to serve a given load pattern with a specified combination of subtransmission and primary feeder voltages.

M.W. Gangel et.al. [13] developed a model for studying the design of primary main circuit, which can be used independently or in conjunction with the models for studying secondary and subtransmission system economics. The method examines each of themany possible primary circuit designs, determines investments and operating costs and compares the total cost with that of other possible designs. The use of the model results in the optimization of the conductor size and the dimensions of the substation feed area. The primary system model when used in conjunction with the secondary system mode produces results form a large number of combinations of primary and secondary systems. The primary method design parameters are taken as (a) characteristics of the secondary and primary lateral systems (b) distribution substation ratings (c) number of equally rated power transformers in the distribution substation (d) primary circuit load level (e) substation feeder area pattern and (f) primary main and lateral conductor sizes. To make the calculated values more accurate,some special features are also incorporated such as use of deviation factor, voltage drop calculation procedure and substation feeder area patterns in [illegible] this model. The input data for primary model are load characteristics and substation data.

R.N. Adams et.al. [14] described a mixed - integer linear programming approach to the planning of electrical power networks. The method is based on an interpretation of fixed costs, transportation type models and includes both network security and costs of network losses. Both single period and multiple period planning problems are considered. A mixed integer programming (m.i.p.) model for optimal power network planning that permits the dynamic requirements of the problem to be represented as a natural extension of network synthesis is described. Fixed cost transportation model can be represented by a two stage cost function consisting of fixed charge and an incremental cost that represents the marginal cost per unit carried.

D.M. Craford et.al.[15] discussed the planning of distribution substation locations, sizes and service boundaries. The techniques discussed uses operations reseach method to simultaneously optimize substation sizes and service boundaries given alternative locations for the substations and reliability constraints. The discussed technique lead to a configuration of substations that will minimize distribution feeder losses and substation construction costs. These models are applicable only to such areas, where the future locations of sinks and sources are known in advance.

R.B. Adler et.al. [16] presented an electric energy distribution/end-user system model for exploring cost trade-offs (capital investment , operation and maintenance and cost of losses) and optimizing system configuration. The model focuses on the treatment of residential, and light commercial service areas with time varying load characteristics including customer load profile changes per customer load growth and service area population growth. Application of the model helps in the selection of primary and secondary voltages; conductor sizing; distribution transformer sizing; change out policies; copper to core loss ratio; and limits on allowable voltage variation at the service entrance. This model presents a method for simulating the sequence of capital investments in a distribution system as the system develops to provide a safe; reliable; and quality electric energy supply to a growing (or declining) residential load. The model also evaluate energy losses and their cost; system operation and maintenance costs, year by year over the planning period. A number of potential, end-user systems (customers meter, breakers circuits, switches and out lets) were studied and modelled.

M. Ponnavaikko and K.S. Prakasa Rao [17] obtained the optimal solutions for the secondary and primary distribution system. This method aims at presenting a model to optimize the substation feed area; feeder service area; feeder lengths number of substations; load carrying limits of the feeders and the conductor size for feeders. The technique discussed will be useful in planning of both urban and rural distribution systems; and it has practically no limitation of problem size. They have developed parametric expressions for various systems parameters. The details of this method are given in Chapter-IV.

CHAPTER-3

CONDUCTOR-GRADATION

CHAPTER -III

CONDUCTOR GRADATION

The inherent characteristic of the radial feeders i.e. the line segments closer to the source carry the maximum load while the segments far away from the source carry lesser loads, enables the choice of multiple conductor cross-section along the length of a single feeder. The effect of growth factors such as load growth in future years of the plan period, The increase in the cost of energy with time etc. is also considered in the optimal conductor grading policy. The non-uniform distribution of loads along the length of the feeder is taken into account. Mathematical formulae to calculate feeder voltage drop, energy loss cost and feeder cost as a function of conductor cross-section have been used to develop an objective function. The objective function consists of capital investment and the present worth of the energy loss cost during the feeder life. The objective function is then minimized subject to voltage drop constraint.

3.1 MATHEMATICAL FORMULATION [7-8]

3.1.1 Feeder Voltage drop:

In a 3-ϕ radial distribution feeder with n-segments feeding loads with lagging power factor the approximate voltage drop can be obtained as

$$V = \sum_{i=1}^{n} \sqrt{3}\,(I_i R_i \cos\phi + I_i X_i \sin\phi) \quad \ldots (3.1)$$

The resistance (in ohms) per phase of the i^{th} line segment of the feeder is given by

$$R_i = \frac{\rho l_i}{a_i} \quad \ldots (3.2)$$

The reactance X_i (in ohms) per phase of the i^{th} line segment of the feeder is obtained as

$$X_i = xl_i \qquad \ldots (3.3)$$

Where

x = per phase reactance (in ohms) per Km of the feeder with a given conductor size, x is dependant more on the line configuration than on the conductor cross-section. The variation in x for different ACSR conductors is very small. It varies between 0.32 and 0.29 for 0.415KV distribution lines and between 0.39 to 0.36 for 11KV lines. So the effect of x on the voltage drop is very small hence x can be assumed constant irrespective of conductor cross-section. Thus keeping x constant, and substituting the value of R_i and x_i from (3.2) and (3.3) respectively into (3.1) we obtained feeder voltage drop as:

$$V = \sum_{i=1}^{n} \left(\frac{K_{1i}}{a_i} + K_{2i} \right) \qquad \ldots (3.4)$$

Where

$$K_{1i} = \sqrt{3}\, I_i l_i \rho \cos\phi \qquad \ldots (3.5)$$

$$K_{2i} = \sqrt{3}\, I^i l_i \, X \sin\phi \qquad \ldots (3.6)$$

3.1.2 Energy loss cost in feeder:

The cost of energy losses in a 3ϕ radial distribution feeder with n-feeder segments, throughout the life period of N years at a discount rate r, assuming the feeder load to remain constant during the feeder life and considering the effect of growth in load factor the cost of energy is given by:

$$C_{ELO} = \sum_{i=1}^{n} 26.28\, I_i^2\, R_i (LLF)\, C \sum_{K=1}^{N} \frac{1}{(1+r)^K} \qquad \ldots (3.7)$$

But the assumption of constant load in a feeder throughout it's expected life period is not valid because the load growth in an area with time is a natural phenomenon. Energy loss cost is effected by the load growth in an area. The growth in feeder load may be due to addition of new loads or due to the incremental additions to the existing loads.

Assuming that the future loads grow at a predetermined annual growth rate of g for a period of M years. The cost of equipments, construction and maintenance increases with time, this results in a continuous increase in the cost of energy with time. The cost of energy losses over the life of the feeder is given by:

$$C_{ELN} = \sum_{i=1}^{n} \frac{K_{3i}}{a_i} \qquad \ldots. (3.8)$$

Where

$$K_{3i} = 26.28\, l_i\, \rho\, I_i^2 \sum_{K=1}^{M} \frac{(1+g)^{2k}\,(LLF)\, C_k}{(1+r)^k}$$

$$+ (1+g)^{2M}(LLF)_M \sum_{K=M+1}^{N} \frac{C_k}{(1+r)^k} \qquad ..(3.9)$$

Where

$$(LLF)_K = A(LF_k)^2 + (B(LLF_k) \qquad \ldots (3.10)$$

$$\text{Where} \quad A + B = 1 \qquad \ldots (3.11)$$

According to Scheer, the system load feeder grows cutting the difference between an ultimate load factor (LF_u) and the present load factor (LF_p), into half over a period of 16 years, the load factor of K^{th} year is given by:

$$LF_K = LF_u - Y_k\ (LF_u - LF_p) \qquad ..(3.12)$$

Where

$$Y_k = (0.5)^{K/16} \qquad ..(3.13)$$

3.1.3 Feeder cost:

The feeder cost is of the form

$$C_F = e + fa \qquad \ldots (3.14)$$

Where

e and f are constants to be determined from cost versus conductor cross-section characteristic of the feeder. The cost of feeder having n-feeder segments can be obtained as:

$$C_F = \sum_{i=1}^{n} (K_{4i} a_i + K_{5i}) \qquad \ldots (3.15)$$

Where

$$K_{4i} = f.l_i \qquad .. (3.16)$$

$$K_{5i} = e.l_i \qquad .. (3.17)$$

3.2 COST FUNCTION:

There are two costs associated with a feeder, namely the feeder cost and the energy loss cost. The cost function is defined for a fixed feeder configuration having a constant main length. The cost function should be a function of both the feeder cost and energy loss cost, because in the optimization process if we minimize the feeder cost alone then it may lead to more energy losses and on the other hand minimizing the energy loss cost independantly, may result in increased feeder cost. Thus cost function is minimized for obtaining the optimal conductor cross sections for the different feeder segments. From equations (3.8) and (3.15) we obtained cost function as:

$$Z = \sum_{i=1}^{n} \left(\frac{K_{3i}}{a_i} + K_{4i} a_i + K_{5i} \right) \qquad ..(3.18)$$

The term $\sum_{i=1}^{n} (K_{5i})$ can be dropped from the objective function(z) because this is independant of conductor cross-section.

The objective function becomes

$$Z = \sum_{i=1}^{n} \left(\frac{K_{3i}}{a_i} + K_{4i} a_i \right) \qquad ..(3.19)$$

The problem can thus be stated as:

$$\underset{a_i \ldots a_n}{\text{Min}} \quad Z = \sum_{i=1}^{n} \left(\frac{K_{3i}}{a_i} + K_{4i} a_i \right) \qquad ..(3.20)$$

subject to

$$\sum_{i=i}^{n} \left(\frac{K_{1i}}{a_i} \right) \leqslant b \qquad ...(3.21)$$

and

$$a_i > 0 \qquad \text{(taking discrete values)}$$

Where

$$b = D - \sum_{i=1}^{n} K_{2i} \qquad ...(3.22)$$

For each segment the particular value of a_i which results in the minimum cost is selected, this choice of conductor sections results in a normally graded feeder. This grading policy should also satisfy the voltage drop constraint, if voltage drop constraint is not satisfied then the choice of sections has to be modified so as to reduce the value of b^1 to a value less than b

$$b' = \sum_{i=1}^{n} \frac{K_{1i}}{a_i} \qquad ...(3.23)$$

To modify the choice of sections, the only way is to increase the conductor sections of some of the segments from their present value. Change of any section results in an increase in the cost function because the existing conductor sections correspond to the minimum cost. If the present cross-section of one of the line segments is modified to a larger section, this results in an increase in the value of the cost function say by an amount of ΔZ and a reduction in the value of b' say by $\Delta b'$. Hence it is possible to assign a cost penalty for each modification, defined as $\Delta Z/\Delta b'$ where

$$\Delta Z' = (K_{3i}/a_2 + K_{4i}a_2) - (K_{3i}/a_1 + K_{4i}a_1) \quad ..(3.24)$$

$$\Delta b' = k_{1i}/a_1 - K_{1i}/a_2 \quad ..(3.25)$$

from equation (3.24) and (3.25) we get

$$\Delta Z/\Delta b' = -\frac{K_{3i}}{K_{1i}} + (K_{4i}/K_{1i})\, a_1 a_2 \quad ..(3.26)$$

Modifications of the sections of a number of segments would be necessary for satisfying the voltage drop constraint. The strategy is to choose that particular modification at each state which has the minimum cost penalty i.e. minimum $\Delta Z/\Delta b'$, satisfying the voltage drop constraint $b' \leq b$ from equation (3.21)

3.3 SOLUTION PROCEDURE:

The solution procedure consists of the following steps:

Steps:

1. Calculate the peak load currents for each segment. The voltage drop D is distributed to all segments in proportion with the KVA-KM of the segments. The tap-off voltages are calculated, to find out the peak load currents at each tap-off point.

2. Calculate the load factor for each year of the load growth period using (3.12)

3. Compute the loss load factor for each year of the load growth period using (3.10)

4. Select conductor size from available conductor sizes.

5. Compute the constants K_{1i}, K_{2i}, K_{3i}, K_{4i} and b using (3.5), (3.6), (3.9), (3.16) and (3.22) respectively.

6. Obtain the cost matrix and voltage drop matrix for all segments using (3.20) and (3.23)

7. Choose the next available conductor size and repeat step 6 till all the conductor sizes have been accounted for

8. Obtain the total cost matrix and voltage drop matrix for all the conductor size and all segments.

9. Select the conductor size with minimum value of Z for each segments.

10. Compute the total voltage drop by adding the corresponding drops of the selected conductor sizes.

11. Compare the b' obtained from step 10 and b. If the constraint is not violated i.e. $b' \leqslant b$, the selection is optimum, if not the choice of the sections is modified so as to reduce the value of b' to a value less than b.

12. Identify the segments which are adjacent to segments having larger conductor sections.

13. Compute ΔZ, $\Delta b'$ and $\Delta Z/\Delta b'$ using (3.24), (3.25) and (3.26) respectively.

14. Select the particular modification which has the minimum $\Delta Z/\Delta b'$ and modify its section to the corresponding new value a_2, and modify b' to $b' - \Delta b'$

15. Check whether $b' \leq b$ if yes, the required modifications are complete, if not, go to step 12.

16. Stop.

3.4 CASE STUDIED AND RESULTS:

A 13-segment radial distribution feeder shown in Fig. 3.1 having data in table 3.1 is studied.

TABLE 3.1

N	Life of the feeder	25 years
M	Load growth period	10 years
g	annual rate of load growth	0.10
r	annual discount rate	0.10
LF_p	Present load factor	0.20
LF_u	Ultimate load factor	0.45
C_k	Cost of energy (constant throughout the feeder life)	Rs.0.25 per KWh
ρ	Resistivity of aluminium	28.1 ohm mm^2/Km
X	Average Reactance	0.38 ohms/KM
Cos ϕ	Power factor	0.8
D	Maximum allowable voltage Drop	495 Volts & 420 Volts
	Conductors Available and their area	Squirrel (20.95 mm^2) Weasel (31.63 mm^2) Rabbit (52.95 mm^2)

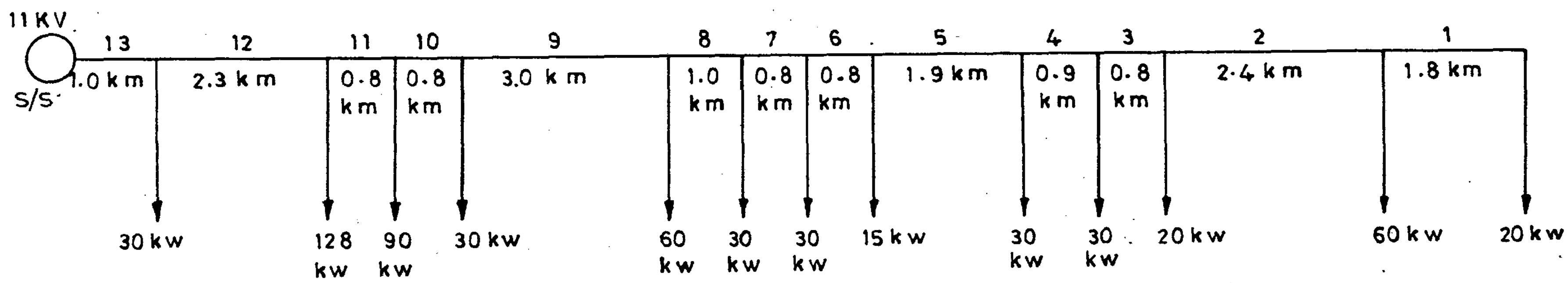


FIG. 3.1 – A 13-SEGMENT PRIMARY DISTRIBUTION FEEDER

The results for the available voltage drop of 495 volts are given in Table (3.2). In this case the voltage drop constraint (Eq^n. 3.21) is not violated hence calculation of penalty function is not needed and the choice of conductors is optimal. In case the allowable voltage drop is specified as 420 Volts the constraint is violated (Table 3.3) hence the selected conductor sizes are to be modified till the constraint is satisfied. This is done by calculating the penalty functions. The results of this case are given in Table (3.4). The conductor sizes have been altered to meet the voltage drop specifications. The value of b' using equation (3.23) works out to 350.25 volts. This value is greater than the value of b (299.01 Volts) i.e. the constraint is violated. Hence the choice of conductor sections is not optimal even though is corresponds to the global minimum of Z. The segments adjacent to segments of larger sections are identified as the 7th and 10th. The existing section of these segments are squirrel and weasel respectively. The next higher sections available for the 7th and 10th segments are weasel and Rabbit respectively. $\Delta Z/\Delta b'$ for 7th segment is smaller than 10th segment, it's section is modified into a weasel section and this results in a value of b' (343.27 Volts) which is still greater than b (299.01 volts). Some more modifications are done, the second stage of modification would be 6th and 10th segments and this procedure is repeated till b' is brought below b. The value of b' reduce to 286.133 Volts after five stage of modification.

With these modifications, the optimal conductor sections for the various segments would be:

Squirrel	for	segments	1 to 4
Weasel	for	segments	5 to 8
Rabbit	for	segments	9 to 13

Thus, the conductor grading procedure presented for radial distribution feeder gives an optimum conductor grading policy which corresponds to the minimum of the sum of the feeder cost and the capitalized energy loss cost. In addition to this, conductor grading policy keeps the voltage drop within the prescribed value.

TABLE 3.2

SELECTED CONDUCTOR SIZES

SEGMENT	COND. NAME	COST(Rs)	DROP (VOLTS)
1.	SQIRL	9931.3	4.6
2.	SQIRL	15773.5	24.7
3.	SQIRL	5759 .6	10.2
4.	SQIRL	7564.1	14.9
5.	SQIRL	18844.1	38.8
6.	SQIRL	8614.0	17.7
7.	SQIRL	10184.3	20.6
8.	WESEL	14545.3	19.5
9.	WESEL	54435.6	73.2
10.	WESEL	16067.6	21.2
11.	RABIT	20214.7	16.1
12.	RABIT	76696.8	61.4
13.	RABIT	35114.6	27.9

TOTAL COST = 293745.60 Rs.
TOTAL DROP = 350.76 VOLTS
SPECIFIED DROP = 372 VOLTS

TABLE 3.3

SELECTED CONDUCTOR SIZES

SEGMENT	COND. NAME	COST(Rs)	DROP (VOLTS)
1.	SQIRL	9931.3	4.56
2.	SQIRL	15773.5	24.33
3.	SQIRL	5759 .6	10,12
4.	SQIRL	7564.1	14.79
5.	SQIRL	18844.1	38.40
6.	SQIRL	8614.0	17.64
7.	SQIRL	10184.3	20.64
8.	WESEL	14545.3	19.56
9.	WESEL	54435.6	73.50
10.	WESEL	16067.6	21.43
11.	RABIT	20214.7	16.31
12.	RABIT	76696.8	61.18
13.	RABIT	35114.6	67,78

TOTAL COST = 293745.60Rs.
TOTAL DROP = 350.25 VOLTS
SPECIFIED DROP = 297 VOLTS

TABLE 3.4

Details of Modifications

Stage	Modifications considered: Case	Segment	From	To	ΔZ (Rs)	$\Delta b'$ (V)	$\Delta Z/\Delta b'$ (Rs/V)	Modification Chosen	b' after Modification (V)
1	(a)	7	Squirrel	Weasel	254	6.96	36.45	Case(a)	343.2786
	(b)	10	Weasel	Rabbit	614	8.62	71.15		
2.	(a)	6	Squirrel	Weasel	784	5.95	131.6	Case(b)	334.64
	(b)	10	Weasel	Rabbit	614	8.62	71.15		
3.	(a)	6	Squirrel	Weasel	784	5.95	131.6	Case (a)	328.69
	(b)	9	Weasel	Rabbit	4645	29.59	156.95		
4.	(a)	5	Squirrel	Weasel	2407	12.96	185.69	Case (b)	299.099
	(b)	9	Weasel	Rabbit	4645	29.59	156.95		
5.	(a)	5	Squirrel	Weasel	2407	12.96	185.69	Case(a)	286.13
	(b)	8	Weasel	Rabbit	2997	7.87	381.2		

CHAPTER-4

PARAMETER-OPTIMIZATION

CHAPTER - IV

PARAMETER OPTIMIZATION

Mathematical models to represent feeder voltage regulation, feeder load distribution substation feed area substation and feeder costs, feeder loss cost and transformation loss cost are used to faciliate the choice of objective functions in the case of parameter optimization which basically aims at optimizing the substation feed area and feeder service area leading to an optimal network configuration. These models are used to calculate the various parameters like substation size, Voltage regulation, loading pattern, conductor size, feeder main lengths and number of feeders per substation. These models are developed taking into consideration of the following assumptions:

(a) The load density is uniform in the area implying that all the consumers are having the same maximum demand and power factor and are situated at equal intervals.

(b) The system is balanced under steady state operating conditions, having no loss or no voltage drop in the neutral wire.

(c) The substations are at the load centre so that all the feeders, running in different directions are equal in length and carry equal loads.

(d) Both the mains and laterals of all the feeders use the same conductor size.

(e) All the feeders are radial.

(f) All the substations have equal number of feeders.

4.1 MATHEMATICAL MODELS [17]

4.1.1 UNIT VOLTAGE REGULATION CONSTANT (H):

The percentage voltage drop in terms of line parameters, power factor angle, circuit voltage and the moment of the loads, in a feeder with n sections can be obtained as:

$$V = \sum_{i=1}^{n} \frac{(KVA_i\ KM_i)(rCos\ \emptyset + x\ Sin\ \emptyset)}{10(KV)^2} \qquad ..(4.1)$$

The moment for a voltage drop 1% in a feeder, H can be defined as:

$$H = \sum_{i=1}^{n} \frac{(KVA_i\ KM_i)}{V} \qquad ..(4.2)$$

Substituting (4.2) in (4.1), we get

$$H = \frac{10(KV)^2}{(rCos\ \emptyset + xSin\ \emptyset)} \qquad ..(4.3)$$

Unit voltage regulation constant (H) remains constant for a given conductor size, power factor and circuit voltage, its unit is KVA-KM. H is independant of percentage voltage regulation, feeder length and the load in the feeder.

4.1.2 LOAD DISTRIBUTION FACTOR (LDF):

Defining load distribution factor becomes necessary because voltage drop is also dependant on load, its distribution and feeder length, load distribution factor is defined as:

$$LDF = \frac{(\text{Load in the feeder in KVA})\times(\text{feeder length in KM})}{(\text{Moment of loads in KVA-KM})} \qquad ...(4.4)$$

Now, from (4.2) and (4.4.), we get

$$LDF = \frac{PL}{HV} = \frac{PL}{M} \qquad ..(4.5)$$

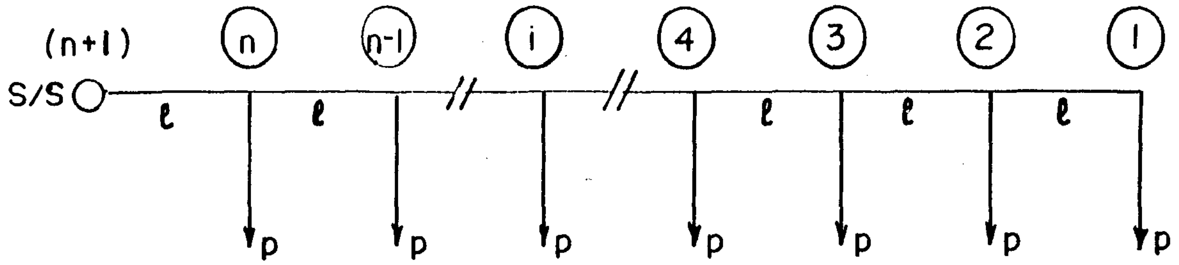


FIG.4.1 A UNIFORMLY LOADED RADIAL FEEDER

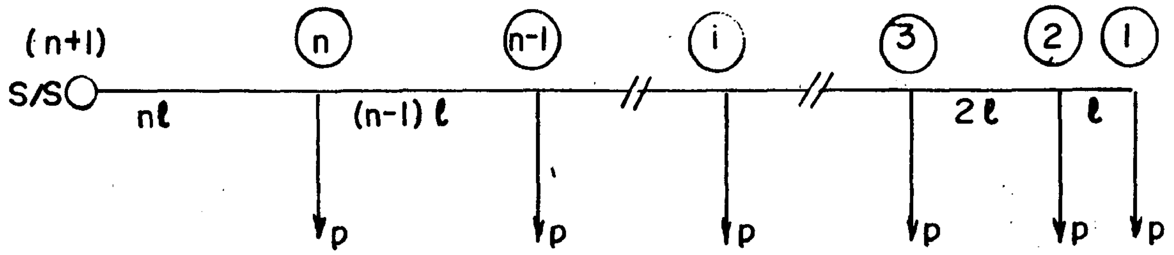


FIG.4.2 A NON-UNIFORMLY LOADED RADIAL FEEDER (Case-a)

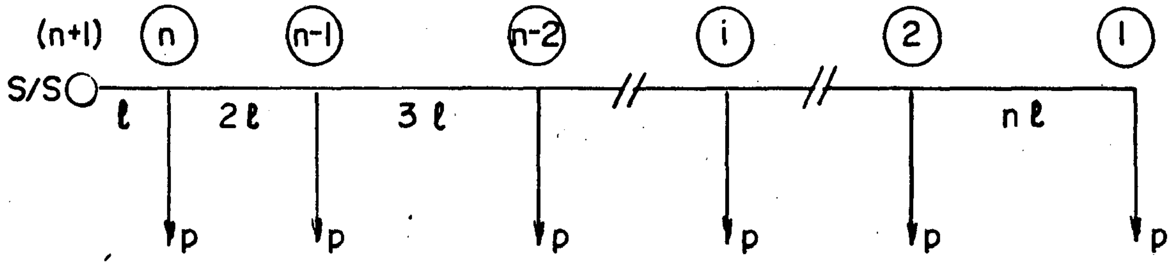
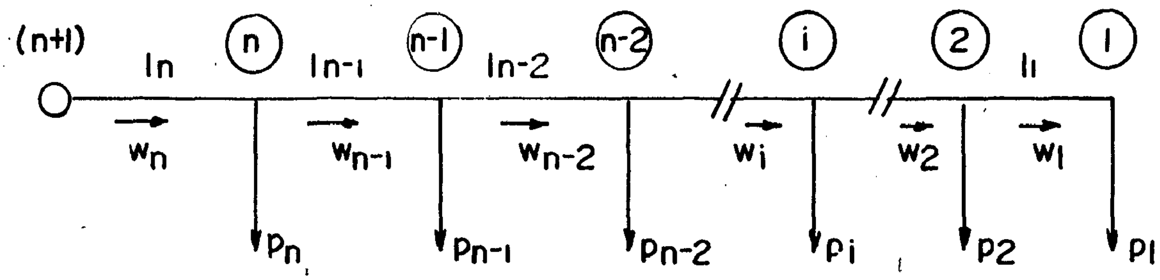


FIG.4.3 A NON-UNIFORMLY LOADED RADIAL FEEDER (Case-b)



i- Node normal, li-Segment length in km., pi-Load in kw,

wi-Power flow in kVA

FIG.4.4 A RADIAL DISTRIBUTION FEEDER.

equation (4.5) gives a general relationship between the line parameters, voltage regulation, load, load distribution and feeder main length and is true for both the uniform and non-uniform load distribution.

LDF, for uniformly loaded feeders fig.(4.1), in terms of the number of take-off points, n as in (4.6) (APPENDIX-B)

$$\text{LDF} = \frac{2n}{n+1} \qquad ..(4.6)$$

LDF for two typical non-uniform cases, i.e.

(a) The spacing of laterals increasing from the far-end towards the substation in the arithmatic progression with equal load in each lateral (fig.(4.2)

(b) The spacing of laterals increasing from the substation towards the far-end in the arithmatic progression with equal load in each lateral fig.(4.3)

For case (a) $$\text{LDF} = \frac{3n}{2n+1} \qquad ..(4.7)$$

case (b) $$\text{LDF} = \frac{n^2(n+1)}{2\sum_{i=1}^{n}\left[i(n-i+1)\right]} \qquad ..(4.8)$$

For uniformly loaded feeders, the value of LDF lies between 1 (for n=1 , a feeder having a concentrated load at the far end) and 2 (for $n = \infty$, a feeder having continuously uniformly distributed loads along the feeder main).

For case (a) of non-uniformly loaded feeder, having most of the loads away from the substation, as n increases more and more loads are pushed towards the far-end. The extreme values of LDF for this case and 1 and 1.5. The case (b), represents an opposite situation, having more loads closer to the substation, increase in the value of n, moves the loads towards the substation. The value of LDF in this case lies between 1 and 3. The values of LDF for practical cases normally lies in the range of 1.8 and 2.2.

4.1.3 POWER LOSS DISTRIBUTION FACTOR(PLDF):

For any given pattern of load distribution in the different deeder segments along the feeder main, the PLDF is defined as the ratio of the power loss that would have occurred in the feeder, if all the loads were concentrated at the far-end of the feeder to the actual power loss in the feeder. For a radial distribution feeder fig.(4.4), the power loss distribution factor is defined as:

$$PLDF = \frac{P^2 L}{\sum_{i=1}^{n} W_i^2 \ell_i} \quad ..(4.9)$$

Where

$$P = \sum_{i=1}^{n} \frac{P_i}{PF} \quad ..(4.10)$$

$$L = \sum_{i=1}^{n} \ell_i \quad ..(4.11)$$

PLDF, for a uniform loaded feeder fig(4.1) and for both the non-uniformly loaded feeders cases fig.(4.2), fig.(4.3) are given in (4.12), (4.13) and (4.14) respectively (APPENDIX-C).

$$PLDF = \frac{6n^2}{(n+1)(2n+1)} \quad ..(4.12)$$

$$PLDF = \frac{n^3(n+1)}{2\sum_{i=1}^{n} i^3} \quad ..(4.13)$$

$$PLDF = \frac{n^3(n+1)}{2\sum_{i=1}^{n} [i^2(n-i+1)]} \quad ..(4.14)$$

The values of PLDF for uniformly loaded feeders lie between 1 and 3. For non-uniformly loaded feeders case (a) PLDF lies between 1 and 2. For non uniformly loaded feeder case(b) PLDF lies between 1 and 5. The value of PLDF for the practical cases normally lies in the range of 2.6 to 3.5 PLDF varies more or less linearly with LDF.

4.1.4 SUBSTATION FEED AREA:

The substation feed area is dependant on the load density, voltage regulation, conductor size load diversity, power factor, load distribution and number of feeders in the substation.

The peak load in KVA per feeder in the area is given as:

$$P = \frac{a_s D}{n_f (DF)(PF)} \qquad ..(4.15)$$

From (4.5) and (4.15), we get

$$a_s = \frac{HV(LDF)(PF)(DF)n_f}{LD} \qquad ..(4.16)$$

In a circular feeder area, the length of main feeder is always more than the radius R, it is due to the development of load in a given system and the geography of the area. The ratio L/R defined as zig-zag factor and denoted by Z, remains more or less constant for all the feeders.

4.1.5 SUBSTATION COST:

The substation cost is a function of the substation size and the number of feeder bays provided at the substation is given as:

$$C_s = e + h(KVA) + fn_f \qquad ..(4.17)$$

e,h can be obtained from the linearised cost versus KVA capacity characteristics of the substation excluding the bay cost. f is the cost per feeder bay.

4.1.6 FEEDER COST:

The cost of a feeder with a given conductor size is only a function of its length as given:

Feeder main cost as:

$$C_{fm} = C_f L \qquad ..(4.18)$$

Cost of lateral as:

$$C_{f_s} = C_f' L_s \qquad ..(4.19)$$

4.1.7 TRANSFORMATION LOSS COST:

The core loss (T_i) and the full load copper loss (T_c) of the transformer in KW are given as:

$$T_i = a' + b'(KVA_t) \qquad ..(4.20)$$

$$T_c = c' + d'(KVA_t) \qquad ..(4.21)$$

Both the T_i and T_c have a linear relationship with the transformer capacity KVA.

From (4.20) and (4.21), energy loss in a transformer corresponding to the power loss is given as:

$$E_t = 8760 \left[T_i + T_c (U.F)^2 (LLF)\right] \qquad ..(4.22)$$

transformer capacity in KVA is obtained as:

$$KVA_t = \frac{D\, a_s}{N_t\,(DF)(PF)(UF)} \qquad ..(4.23)$$

Where

N_t - number of transformers at every substation,

and $$a_s = \frac{A}{n_s} \qquad ..(4.24)$$

Energy loss in a substation is obtained from equation (4.20) to (4.24) as:

$$E_{ts} = \left[a' + b'(KVA_t) + \left\{c' + d'(KVA_t)\right\} (U.F)^2 LLF\right] 8760$$

$$= \left[a' + b' \frac{D.a_s}{N_t(DF)(UF)(PF)} + \left\{ c' + d' \frac{D.a_s}{N_t(DF)(UF)(PF)} \right\} (UF)^2 LLF \right] 8760$$

$$= 8760 \left[a' + c'(UF)^2 LLF \right] + \frac{8760\ AD}{N_t(DF)(UF)(PF)n_s} \left[b' + d'(UF)^2 LLF \right]$$

$$= 8760N_t \left[a' + c'(UF)^2 LLF \right] + \frac{8760 AD\ n_s^{-1}}{(DF)(PF)(UF)} \left[b' + d'(UF)^2 LLF \right]$$

$$= a_1' + b_1' n_s^{-1} \qquad \ldots(4.25)$$

Where

$$a_1' = 8760N_t \left[a' + c'(UF)^2 LLF \right]$$

$$b_1' = \frac{8760\ AD}{(DF)(PF)(UF)} \left[b' + d'(UF)^2 LLF \right]$$

$$\ldots\ldots(4.26)$$

The present worth of the cost of energy losses during the expected life of the substation by considering the increase in the cost of energy and LLF is given as:

$$C_{e\ell s} = a_1 + b_1 n_s^{-1} \qquad \ldots(4.27)$$

Where

$$a_1 = 8760N_t \left[a' \sum_{K=1}^{NLS} \frac{C_{eK}}{(1+U)^K} + c'(UF)^2 \sum_{K=1}^{NLS} \frac{(LLF_K)\ C_{eK}}{(1+U)^K} \right]$$

$$b_1 = \frac{8760AD}{(DF)(PF)(UF)} \left[b' \sum_{K=1}^{NLS} \frac{C_{eK}}{(1+U)^K} + d'(UF)^2 \sum_{K=1}^{NLS} \frac{(LLF_K)C_{eK}}{(1+U)^K} \right]$$

$$\ldots(4.28)$$

and

$$LLF_K = A(LF_K)^2 + B(LF_K), \qquad A+B = 1$$

$$LF_K = LF_u - Y_K\ (LF_u - LF_p)$$

$$Y_k = (0.5)^{K/16} \qquad \ldots(4.29)$$

4.1.8 FEEDER LOSS COST:

The feeder loss depends on the loading pattern in the feeder main as well as in the laterals, and is due to the losses in the main feeder and the laterals.

4.1.8.1 Power Loss in the Feeder Mains (Primary or Secondary Distribution Feeders):

The peak load in KVA, in a feeder main with the feeder service area a_f , is given as:

$$P = \frac{D\ a_f}{(DF)(PF)} \qquad ..(4.30)$$

Power loss in a feeder can be obtained (Appendix-E) as:

$$P_L = \frac{0.001r}{(KV)^2} \left(\frac{LDF}{PLDF}\right) MP \qquad ..(4.31)$$

From (4.5), (4.30) and (4.31), we get the power loss in the feeder main as:

$$P_{LM} = \frac{0.001rLP^2}{(KV)^2 PLDF}$$

$$= \frac{0.001r(a_f.D)^2 L}{(PLDF)(KV)^2(DF)^2(PF)^2}$$

$$= \frac{0.001rD^2L}{(KV)^2(PF)^2(DF)^2 PLDF} a_f^2 \qquad ..(4.32)$$

4.1.8.2 Power Loss in the Secondary Distribution Feeder Laterals:

In a secondary distribution feeder, consider the feeder service area a_f to be rectangular in shape with dimensions L × ($2L_S$), Fig.(4.5), in this case the length of laterals, L_s is given by:

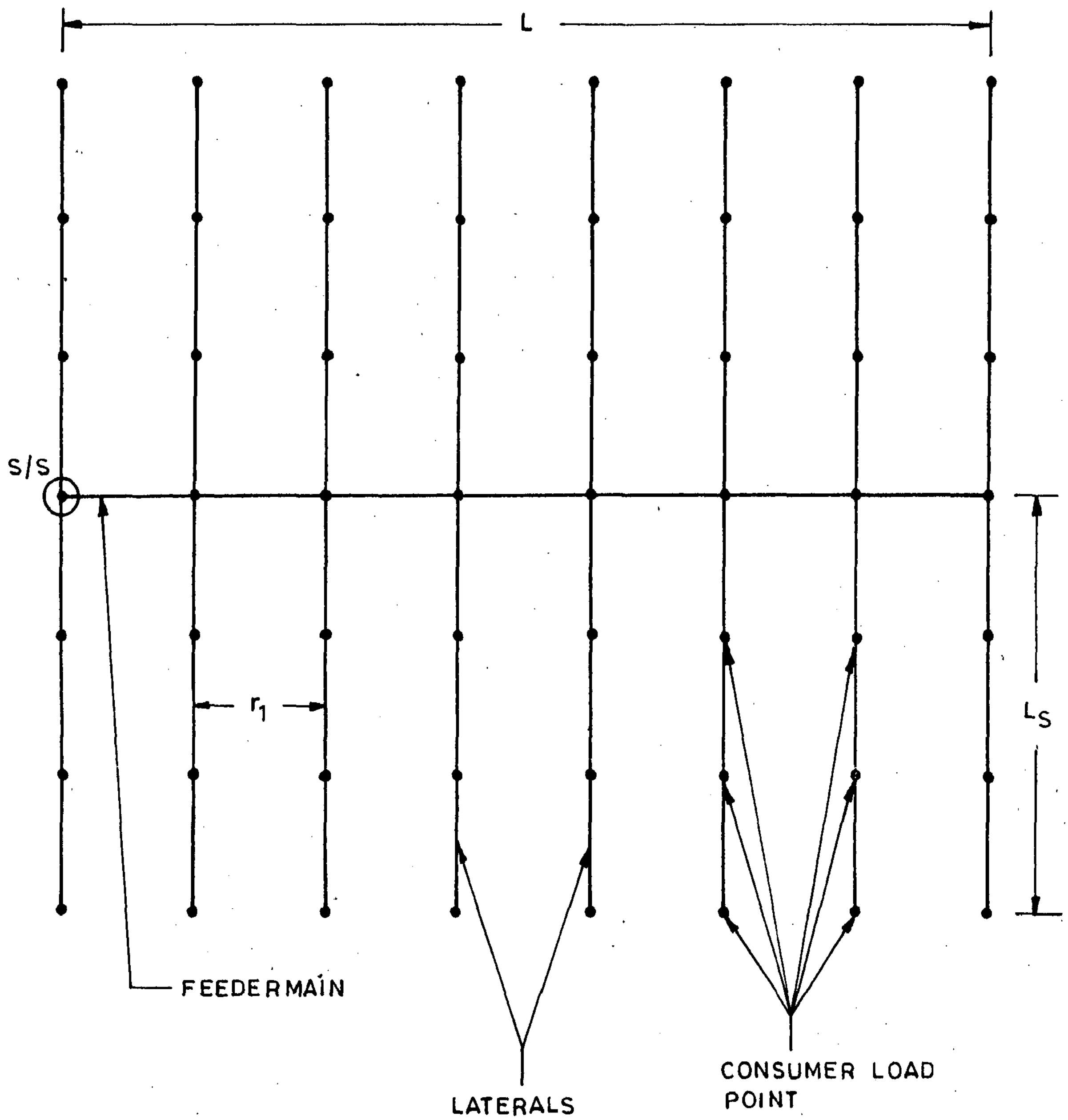


FIG. 4·5 – A SECONDARY DISTRIBUTION FEEDER WITH RECTANGULAR SHAPED SERVICE AREA

$$L_S = \frac{a_f}{2L} \qquad ..(4.33)$$

The average loading (P_S in KVA), in a lateral with lateral spacing ℓ can be obtained as:

$$P_S = \frac{a_f\ D}{2L(DF_S)(PF)} \qquad ...(4.34)$$

n, the number of take off points is defined as:

$$n = \frac{L}{\ell} \qquad ...(4.35)$$

From (4.31), (4.33), (4.34) and (4.5) power loss in a lateral feeder is given as:

$$P_{lS} = \frac{0.001r\ L_S\ \ a_f^2\ D^2\ \ell^2}{(KV)^2(PLDF)\ 4L^2(DF_S)^2(PF)^2}$$

$$= \frac{0.001r\ a_f\ .\ a_f^2\ D^2\ \ell^2}{8(KV)^2L^3(DF_S)^2(PF)^2(PLDF_S)}$$

$$= \frac{0.001r\ D^2\ell^2}{8(KV)^2(DF_S)^2(PF)^2\ \ (PLDF_S)\,L^3}\ a_f^3 \qquad ..(4.36)$$

The total loss in a lateral feeder having 2n laterals is obtained by multiplying (4.36) by 2n and substituting for n from (4.35) as:

$$P^s_{\ell s} = \frac{0.001r'\ D^2\ell^2\ 2n}{8(KV)^2(DF_S)^2(PF)^2(PLDF_S)\ \ L^3}\ a_f^3$$

$$= \frac{0.001r'\ D^2\ell^2\ L/\ell}{4(KV)^2(DF_S)^2(PF)^2(PLDF_S)\ \ L^3}\ a_f^3$$

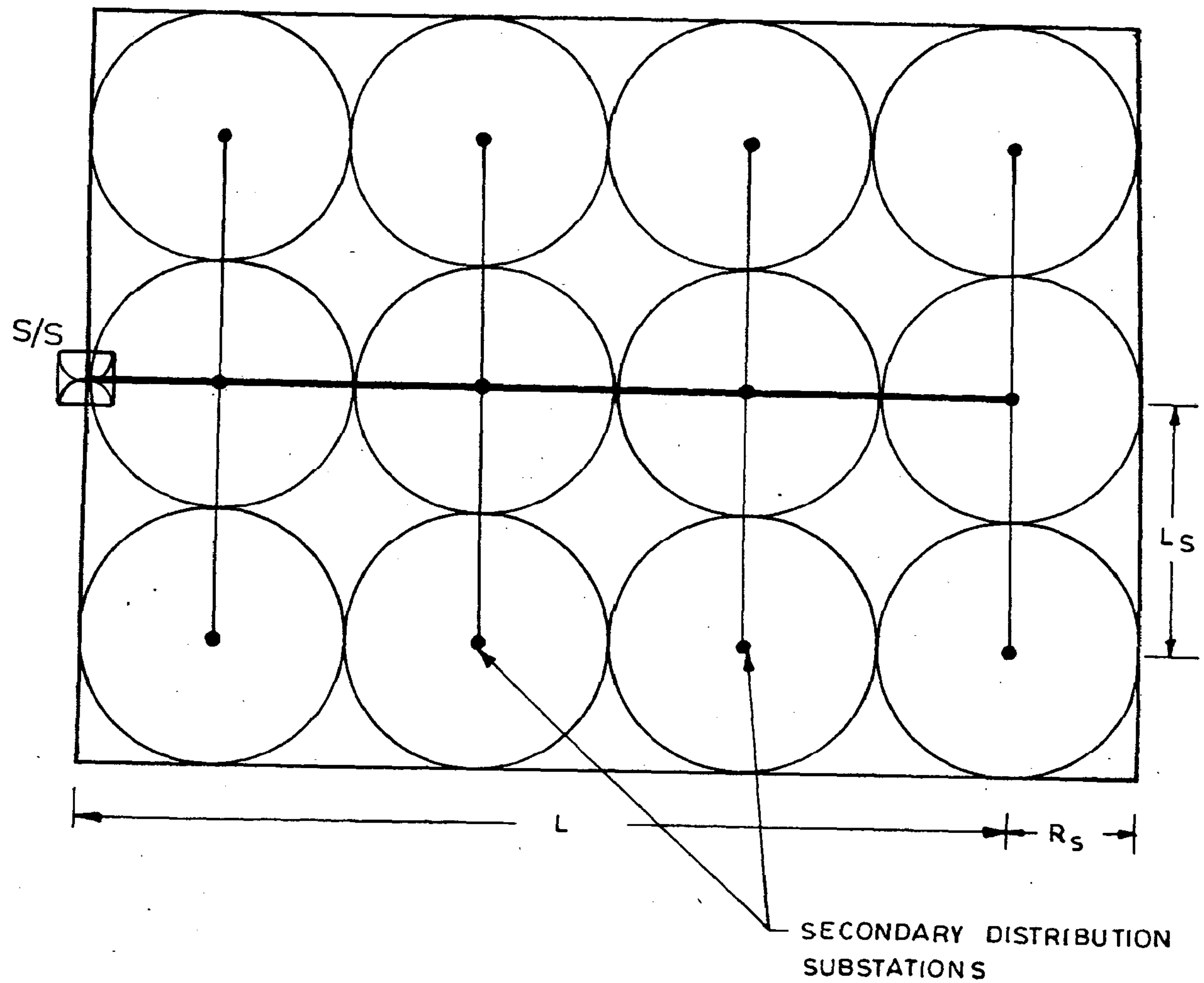


FIG. 4.6 – A PRIMARY DISTRIBUTION FEEDER WITH RECTANGULAR SHAPED SERVICE AREA

$$= \frac{0.001\ r'\rho D^2}{4(KV)^2(DF_S)^2(PF)^2(PLDF_S)L^2}\ a_f^3 \qquad ..(4.37)$$

4.1.8.3 Power Loss in Primary Distribution Feeder Laterals:

For primary distribution feeder having a rectangular shaped service area fig.(4.6), the lateral feeder length L_S' can be obtained as:

$$L_S' = \frac{a_f}{2(L + R_S)} - R_S \qquad ...(4.38)$$

Lateral spacing here is equal to $2R_S$. In this case the number of lateral take off points n is given by:

$$n = \frac{(L + R_S)}{2R_S} \qquad ...(4.39)$$

The load (P_S), in a lateral with 2n number of laterals is given by:

$$P_S = \frac{a_f\ D\ R_S}{(DF_S)(PF)(L + R_S)} \qquad ...(4.40)$$

From (4.5), (4 31), (4.38) and (4.40), the power losses in all the laterals in a primary feeder is given as:

$$P_{LS}^{p} = \frac{0.001r'\ D^2\ R_S^2\ \ 2(L + R_S)/2R_S}{(KV)^2(PLDF)(DF_S)^2(PF)^2(L + R_S)^2}\left[\frac{a_f^3}{2(L + R_S)} - R_S\ a_f^2\right]$$

$$= \frac{0.001r'\ D^2\ R_S}{(KV)^2(PLDF_S)(PF)^2(DF_S)^2(L + R_S)}\left[\frac{a_f^3}{2(L + R_S)} - R_S a_f^2\right]$$

...(4.41)

4.1.8.4 Present Worth of the Feeder Loss Cost:

During the expected life of the feeder, the present worth of the cost of energy losses in the feeder taking into account the growth in load factor and cost of energy is given as:

$$C_f = (P_{LM} + R_{LS})\, 8760 \sum_{K=1}^{NLF} \frac{C_{e_k}(LLF_K)}{(1+U)^K} \qquad \ldots(4.42)$$

4.9 COST OF IN-FEED CIRCUITS TO THE DISTRIBUTION SUBSTATIONS:

The cost of In-feed circuits is a function of the number of source stations (available to feed the sub-stations) and the radius of the substation feed area. The cost of in-feed circuits, in an area where the substations are n_s, can be obtained as:

$$C_{inf} = \frac{2L}{Z}(n_s - N)C_{fe} \qquad ..(4.43)$$

4.10 OBJECTIVE FUNCTION:

For optimizing the system parameters, two cost functions F_s and F_v are defined. F_s represents the entire system cost, assuming constant the conductor size and voltage regulation while F_v represents the substation cost, here the substation feed area, conductor size are maintained constant and the voltage regulation is allowed to vary.

The function F_s constitute the capital investment and the present worth of the energy loss cost during the life of the system, and given as:

F_s = (Capital investment required for feeder mains)

+ (Capital investment required for laterals)

+ (Capital investment required for in-feed circuits to the substations)

+ (Capital investment required for substations)

+ (Present worth of the energy loss costs in the transformers during the expected service period of transformers)

+ (Present worth of the energy loss costs in the feeders during the expected service period of the feeders).

.... (4.44)

The term corresponding to feeder loss cost may be dropped from (4.44) because, if the voltage drop in the feeders is kept constant the total energy losses in the system will remain constant irrespective of substation feed area.

F_s, for secondary distribution system can be represented by assuming a constant system area A, with n_s substations and n_f feeders per substation.

$$F_s^s = C_f \, L n_f n_s + \frac{a_f}{\ell} n_f n_s C_f' + (e + h(KVA) + f n_f) n_s + \frac{2L}{Z}(n_s - N) C_{f_e} + (a_1 + b_1 n_s^{-1}) n_s \qquad \text{....(4.45)}$$

The above used variations such as L, n_f, a_f, n_s and substation capacity (KVA) can be represented in terms of a_s as:

$$L = \left(\frac{Z}{\Lambda^{\frac{1}{2}}}\right) a_s^{\frac{1}{2}} \qquad \text{..(4.46)}$$

$$n_f = \left[\frac{1}{\Lambda^{3/2} K_1^3 V}\right] a_s^{3/2} \qquad \text{..(4.47)}$$

Where

$$K_1 = \left[\frac{H(LDF)(DF)(PF)}{DZ}\right]^{1/3} \qquad ..(4.48)$$

$$n_s = Aa_s^{-1} \qquad ..(4.49)$$

$$a_f = a_s\, n_f^{-1}$$

$$= (\pi^{3/2} K_1^3\, V)\, a_s^{-\frac{1}{2}} \qquad ..(4.50)$$

$$KVA = \frac{Da_s}{(DF)(PF)(UF)} \qquad ..(4.51)$$

Substituting for L, n_f, n_s, a_f and KVA from (4.46), (4.47), (4.50), (4.51) in (4.45) and setting f = 0 for secondary distribution system, F_s^S can be written as:

$$F_S^S = \frac{G_1 C_f}{V} a_s + \frac{A}{\ell} C_f' + eAa_s^{-1} + \frac{hDA}{(DF)(PF)(UF)}$$

$$+ G_4\, C_{fe}\, a_s^{-\frac{1}{2}} - G_2\, C_{fe}\, a_s^{\frac{1}{2}} + a_1 Aa_s^{-1} + b_1$$

$$= \frac{G_1 C_f}{V} a_s - G_2 C_{fe} a_s^{\frac{1}{2}} + \left(\frac{A}{\ell} C_f' + b_1 + \frac{hDA}{(DF)(PF)(UF)}\right)$$

$$+ G_4 C_{fe} a_s^{-\frac{1}{2}} + (eA + a_1 A)\, a_s^{-1} \qquad .....(4.52)$$

Where,

$$G_1 = \frac{AZ}{\pi^2 K_1^3}\ ; \qquad G_2 = \frac{2N}{\pi^{\frac{1}{2}}}\ ; \qquad G_4 = \frac{2A}{\pi^{\frac{1}{2}}}$$

By differentiating equation (4.52) with respect to a_s and equating to zero, we get

$$a_s^{*2} - \frac{G_2 C_{fe} V}{2G_1 C_f} a_s^{*3/2} - \frac{G_4 C_{fe} V}{2G_1 C_f} a_s^{*\frac{1}{2}} = (eA + a_1 A) \qquad \ldots(4.53)$$

Solution of (4.53) gives the optimal substation feed area a_s^*.

The objective function F_s for primary distribution system:

$$F_s^P = C_f L n_f n_s + \left[\frac{a_f}{2(L + R_s)} - R_s\right] 2 \left[\frac{L + R_s}{2R_s}\right] n_f n_s C_f'$$

$$+ (e + h(KVA) + f n_f) n_s + \frac{2L}{Z}(n_s - N) C_{fe}$$

$$+ (a_1 + b_1 n_s^{-1}) n_s \qquad \ldots(4.54)$$

From (4.46), (4.47), (4.49), (4.50), (4.51) and (4.54)

$$F_s^P = \frac{G_1(C_f - C_f')}{V} a_s - \left[-\frac{R_s C_f' A}{\pi^{3/2} K_1^3 V} + G_2 C_{fe} + \frac{fA}{\pi^{3/2} K_1^3 V}\right] a_s^{\frac{1}{2}}$$

$$+ \frac{hAD}{(PF)(UF)(DF)} + b_1 + \frac{AC_f'}{2R_s} + G_4 C_{fe}\, a_s^{-\frac{1}{2}} + (a_1 A + eA) a_s^{-1}$$

$$= \frac{G_1 (C_f - C_f')}{V} a_s + \left[\frac{G_5(f - R_s C_f')}{V} - G_2 C_{fe}\right] a_s^{\frac{1}{2}}$$

$$+ G_6 + G_4 C_{fe} a_s^{-\frac{1}{2}} + (eA + a_1 A) a_s^{-1} \qquad \ldots(4.55)$$

Where

$$G_5 = \frac{A}{\pi^{3/2} K_1^3}$$

$$G_6 = \frac{ADh}{(PF)UF)(DF)} + b_1 + \frac{AC_f'}{2R_s}$$

By differentiating (4.55) with respect to a_s and equating to zero, we obtained

$$a_s^{*2} + \frac{G_7}{2G_8} a_s^{*3/2} - \frac{G_4 C_{fe}}{2G_8} a_s^{*\frac{1}{2}} = \frac{(e + a_1)A}{G_8} \qquad ..(4.56)$$

Where

$$G_7 = \frac{G_5(f - R_s C_f')}{V} - G_2 C_{fe}$$

$$G_8 = \frac{G_1(C_f - C_f')}{V}$$

Solution of (4.56) gives the optimal substation feed area for the primary.

The feeder voltage regulation is kept constant while optimizing the substation feed area a_s it is necessary to consider the voltage regulation variable in the optimization process as it has significant influence on the cost function. This is achieved by optimizing the feeder service area a_f with constant a_s optimization of a_f automatically results in optimum voltage regulation because voltage regulation is simply a function of the feeder service area a_f, when the substation feed area a_s is kept constant.

F_V, another objective function representing the cost of one substation of area a_s is defined as:

F_v = (Capital cost of the n_f feeders with the substation feed area including the laterals)

+ (Capital cost of the feeder bays)

+ (Present worth of the cost of the energy losses in the feeders during the expected life of the feeders)

F_v for secondary distribution system can be obtained from (4.19), (4.32), (4.37) and (4.42) and also treating, the feeder bay cost (f) as negligible as:

$$F_v^s = C_f L n_f + \frac{a_f\, n_f\, C_f'}{\ell} + (P_{LM} + P_{Ls})\,8760 \sum_{K=1}^{NLF} \frac{C_{e_k}(LLF_k)}{(1+U)^k}$$

$$= C_f L n_f + \frac{a_f n_f C_f'}{\ell} + G_9\, a_f^2\, n_f + G_{10}\, a_f^3\, n_f \qquad \text{.....(4.58)}$$

n_f in terms of a_f can be written as

$$n_f = \frac{a_s}{a_f} \qquad \text{..(4.59)}$$

From (4.58) and (4.59), we get

$$F_v^s = C_f L a_s a_f^{-1} + \frac{a_s C_f'}{\ell} + G_9 a_s a_f + G_{10} a_s a_f^2 \qquad \text{..(4.60)}$$

Where

$$G_9 = \frac{8.76\ r\ D^2 L}{(KV)^2 (PLDF)(DF)^2 (PF)^2} \sum_{K=1}^{NLF} \frac{C_{ek}(LLF_k)}{(1+U)^k} \qquad \text{..(4.61)}$$

$$G_{10} = \frac{2.19\ r' D^2 \ell}{(KV)^2 (PLDF_s)(DF_s)^2 (PF)^2 L^2} \sum_{K=1}^{NLF} \frac{C_{ek}\ (LLF_k)}{(1+U)^k} \qquad \text{..(4.62)}$$

The optimal feed area of the secondary distribution feeder, a_f^* is obtained by differentiating (4.60) with respect to a_f (keeping a_s constant) and equating to zero

$$a_f^{*3} + \frac{G_9}{2G_{10}} a_f^{*2} = \frac{C_f L}{2G_{10}} \qquad ..(4.63)$$

For primary distribution system, F_v can be obtained from (4.57) using (4.19), (4.32), (4.41) and (4.42) as:

$$F_v^P = C_f L n_f + \frac{a_f n_f C_f'}{\ell} + f n_f + G_9 a_f^2 n_f + G_{11}\left[\frac{a_f^3}{2(L+R_s)} - R_s a_f^2\right] a_f \qquad ....(4.64)$$

From (4.64) and (4.59), we get

$$F_v^P = C_f L a_s a_f^{-1} + f a_s a_f^{-1} + G_9 a_s a_f + G_{11} a_s \left[\frac{a_f^2}{2(L+R_s)} - R_s a_f\right] \qquad ...(4.65)$$

The optimal feed area a_f the primary distribution feeder a_f^* can be obtained by differentiating (4.65) and equating it to zero, as:

$$a_f^{*3} + \frac{(G_9 - G_{11} R_s)(L + R_s)}{G_{11}} a_f^{*2} = \frac{(C_f L + f)(L + R_s)}{G_{11}} \qquad ...(4.66)$$

4.11 SOLUTION ALGORITHM:

The optimization of the substation size, voltage regulation, feeder main length and number of feeders per substation in the secondary and/or primary distribution systems is done through the feed area mathematical models suggested above. The optimization of conductor size is done by repeating the feed area optimization process for different conductor sizes and choosing the best size from the results thus obtained. The optimal parameters values for growing load densities can be obtained by repeating the whole process for the corresponding load densities.

Two level optimization procedure involved the following steps. The steps are identical for both the secondary and primary distribution systems.

STEPS:

1. Choose a value of conductor size from the sizes available in the inventory.
2. Assume a suitable value for percentage voltage regulation, V for starting computations.
3. Compute the coefficients in (4.53) or (4.56) using system data and the values for load density, conductor size and voltage regulation.
4. Solve for a_s^* from (4.53) or (4.56).
5. Compute the coefficients from (4.63) or (4.66) using a_s^* computed in step 4 and other system data.
6. Solve for a_f^* from (4.63) or (4.66).
7. Calculate the new voltage regulation V_n, corresponding to a_f^* computed in step 6 using (4.50).

8. Compute the difference between the old and new values of voltage regulation, difference (ΔV) = $(V_0 - V_n)/V_0$ if ΔV is not within the tolerance limited ($\leqslant$ 0.01) set V at new value and go to step 3.

9. Calculate the corresponding optimal values of substation capacity, number of feeders per substation, voltage regulation and feeder main length, using a_s^* and a_f^* from (4.51), (4.47), (4.50) and (4.46) respectively and store the results. Also compute the values of the cost function using (4.52) or (4.54) and store. If the number of substations or number of feeders do not come out as integers then they are rounded off to the nearest integer values and the parameters are modified accordingly.

10. Repeat the computations from step 3 to step 9 for all available conductor sizes.

11. Compare the cost functions for different conductor sizes considered and select the size for which the cost function is minimum.

12. If the computations are to be done for different load densities repeat steps 1 to 11.

13. Stop.

4.12 SYSTEM STUDIED AND RESULTS:

The problem of parameter optimization is solved using the two level optimization procedure discussed above, and the results are presented for both the primary and secondary distribution systems.

For the study, the system data used is given below in Table (4.1).

TABLE 4.1

A	Area of the system studied	= 11170 Sq. Km.
ACL	Average consumer load	= 1.5 KW
	Average distance between consumbers	= 0.18Km.
P_f	Load power factor	= 0.8
D	Load densities considered	= 10, 15,20,30, 40 and 50 KW/Sq.Km.
U	The annual discount rate	= 10%
	The annual discount rate of growth of cost of energy	= 5%
NLF	Life of the Lines	= 25 years
NLS	Life of the Transformers	= 25 years
KV	System voltage	
	Secondary distribution voltage	= 0.415 KV
	Primary distribution voltage	= 11 KV
	Sub-transmission voltage	= 33 KV
C_{fe}	Cost of 33 KV lines	= Rs. 40,000 per Km.
N	Number of source grid stations	= 1-5 (for the load densities 10-50 KW/Sw.Km.

		Secondary Distribution	Primary Distribution
LF	Load factor (for densities 10-50 KW/Sq.Km.)	0.12 -0.20	0.17 - 0.30

DF	Average diversity factor	1.50	2.50
Z	Average zig-zag factor	1.45	1.40
LDF	Average load distribution factor	1.70	2.12
PLDF	Power loss distribution factor	2.48	3.35
e.	Substation cost coefficient	Rs.6000	Rs.6,30,000
h	-do-	Rs.105/KVA	Rs.60.38/KVA
f	-do-	0.0	Rs.75,000
a'	Transformer loss coefficients	0.06KW	0.725KW
b'	-do-	0.0023KW per KVA	0.001155KW per KVA
c'	-do-	0.35KW	3.9KW
d'	-do-	0.015 KW per KVA	0.00605 KW per KVA
C_{e_k}	Cost of energy	Rs.0.5/KWh	Rs.0.35/KWh

Line data for secondary and primary distribution feeders are given in table (4.2).

TABLE 4.2

Conductor Code-name	Area of conductor cross-section (mm^2)	Per Phase resistance (Ohm/Km)	Per Phase Reactance (Ohm/Km)	Cost per Km. (Rs.)
1. Secondary Distribution Lines:				
SQUIRREL	20.71	1.539	0.322	11,000
GOPHER	25.91	1.230	0.317	12,600
WEASEL	31.21	1.021	0.312	14,500
FERRET	41.87	0.761	0.306	17,000
RABBIT	52.21	0.610	0.299	19,600
2. Primary Distribution Lines:				
SQUIRREL	20.71	1.539	0.392	10,400
GOPHER	25.91	1.230	0.386	11,900
WEASEL	31.21	1.021	0.382	13,800
FERRET	41.87	0.761	0.375	16,200
RABBIT	52.21	0.610	0.369	18,600

The results obtained for secondary and primary distribution systems are given in Tables (4.3), (4.4). The effect of variation of cost parameters viz. fixed sub-station cost, feeder bay cost and cost of energy has also been studied and the results are given in Tables (4.5), (4.6) and (4.7).

TABLE 4.3

OPTIMAL DISTRIBUTION SYSTEM PARAMETERS

SECONDARY DISTRIBUTION SYSTEM:

Connected load density (KW/Sq.KM)	Load factor	Substation feed area (Sq.KM)	Feeder service area (Sq.KM)	No. of sub-stations	No. of feeders per sub-stations	Sub-station capacity (KVA)	Feeder length (KM)	Conductor (Code-name)	Feeder Voltage Regu-lation (%)
10	0.12	3.06	3.06	3650	1	28	1.43	GOPHER	14.6
15	0.14	1.86	1.86	6027	1	26	1.16	WEASEL	8.9
20	0.15	1.75	1.75	6383	1	32	1.1	WEASEL	10.8
30	0.18	1.08	1.08	10343	1	30	0.85	FERRET	6.2
40	0.19	1.10	0.55	10163	2	41	0.86	FERRET	4.3
50	0.20	0.69	0.69	16218	1	32	0.68	RABBIT	4.5

TABLE 4.4

OPTIMAL DISTRIBUTION SYSTEM PARAMETER

PRIMARY DISTRIBUTION SYSTEM:

Connected load density (KW/Sq.KM)	Load factor	Sub-station feed area (Sq.KM)	Feeder Service area (Sq.KM)	No. of Sub-Stations	No. of Feeders per sub-station	Sub-station capa-city (KVA)	Feeder length (KM)	Conductor (Code-Name)	Feeder Voltage Regulation (%)
10	0.17	1861	310	6	6	11631	34.07	RABBIT	14.6
15	0.19	1596	177	7	9	14962	31.55	RABBIT	11.58
20	0.21	1241	177	9	7	7756	27.82	RABBIT	13.61
30	0.25	1015	78	11	13	19031	26.06	RABBIT	8.14
40	0.28	931	85	12	11	5813	24.08	RABBIT	11.19
50	0.30	532	44	21	12	16625	18.2	RABBIT	5.2

TABLE 4.5

The Effect of Variation in the Fixed Sub-station Cost on Optimal Parameters (for a load-density of 20KW/Sq.KM)

Sub-station fixed cost (Rs.)	Sub-station feed area (Sq.Km)	Feeder service area (Sq.Km)	No. of sub-stations	No. of feeders per sub-station	Sub-station capacity (KVA)	Feeder length (KM)	Con-ductor size (Code-Name)	Feeder Voltage Regu-lation (%)	System Cost (Rs. in million)
1. SECONDARY DISTRIBUTION SYSTEM:									
3000	1.59	1.59	6981	1	29.4	1.03	GOPHER	9.4	1346
6000 (normal)	1.75	1.75	6383	1	32	1.16	WEASEL	10.8	1368
12000	1.89	1.99	5910	1	36	1.15	GOPHER	13.1	1407
2. PRIMARY DISTRIBUTION SYSTEM:									
315000	1117	186	10	6	6981	26.4	RABBIT	13.57	154.7
630000 (normal)	1241	177	9	7	7756	27.8	RABBIT	13.6	157.9
1260000	1596	199	7	8	9975	31.5	RABBIT	17.1	163.4

TABLE 4.6

The Effect of Variation in the Feeder bay cost on Optimal Distribution Parameters (For a load density of 20 KW/Sq.KM)

Feeder bay cost (Rs.)	Sub-station feed area (Sq.Km)	Feeder Service area (Sq.Km)	No. of sub-stations	No. of feeders per sub-stations	Sub-station capacity (KVA)	Feeder length (Km)	Conductor size (Code-name)	Feeder Voltage Regulation (%)	System cost (Rs. in Million)
37500	1396	174	8	8	8725	29.5	RABBIT	16.2	154.4
75000 (normal)	1241	177	9	7	7756	27.8	RABBIT	13.6	157.9
150000	1117	223	10	5	6981	26.4	RABBIT	16.3	164.7

TABLE 4.7

The Effect of Variation in the Cost of Energy on Optimal Parameters (for a load density of 20KW/Sq.KM)

Cost of Energy (Rs./KWh)	Sub-station feed area (Sq.Km)	Feeder service area (Sq.Km)	No. of sub-stations	No. of feeders per sub-station	Sub-station capacity (KVA)	Feeder length (Km)	Conductor size (Code-Name)	Feeder Voltage Regulation (%)	System Cost (Rs. in million)
1. SECONDARY DISTRIBUTION SYSTEM:									
0.25	1.67	1.66	6709	1	31	1.05	WEASEL	9.9	1334
0.50 (normal)	1.75	1.75	6383	1	32	1.1	WEASEL	10.8	1368
1.00	1.91	0.95	5848	2	35	1.13	WEASEL	6.13	1606
2. PRIMARY DISTRIBUTION SYSTEM:									
0.175	1241	248	9	5	7756	27.82	RABBIT	19.08	151.9
0.35 (normal)	1241	177	9	7	7756	27.82	RABBIT	13.6	157.9
0.700	1396	127	8	11	8725	29.51	RABBIT	10.36	170.3

CHAPTER-5

DISCUSSION & CONCLUSSION

CHAPTER-V

DISCUSSION AND CONCLUSION

5.1 DISCUSSION:

5.1.1 CONDUCTOR GRADATION:

The optimal grading of conductor cross-section along the feeder main results in the most economical system. To provide the overall optimal solution to the system studied, the effects of load growth in load factor and increase in the cost of energy are also considered. The system cost for the proposed conductor configuration comes out to be Rs.293789.70 and the voltage drop is also within the limits. If same conductor size is assumed throughout the feeder length then the cost increases, for example, if the smallest available conductor sise squirrel is used then the cost comes out to be Rs.386853.30 and the voltage drop exceeds the specified drop. In this case the capital investment is reduced but the cost of energy loss increases. This results in an overall increase in the system cost. Furthermore, the reduced conductor cross-section results in larger voltage drops which is the cause of the violation of voltage drop constraint. On the other hand, if the largest available conductor cross-section, Rabbit is used all along the feeder length then the cost is Rs.365558.10 and the voltage drop is within desired limits. In this case the capital investment is more but the cost of energy loss is lesser due to large conductor cross-section. Hence it is quite evident that the selected schemes is the most economical alternative.

The method is also applicable for modifying conductor sizes if the voltage constraint is violated by the selected conductor configuration. This is done by simple procedure of modifying conductor sizes in conjunction with a penalty function. The results in Table (3.3) are for the case where the voltage drop exceeds the specified limits. The comparison of Table(3.3) and (3.4) shows the modification incoporated to reduce the voltage drop. In this case the system configuration is not the most economical one (but is still less costlier than using the same conductor size for all segments), but has the best balance between economy and voltage drop constraint. Out of certain limitations to this procedure, the important one is that the feeder configuration will be altered when a new substation is installed in the system. The conductor size will be modified because of additional in-feed circuits. Hence, it becomes necessary to foresee any expected future development, which may result in system modification and take into account in the optimal conductor configuration.

5.1.2 PARAMETER OPTIMIZATION:

From the optimal parameters obtained, it can be seen that in the areas of low load density, the optimal feeder voltage regulation is quite large in comparison to the areas of high load densities. So it is advisable not to adopt a single standardized value for voltage regulation for the entire system area having different zones with different load densities. For optimal distribution system parameters, the base load factor is different for different load densities. Since at low load densities the load factor is much lower in comparison to higher load densities. Hence, it is necessary to determine the values of base load factor at different load densities beforehand for parameter optimization.

From the results it is evident that as the load density increases, the substation feed area, feeder service area and the feeder voltage regulation change quite sharply for both the primary and secondary distribution systems. For secondary distribution systems the substation capacity remains more or less constant with growing load densities. This is due to substantial increase in number of substations with load growth.

The effects on the optimal parameter due to the variation in the cost components are highlighted through Tables (4.5),(4.6) and (4.7) as:

Due to the increase in the substation fixed cost Table (4.5), the substation feed area increases and the number of substations decreases. By decreasing the fixed substation cost the substation feed area decreases, and the number of substations increases. The increase in the feeder bay cost Table(4.6) increases the feeder service area, while the substation feed area. the number of feeders per substation is reduced. The variation in the cost of energy Table (4.7) also influences the optimal values of parameters, while the conductor size remains the same.

5.2 CONCLUSION:

5.2.1 CONDUCTOR GRADATION:

The presented conductor grading procedure for radial distribution feeders is efficient and gives an optimum conductor policy which corresponds to the minimum of the sum of the capitalized feeder loss cost and feeder cost, keeping the voltage drop within limits. This procedure is simple and requires little computational efforts. This method is also applicable for obtaining conductor grading for several feeders corresponding upto five different conductor cross-sections.

5.2.2 PARAMETER OPTIMIZATION:

The parameter optimization method can serve as a powerful planning tool for economical distribution system design. It gives optimal values of substation feed area, feeder service area, number of substations and number of feeders per substation. These parameters can serve as a guideline for system planner. Moreover, this method is very efficient, fast and accurate in obtaining the optimal distribution system parameters.

FUTURE SCOPE OF THE WORK:

The conductor gradation method in the present is applicable only for radial feeders, some modifications may be carried out to make it applicable to interconnected systems. The voltage drop constraint need to be modified, so as to take the load growth into account.

The parameter optimization method may be applied to area with non-uniform load densities. Moreover the utilization factors used for substation transformers may be the optimum utilization factors for the size of the transformers used.

REFERENCES

1. Anthony J. Pansini, EE, PE, 'ELECTRICAL DISTRIBUTION ENGINEERING' Mc Graw Hill.

2. Pabla A.S. 'Electric Power Distribution System', Tata Mc Graw Hill.

3. Rao S.S. 'Optimization Theory and Applications', Willey Eastern Limited.

4. A.W. Funkhouser and R.P. Huber, "A Method of determining Economical ACSR Conductor sizes for Distribution System", AIEE Trans. on PAS Vol. 74, pp. 479-484

5. K.S. Hindi, A. Brameller and Y.M. Hamam, 'Optimal cable profile of L.V. radial distributors: Two Mathematical programming Methods', Proc. IEE, Vol. 123(4), April 1976

6. W.G. Kirn and R.B. Adler, "A Distribution System cost Model and its application to optimal conductor sizing", IEEE Trans. on PAS Vol. 101, pp 271-275, Feb. 1982

7. M. Ponnavaikko and K.S. Prakasa Rao, "An approach to optimal distribution system planning through conductor gradient", IEEE Trans. on PAS Vol. 101, pp. 1735-1742, June 1982.

8. P.S. Nagendra Rao, "An extremely simple method of determining optimal conductor sections for radial distribution feeders", IEEE Trans. on PAS Vol.104, pp. 1439-1492, June 1985

9. A.H. Kidder and J.H. Neher, "Power Distribution Parameters, AIEE Trans. on PAS Vol.- pp. 125-142, April 1955

10. W.J. Denton and D.N. Reps, "Distribution Substation and Primary Feeder Planning", AIEE Trans. on PAS Vol. 74, pp. 484-489, June 1955.

11. R.F. Larence, D.N. Reps and A.D. Patton, "Distribution System Planning through Optimized Design I - Distribution Transformers and Secondaries", AIEE Trans. on PAS Vol. 79, pp.199-204, June 1960.

12. R.F. Lawrence, D.N. Reps and A.D. Patton, "Distribution System planning through Optimized Design II - Comparative Economics of System Voltages", AIEE Trans. on PAS Vol. 79, pp.204-213, June 1960.

13. M.W. Gangel, J.P. Siken, J.A. Smith and H.V. Taylor, "Optimized Distribution and Subtransmission System planning by digital computer III - Primary Main Circuit Design", AIEE Trans. on PAS Vol. 84, pp.1150 December 1965.

14. R.N. Adams and M.A. Laughton, "Optimal planning of Power Networks using Mixed - Integer programming", Proc. IEE Vol. 121, No.2, pp.139-148, Feb.1974.

15. D.M. Crafold and S.B. Holt Jr., "A Mathematical Optimization Technique for locating and sizing distribution substations and deriving their optimal service areas", IEEE Trans. on PAS Vol. 94, pp. 230-235, March/April, 1975.

16. R.B. Adler, W.G. Kirn and G.A. Hozerlrig, "A Distribution System and user Cost Model", IEEE Trans. on PAS Vol. 100, pp. 3590-3598, July 1981.

17. M. Ponnavaikko and K.S. Prakasa Rao, "Optimal Distribution System Planning", IEEE Trans. on PAS Vol. 100, pp. 2969-2977, June 1981.

APPENDIX - A

DESCRIPTION OF COMPUTER PROGRAM FOR CONDUCTOR GRADATION:

For the selection of conductor size through conductor gradation, a computer program was developed, which consists of a main program and three subroutines. The brief description of the computer program is as follows:

A.1 MAIN PROGRAM:

Main Program calculates the cost matrix and voltage drop matrix by reading input data. This program also selects the optimum conductor cross-sections by inspecting the cost matrix and checks the voltage drop constraint; if the voltage drop constraint is violated it calls SUBROUTINE PENLTY for necessary conductor size modifications, and also calls SUBROUTINES CURENT and SUBROUTINE OUTPUT.

A.2 SUBROUTINE CURENT:

This SUBROUTINE calculates the peak load currents in each segment, to calculate the value of constants in main program.

A.3 SUBROUTINE PENLTY:

This SUBROUTINE is used to choose the particular modification at each stage which has the minimum penalty cost. It is only used in case of violation of voltage drop constraint.

A.4 SUBROUTINE OUTPUT:

This SUBROUTINE is called in the MAIN PROGRAM to PRINT OUT the results in a tabular form.

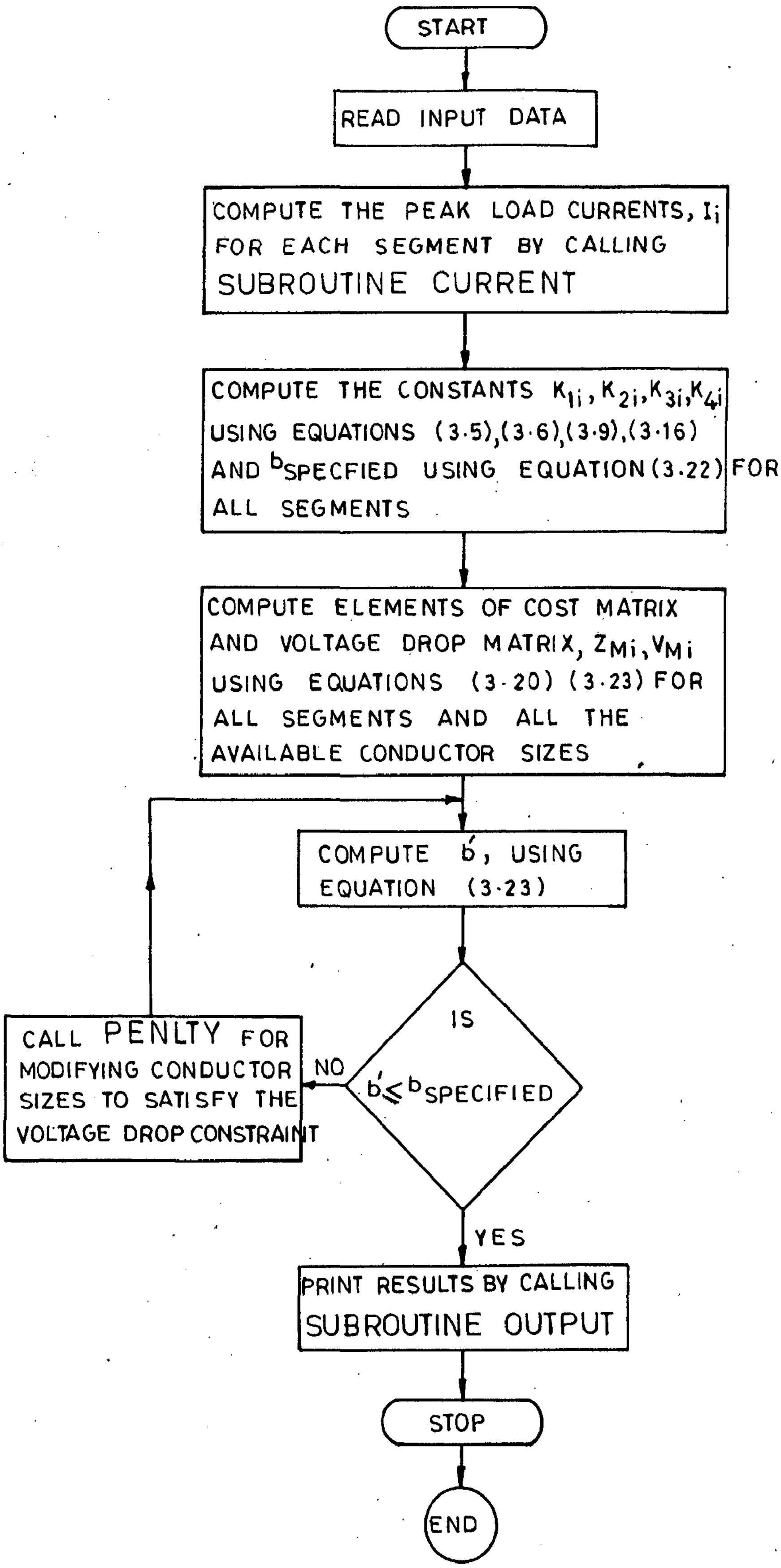


FIG. A-1 — FLOW CHART OF PROGRAM FOR CONDUCTOR GRADATION

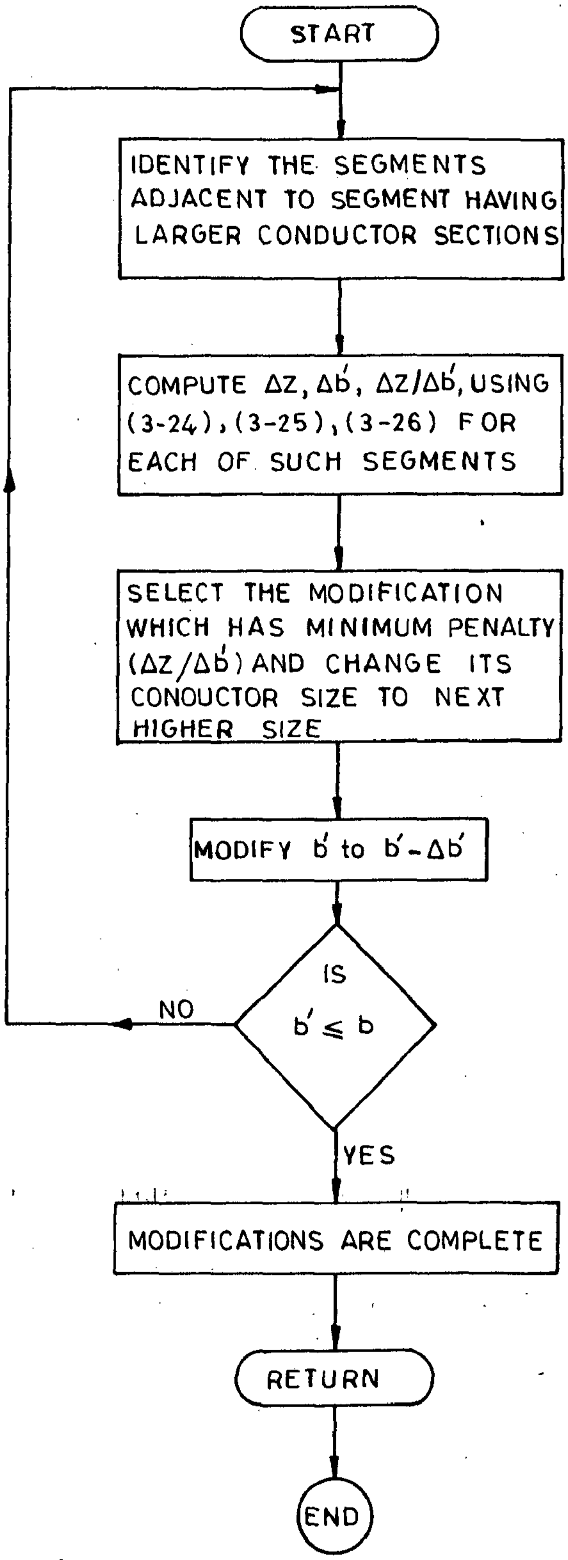


FIG. A-2 — FLOW CHART FOR SUBROUTINE PENLTY

APPENDIX - B

UNIFORMLY LOADED FEEDERS:

Load distribution factor (LDF) for uniformly loaded radial feeders shown in fig. 4.1 can be obtained from its definition given as:

$$LDF = \frac{PL}{M} = \frac{PL}{HV} \qquad ..(B.1)$$

Where, V is the percentage voltage drop in the feeder, P is the total load in the feeder, H is the unit voltage regulation constant for a given conductor size, a power factor and circuit voltage, L is the feeder length and M is the moment of loads.

The total load P $= \frac{np}{(PF)}$ ..(B.2)

The length of the feeder =

$$L = n\ell \qquad ..(B.3)$$

The moment of the loads,

$$M = \frac{p\ell}{(PF)} (1+2+3+\ldots\ldots\ldots\ldots+n)$$

$$= \frac{p}{(PF)} \cdot \frac{n(n+1)}{2} \qquad ..(B.4)$$

Substituting for P, L and M from (B.2), (B.3), and (B.4) in (B.1), we get

$$LDF = \frac{2n}{n+1} \qquad ..(B.5)$$

NON-UNIFORMLY LOADED FEEDERS- CASE(a):

Similarly, for a case of non-uniformly loaded radial feeder as shown in fig. (4.2)

$$P = \frac{np}{(PF)} \qquad \text{.. (B.6)}$$

$$L = \frac{n(n+1)}{2}\ell \qquad \text{.. (B.7)}$$

$$M = \frac{p\ell}{(PF)}\left(1^2 + 2^2 + 3^2 + \ldots\ldots + n^2\right)$$

$$= \frac{p\ell}{(PF)} \cdot \frac{n}{6}(n+1)(2n+1) \qquad \text{.. (B.8)}$$

Substituting for P, L, M from (B.6), (B.7) and (B.8) in (B.1) LDF can be obtained as:

$$LDF = \frac{3n}{2n+1} \qquad \text{... (B.9)}$$

<u>NON-UNIFORMLY LOADED FEEDERS -CASE(b)</u>:

By following the same procedure, for the non-uniform loaded radial feeder shown in fig.(4.3) can be obtained as:

$$P = \frac{np}{(PF)} \qquad \text{...(B.10)}$$

$$L = \frac{n(n+1)}{2}\ell \qquad \text{...(B.11)}$$

$$M = \frac{p\ell}{PF}\left(n.1 + (n-1).2 + \ldots\ldots + i(n-i+1) + \ldots\ldots + 2.(n-1) + 1.n\right)$$

$$= \frac{p\ell}{PF}\sum_{i=1}^{n}\left[i \cdot (n-i+1)\right] \qquad \text{....(B.12)}$$

From (B.10), (B.11), (B.12) and (B.1)

$$LDF = \frac{n^2(n+1)}{2\sum_{i=1}^{n}\left[i(n-i+1)\right]} \qquad \text{...(B.13)}$$

APPENDIX -C

PLDF EXPRESSIONS FOR UNIFORMLY AND NON-UNIFORMLY LOADED FEEDERS

UNIFORMLY LOADED FEEDERS:

Power less distribution factor (PLDF) for uniformly loaded feeders as shown in fig. 4.1. In this case $p_i = P$ and $\ell_i = \ell$, $i = 1, \ldots\ldots n$. The feeder peak load in KVA is given as:

$$P = \frac{np}{PF} \qquad \ldots(C.1)$$

The length of the feeder,

$$L = n\ell \qquad \ldots(C.2)$$

The power flow in i^{th} section is given as

$$W_i = \sum_{j=1}^{i} \frac{p_i}{PF} = \frac{ip}{PF} \qquad \ldots(C.3)$$

From the definition of PLDF

$$PLDF = \frac{P^2 L}{\sum_{i=1}^{n} W_i^2 \ell_i} \qquad \ldots(C.4)$$

Where

$$P = \sum_{i=1}^{n} \frac{P_i}{PF} \qquad \ldots(C.5)$$

$$L = \sum_{i=1}^{n} \ell_i \qquad \ldots(C.6)$$

$$\sum_{i=1}^{n} w_i^2 \ell_i = \sum_{i=1}^{n} \left(\frac{iP}{PF}\right)^2 \ell$$

$$= \frac{P^2 \ell}{(PF)^2} \sum_{i=1}^{n} i^2$$

$$= \frac{P^2}{(PF)} \left[\frac{n(n+1)(2n+1)}{6}\right] \qquad \ldots(C.7)$$

Substituting (C.5)m (C.6) and (C.7) in (C.4) we get PLDF for uniformly loaded radial feeders as given in (C.8)

$$PLDF = \frac{6n^2}{(n+1)(2n+1)} \quad ..(C.8)$$

NON UNIFORMLY LOADED FEEDERS -CASE(a):

In this case equations (C.1) and (C.3) i.e. the feeder peak load (in KVA) and the peak power flow in feeder sections are same as in previous case i.e. uniformly loaded feeders Fig.(4.2). In this case equation (C.2) is different to previous case and is given as below:

$$\ell_i = i\ell \quad , \quad i = 1, 2, \ ......n \quad ,..(C.9)$$

$$L = \sum_{i=1}^{n} \ell_i = \sum_{i=1}^{n} i\ell = \frac{n(n+1)}{2}\ell \quad ...(C.10)$$

From equations (C.3) and (C.9)

$$\sum_{i=1}^{n} W_i^2 \ell_i = \sum_{i=1}^{n} \frac{ip}{PF}^2 (i\ell) = \frac{P^2}{(PF)^2} \sum_{i=1}^{n} i^3 \quad ..(C.11)$$

By substituting (C.1), (C.10) and (C.11) in equation (C.4) we get PLDF for this case as:

$$PLDF = \frac{n^3(n+1)}{2\sum_{i=1}^{n} i^3} \quad ..(C.12)$$

NON-UNIFORMLY LOADED FEEDER-CASE (b):

In this case (C.1), (C.3) and (C.10) i.e. feeder peak load (in KVA), peak power flow (in KVA) in feeder sections and the feeder main length are same as in the non-uniformly loaded feeder-case(a) fig. (4.3), but in this case the lengths of feeder segments are not same to case(a), and is given as:

$$L\ \ell_i = (n-i+1)\ell \quad , \quad i=1,.......n$$

Equation (C.11) in this case can be written as in (C.13)

$$\sum_{i=1}^{n} W_i^2 \ell_i = \sum_{i=1}^{n} \left(\frac{ip}{PF}\right)^2 (n-i+1)\ell \qquad ..(C.13)$$

By substituting (C.1), (C.10) and (C.13) in (C.4), we get PLDF for this case as in (C.14)

$$PLDF = \frac{n^3(n+1)}{2\sum_{i=1}^{n}\left[i^2(n-i+1)\right]} \qquad ..(C.14)$$

APPENDIX-D

DESCRIPTION OF COMPUTER PROGRAM FOR PARAMETER OPTIMIZATION

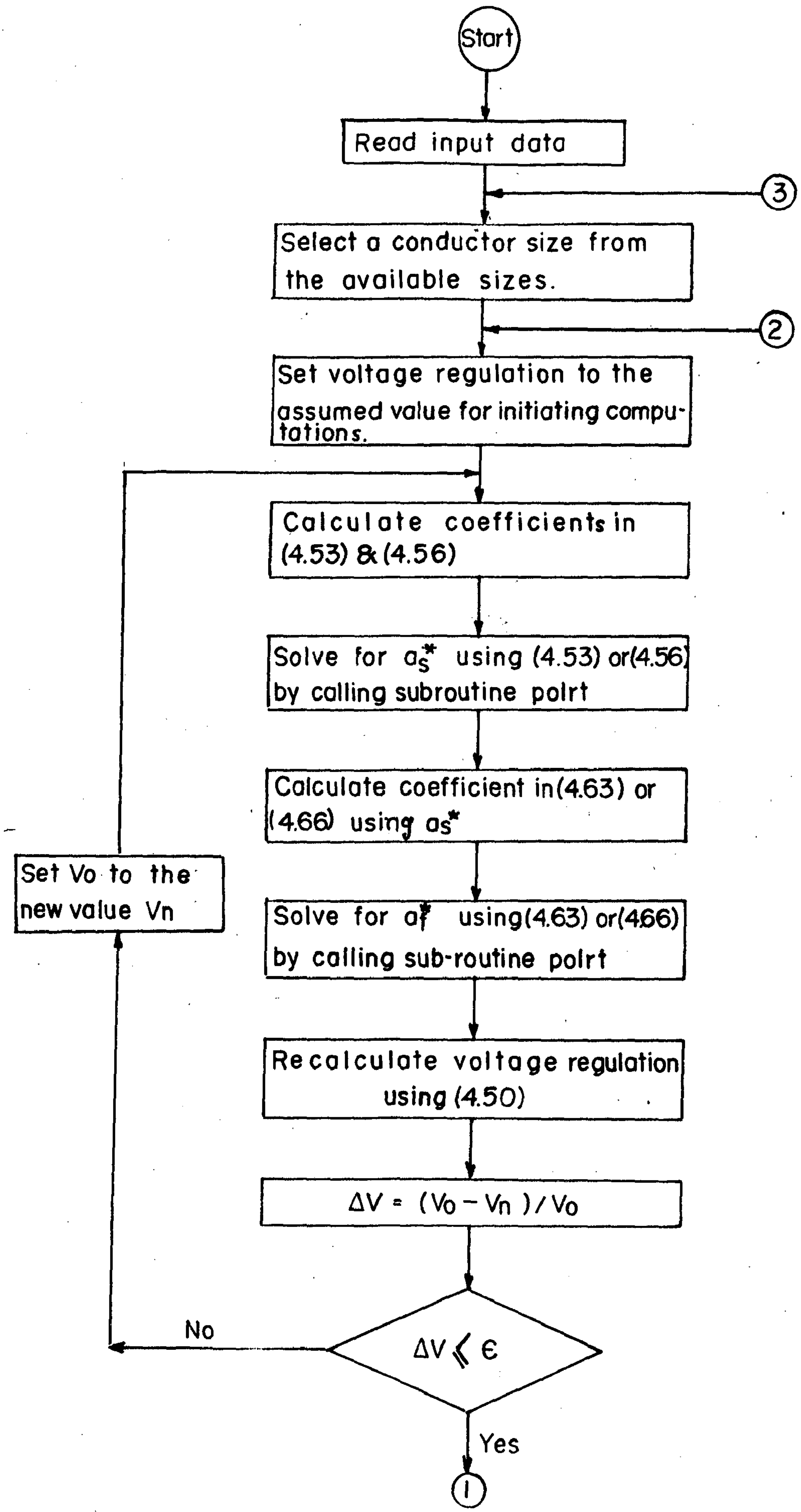
Two separate computer programs for primary and secondary distribution system optimal parameters were developed. The flow chart of the computer program is shown in fig. D-1. Each computer program consists of one main program and one sub-routine. The brief description of the computer program is as follows:

MAIN PROGRAM:

This program reads the input data and computes the co-efficients. This program also calls the subroutine POLRT to solve the polynomials in terms of substation feed area and feeder service area. Using these optimal values of substation feed area and feeder service area the optimal system parameters are calculated. This program also calculates the cost functions with respect to conductor sizes considered and selects the conductor size which corresponds to minimum cost function.

SUBROUTINE POLRT:

This subroutine computes the real and complex roots of a real polynomial. In this Newton Raphson iterative technique is used. The final iterations on each root are performed using the original polynomial rather than the reduced polynomial.


Start
Read input data
3
Select a conductor size from the available sizes.
2
Set voltage regulation to the assumed value for initiating computations.
Calculate coefficients in (4.53) & (4.56)
Solve for a_s^* using (4.53) or (4.56) by calling subroutine polrt
Calculate coefficient in (4.63) or (4.66) using a_s^*
Solve for a_f^* using (4.63) or (4.66) by calling sub-routine polrt
Recalculate voltage regulation using (4.50)
$\Delta V = (V_0 - V_n)/V_0$
$\Delta V \leqslant \epsilon$
No
Yes
Set Vo to the new value Vn
1

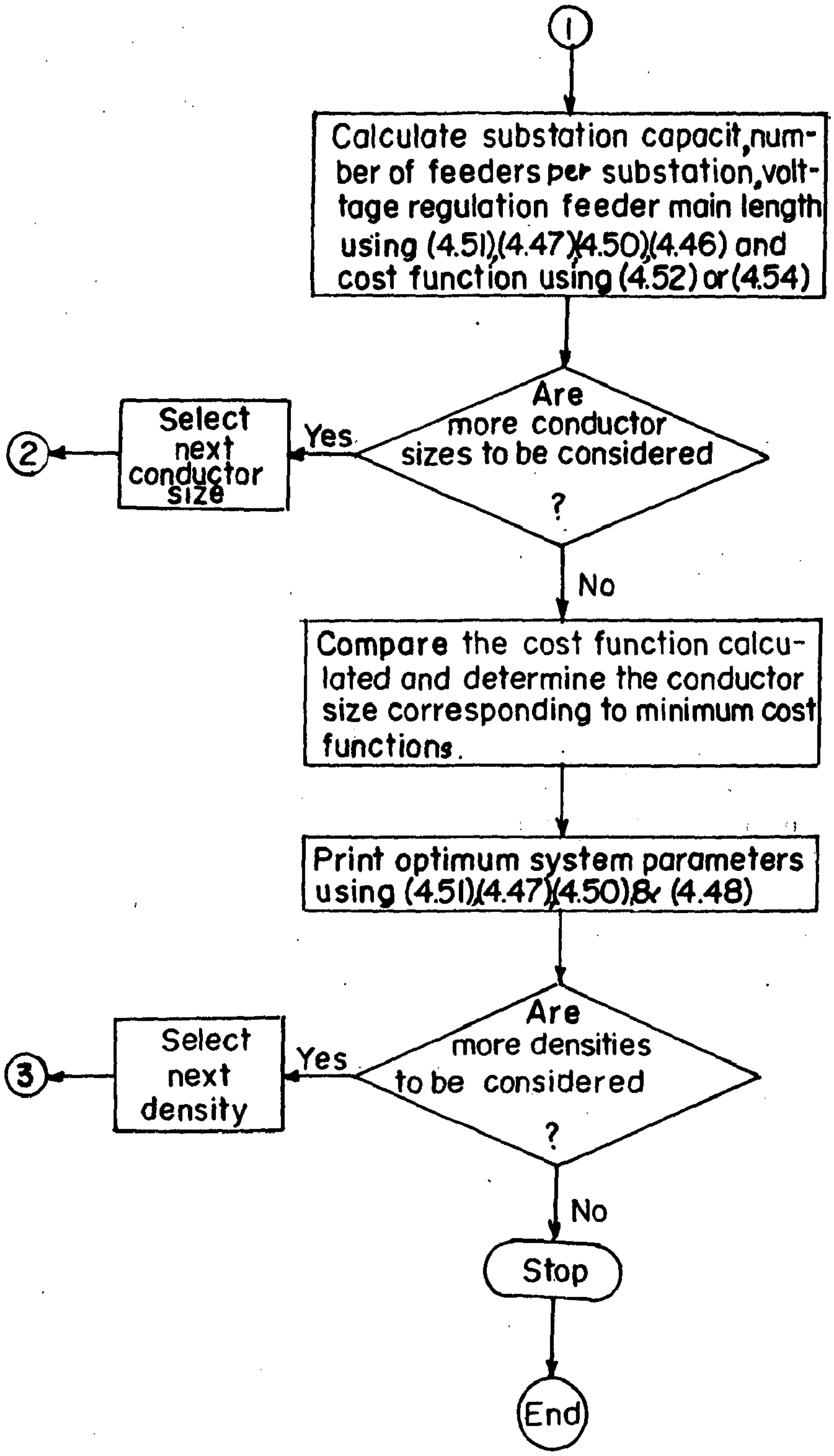


FIG.1 FLOW CHART OF MAIN PROGRAM FOR PARAMETER OPTIMIZATION.

APPENDIX-E

FEEDER LOSS DETERMINATION

In a radial distribution feeder as shown in fig. 4.4, the power loss (in KW) in the three-phase line with sectional resistance R_i and the sectional current flow of I_{w_i} is given by:

$$P_L = 0.003 \sum_{i=1}^{n} I_{wi}^2 R_i \tag{E.1}$$

By substituting for R_i and I_{wi} in terms of the power flow w_i and length of the feeder section ℓ_i in (E.1), we get:

$$P_L = \frac{0.001r}{(KV)^2} \sum_{i=1}^{n} w_i^2 \ell_i \tag{E.2}$$

LDF for the feeder shown in fig. 4.4 as defined in (4.5) is given by:

$$LDF = \frac{PL}{\sum_{i=1}^{n} w_i \ell_i} \tag{E.3}$$

Dividing (E.3) by (4.9), we get

$$\sum_{i=1}^{n} w_i^2 \ell_i = \left(\frac{LDF}{PLDF}\right) P \sum_{i=1}^{n} w_i \ell_i \tag{E.4}$$

$$M = \sum_{i=1}^{n} w_i \ell_i \tag{E.5}$$

From (E.2), (E.4) and (E.5), we get

$$P_L = \frac{0.001r}{(KV)^2} \left(\frac{LDF}{PLDF}\right) MP \tag{E.6}$$