GIS BASED DISTRIBUTION SYSTEM PLANNING

A DISSERTATION

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

of

MASTER OF TECHNOLOGY

in

ELECTRICAL ENGINEERING

(With Specialization in Power System Engineering)

By

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CANDIDATE'S DECLARATION

I hereby declare that the work presented in this dissertation entitled **"GIS BASED DISTRIBUTION SYSTEM PLANNING"** submitted in partial fulfillment of the requirements for the award of the degree of Master of Technology with specialization in Power System Engineering in the Department of Electrical Engineering, Indian Institute of Technology, Roorkee, is an authentic record of my own work which has been carried out from July 2004 to June 2005 under the guidance of Dr. J D Sharma, Professor, and Shri Bharat Gupta, Assistant Professor, Department of Electrical Engineering, Indian Institute of Technology, Roorkee.

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

Date: 9 June 2005

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CERTIFICATE

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

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ABSTRACT

Distribution system constitutes to be a significant part of the total power system. Out of total system losses, distribution system losses constitute a major part ranging from 75 to 80 percent and 99 percent of consigner outages are attributable to distribution system. This brings about the realization that optimal planning studies are essential in the distribution system. In this work, load estimation, substation sitting, load flow analysis, conductor grading and capacitor allocation problems for radial distribution system planning have been considered using a geographic information system (GIS) platform.

A GIS is a system for management, analysis and display of geographic knowledge, which is represented using a series of information sets such as maps, geographic data sets, processing and work flow models, data models, and metadata. The GIS can be regarded as a collection of computer hardware, software, geographic data, procedures, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of spatially referenced data. It is a system of mapping of complete electrical network including low voltage system and customer supply points with latitude and longitudes overloaded on satellite imaging and/or survey of India maps. Layers of information are contained in these map representations. The first layer corresponds to the distribution network coverage. The second layer corresponds to the land background containing roads, landmarks, buildings, rivers, railway crossings etc. The next layer could contain information on the equipment viz poles, conductors, transformers etc. A GIS is chiefly used to collect, manipulate, analyze and present information that is linked to a location on the earth's surface. Most of the electrical network/equipment has a geographical location and the full benefit of any network improvement can be had only if the work is carried out in the geographical context.

Distribution system planning involves great amount of spatial information. GIS provides a platform for collecting, processing data and display of results. With the help of GIS the attribute data of e lectrical facilities can be retereived, modified and displayed with graphics. Analyses such as the selection of suitable areas, the optimum path finding, the profile analyses,

the engineering design of towers and wires, and the cost estimation can be done using GIS. Several other application programmes can be integrated with GIS to share such an efficient environment. The integration of GIS enables the representation of distribution system in more detail and provides the planner with a new way of looking at the distribution system. Thus the use of GIS in distribution system planning is inevitable.

The aim of the distribution system planner is to determine the magnitude and geographic location of load centres in an area; then the distribution substations must be located and sized in such a way as to serve the area load at maximum cost effectiveness by minimizing feeder losses and construction costs while considering the constraint of service reliability. The purpose of a substation is to draw power at high voltage from the transmission or sub-transmission system, reduce its voltage, and feed it in a number of feeders for distribution in the area. Substations therefore play an inordinately large role in influencing the cost and performance.

After having finalized the substation location, the next task is to find the optimal feeder routing. GIS has been used for optimizing the routing of feeders. This is capable of efficiently accessing and manipulating geographically referenced data from a facilities management system database.

Having finalized the routing of the feeders the next task is to select the conductor size, such that the losses are minimized and voltage drop constraint is satisfied. The currents carried by the distribution feeders are always decresing in order from source point to far end load point. Therfore, for an economical sizing of a feeder should be in accordance with the currents carried by them. This necessisates desinging the radial feeder using multiconductor cross sections, so as to minimise the cost of feeder. The method for finding optimum conductor size in a radial distribution feeder has been presented. The approach includes an economical current density based method and a heuristic method, which together enable a satisfactory solution to be quickly achieved at planning stage.

To check that the voltage limits are not violated the system needs to be analysed using a load flow algorithm. The load flow analysis is based on a new formulation, which takes into consideration the special topological characteristics of distribution networks to make the direct solution possible.

Loads on feeders vary continuously during entire day and season. The installation of shunt capacitors on radial distribution systems is required under heavy load conditions, voltage profile management, and losses minimization. Therefore, it is important to find the optimal size and location of capacitors to be installed in the distribution system to minimize feeder losses. A heuristic technique has been used for finding optimum allocation of capacitors in distribution feeders. The problem is formulated as an optimisation problem.

These methods have been implemented on GIS platform, which is the interactive part of this work. The databases as well as the results of the software are linked with the map of the network and an interactive display of data is made on the map itself. This is very helpful to enable the designer to observe and properly judge the system behaviour and condition for further analysis and modification purposes.

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CHAPTER 1

INTRODUCTION

Power system planning is essential to meet the growing demand of electricity. Increasing demand for electric power combined with a scarcity of resources has put a burden on the system planner for optimizing the capital investment and running costs of the power system. This has led to development of methods which can be used to aid the decision making process for selecting the best alternative. The major objective of a utility is to meet the power demand with good quality of service, which requires proper planning of the system. The distribution system constitutes a significant part of the total power system. The capital expenditure incurred in distribution systems forms about 40 percent of the total expenditure.

Further, since the distribution system operates at low voltage level and is extensive, it is prone to have more energy losses compared to other parts of the system. While quantifying the losses in the power system it has been observed that the distribution system losses constitute a major part of the losses, ranging from 75 to 80 percent of the total system losses [1]. Further the need for quality and reliability of service to consumers, particularly in an industrial complex needs no elaboration. Again the quality and reliability of service depend mainly on adequacy of distribution system. It is evident from the studies [2] that 99 percent of consumer outages are attributable to distribution systems. This brings about the realization that accurate planning techniques are essential for distribution systems. Also any haphazard planning of a distribution system may further increase the losses in the system as well as will detoriate performance of the system. Moreover the cost of energy in a power system is maximum at the distribution level; therefore haphazard planning may also lead to serious economic problems to the power utility. The above facts again justify the need for proper planning strategies for the distribution system, to provide an adequate and reliable supply to its consumers at a reasonable economic cost.

In the distribution system planning, service quality and economy are the main considerations. The service quality means, to supply power to the consumer at the specified voltage, which in turn depends on the voltage regulation, tap setting of transformers and voltage received at the source station. The system planner has a very little control on these variables except for the voltage regulation in the feeder. Design of a distribution system with high voltage regulation may result in more distribution losses and consequently higher voltage levels at the substations as compared to an alternative design of low voltage regulation. The design of distribution systems based on high voltage regulation may result in higher recurring expenditure and low initial investment. On the contrary a system with low voltage regulation will have less expenditure and more initial investment. The source voltage and the desired voltage at the consumer point further control the voltage regulation. If the voltage at the consumer end is also fixed to provide a good quality of service, the voltage regulation for the distribution system will also be fixed, on which the other dependent variable parameters of the distribution system will depend. These parameters are feeder voltage, size and feeder length etc. Hence the optimization of these parameters is virtually essential for distribution system planning. The basic independent variables, on which these parameters depend are load, power factor and load distribution etc.

Since all the elements in the power system have a specific physical location on ground, they can be placed on the digital map and on the computer in the form of database and the full benefit of any system improvement can be had only if the work is carried out in the geographical context. Even while doing something as relatively simple as adding a new service connection; it is vital to know that users of the system are not affected by this addition. GIS in conjunction with system analyses tools helps to do this. The GIS is an organized collection of computer hardware, software, geographic data, procedures, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of spatially referenced data. It is a system of mapping of complete electrical network including low voltage system and customer supply points with latitude and longitudes overloaded on satellite imaging and/or survey of India maps. Layers of information are contained in these map representations. The first layer corresponds to the distribution network coverage. The second layer corresponds to the land background containing roads, landmarks, buildings, rivers, railway crossings etc. The next layer could contain information on the equipment viz poles, conductors, transformers etc. The extensive application of GIS has enabled the representation of distribution system in more detail for optimum operation and planning purpose. The GIS provides an environment for building a database, which contain both graphic information and non-graphic facility data. This data can be accessed by a click of the mouse on the digital map. Thus the use of GIS in distribution system planning is inevitable.

The determination of substation location is crucial from the viewpoint of effective planning of the distribution system. The location of the substation is based on the load distribution throughout the service area. To minimise losses and reduce the initial expenditure the location of the substation should be closer to the centroid of the load area to be supplied by it. Thus the service area is divided into various smaller areas based on the load density. Load distribution maps are used to define the load points. Thereafter the load centre of the load points is determined. Once the load points and the location is finalised the next task is to find the shortest path for the distribution feeders.

In distribution system mostly the feeders are radial in configuration, either straight or branched. Hence the loading on the feeder is in a decreasing order from feed point to end point of the feeder. This inherent feature of the feeders provides the possibility of multi conductor cross section configuration for a feeder by way of making provision for lower size of conductor cross sections towards the far ends of the feeder, in number of stages subject to availability of size in the inventory. The proper choice of multi-conductor cross section for radial feeders in the distribution system improves the system economy without affecting technical requirements of the system.

After finding out the routing of feeders it needs to be analysed to find out the various electical parameters under different loading conditions of the system. Thus a load flow study; forms an important part of power system analysis. It is necessary for planning, economic operation and control of an existing system. In addition, distribution systems extends to wide areas and contain a very large number of elements, like substations, line sections, loads of different types etc. The distribution system comprises of many feeders operating radially in normal operating conditions. Therefore in the distribution system analysis a repeated number of calculations are often required, because of large number of alternative solutions that must be examined.

The distribution system is operated radially and therefore the voltage at the end node on a particular feeder is likely to be low as compared to that at the start node. Thus maintenance of the system voltage at a certain acceptable limit is one of the important control schemes in a distribution system. The voltage profile of the distribution system can be improved by the installation of shunt capacitor. The provision of excessive shunt compensation or fixed shunt compensation for full load, at off peak hours, may result in undesirable high voltages in the system. Thus the economic benefits of the capacitor depend mainly on where and what capacities of the capacitor are installed for different load levels. The installation of capacitors nearer to the load points yields maximum benefit. Hence probable locations of capacitor installation are the load points on the feeder. Thus it is essential to make proper choice of the number, size and location of the capacitor banks along the radial feeder to achieve maximum economy.

In this dissertation work a GIS platform has been used for planning of the distribution system. The various aspects covered are:-

- Load Estimation
- Selection of optimal location of substation
- Finding the optimal feeder path
- Selection of optimal conductors
- Power system analysis
- Selection of optimal capacitor size and location to improve system voltage

The distribution system planner must determine the magnitude of the load and its geographical location. Thereafter the distribution substation must be placed and sized in such a way as to serve the load at maximum cost effectiveness by minimizing feeder losses and construction costs, while considering the constraints of service reliability. This can be achieved by optimal feeder routing and accurate selection of the feeders. The distribution system also needs to be analysed to check if the system voltage is within permissible limits. In case of any excess voltage reduction capacitors may be applied to boost the voltage and maintain the voltage profile at the desired level. The entire process of the distribution system planning can be summarised in a flowchart as shown in Fig 1.1.

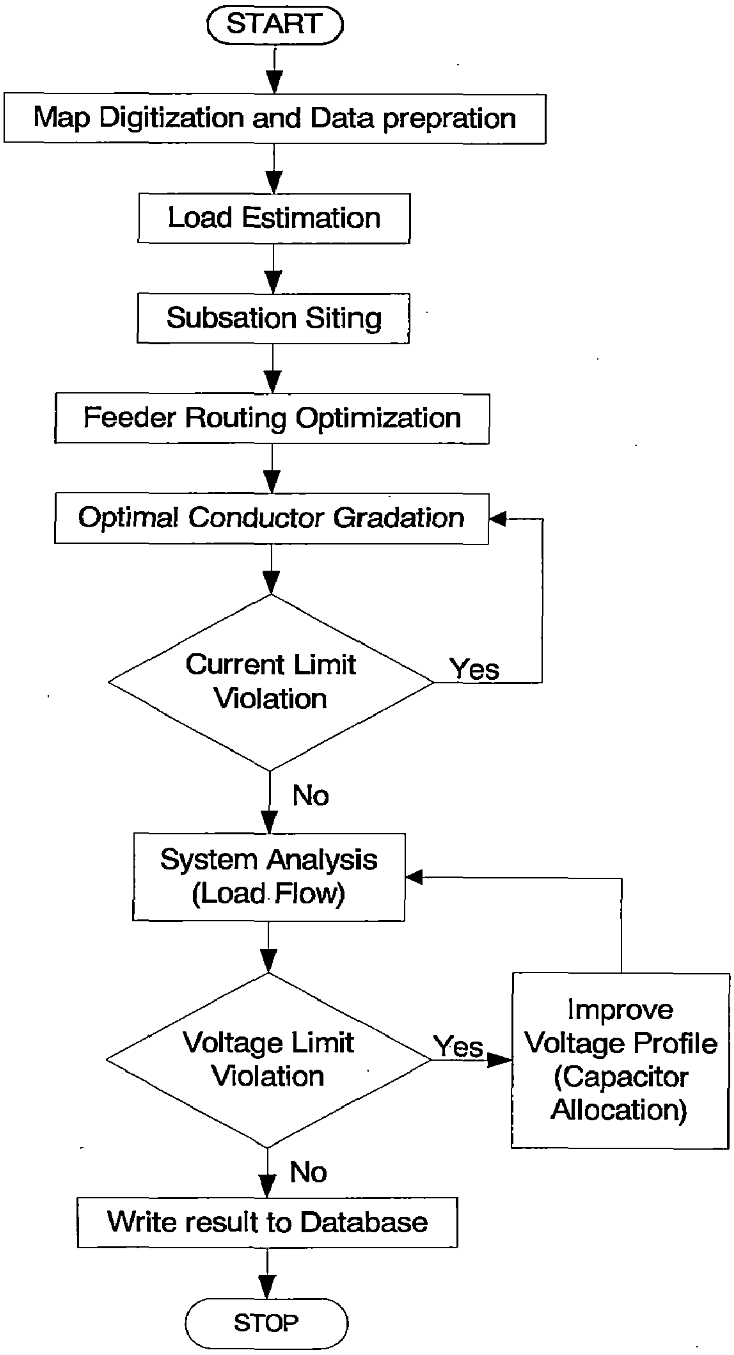


Fig 1.1 Flow chart for Distribution System Planning Process

In this work a street map has been taken as reference. The load areas are assigned based on the load density and the load at each load centre is determined. Based on the load distribution, the location of the substation is determined on the map. After selection of the location of the substation the possible feeder routes are traced on the map and thereafter the shortest path is determined. A model for optimum conductor sizing has also been developed. The load flow program required for the planning purpose has been developed. The optimal size of the capacitors to be installed at different feeder nodes is determined.

The graphical representation of the network of these feeders and results obtained by the software is another feature of the work. The relevant information about the feeder such as feeder name, segment number, and type of conductor used, diameter, length of the segment, etc. can be obtained by clicking the mouse on the desired segment of feeder on the map. Similarly the values of voltages and capacitors installed at different nodes can also be displayed on the map by the clicking of the mouse on the respective node.

Thus the package developed, coupled with graphical display of data becomes a useful tool for distribution system planning purpose.

CHAPTER 2

LITERATURE REVIEW

2.1 SUB STATION SITING

Distribution planners must determine the peak load magnitude and its geographic location, and then distribution substations must be placed and sized in such a way as to serve a certain load at minimum cost. The choice of substation rating and location is dependent on several factors, e.g. load density, geographical limitations, etc. In a large distribution system, the number of possible choices is extremely large. To determine the least system cost that satisfies the load requirements is not an easy task.

Several methodologies have been proposed in the literature for the solution of the electric distribution substation location problem. Masud [3] has developed a powerful method for addressing the problem of substation size. The method depends on a sequential application of different optimization models. The decision of building a substation depends on voltage drop consideration. Crowford and Holt [4] have presented an optimization approach based upon the well-known Dijskstra's [5] minimum path algorithm and Ford and Fulkerson's transportation algorithm [6] for locating, sizing and deriving service area of distribution substations. The model is based on solving a transportation problem in which the objective function prevents transporting power over a large distance. Thompson and Wall [7] have presented a branch-and-bound model for the selection of an optimal substation location based on fixed charge transshipment for choosing substation location. The model objective function represents both fixed and variable cost associated with the substation, and is solved using integer branch-and-bound optimization technique. Fawzi et al [8] has proposed an iterative optimization procedure, using successive linearization as well as heuristic relaxation and bounding procedures. Sun et al [9] have introduced a flexible model for optimal planning of distribution substation and/or primary feeder using fixed branch-and-bound algorithm and includes an explicit modeling of fixed and variable cost components.

2.2 LOAD FLOW ANALYSIS

Different approaches are there for solving load flow problem of the distribution system. An earlier approach of radial system power flow analysis utilized linear network theory by approximating all the constant power loads as admittances calculated corresponding to assumed bus voltages. Network reduction techniques are used to get an equivalent circuit and new bus voltages are calculated by unfolding the network. The process is iterative and repeated till converges. Next proposed solution took advantage of the structure of the radial system and is referred to as ladder network approach. In this method iterations are started with estimates of ending bus voltages and reverse trace is then performed for determining the various bus voltages leading to a calculated value of the source voltage. New estimates for the ending bus voltages are determined based on the mismatch between the calculated and specified source voltage. Iterations are continued till specified source voltage is achieved within accuracy limit. General load flow method of Newton however has the disadvantage of complexity in program, higher memory requirements and more calculation time.

The exclusive methods are as enumerated in the succeeding paras.

2.2.1 Forward/Backward Sweep Technique

This method take the advantage of specific feature of the radial nature of distribution systems, that there is a unique path from any given bus to the source. Given the voltage at the root node and assuming a flat profile for the initial voltages at all other nodes, the iterative algorithm consists of three steps:

(i) **Nodal Current Calculation**: The nodal current injection, at each system node is calculated.

(ii) **Backward Sweep**: Starting from the branches in the last layer and moving towards the branches connected to the root node the current in branches is calculated.

(iii) **Forward Sweep**: Nodal voltages are updated in a forward sweep starting from the branches in the first layer and moving towards the branches in the last.

These three steps are repeated until convergence is achieved.

Ciric et al [10] have used this technique to solve the load flow considering the neutral grounding. The neutral wire is usually merged into phase wires using Kron's reduction. Since the neutral wire and the ground are not explicitly represented, neutral & ground currents and voltages remain unknown. In some applications like power quality and safety analyses, loss analysis, etc, knowing the neutral & ground currents and voltages could be of special interest. In this technique both the neutral wire and ground are explicitly represented, as also the neutral & ground currents and voltages have been calculated. In this method it expands the 3x3 network representation to a 5x5 representation, considering three-phase wires, neutral wire and assumed ground wire. A problem of three-phase distribution system with earth return, as a special case of a four-wire network, is also elucidated. The developed distribution power flow method is of general usage since it can be applied for most of the existing distribution networks (DNs) viz medium voltage (MV), low voltage (LV), three wire, four-wire with (solidly) grounded neutral, or isolated neutral wire and single-wire DNs with earth return. Results obtained from several case studies, using medium and low voltage test feeders with unbalanced load, are also discussed.

2.2.2 Compensation Based Power Flow Method

In this method an inter-connected system is first broken in the line sections at a number of points called breakpoints to convert the network into radial one. Each breakpoint opens one simple loop. The radial network is then solved by direct application of KVL and KCL. The breakpoint currents are calculated using multiport compensation method. The numerical efficiency however decreases as the number of breakpoints increase.

Cheng and Shiromohammadi [11] have extended the compensation based power flow method for weakly meshed distribution systems from single phase to three-phase. To eliminate the voltage magnitude mismatches at PV nodes compensation is applied, making this method capable of handling dispersed generation in primary distribution systems. Other issues involved in distribution system operation, such as multi-phase operation with unbalanced and distributed loads, voltage regulators and shunt capacitors with automatic local tap controls can also be addressed within the same algorithm. These modeling challenges can be accommodated and still maintain a high execution speed required for real time application in distribution automation systems.

Zkang et al [12] have developed a technique for accurate determination of power flow in both normal and faulted unbalanced distribution systems, based on hybrid compensation technique with backward-forward sweep method, this algorithm has the following important features:-

(a) The internal impedances of power source are under consideration.

(b) Various types of single or multiple faults are simulated in a complete uniform model without any extra processing for a certain fault.

(c) Full consideration has been given for both direct short circuits and faults through impedance.

(d) To deal with the ungrounded source transformer, a novel Thevenin equivalent circuit has been developed.

(e) The influence of capacitance of lines is studied, which is especially important in an ungrounded system.

(f) Some acceleration techniques for large-scale distribution systems are developed which reduces the computation time significantly.

Zhu and Tomsovic [13] have developed an adaptive distributed power flow solution based on the compensation-based method for a 3-phase unbalanced system. The extensions incorporated are:-

(a) Distribution system elements including lines, capacitors, dispersed generation units, nonlinear loads, and transformer connections are comprehensively modeled.

(b) The convergence rate of the compensation-based power flow method is exploited based on different situations, including load unbalance, sudden change in 1-phase loads, the number and position of mesh breakpoints, and the number and position of *PV* nodes.

An adaptive compensation-based power flow method is fast and reliable, while maintaining necessary accuracy. This method is appropriate for simulation of slow dynamics on the distribution system.

2.2.3 Based on the Y_{BUS} Formulation

Lee et al [14] have formulated a fast, reliable and efficient method for solving the load flow problem for ill-conditioned distribution systems. It is assumed that the distribution system is fed at only one point and the voltage magnitude of sub-station is maintained as a specified value by Tap Changing under Load (TCUL). Under this assumption, an efficient algebraic matrix equation to solve the load flow problem is derived from the complex power balance equation using the Y_{BUS} formulation. Since only second order terms are required to be neglected in the linearization procedure, this method shows better convergence characteristics than the conventional NR and the FDLF methods. The complex matrix in the proposed linearized equation is split into real and imaginary parts to keep the sparsity. The feature of this method is that all the off diagonal elements of the real-valued matrices are the same as those of the real and imaginary parts of the admittance matrix with high sparsity. In this algorithm, only the diagonal elements and the current mismatch vector are required to be updated every iteration. This method can be applied to the radial and meshed networks as well with fast calculation speed.

2.2.4 Current Injection Method

Garcia et al [15] have presented a new sparse formulation for the solution of unbalanced three-phase power systems using the Newton Raphson (NR) method. The current injection technique is extended for unbalanced three-phase systems. The three-phase current injection equations are written in rectangular coordinates resulting in an order *6n* system of equations. The Jacobian matrix is composed of *6x6* block matrices and the structure is similar to the nodal admittance matrix. Balanced and unbalanced system operating conditions are tested to verify the robustness of the proposed TCIM technique. Constant impedance and constant power load models have been used. The initial values of the load and of the R/X ratios of the feeders were gradually increased up to the point were convergence was no longer attained. An interesting property of the TCIM formulation is that the number of elements required to be recalculated during the iteration process is very small. For strictly radial distribution systems, with no cogeneration plants, the Jacobian matrix will be constant.

Carneiro et al [16] have briefly described the current injection method for three-phase system and its potentialities to model co-generation plants (PV or PQV buses), the representation of sub-station systems and FACTS control devices is also outlined. The three-phase current injection equations are written in rectangular coordinates resulting in an order *6n* system of equations. The Jacobian Matrix is composed of 6x6 block matrix and retains the same structure as the nodal admittance matrix and the current mismatches are expressed as a function of active and reactive powers. The main advantages of the proposed technique are:-

(a) It is very robust and converges in less iteration than the backward/forward sweep method especially for heavily loaded systems.

(b) The structure of the Jacobian Matrix is the same as the bus admittance matrix and thus retains its sparsity properties.

(c) The number of elements that are required to be recalculated during the iteration process is very small compared to the conventional Newton Raphson method.

(d) Wider meshed networks including sub-transmission systems and any number of PV buses can be represented.

(e) The augmented power flow formulation allows the representation of FACTS control devices of any type.

2.2.5 Fast Decoupled Power Flow

Teng et al [17] have introduced an exact three phase fast decoupled power flow solution. A general purpose algorithm has been pursued, which works efficiently with radial, weakly-meshed or looped networks. The method utilizes Newton Raphson algorithm in rectangular coordinates. The Jacobian matrix can be decoupled both on phases as well as on real and imaginary parts. The memory requirement is also reduced to only one-sixth, and the mutual coupling terms can be avoided. The distribution system can also be solved with line conductances only i.e. an exact three phase distribution load flow program can be executed with minimum data preparation to substantially offload the burden of distribution engineers. Tests have shown 10 to 100 times better performance than the other methods for test systems with 45 to 270 buses.

2.2.6 Object Oriented Load Flow

Losi and Russo [18] have developed an object oriented (OO) algorithm based on the Newton Raphson technique. It reaches convergence in few iterations, even in extreme operating conditions of weakly meshed topologies. Certain approximations to the Jacobian matrix have been introduced. A detailed study of the convergence characteristics is given and sufficient conditions for convergence are derived. Though this method introduces a message passing overhead, heavy computations are not required for each iteration. The relationship between the electrical parameters and the mathematical parameters influence the convergence properties of the algorithm. The OO based modeling gives new features to the software, such as flexibility, extensibility, easiness of maintenance, and can best exploit the advantages of distributed computing in open system architectures.

2.2.7 Newton Raphson Based Method

Chang and Teng [19] have used the branch voltages as state variables and employ the NR algorithm to solve the load flow problem. By utilizing branch voltages as state variables, a constant Jacobian Matrix can be obtained and utilizes an improved solution technique to obtain the load flow solution. The LU factorization of the Jacobian Matrix is not necessary, and the ill-conditioned problem occurring at the factorization of the Jacobian Matrix does not exist. A solution technique, which takes the network structure and computer economy into account has also been developed. This method is an efficient three-phase load flow method and has great potential for real-time use for power flow calculations in large scale distribution systems.

Chang and Teng [20] have presented a "novel but classic" technique. This method is novel since it takes advantage of the topological characteristics of distribution systems and solves the distribution load flow efficiently. This method is classic since its input data is the same as the conventional bus-branch oriented data. This method is based on the NR formulation and utilizes the branch voltage as state variables. The solution technique takes into account the network structure to avoid the time-consuming lower and upper triangular (LU) factorization. Since the factorization procedure can be avoided, this method saves computation time. Any power system equipment can be integrated into this method if its equivalent current injection or admittance matrix is obtained. Test results demonstrate that this method is an effective three-phase load flow method and has great potential for real-time use.

2.2.8 Direct Approach : Network Topology Based

Teng [21] has taken into consideration the special topological characteristics of distribution networks to make the direct solution possible. The only input data to this algorithm is the conventional bus-branch oriented data. Two matrices have been developed namely the bus-injection to branch-current (BIBC) matrix and the branch-current to bus-voltage (BCBV) matrix, thereafter a simple matrix multiplication is used to obtain load flow solution. The BIBC and BCBV matrices are developed based on the topological structure of distribution systems. The BIBC matrix represents the relationship between bus current injections and branch currents. The corresponding variations at branch currents, generated by the variations at bus current injections, can be calculated directly by the BIBC matrix. The BCBV matrix represents the relationship between branch currents and bus voltages. The corresponding variations at bus voltages, generated by the variations at branch currents, can be calculated directly by the BCBV matrix. The time-consuming LU decomposition and forward/backward substitution of the Jacobian matrix or admittance matrix required in the traditional Newton Raphson and Gauss implicit Z matrix algorithms are no longer necessary. The treatments for weakly meshed distribution systems have also been included. This method is robust and time-efficient compared to the conventional methods and has great potential to be used in distribution automation applications.

2.3 CONDUCTOR SIZING

F.W. Walkden [22] has suggested a method for the design of low voltage distributors from cables of different sizes by minimizing volume of conductor and taking voltage regulation as limiting factor with uniformly distributed load and solved it by an analytical method based on study made by Davies [23]. Ramirez and Gonen [24] employed a mixed-integer programming method to take into account the discrete values for conductor sizes, but this method can't deal with a large-scale distribution system. Based on the needs for both the total cost decrease and the high quality of voltage, the optimization problem of conductor size selection has been studied. Ponnavaikko and Rao [25] made an attempt for optimal distribution system planning through conductor gradation by developing a method based on dynamic programming approach for straight radial distribution feeder considering the aspect of non uniform loading conditions. However, this method still can't handle a large size system. Tram and Wall [26] proposed an improved algorithm. Although their algorithm is based on realistic assumptions and reliable optimization techniques, it is relatively complicated to be handled by utility engineers, and needs a sophisticated software to yield the solution. Wang et al [27] have used certain fundamental mathematical models developed in [25]. The approach includes an economical current density based method and a heuristic method, which together enable a satisfactory solution to be quickly achieved. The authors have considered the standardized types of conductors. The approach stays away from complicated optimization formulations and instead relies on reasonable approximations, and thus makes it very easy for utility engineers to adopt.

2.3 ALLOCATION OF SHUNT CAPACITORS

The installation of shunt capacitors on radial distribution systems is essential for power flow control, improving system stability, power factor correction, voltage profile management, and losses minimization. Therefore, it is important to find the optimal size and location of capacitors required to minimize feeder losses (power and energy), and the suitable time to switch the capacitors on and off. It was in 1940s that the application of shunt capacitors on distribution system for power factor improvement started.

Schmill [28] studied that the optimum location, sizing and timing of capacitor banks on feeders with uniformly distributed loads and randomly varying spot loads to evaluate reduction in costs of active and reactive losses without taking into account voltage regulation problem. He suggested a procedure of moments of the loads with respect to feeder's resistance or reactance to calculate optimum ratings and locations of capacitor banks installed on a distribution feeder. Duran [29] used dynamic programming technique for obtaining optimum number, location and size of shunt capacitors in a radial distribution feeder with discrete lumped loads, by minimising savings due to reduction in power and energy losses against the cost of capacitors. Chang [30] represented feeders by a number of line segments feeding combination of concentrated and uniformly distributed loads and developed a method for locating and sizing capacitors on primary feeders by maximising total return due to reduction in peak power losses and energy losses against costs of capacitor banks. Later he developed generalised equations for calculating power and energy loss reduction in a feeder, considering both concentrated and uniformly distributed loads. Ponnavaikko and Rao [31] suggested a method for an optimal choice of fixed and switched capacitors on randomly and discretely loaded radial feeders. The objective function consisting of cost saving due to energy loss reduction and release in other system capacitors less cost of capacitor bank is maximised, subject to voltage rise constraint during off peak hours. The load growth, growth in load factor and increase in cost of energy is considered in their model.

Heuristic search techniques were introduced for distribution system loss reduction first by reconfiguration. Civanlar et al [32] presented a formula for estimating the change in loss, caused by the transfer of a group of loads from one feeder to another by the closing and opening of some connecting switches. Taylor and Lubkeman [33] developed a feeder reconfiguration strategy using heuristics for the removal of transformer overloads and feeder constraint problems. Recently, researchers adapted the ideas presented in [32] and [33] to the field of capacitor placement for reactive power compensation in distribution feeders. Salam et al [34] proposed a heuristic strategy to reduce system losses by identifying sensitive nodes at which capacitors should be placed. These nodes are determined by first identifying the branch in the system with largest losses due to reactive currents. Then the node, which contributes the largest load affecting the losses in that branch, is selected as the candidate node. The capacitor size is the value that yields minimum system real losses. This method does not guarantee a minimization in the cost function or maximization in the net saving function. Jayaram et al [35] have modified the method of [34] to overcome this disadvantage, thus their technique attained good results in loss and cost reductions but they are still not the best reductions that can be achieved. Haque [36] proposed a method of minimizing the loss associated with the reactive component of branch currents by placing optimal capacitors at proper locations. The method first finds the location of the capacitors in a sequential manner. Once the capacitor locations are identified, the optimal capacitor size at each selected location for all capacitors is determined simultaneously, to avoid overcompensation at any location, through optimizing the loss-saving equations. This involves the solution of a set of linear algebraic equations. The disadvantage of this method is that it neglects the cost-benefit analysis which, in turn, depends on the cost of capacitor bank and energy saving. Mekhamer et al [36] extended previous heuristic works. They have introduced two new techniques that lead to better results. The first technique is to place a capacitor with such a size and location so that the system cost reduction is maximized whereas the second technique is to place a capacitor with a size and at a location so that the system-loss reduction is maximized. These new techniques can be considered as a generalization of previous heuristic approaches for capacitor placement in radial distribution feeders.

CHAPTER 3

GEOGRAPHIC INFORMATION SYSTEM

3.1 What Is GIS?

The term GIS is an acronym, which is commonly used in reference to Geographic Information Systems. A geographic information system is a system for management, analysis and display of geographic knowledge, which is represented using a series of information sets such as maps, geographic data sets, processing and work flow models, data models, and metadata. Although many definitions for GIS exist, most users agree that a GIS is a network of computer software, hardware, spatial data, procedures, and personnel. This network is primarily used to collect, manipulate, analyze, and present information that is linked to a location on the earth's surface. However, the real power of a GIS lies in its ability to uncover spatial relationships and patterns within data that may not be revealed using other methods. Today, GIS technology plays an ever-increasing role in the decision-making process for a variety of governmental agencies, commercial businesses, and educational institutions.

3.2 Definition of GIS

The definitions of GIS from three of the leaders in field of geographic information systems technology are given in the subsequent paras. As seen from each definition, the components that make up a GIS and the functions they perform are fundamentally the same.

3.2.1. Environmental Systems Research Institute (ESRI). The world leader in Geographic Information System software and technology, defines a GIS as:

"An arrangement of computer hardware, software, and geographic data that people interact with to integrate, analyze, and visualize the data; identify relationships, patterns, and trends; and find solutions to problems. The system is designed to capture, store

and update, manipulate, analyze, and display the geographic information. A GIS is typically used to represent maps as data layers that can be studied and used to perform analyses".

3.2.2. United States Geological Survey (USGS). The Federal source for science about the Earth, defines a GIS as:

"A GIS is a computer system capable of capturing, storing, analyzing, and displaying geographically referenced information; that is, data identified according to location. Practitioners also define a GIS as including the procedures, operating personnel, and spatial data that go into the system".

3.2.3. Pennsylvania Spatial Data Access (PASDA). The official geo-spatial information clearinghouse for the state of Pennsylvania, defines a GIS as:

"A Geographic Information System is a system of computer software, hardware and data, and the personnel that make it possible to enter, manipulate, analyze, and present information that is tied to a location on the earth's surface".

As can be seen, the key components of a GIS network are computer hardware, software, spatial data, procedures and personnel. In addition, each definition recognizes the fact that a GIS is chiefly used to collect, manipulate, analyze and present information that is linked to a location on the earth's surface.

3.3 Components of a GIS

A Geographic Information System is a network of computer software, hardware, spatial data, procedures, and personnel. The network of GIS components provides a framework in which users can access, utilize, and share spatial information via the Internet or an intranet. The GIS components themselves are used for collecting, manipulating, analyzing, and presenting information that is tied to a location on the earth's surface. Procedures such as methods, flowcharts, scripts and data models can also be incorporated into the network when data analysis becomes complex or tedious. As with other types of technology, users must first be trained in utilizing these components before they can become proficient in their use.

The components are divided into five individual parts:

(a) Hardware
(b) Software
(c) Spatial data
(d) Procedures
(e) Personnel

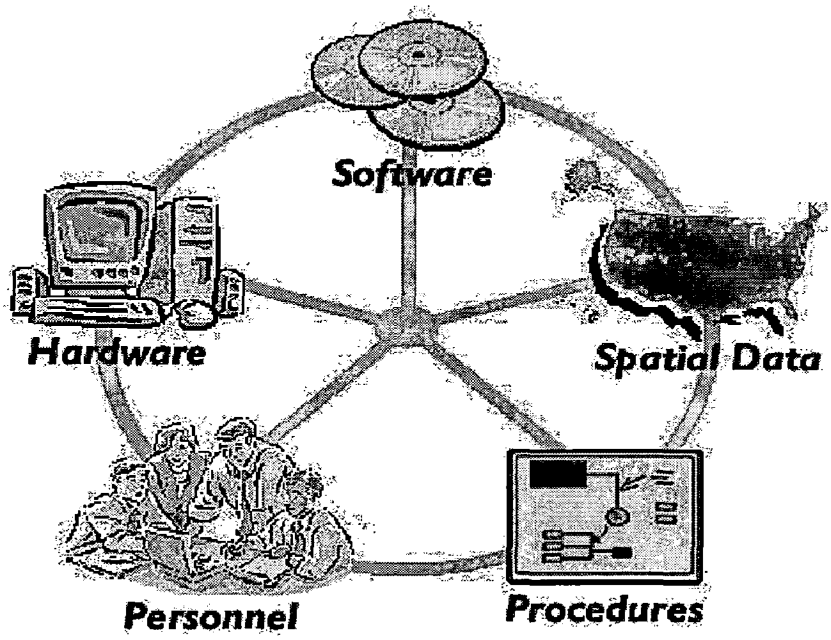


Fig 3.1 components of GIS

3.4 Gathering the Spatial Information

Gathering the spatial information is carried out on GIS platform. To begin with, the city map, which is digitalized, is divided into few layers such as road layer, resident layer, school layer, commercial centre layer, industrial park etc. To each section, the area of each land style in existence and the blank area likely to be used in the future development are analyzed. Three aspects reflect the section characteristic viz

(a) The condition of the section itself, e.g. the flatness, and whether the town planning restricts the development;

(b) The distance index of the section, e.g. the distance between the section and the centre of town and the road and the school;

(c) The environment factors, e.g. the commercial status around the section and number of the resident.

All of these characteristics can be picked up from GIS system.

3.5 GIS in Distribution System

GIS is a system of mapping of complete electrical network including low voltage system and customer supply points with latitude and longitudes overloaded on satellite imaging and/or survey of India maps. Layers of information are contained in these map representations. The first layer corresponds to the land background containing roads, landmarks, buildings, rivers, railway crossings etc. The second layer corresponds to the distribution network coverage. The next layer could contain information on the equipment viz poles, conductors, transformers etc. Most of the electrical network/equipment has a geographical location and the full benefit of any network improvement can be had only if the work is carried out in the geographical context. Even while doing something as relatively simple as adding a new service connection; it is vital to know that users of the system are not affected by this addition. GIS in conjunction with system analysis tools helps to do this. The integration of GIS can be done as shown in Fig 3.2.

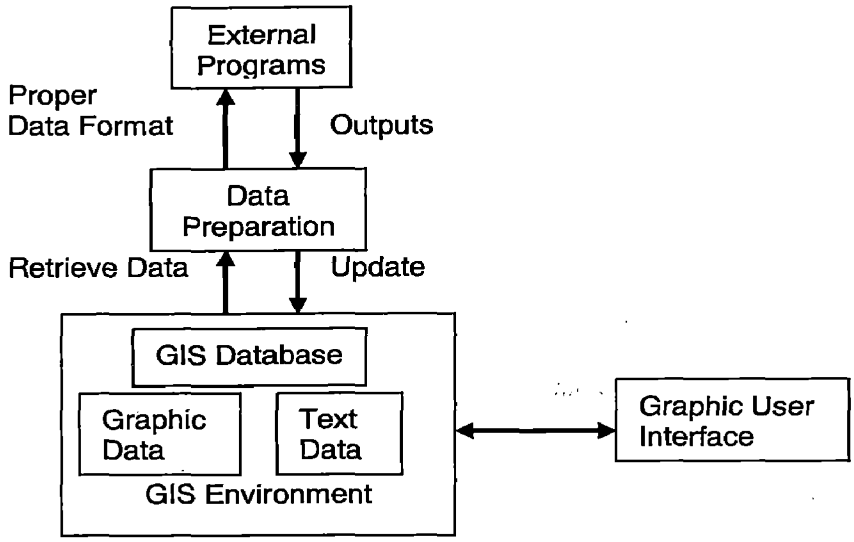


Fig 3.2 GIS Integration

GIS has been use in a number of applications by Electrical Engineers. It has been used for Load Estimation (LE), Optimal Planning of Substation Location, Management of sub-transmission and distribution system, automated selection of primary router etc.

GIS when integrated with real time SCADA can help in sending the right signals to the communication network. Outages can be isolated faster than even before and maintenance crews dispatched with critical information including location of the fault.

Thus the use of GIS in distribution system planning (DSP) is inevitable. DSP is a complex systemic project and requires a great deal of the city development history data, analysis of city network and future city development. DSP involves a great amount of spatial information. DSP must have a platform, i.e. GIS platform, to correlate the characteristic of distribution planning. GIS platform not only provides an environment of distributing devices' spatial data (e.g. location, shape and connecting relation) correlating with the properties' data, but also supplies the analytical tools (devices' connection analysis, shortest path analysis) which allow the distribution system exploring staff to solve the professional problem on high point.

The mode of planning will change by introducing GIS platform into DSP.

Firstly, GIS is convenient for the management of planning data and improve the productivity of planning staff. Meanwhile the planning process is more direct and more interactive.

Secondly, GIS conveniently assists planning staff to decide location of the selected substation and corridor of aerial-wire and path of cable, which may shorten the searching scopes of optimal planning procedure and let the planning result more accordant with the practice.

Thirdly, the introduction of GIS platform can synchronize the DSP with the city planning.

GIS can provide a platform of collecting, processing data and display results. GIS environment hosts a wealth of presentation techniques that enable fast and accurate interpretation of results from power flow results to short circuit analysis.

It is proposed to develop an efficient method for analysis and planning of distribution system using GIS as front-end. In which an effective method will be developed to determine the feeder planning based on the shortest path. A GIS with distribution database, state of the art computer graphics and proposed algorithms are integrated to solve the sizing and siting problems of distribution substations and to perform feeder routing. The GIS provides an environment for building a database which contains both graphic information and non-graphic facility data. The proposed process will provide a physical environment and man-machine interface (MMI) for planners to perform the distribution planning.

CHAPTER 4

LOAD ESTIMATION AND SUBSTATION LOCATION

4.1 Load Estimation

Load estimation is one of the most difficult problems in distribution planning and analysis. Besides the uncertainty of load, another important issue is that there are very few instruments in distribution system and therefore load data can not be obtained from direct measurement. However, not only historical load data of a feeder play a very important role on distribution system planning, but also better load estimates are needed in advanced functions of distribution automation, such as fault isolation, service restoration and demand side management, etc. Although load data are not available directly by measurements, there still exists a lot of information in distribution system, which include billing data, socioeconomic and demographic data, and load survey results, etc. All these information can be mined for abstraction of load information. Therefore, it is necessary to develop a load estimation system, which is able to provide necessary data to distribution planning and analysis.

The knowledge of loads at system buses is one of the most important requirements for efficient operation of power distribution systems. One of the first steps in distribution system planning is to forecast the loads, loads which the system has to supply. The load estimation used in electrical systems planning must consider not only the future loads, but also their geographical positions, for permitting the designer to locate and to dimension the electrical equipment. The load estimation influences various aspects of distribution system planning such as peak load demand period, transformer sizing, conductor sizing, capacitor placement, and so on. Hence, the load estimation is a problem of special interest.

The aim of the distribution planner is to determine the load magnitude and its geographic location; then the distribution substation must be placed and sized in such a way as to serve the load at maximum cost effectiveness by minimizing feeder losses and construction costs, while considering the constraint of service reliability.

One of the methodologies for load estimation is to divide the service area of the power distribution system into polygons called 'Sectors', each having a load point at its centroid. The load magnitude of each sector is the product of the load density and the area of the sector.

4.2 Substation Location

The decision of the location of substations is a crucial aspect of the distribution system planning, with a strong impact on the investment and operation costs. The distribution substations must be placed and sized in such a way as to serve a certain load at minimum cost. The location of a substation site depends upon several factors, such as the voltage levels, voltage regulation, load density, geographical limitations, substation costs, primary feeders, distribution transformers, and sub transmission costs, etc. In a large distribution system, the number of possible choices is extremely large. To determine the least system cost that satisfies the load requirements is not an easy task. The points to be borne in mind while selecting the location for a distribution substation are as follows:-

- The substation must be as close as possible to the load center of its service area, in order to reduce the product of the load and the distance from the substation.
- Proper voltage regulation can be obtainaed without taking extensive measures.
- Provide proper access for incoming sub transmission lines and outgoing primary feeders and also allow future growth.
- Provide enough space for the future substation expansion.
- Comply with land use regulations and local ordinances.
- Reduce the number of customers affected by any service discontinuity.
- Other considerations such as adaptability, emergency, etc.

The purpose of a substation is to take power at high voltage from the transmission or sub-transmission level, reduce its voltage, and route it onto a number of primary voltage feeders for distribution in the area surrounding it. In addition, it performs operational and contingency switching and protection duties at both the transmission and feeder levels, and provides a convenient local site for additional equipment such as communications, storage of tools, etc.

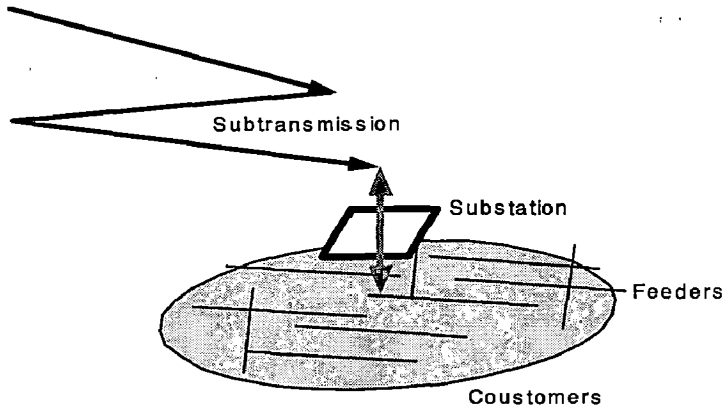


Fig 4.1 Substation as a Link

Substations are more important to system performance and economy than their cost alone as they are the meeting place of the transmission and distribution systems, and therefore play an inordinately large role in influencing the cost and performance of both these levels as well as their own. From the cost and reliability standpoint, their interaction with the transmission and distribution systems is often more important than they themselves, in the sense that their influence on transmission and distribution reliability and costs often outweighs their own costs and reliability contributions. Thus, in many ways, good planning of the substation level is the key to good distribution system planning. Certainly, poor substation-level planning forfeits any hope of achieving outstanding performance and economy at the distribution level.

Substations represent the end delivery points for the transmission system. They are the sites to which the transmission system must deliver power, and their cumulative demands (the sums of all feeder loads at each substation) are the loads used in transmission level planning (e.g., load flow analysis generally lumps all the feeder loads into a single demand at each site). Substations' performance and economy interact greatly with the transmission system.

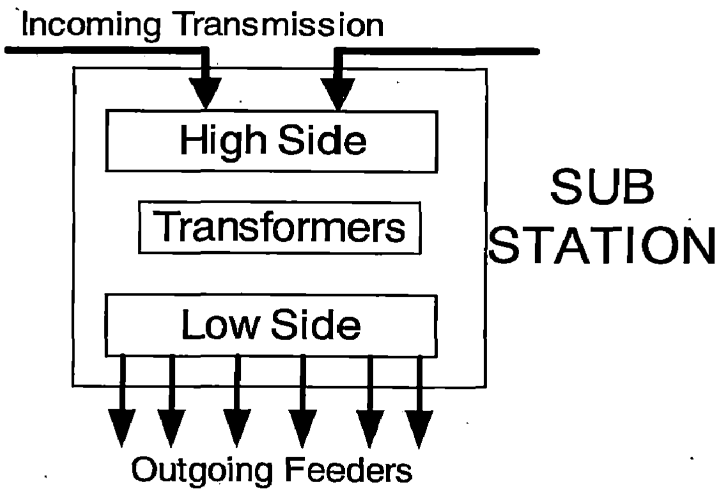


Fig 4.2 Parts of Substation

The substation consists of four fundamental parts: -

- The site
- The incoming transmission
- The Transformers
- The outgoing distribution feeders

On the low voltage side, substations are the starting points for the feeder system. A set of feeders emanates from each substation, serving the area around it, and in combination with those of other substations, serving the utility's entire load. The location and capacity of the substation materially affects the feeder system attached to it. If the substation is in a poor location from the standpoint of the feeder system, it increases feeder cost and decreases reliability. If it has insufficient capacity, then the feeder system may not be provided with the power it needs at its site, and service or economy may suffer when service has to be provided by substations located at sites farther away.

The method [38] is used to locate the load centres of the load points, which is the optimal site with minimal feeder losses. The site coordinates X_S and Y_S of the load centre are calculated using the following formulae.

$$X_s = \frac{\sum_{i=1}^{n} L_i^2 X_i}{\sum_{i=1}^{n} L_i^2} \qquad Y_s = \frac{\sum_{i=1}^{n} L_i^2 Y_i}{\sum_{i=1}^{n} L_i^2}$$

where,

- (X_S, Y_S) are the coordinates of the Load Centre
- (X_i, Y_i) are the coordinates of the Load Point i
- n is the number of Load Points
- L_i is the demand of Load Point i

CHAPTER 5

OPTIMAL FEEDER SELECTION

5.1 Introduction

The distribution feeders share a major part of the cost of distribution system. Thus, an optimal design of the distribution feeder is an essential activity of the distribution system planning. The feeders are usually radial in configuration. The currents carried by the distribution feeders are always decresing in order from source point to far end load point. Therfore, for an economical design of a feeder should be in accordance with the currents carried by them. This necessisates desining the radial feeder using multiconductor cross sections, so as to minimise the cost of feeder. Thus in this chapter a model for optimal design of milticonductor cross section radial feeder has been developed which is a constrained minimization problem.

5.2 Optimization Problem of Conductor Size Selection

The optimization problem of conductor size selection in planning radial distribution systems is to select the conductor sizes with the minimal total cost under the constraints of:

- Maximum allowable voltage drop,
- Demand/supply balance, and
- Radial configuration.

For the sake of simplicity, the following assumptions have been made:

A. Only a peak load for a planning period of one year is considered.
B. The feeder configuration is known.

5.3 Formulation of the Optimization Problem

The optimization problem [27] can be formulated as an integer programming problem as follows:-

5.3.1 Objective Function:

$$\min C_c=\sum_{k=1}^{b}\left[\cdot\left(P_k^2+Q_k^2\right)/A_k+\cdot A_k\right]L_k \qquad (5.1)$$

where,

- C_c is the cost to be minimized, which involves the areas of conductor cross-sections;
- b is the number of all feeder segments;
- P_k and Q_k are respectively the real and reactive powers through feeder segment k in the base year ($P_k > 0$ and $Q_k > 0$);
- A_k is the decision variable for the area of conductor cross-section of feeder segment, which takes one of the discrete values of cross-section areas for the conductors available in the inventory;
- L_k is the length of feeder segment ;
- β is a constant concerning the variable installation cost of the line, which can be determined from the cost versus conductor cross-section characteristic of the line;
- α is a constant related to the peak power/energy losses costs, and can be formulated as follows:

$$\alpha = 26.28\rho\left[\sum_{k=1}^{M}\frac{(1+g)^{2k}(LLF)_{kCk}}{(1+r)^k}+(1+g)^{2M}(LLF)_M\sum_{k=M+1}^{N}\frac{C_k}{(1+r)^k}\right]\Big/ V_N^2 \qquad (5.2)$$

where,

- ρ is the resistivity of conductor material;
- M is a plan period up to which the line can take load growth;
- g is an annual load growth rate;
- $(LLF)_k$ the loss load factor in the k^{th} year;
- C_k is the cost of energy in the k^{th} year;
- r is an annual discount rate;
- N is the life period of line;
- V_N is the rated phase-to-phase voltage of distribution line.

Thus, it can be seen that α and β are not fixed parameters for all cases, but dependent on some other technical and economic parameters.

5.3.2 Constraints

a) Condition for radial configuration

$$b = n-1 \qquad \text{(with connected graph)} \qquad (5.3)$$

where, *n* is the number of all nodes.

b) Kirchhoff's current law

$$\sum_{k \in B_i} \cdot_k \left(P_k + jQ_k\right) = S_i \qquad (i\ .\ N_1) \qquad (5.4)$$

where,

- $\cdot_k$ is 1 or -1 (if P_k enters node i, $\cdot_k$ is 1; otherwise, $\cdot_k$ is -1);
- B_i is the set of the line segments directly connected to node i;
- S_i is the load demand at node;
- N_1 is the set of the nodes excluding the substation node.

c) Node voltage constraints

$$\sum_{k \in M_i} L_k \left(\rho P_k / A_k + Q_k x\right) / V_N \le \Delta\overline{V} \qquad (i\ .\ N_2) \qquad (5.5)$$

where,

- x is the per-phase, per-kilometer reactance of distribution line, which is assumed constant for a given range of conductor sizes;
- M_i is the set of the feeder segments through which load S_i flows;
- $\Delta\overline{V}$ is the value of maximum allowable voltage drop;
- N_2 is the set of the end nodes of radial feeders.

5.4 Solution Methodology

In this section, the practical approach has been described and discussed. This approach combines two methods, namely an economical current density based method and a heuristic method, and, thus, allows one to efficiently find the cross-section areas. The heuristic method employs an index, the ratio of cost increase to voltage decrease because of the change in conductor size, and thus is called "RCV index method" hereafter.

5.4.1 Economical Current Density Based Method

Given the feeder configuration, the economical current density based method is employed to obtain initially selected cross-section areas (referred to as "initial cross-section areas" hereafter) and approximate power flows for all feeder segments, with (5.5) being ignored. The approximate power flows can be found by using the same V_N for all node voltages and the initial cross-section areas. For the problem of conductor sizing, the approximate power flows can result in less computational effort compared to the actual power flows, and also produce satisfactory results. For any line segment *k*, with its power flows being known, a continuous value A_k of its cross-section area can be given from (5.1) by

$$A_k = \sqrt{\alpha\left(P_k^2 + Q_k^2\right)}/\beta \qquad (5.6)$$

For the feeder segments starting from the far (or end) ones and moving along all the feeder branches toward the substation node, alternate the following activities:

i) Find their approximate power flows by employing the node power balance method of power flow analyzes and

ii) Calculate their A_k's by (5.6), and then determine their initial discrete cross-section areas, which result in, less costs between their two optional cross-section areas (whose values are, respectively, next to their corresponding A_k's) or which are, respectively, their only available cross-section areas (next to their corresponding A_k's).

If the initial cross-section areas can satisfy (5.5), an optimal solution has been achieved; otherwise, they should be modified by the following heuristic method, and, for any line segment, the cross-section areas whose values are smaller than that of its initial one, shouldn't be taken into account afterwards.

5.4.2 RCV Index Method

Based upon the previously obtained cross-section areas, the RCV index method can be employed:

i) To dynamically produce a priority list of the indexes to be defined below, and, thus,

ii) To efficiently find the improved cross-section areas for the line segments in a radial branching feeder so as to meet the requirements of (5.5).

Fig.5.1 shows a flow chart of this method.

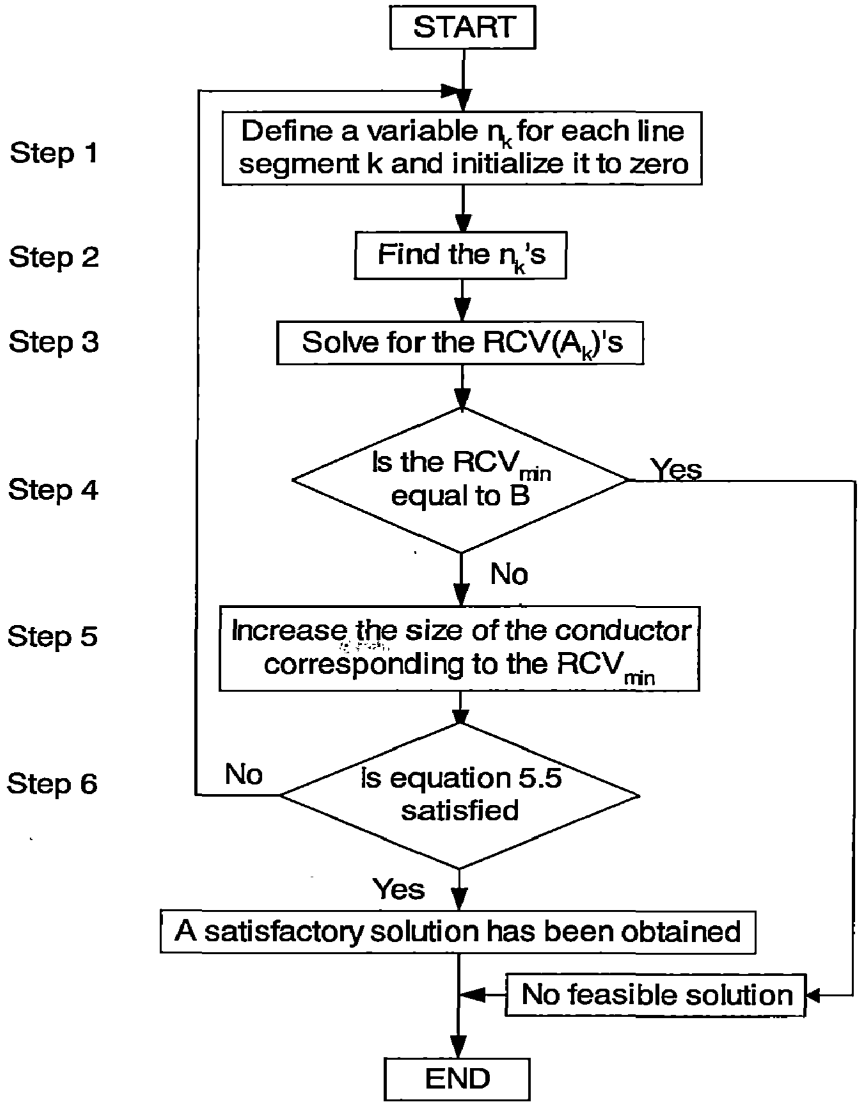


Fig 5.1 RCV Index Method

The steps for the algorithm are as follows:

Step 1 Define a variable n_k for any line segment k and initialize it to zero.

Step 2 For each end node, find the voltage drop between it and the substation node; if a voltage drop exceeds $\Delta\overline{V}$, increase by 1 the n_k's for the line segments through which the load at the corresponding end node flows.

Step 3 Assume that the cross-section area A_k for any line segment is replaced with an immediately greater one A_k' available and define a $RCV(A_k)$ index as being directly proportional to the resulting increase in C_c and inversely proportional to both the n_k and the resultant decrease in voltage drop. Therefore, from (5.1) and (5.5), RCV (A_k) may be given by

$$RCV(A_k) = [\beta A_k A_k' - \alpha(P_k^2 + Q_k^2)]/(P_k n_k) \quad (5.7)$$

Note: If n_k =0 or there is not any greater available cross-section area compared with A_k, let RCV (A_k) =B (a very large number).

Step 4 If the smallest value RCV_{min} among the existing RCV (A_k)'s equals B, stop with no feasible solution.

Step 5 Replace the cross-section area corresponding to the existing RCV_{min} with an immediately greater one available.

Step 6 If (5.5) still can't be satisfied; go to Step 1; otherwise, stop with a near-optimal solution, namely the existing cross-section areas A_k's.

Here the points to be noted are:

i) The direction of the indexes in the RCV index method is to efficiently find a relatively accurate solution, as the increase in the size of the conductor of the RCV tends to result in less total cost provided that the same amount of voltage drop decrease is achieved,

ii) The RCV index method can't assure us that the resulting cross-section areas provide the optimal solution, because the value of a RCV(A_k) is independent of the corresponding voltage drop decrease, and

iii) The RCV index method can produce a satisfactory approximately optimal solution, as the replacement of one conductor size by an immediately greater size can generate only very small changes in both voltage drop and total cost.

5.4.3 Combined Usage of the Two Methods

The approach is an organic combination of the economical current density based method and the heuristic RCV index method, and is applicable to all types of radial feeders in practice. Its main steps can be summarized as follows:

Step 1 Obtain the approximate power flows and initial cross-section areas for all the feeder segments through the use of the economical current density based method.

Step 2 If the initial cross-section areas can satisfy (5.5), stop with the found cross-section areas being optimal; otherwise, proceed to Step 3.

Step 3 Modify the initial cross-section areas by the RCV index method.

CHAPTER 6

LOAD FLOW ANALYSIS

Load flow is a very important and fundamental tool for the analysis of any power system and is used in the operation as well as planning stages. Certain applications particularly in distribution automation and optimization of a power system require repeated load flow solutions. In these applications it is very important to solve the load flow problem as efficiently as possible. The distribution networks are inherently ill conditioned because of their radial configuration, and high resistance to reactance ratio. So the traditional load flow methods used in transmission systems, fail to meet the requirements both in performance and in robustness aspects in the distribution system applications.

Several load flow algorithms specially designed for distribution systems have been proposed in the literature but these methods do not explicitly exploit the radial and weakly meshed network structure of distribution systems and, therefore, requires solving a set of equations whose size is proportional to the number of buses. Recently researches have proposed some new ideas on how to deal with the special topological characteristics of distribution systems, but these ideas require new data format or some data manipulations. To overcome these difficulties a new algorithm has been proposed by J H Teng [21].

The algorithm takes advantage of the topological characteristics of distribution systems and the input data to this algorithm is the conventional bus-branch oriented data. This method does not require the time-consuming LU decomposition and forward/backward substitution of the Jacobian matrix or the admittance matrix which is required in the traditional Newton Raphson and Gauss implicit matrix algorithms. Two matrices namely, the bus-injection to branch-current (BIBC) matrix and the branch-current to bus-voltage (BCBV) matrix are developed and matrix multiplication is done to obtain load flow solutions. This method can also be extended to weakly meshed distribution systems also.

6.1 Three-Phase Line Model

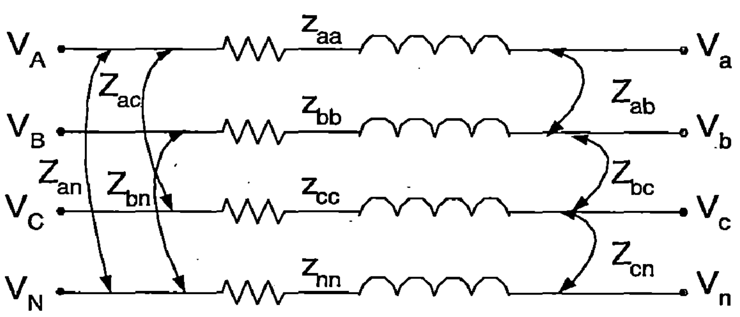


Fig.6.1. Three-phase line section model.

A three-phase line section between bus and *i* and *j* is shown in Fig. 6.1. The line impedances can be obtained with the help of equation (6.1) and (6.2) as given in [39].

$$Z_{aa}=r_a+.0015884.f+j.002022.f(\ln.1/GMR_a+7.6786+.5\ln.R/f) \quad \textbf{(6.1)}$$

$$Z_{ab}=.0015884.f+j.002022.f(\ln.1/D_{ab}+7.6786+.5\ln.R/f) \quad \textbf{(6.2)}$$

A 4x4 matrix, which takes into account the self and mutual coupling effects of the unbalanced three phase line section, can be expressed as

$$[Z_{abcn}]=\begin{bmatrix} Z_{aa} Z_{ab} Z_{ac} Z_{an} \\ Z_{ba} Z_{bb} Z_{bc} Z_{bn} \\ Z_{ca} Z_{cb} Z_{cc} Z_{cn} \\ Z_{na} Z_{nb} Z_{nc} Z_{nn} \end{bmatrix} \quad (6.3)$$

After Kron's reduction is applied, the effects of the neutral or ground wire are still included in this model as shown in (6.4)

$$[Z_{abc}]=\begin{bmatrix} Z_{aa-n} Z_{ab-n} Z_{ac-n} \\ Z_{ba-n} Z_{bb-n} Z_{bc-n} \\ Z_{ca-n} Z_{cb-n} Z_{cc-n} \end{bmatrix} \quad (6.4)$$

The relationship between bus voltages and branch currents for Fig. 6.1 can be expressed as

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} - \begin{bmatrix} Z_{aa-n} Z_{ab-n} Z_{ac-n} \\ Z_{ba-n} Z_{bb-n} Z_{bc-n} \\ Z_{ca-n} Z_{cb-n} Z_{cc-n} \end{bmatrix} \begin{bmatrix} I_{Aa} \\ I_{Bb} \\ I_{Cc} \end{bmatrix} \quad (6.5)$$

In case any of the phase(s) are absent, the corresponding row and column in this matrix will contain null-entries.

6.2 ALGORITHM DEVELOPMENT

The algorithm is based on the bus-injection to branch-current (BIBC) matrix, the branch current to bus-voltage (BCBV) matrix and equivalent current injections.

For bus *i*, the complex load S_i is expressed as

$$S_i = (P_i + jQ_i) \qquad (6.6)$$

And corresponding equivalent current injection at the k^{th} iteration of solution is

$$I_i^k = I_i^r(V_i^k) + jI_i^i(V_i^k) = \left(\frac{P_i + jQ_i}{V_i^k}\right)^* \qquad (6.7)$$

where, V_i^k and I_i^k are the bus voltage and equivalent current injection of bus *i* at the k^{th} iteration respectively. I_i^r and I_i^i are the real and imaginary parts of the equivalent current injection of bus i at the k^{th} iteration respectively.

6.3 Relationship Matrix Development

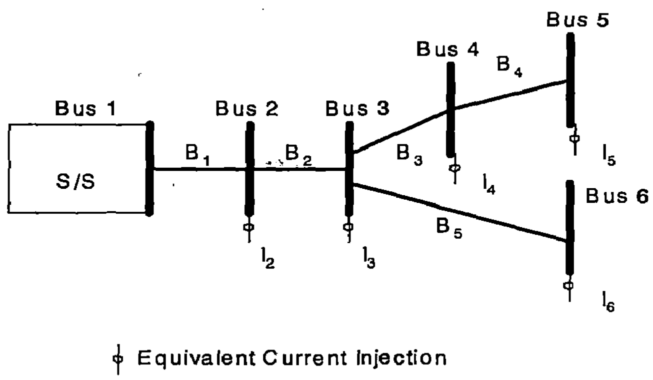


Fig. 6.2 Simple distribution system

Fig. 6.2 shows an example distribution system. The power injections can be converted to the equivalent current injections by (6.7), and the relationship between the bus current injections and branch currents can be obtained by applying Kirchhoff's Current Law (KCL) to the distribution network. Thereafter the branch currents can be formulated as function of equivalent current injections. For example, the branch currents, can be expressed by equivalent current injections as

$$B_1 = I_2 + I_3 + I_4 + I_5 + I_6 \qquad (6.8)$$

$$B_3 = I_4 + I_5$$

$$B_5 = I_6$$

Therefore, the relationship between the bus current injections and branch currents can be expressed as

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} \qquad (6.9a)$$

Equation (6.9a) can be expressed in general form as

$$[B] = [BIBC]\,[I] \qquad (6.9b)$$

where, BIBC is the bus-injection to branch-current (BIBC) matrix.

The constant BIBC matrix is an upper triangular matrix and contains values of 0 and 1 only.

The relationship between branch currents and bus voltages as shown in Fig. 6.2 can be obtained by (6.5). For example, the voltages of bus 2, 3, and 4 are

$$V_2 = V_1 - B_1 Z_{12} \qquad (6.10a)$$

$$V_3 = V_2 - B_2 Z_{23} \qquad (6.10b)$$

$$V_4 = V_3 - B_3 Z_{34} \qquad (6.10c)$$

Where, V_i is the voltage of bus i, and Z_{ij} is the line impedance, between bus i and bus j.

Substituting (6.10a) and (6.10b) into (6.10c), (6.10c) can be rewritten as

$$V_4 = V_1 - B_1 Z_{12} - B_2 Z_{23} - B_3 Z_{34} \qquad (6.11)$$

From (6.11), it can be seen that the bus voltage can be expressed as a function of branch currents, line parameters, and the substation voltage. Similar procedures can be performed on other buses; therefore, the relationship between branch currents and bus voltages can be expressed as

$$\begin{bmatrix} V_1 \\ V_1 \\ V_1 \\ V_1 \\ V_1 \end{bmatrix} - \begin{bmatrix} V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{bmatrix} = \begin{bmatrix} Z_{12} & 0 & 0 & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & Z_{45} & 0 \\ Z_{12} & Z_{23} & 0 & 0 & Z_{36} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} \qquad (6.12a)$$

Equation (6.12a) can be rewritten in general form as

$$[\Delta V] = [BCBV]\,[B] \qquad (6.12b)$$

where, BCBV is the branch-current to bus-voltage (BCBV) matrix.

6.4 Building Formulation Development

From equation (6.9), the building algorithm for BIBC matrix can be developed as follows:

Step1. For a distribution system with *m*-branch section and *n*-bus, the dimension of the BIBC matrix will be *m x (n-1).*

Step2. If a line section (B_k) is located between bus *i* and bus *j*, copy the column of the *i* th bus of the BIBC matrix to the column of *j* th bus and fill a +1 to the position of the *k* th row and the *j* th bus column.

Step 3. Repeat step 2 until all line sections have been included in the BIBC matrix.

From (6.12), a building algorithm for BCBV matrix can be developed as follows.

Step 4. For a distribution system with *m*-branch section and *n*-bus, the dimension of the BCBV matrix is *(n-1) x m.*

Step 5. If a line section (B_k) is located between bus *i* and *j* bus, copy the row of the *i* th bus of the BCBV matrix to the row of the *j* th bus and fill the line impedance (Z_{ij}) to the position of the *j* th bus row and the *k* th column.

Step 6. Repeat step 5 until all line sections have been included in the BCBV matrix.

For a multiphase system, if the line section between bus *i* and bus *j* is a three-phase line section, the corresponding branch current B_i will be a 3 x 1 vector and the +1 in the BIBC matrix will be a 3 x 3 identity matrix. Similarly, the Z_{ij} in the BCBV matrix in (6.4) is a 3 x 3 impedance matrix.

It is seen that the building algorithms of the BIBC and BCBV matrices are similar. In fact, these two matrices can be built in the same subroutine of the computer program. Therefore, the computation resources needed are saved. Since, the building algorithms have been based on the traditional bus-branch oriented database; the time required for data preparation has been reduced.

6.5 Solution Technique Developments

The BIBC and BCBV matrices are developed based on the topological structure of distribution systems. The BIBC matrix represents the relationship between bus current injections and branch currents. The corresponding variations at branch currents, generated by the variations at bus current injections, can be calculated directly by the BIBC matrix. The BCBV matrix represents the relationship between branch currents and bus voltages. The corresponding variations at bus voltages, generated by the variations at branch currents, can be calculated directly by the BCBV matrix. Combining (6.9b) and (6.12b), the relationship between bus current injections and bus voltages can be expressed as

$$[.\ V] = [BCBV]\,[BIBC]\,[I]$$
$$= [DLF]\,[I] \qquad (6.13)$$

And the solution for distribution load flow [DLF] can be obtained by solving equation (6.14) iteratively

$$I_i^k = I_i^r(V_i^k) + jI_i^i(V_i^k) = \left(\frac{P_i + jQ_i}{V_i^k}\right)^* \qquad (6.14a)$$

$$[.\ V^{k+1}] = [DLF]\ [I^k] \qquad (6.14b)$$

$$[V^{k+1}] = [V^0] - [.\ V^{k+1}] \qquad (6.14c)$$

The number of arithmetic operation required for LU factorization is approximately proportional to N^3. For a large value of N, the LU factorization will take a large amount of the computational time. In this load flow method since the LU factorization is not required it saves tremendous computational resources and hence this method is suitable for online operation.

CHAPTER 7

ALLOCATION OF SHUNT CAPACITORS

7.1 Introduction

To improve the voltage regulation and power factor, capacitors have generally been in use. The load such as induction motors, inverters etc demand a high reactive power. The system power factor is further worsened by the reactance offered by the large distribution transformers in the distribution system. At times, excessive shunt compensation leads to undesirable voltage rise and increased energy losses in the system. The feeders are generally radial in configuration with random load tapping at various nodes of the feeder. Thus a feeder section nearer to the source will carry more reactive load as compared to its succeeding sections. To compensate these reactive loads, different sectional capacitor bank placed at one point will not suffice since it may over-compensate some sections whereas others may remain under compensated. Hence a number of capacitor banks, smaller in size as compared to a single capacitor bank, along the feeder main at suitable points should be placed. The installation of capacitor banks nearer to the load points yields maximum benefit. Hence probable locations of capacitor installation are the load points on the feeder. Thus it is essential to know proper number, size and location of capacitors banks along the radial feeder to achieve maximum economy.

In this chapter a heuristic technique for reactive power compensation in radial distribution feeders has been explained.

7.2 Problem Formulation

The total reactive power loss for a distribution system with *n* branches can be written as

$$P = \sum_{i=1}^{n} I_i^2 R_i \qquad (7.1)$$

where I_i and R_i are the current magnitude and resistance, respectively, of branch i. The branch current can be obtained from the load flow solution. This current has two components; active (I_a) and reactive (I_r). Thus, the system losses can be written as

$$P = \sum_{i=1}^{n} I_{ai}^2 R_i + \sum_{i=1}^{n} I_{ri}^2 R_i \quad (7.2)$$

The cost function is defined as

$$S=K_p P+K_{ck} Q_{ck} \quad (7.3)$$

7.3 Method Explanation

The aim is to place a capacitor with such a size and at a location so that the system cost reduction is maximized. The governing equations can be derived as follows: -

If a capacitor of current I_{ck} is placed at a node k, the system losses are

$$P = \sum_{i=1}^{n} I_{ai}^2 R_i + \sum_{i=1}^{k} \left(I_{ri} - I_{rlk}\right)^2 R_i + \sum_{i=k+1}^{n} I_{ri}^2 R_i \quad (7.4)$$

Subtracting (7.4) from (7.2), we obtain the loss reduction as ΔP_k as

$$.\ P_k = -2 I_{ck} \sum_{i=1}^{k} I_{ri} R_i - I_{ck}^2 \sum_{i=1}^{k} R_i \quad (7.5)$$

Assuming that there is no significant change in the node voltage after setting the capacitor and using (7.3), the cost reduction can be defined as

$$\Delta S = K_p\, \Delta P - K_{ck} Q_{ck}$$

$$= -2 K_p I_{ck} \sum_{i=1}^{k} I_{ri} R_i - K_p I_{ck}^2 \sum_{i=1}^{k} R_i - K_{ck} I_{ck} V_k \quad (7.6)$$

where

$$Q_{ck} = I_{ck}\, V_k \quad (7.7)$$

Now define I_{ck} as the value that maximizes the cost reduction, which means that

$$\frac{\partial. S}{\partial I_{ck}} = 0 \tag{7.8}$$

From 7.8 we get

$$I_{ck} = \frac{2K_p \sum_{i=1}^{k} I_{ri} R_i + K_{ck} V_k}{2K_p \sum_{i=1}^{k} R_i} \tag{7.9}$$

Subtracting from (7.9) into (7.5) to (7.7), we get

$$. S_{ck} = \frac{\left[2K_p \sum_{i=1}^{k} I_{ri} R_i + K_{ck} V_k\right]^2}{4K_p \sum_{i=1}^{k} R_i} \qquad 7.10)$$

and

$$(. P)_{max.. a} = \frac{4K_p^2 \left(\sum_{i=1}^{k} I_{ri} R_i\right)^2 - K_{ck}^2 V_k^2}{4K_p^2 \sum_{i=1}^{k} R_i} \tag{7.11}$$

Using (7.7) and (7.9)–(7.11), respectively, we can calculate the size of the capacitor used at a certain node that maximizes the total system cost reduction and we can compute this maximum cost reduction as well as the corresponding loss reduction. As seen from (7.10), the maximum cost reduction is always positive, keeping the term

$$2K_p \sum_{i=1}^{k} I_{ri} R_i$$

positive or negative but having an absolute value that is smaller than $(K_{ck}V_k)$. This is a constraint during implementation of this method. Also, from (7.11) it is seen that the corresponding loss reduction is positive only if

$$4K_p^2\left(\sum_{i=1}^{k} I_{ri}R_i\right)^2 > K_{ck}^2 V_k^2$$

This also has been taken into account at each step of method implementation.

7.4 Algorithm

The steps of the algorithm can be summarized as follows.

I. Run the load flow program for the original uncompensated feeder.

II. Assume that every node is a candidate node and apply (7.7), (7.9)–(7.11). Assume initial capacitor cost as the average cost of all available standards. This value is corrected later after finding the nearest standard capacitor to the resulting size.

III. Select the node that provides the maximum cost reduction so that the evaluated loss reduction and capacitor size are positive.

IV. Take the nearest standard capacitor size to the evaluated value and the corresponding exact capacitor cost value K_{ck}.

V. Set the standard Q_{ck} at this node and perform the load flow calculations again to ensure that no voltage violation takes place. If there is a voltage violation, remove this capacitor and select the next candidate node and go to step IV.

VI. Repeat starting from step II only if the loss reduction and cost reduction are not negative, and the capacitor size at the new candidate node is not negative. Stop if one of these conditions is not met.

CHAPTER 8

THE PROGRAM

In this Dessertation work a GIS based package for Distribution System Planning has been developed. This package uses ArcGIS ArcINFO 9.0 software to manipulate and analyse the data and display the results, Microsoft Visual Basic 6.0 for processing the data and calculation of various electrical parameters, Microsoft Access for creating the database, TURBO C for forming the minimum spanning tree and Visual Basic for applications (VBA) for creating the macros. The package has been made userfriendly by incorporating various help objects and GUIs which become visible when the mouse is taken over the relevant box/button. Various checks have been incorporated in the program and will give appropriate message when any of the criteria is not met. The other codes which have been written for computation of other electrical parameters have been converted either into VBA macros or executable files to make it userfriendly.

When ArcGIS ArcCatalog is invoked, from the start menu the Catalog Tree appears as shown in Fig 8.1.

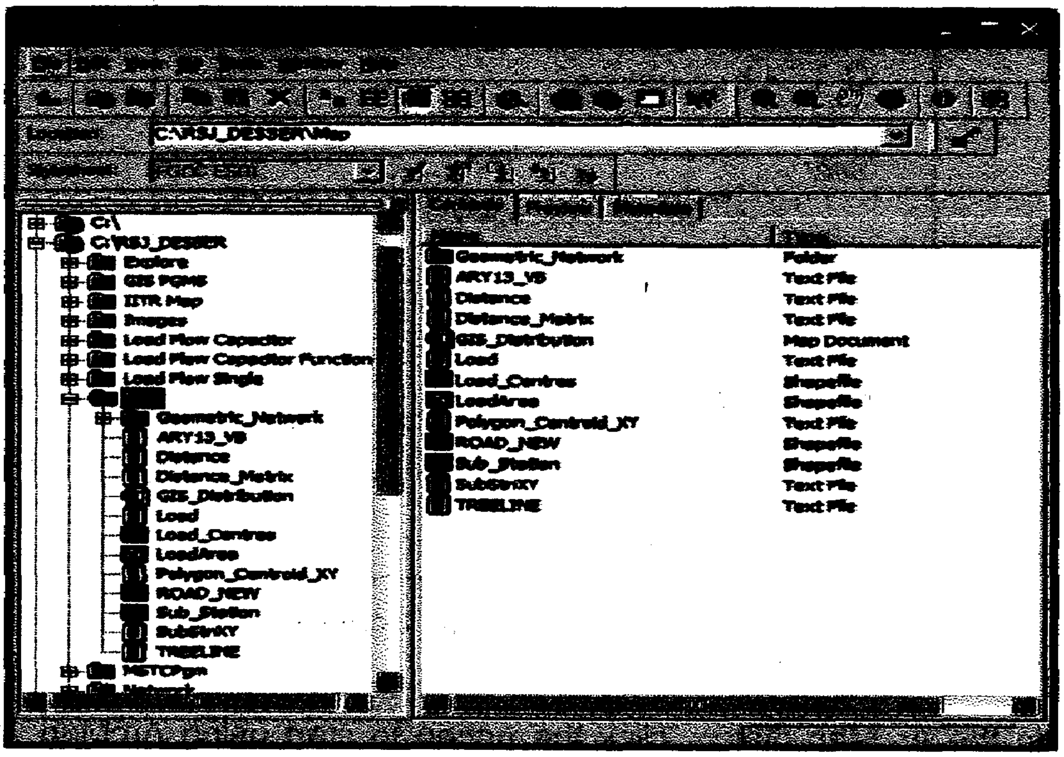


Fig 8.1 The Catalog Tree

The Catalog Tree, which is similar to Microsoft's Windows Explorer, is used to browse the files in the directory. The content of the file can be previewed in the ArcCatalog by selecting the file. A file from the Catalog Tree can be dragged and dropped directly into ArcMap. The files can even be dragged and dropped from ArcCatalog into the Arc Toolbox wizard and tools.

The first task in the planning is to obtain the road map in the digitized form. It can be digitized from a survey map sheet in the ArcMap using the digitizer tool and a digitizer. The digitized map is stored in a shape file with the extension ".shp". In this work a digitized map has been used and the name of the shape file is given as "Road_new". In the Catalog Tree check the spatial reference of the shape file and if you want to modify the spatial reference, it can be done in the Catalog Tree, if so desired. From the ArcCatalog or Start menu, run the ArcMap. Upon entering ArcMap, the ArcMap dialog appears on top of the application window which is shown Fig 8.2.

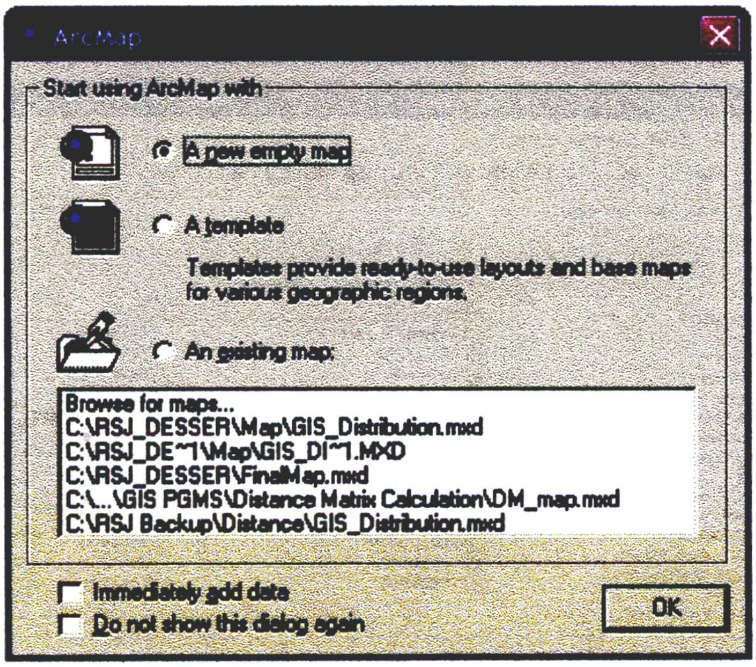


Fig 8.2 ArcMap Dialog Screen

In the ArcMap dialog, click the option to start using ArcMap with a new empty map. If the project has been saved, click the option to start using ArcMap with an existing map. In the scrolling box at bottom of the dialog, the phrase "Browse for Maps...." is highlighted or the maps which have been recently used are also listed, which can be selected with the click of the mouse. Click OK.

Add the file "Road_new" to ArcMap. The ArcMap application window appears as shown in Fig 8.3.

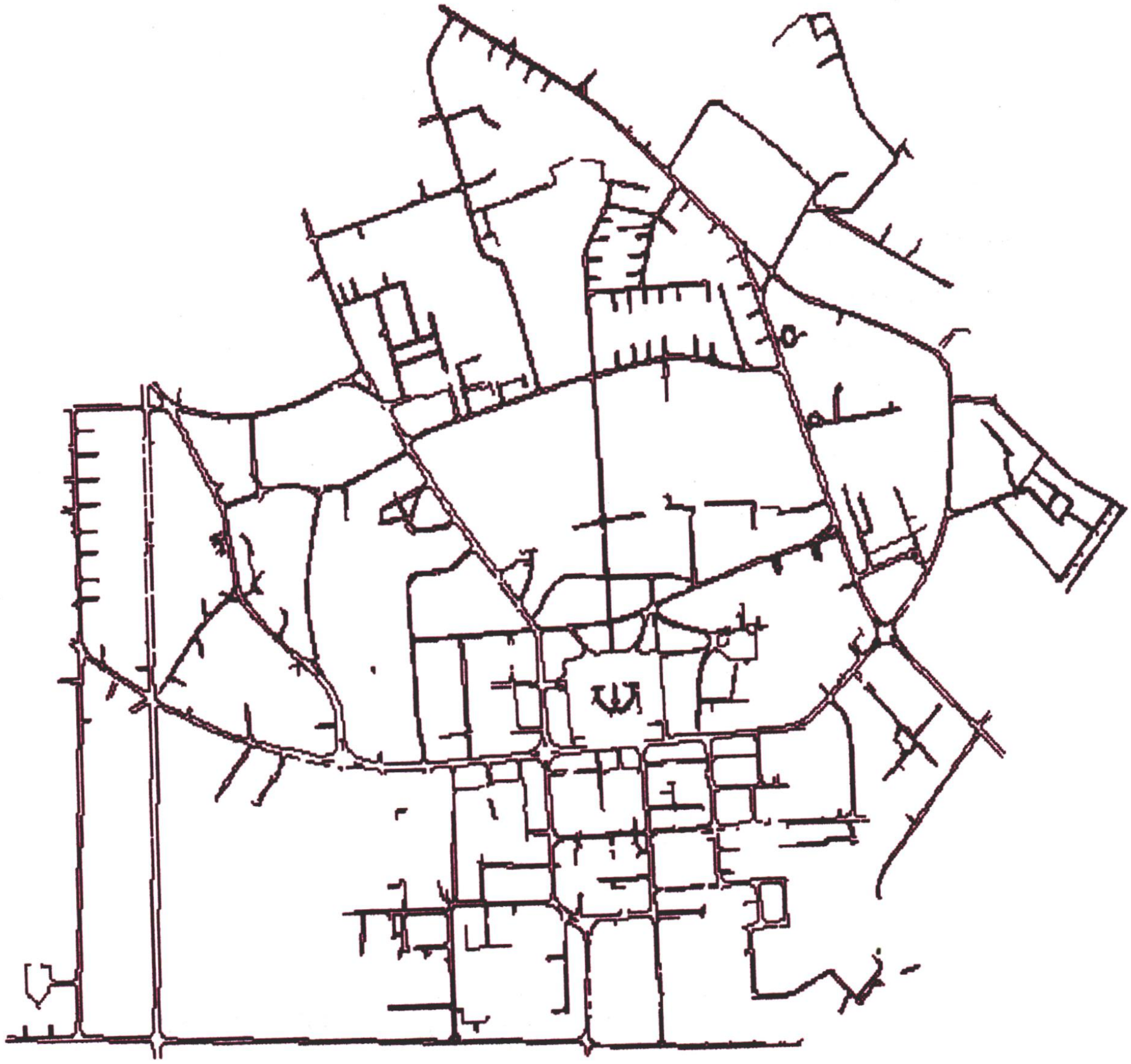
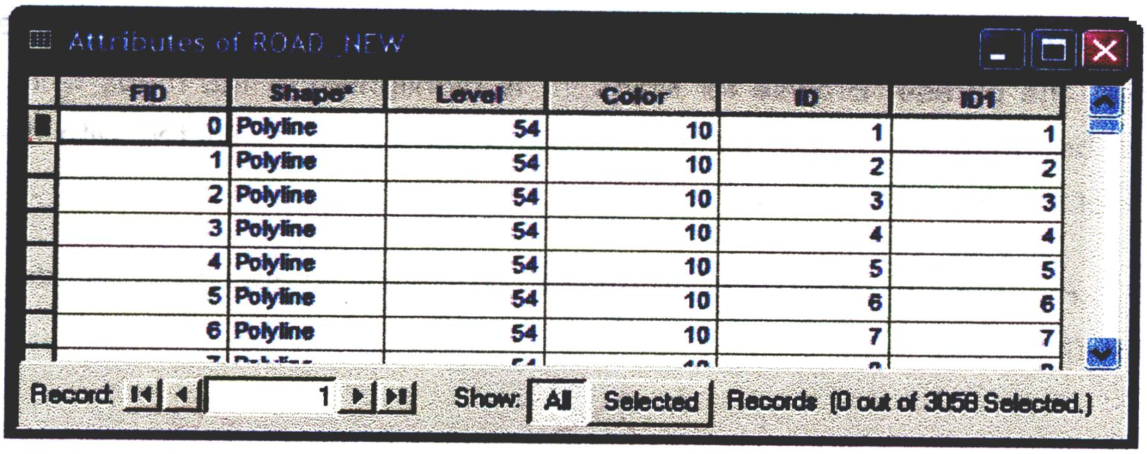


Fig 8.3 Reference Street Map

The extract of the attribute table of the "Road_new" shape file is as shown in Fig 8.4



FID	Shape*	Level	Color	ID	ID1
0	Polyline	54	10	1	1
1	Polyline	54	10	2	2
2	Polyline	54	10	3	3
3	Polyline	54	10	4	4
4	Polyline	54	10	5	5
5	Polyline	54	10	6	6
6	Polyline	54	10	7	7

Fig 8.4 Attribute Table of "Road_new" Shape File

Next task is to create a shape file for depicting the Load Areas. In the Catalog Tree right click the folder in which the new shape file is to be created and point to New and select Shape file as shown in Fig 8.5.

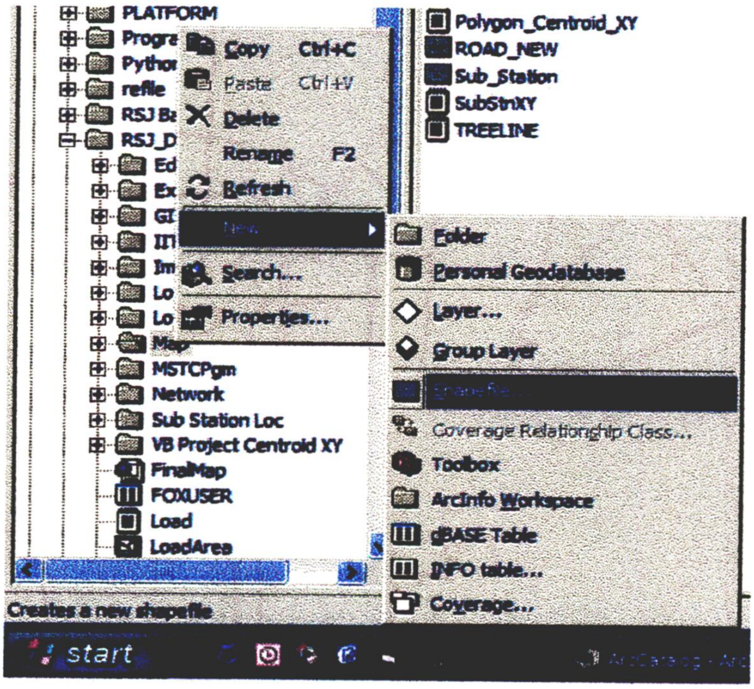


Fig 8.5 Creating a New Shape File

Type the name of the new file as "LoadArea" and the file geometı as Polygon, also import the spatial reference from the "Road_new" shap file and click OK. The new shape file "LoadArea" is created. Add this to th Map. In the Table of Contents the name "LoadArea" appears. Now staı editing this file to create the load areas by drawing the polygons representing the load areas, stop editing and save the edits. To start editing click Editor and select Start Editing as shown in Fig 8.6

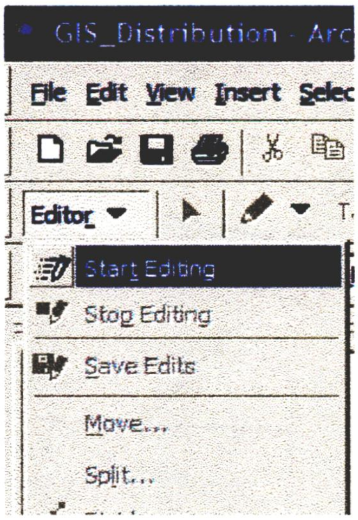


Fig 8. 6 Selection for Start Editing

To Stop editing click Editor and select Stop Editing as shown in Fig 8.7.

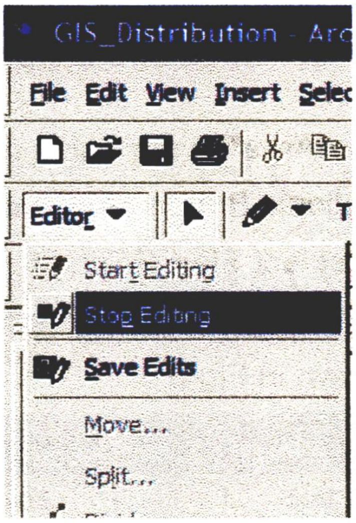


Fig 8. 7 Selection for Stop Editing

The edited "LoadArea" shape file looks as in Fig 8.8. All the polygons are in same colour. Now the colour can be changed to represent the different types of areas based on the Load Density.

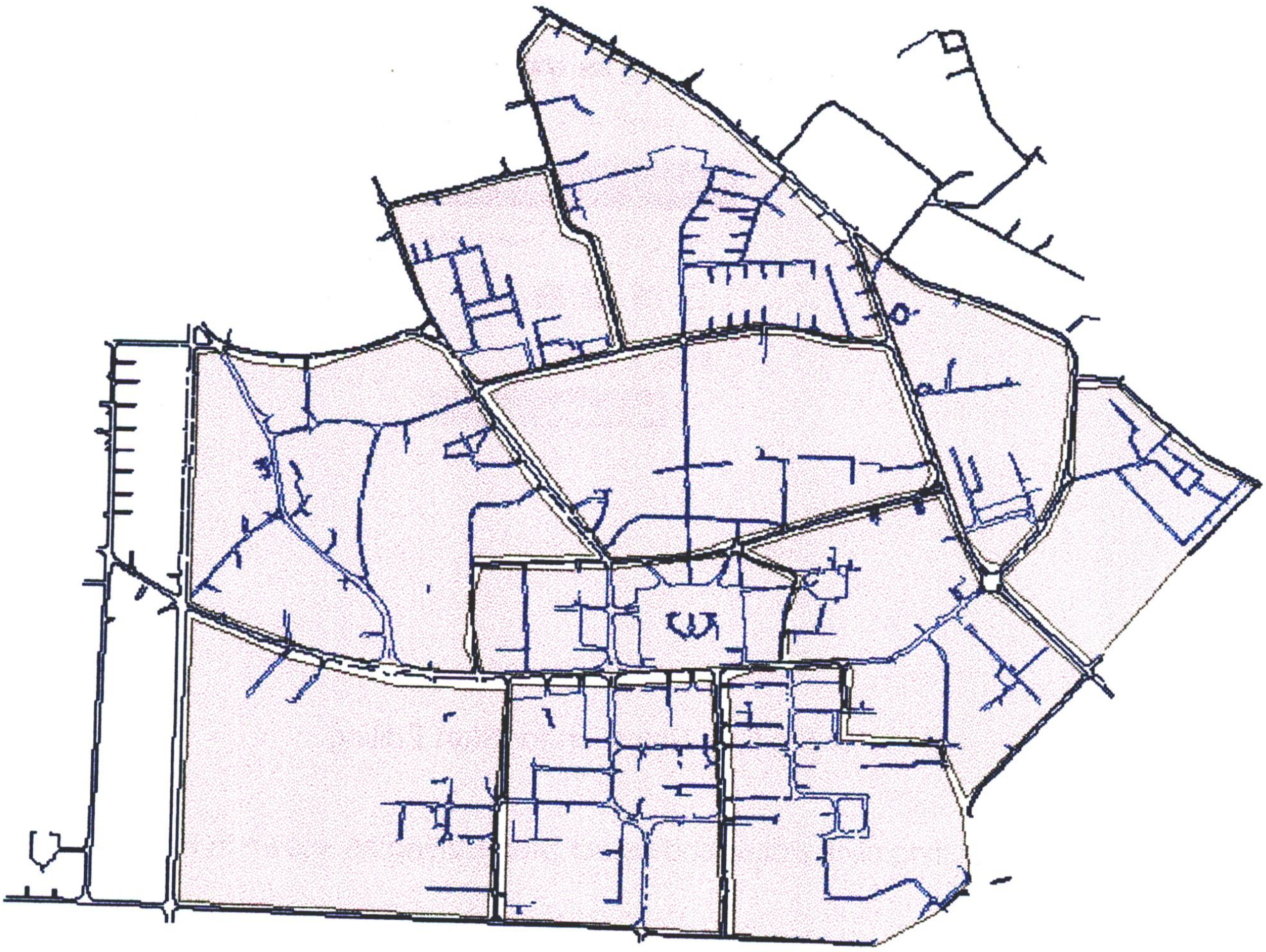
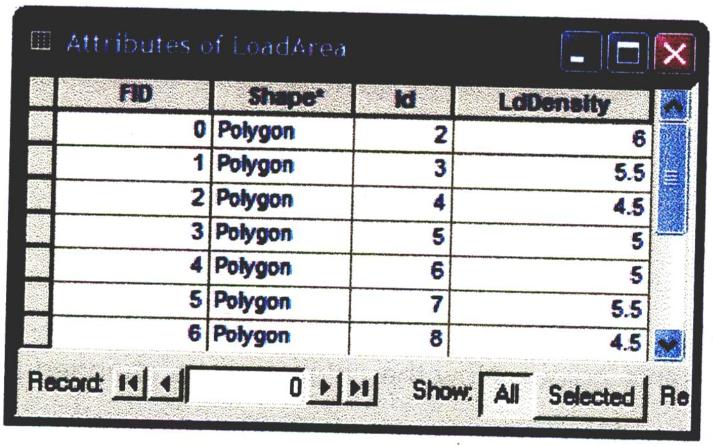


Fig 8.8 Editrd LoadArea Shape File

Now right click on "LoadArea" in the Table of Contents and open the attribute table. Click the Options Button and create a new field named LdDensity. Now click Editor, select Start Editing to add the data in the field. Once the complete data has been added, Stop editing and save data. The attribute table appears as shown in Fig 8.9.



Attributes of LoadArea

FID	Shape*	Id	LdDensity
0	Polygon	2	6
1	Polygon	3	5.5
2	Polygon	4	4.5
3	Polygon	5	5
4	Polygon	6	5
5	Polygon	7	5.5
6	Polygon	8	4.5

Record: 0 Show: All Selected Re

Fig 8.9 Attribute Table of LoadArea Shape File

Right click on "LoadArea" in the Table of Contents and select properties. The Layer Properties window appears as shown in Fig 8.10.

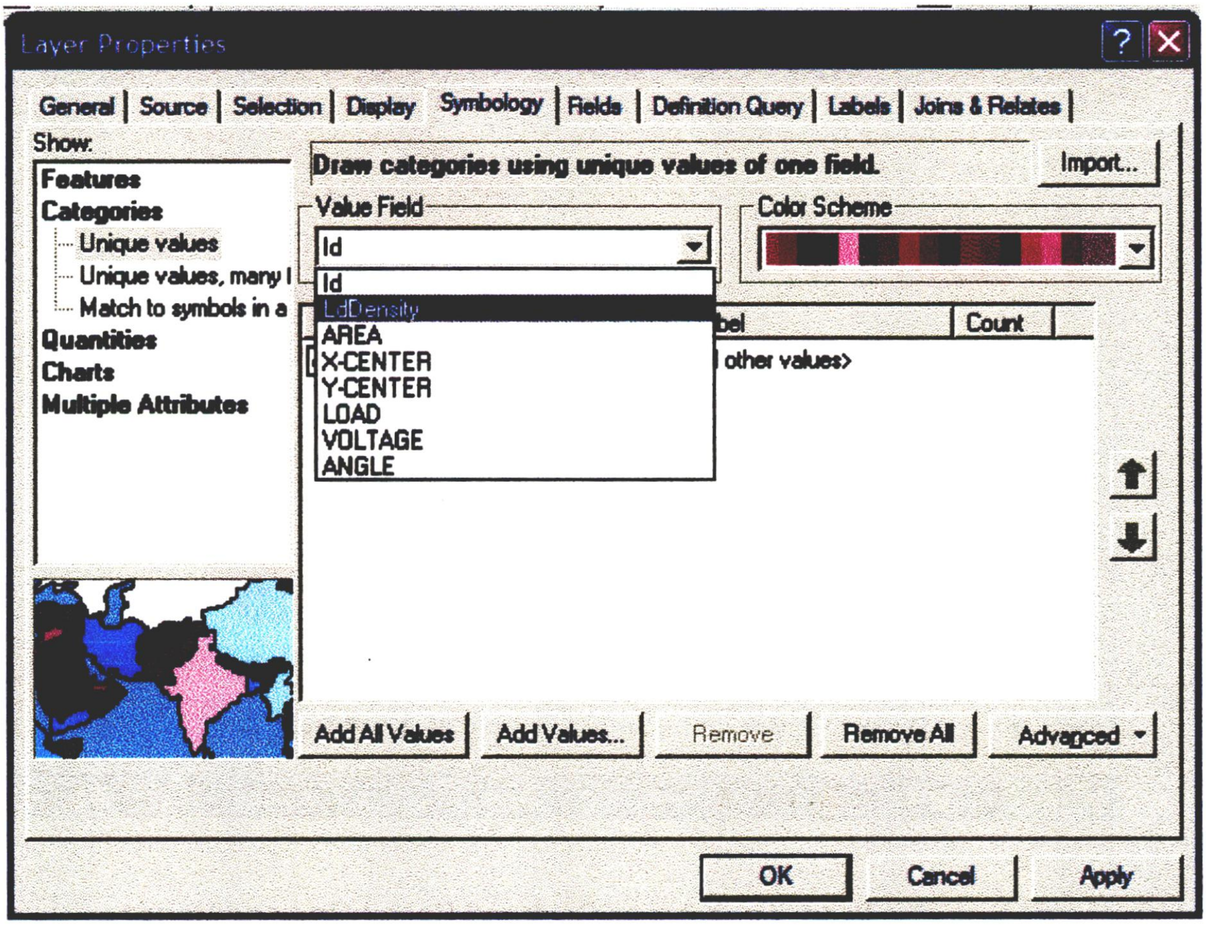


Fig 8.10 Layer Properties Window

Click on the Symbology Tab, choose the Catagories in Show box and set the Value field to LdDensity and click Add All Values Botton and finally click OK. The screen is changed as shown in Fig 8. 11. The colour code given to the load ares corresponds to the Load Density specified in the attribute table. Each colour representing a different load density.

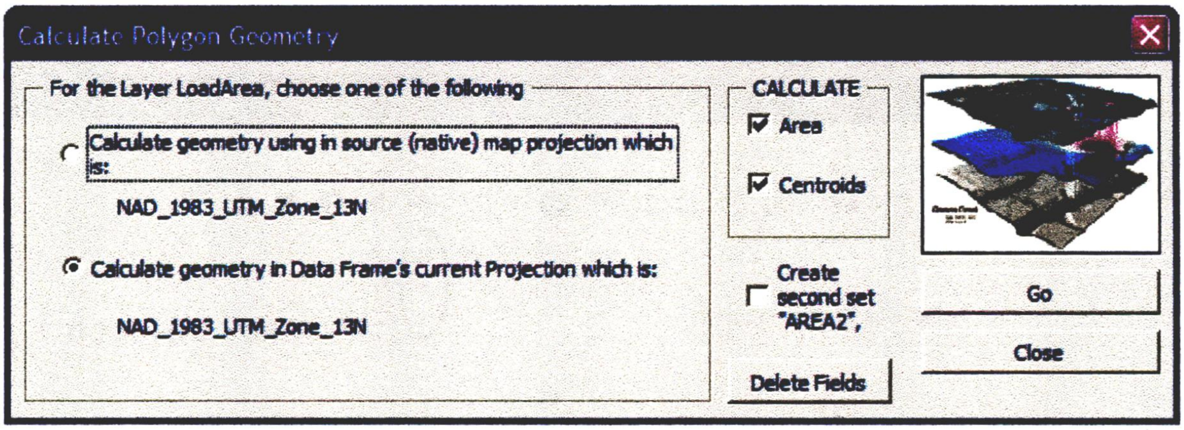
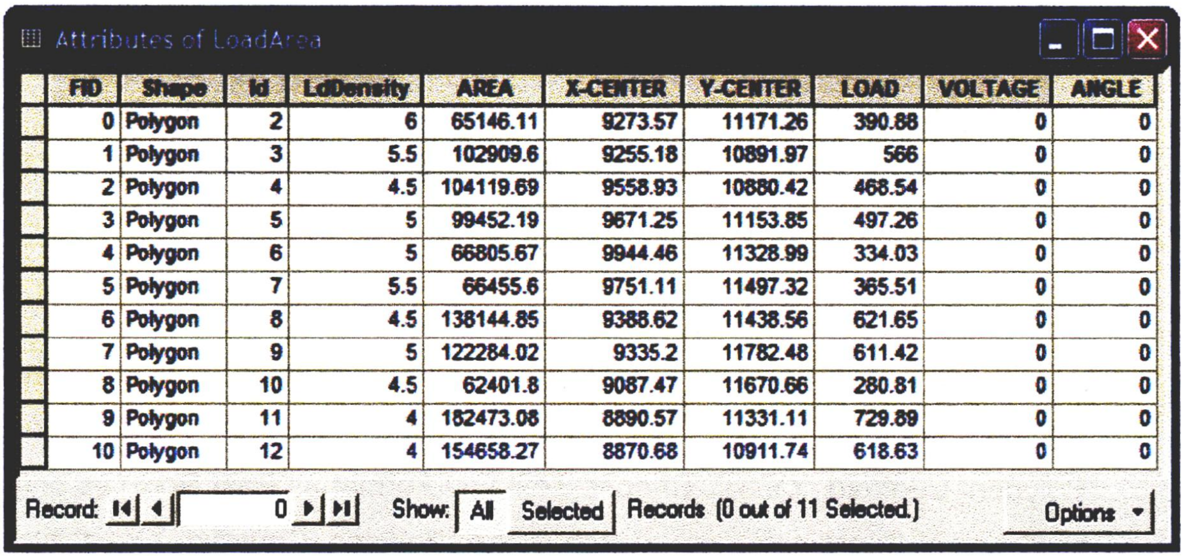


Fig 8.13 Calculate Polygon Geometry Screen

Click the Go Button.

Open the attribute table once again, the values for Area, X-Centre, Y-Centre and the Load have been written to the attribute table and two new fields namely VOLTAGE-KV and ANGLE-DEG have also been added to the table which will be filled once the load flow program is run at a later stage. The table looks as in Fig 8.14.



Attributes of LoadArea

FID	Shape	Id	LdDensity	AREA	X-CENTER	Y-CENTER	LOAD	VOLTAGE	ANGLE
0	Polygon	2	6	65146.11	9273.57	11171.26	390.88	0	0
1	Polygon	3	5.5	102909.6	9255.18	10891.97	566	0	0
2	Polygon	4	4.5	104119.69	9558.93	10880.42	468.54	0	0
3	Polygon	5	5	99452.19	9671.25	11153.85	497.26	0	0
4	Polygon	6	5	66805.67	9944.46	11328.99	334.03	0	0
5	Polygon	7	5.5	66455.6	9751.11	11497.32	365.51	0	0
6	Polygon	8	4.5	138144.85	9388.62	11438.56	621.65	0	0
7	Polygon	9	5	122284.02	9335.2	11782.48	611.42	0	0
8	Polygon	10	4.5	62401.8	9087.47	11670.66	280.81	0	0
9	Polygon	11	4	182473.08	8890.57	11331.11	729.89	0	0
10	Polygon	12	4	154658.27	8870.68	10911.74	618.63	0	0

Record: 0 Show: All Selected Records (0 out of 11 Selected.) Options

Fig 8.14 Attribute Table of LoadArea Shape File

The values of X-Centre and Y-Centre are also written to a text file named "Polygon_Centroid_XY.txt" and saved in the default directory.

The next task is to show these load centers on to the map. The program to perform this task has been converted to a DLL file and added to the ArcMap as an Icon as shown in Fig 8.15.

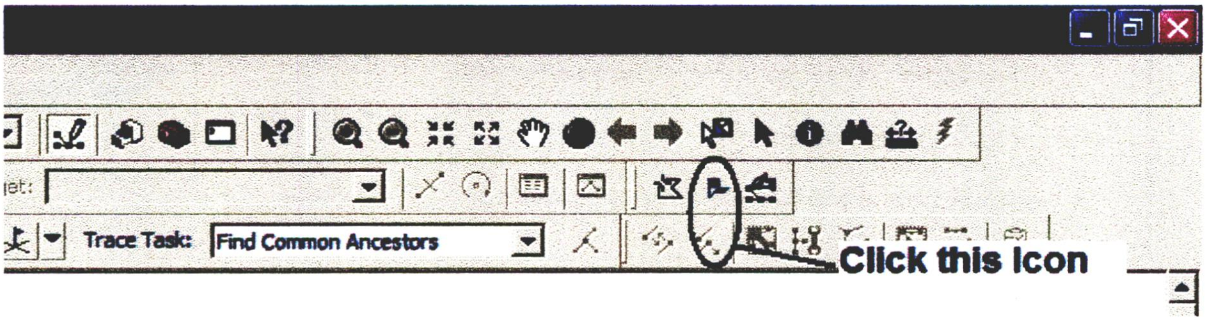


Fig 8.15 Icon for Creating a Shape File from Text File

As the icon is clicked "Import XYZ" window appears on the screen as shown in Fig 8.16.

Fig 8.16 Sreen for Creating a Shape File from Text File

Click "Open" and browse to the directory where the "Polygon_Centroid_XY.txt" is saved and double click on "Polygon_Centroid_XY.txt". Choose Text File Format as East North as only the X and Y Coordinates are written in the "Polygon_Centroid_XY.txt" file. Click Save and enter the Shapefile Name as "Load_Centres". Finally click Import. A new shape file named "Load_Centres" is created and added to the ArcMap application window as shown in Fig 8.17, wherein the triangles represent the load centres of the respective load area.

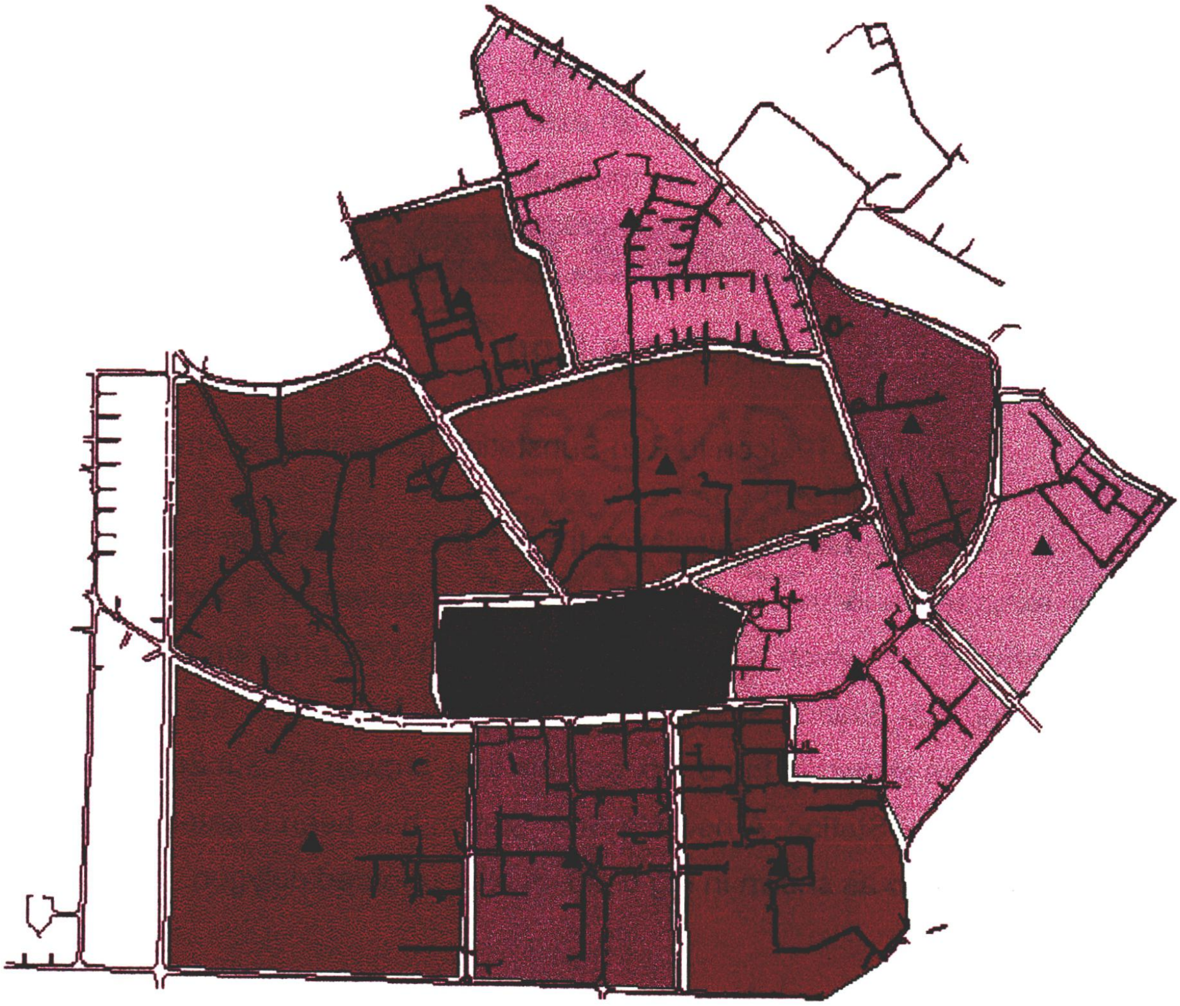


Fig 8.17 Representation Of Load Centers

The attribute table for the Load Centers shape file is shown in Fig 8.18

Attributes of Load_Centres

FID	Shape	Name	East	North
0	Point		9273.57332	11171.261732
1	Point		9255.17575	10891.970201
2	Point		9558.93283	10880.418311
3	Point		9671.24845	11153.845193
4	Point		9944.46289	11328.990705
5	Point		9751.11309	11497.322231
6	Point		9388.62054	11438.563625
7	Point		9335.19609	11782.479434
8	Point		9087.47380	11670.659121
9	Point		8890.57262	11331.114877
10	Point		8870.67822	10911.744596

Record: 1 Show: All Selected

Fig 8.18 Attribute Table of Load Centres Shape File

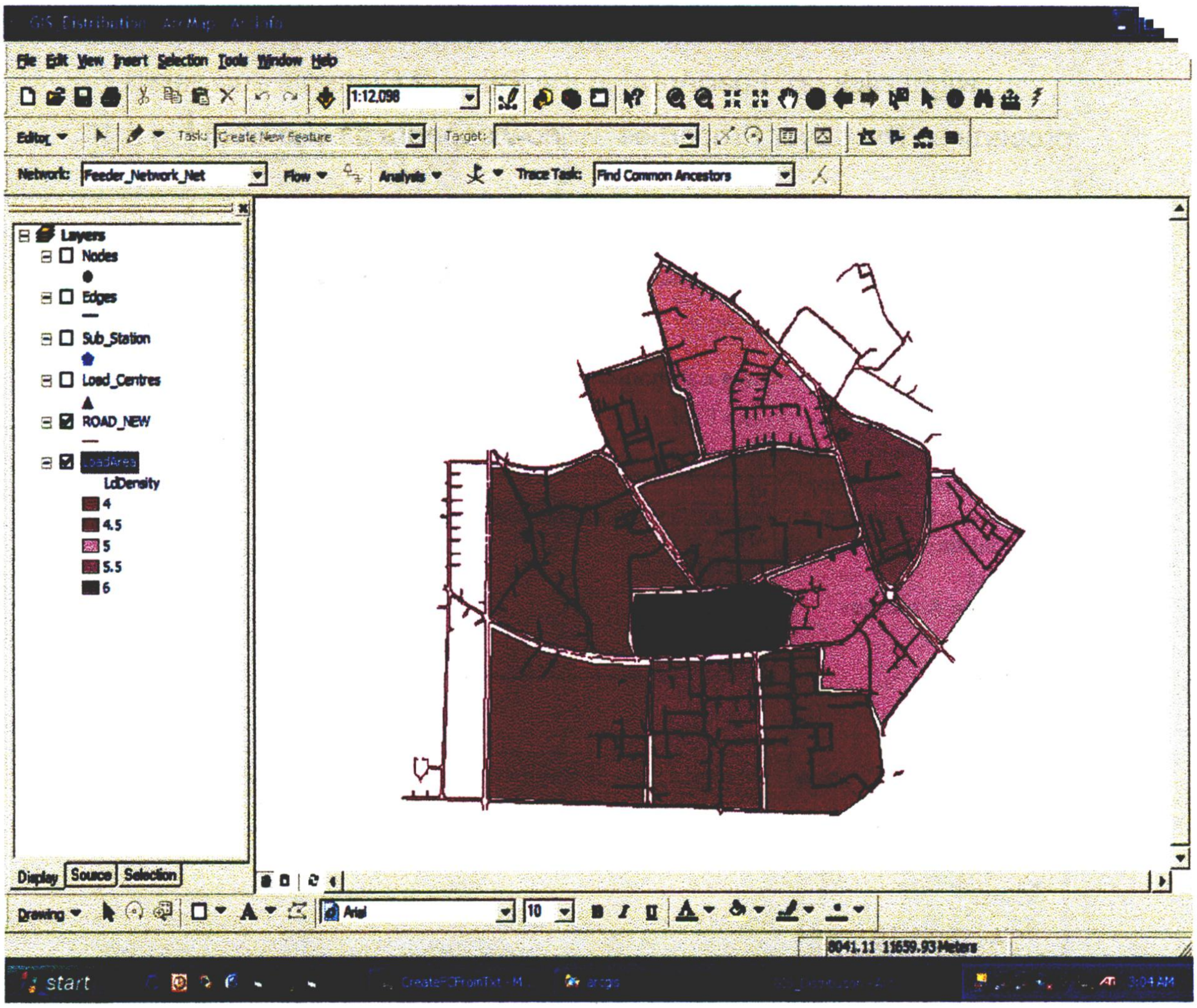


Fig 8. 11 Load Areas Coloured Based On Load Density

Now run the macro to calculate the Area, X-Centre, Y-Centre and the Load. Click on the icon in the ArcMap as shown in Fig 8.12.

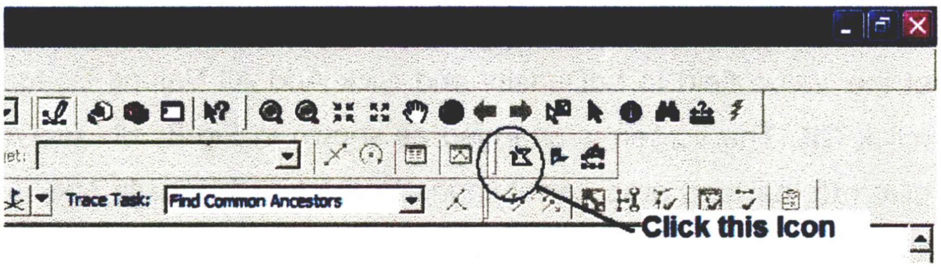


Fig 8.12 Icon for Running Calculate Polygon Geometry Macro

The screen as shown in Fig 8. 13 appears.

Now based on the load and the X, Y coordinates of the load centers, we find the location of the substation. The algorithm for this has been programmed and converted to an executable file, the shortcut for which is placed on the taskbar. Click on the shortcut as in Fig 8.19.

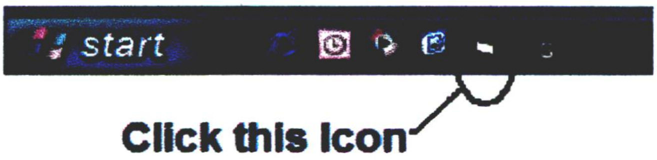


Fig 8.19 Icon to Run Substation Location Program

The program for calculating the X & Y coordinates for the sub station is executed and the calculated values are written in a text file named "SubStnXY.txt" which is utilized by the Import XYZ program to create and add the Sub_Station shape file to the map. Now rerun the Import XYZ program as shown in Fig 8. 15, but this time browse to "SubStnXY.txt" and save as Sub_Station. A new file Sub_Station has been created and added to the ArcMap as shown in Fig 8. 20, in blue coloured polygon.

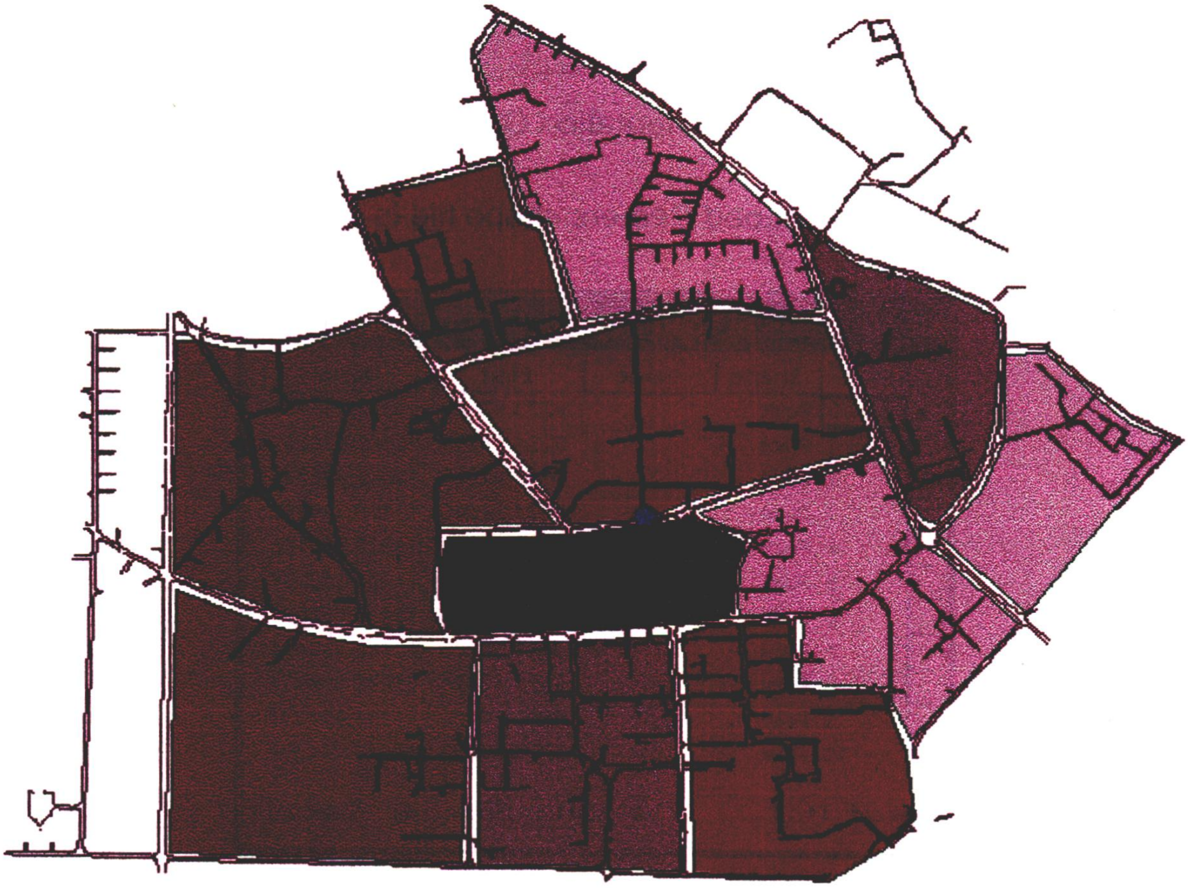


Fig 8. 20 Position of Substation

e attribute table for the Sub_Station shape file is shown in Fig 8. 21

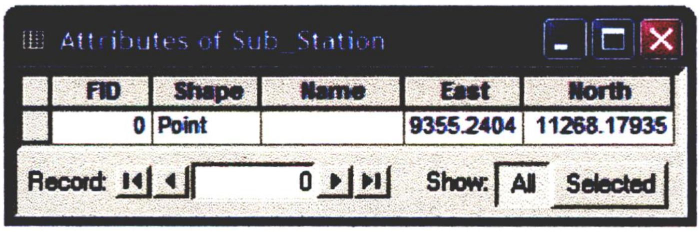


Fig 8.21 Attribute Table of Sub_Station Shape File

Now for the analysis of the network and to find the Minimum ıning Tree we need to draw the geometric network. In the Catalog Tree click on the folder in which this network is to be created, point to New :lick Personal Geodatabase as shown in Fig 8.22.

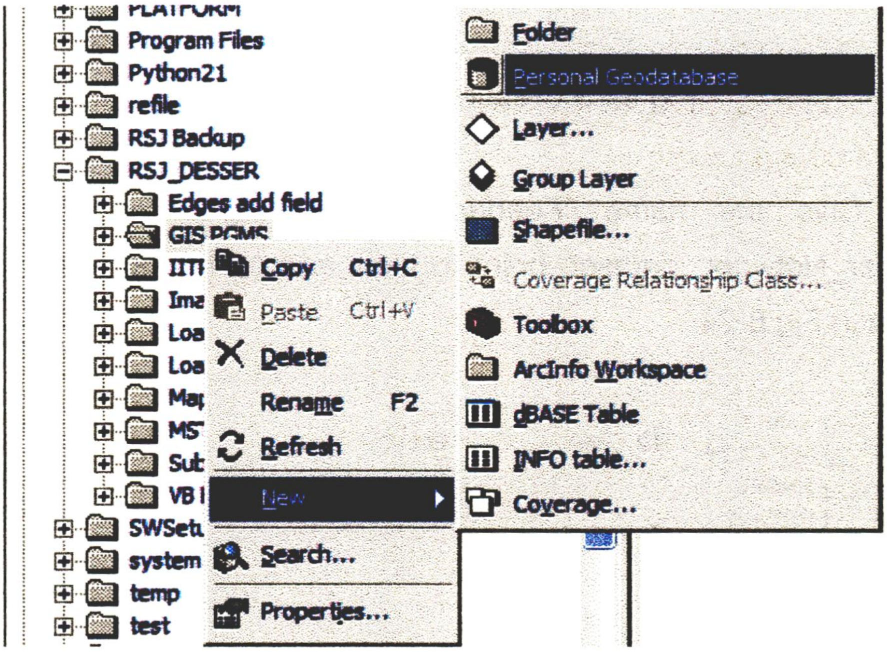


Fig 8.22 Creating New Personal Geodatabase

Give the name "Network". Also set the spatial refrence as done earlier for the other shape files. Import the spatial refrence from the Road_new shapefile.

Now right click on the "Network" database, point to New, and click Feature Dataset as shown in Fig 8.23.

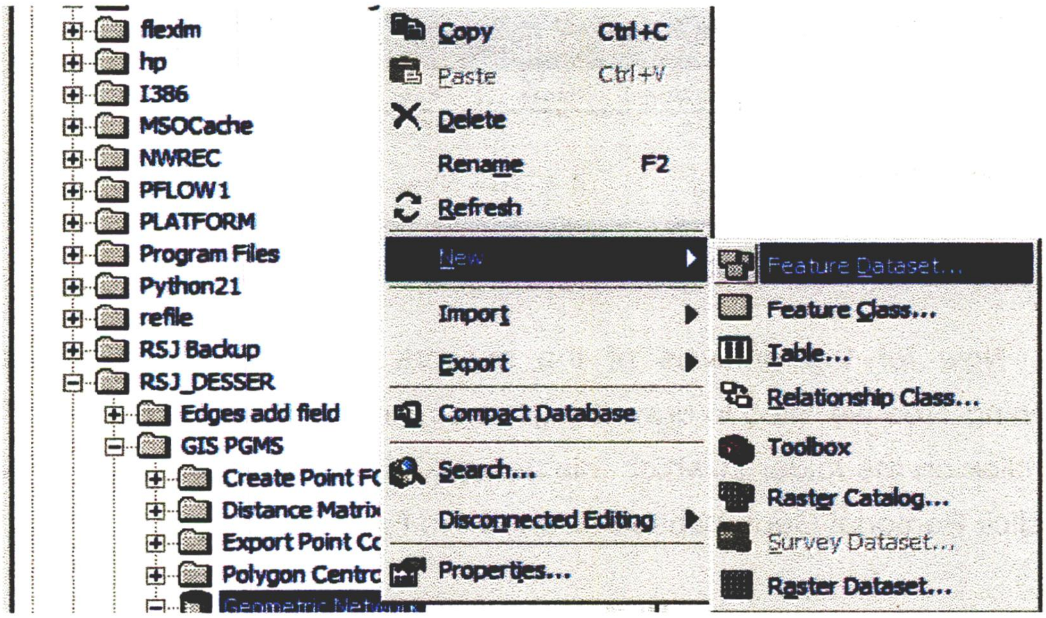


Fig 8.23 Creating New Feature Dataset

Give the name "Feeder_Network". Again right click on the "Feeder_Network" dataset, point to New and click Geometric Network as shown in Fig 8.24.

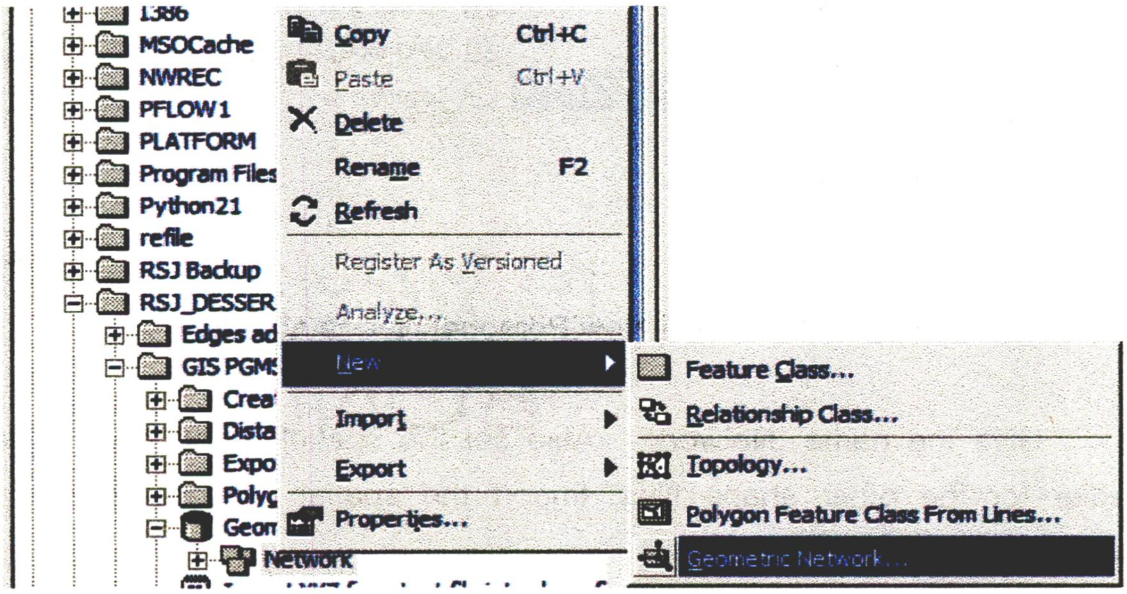


Fig 8.24 Creating New Geometric Network

Give the name ""Feeder_Network_Net" also specify the weights which this network is going to use, in the present case the weight is Length.

Again right click on the "Feeder_Network" dataset, point to New and Click Feature Class as shown in Fig 8.25.

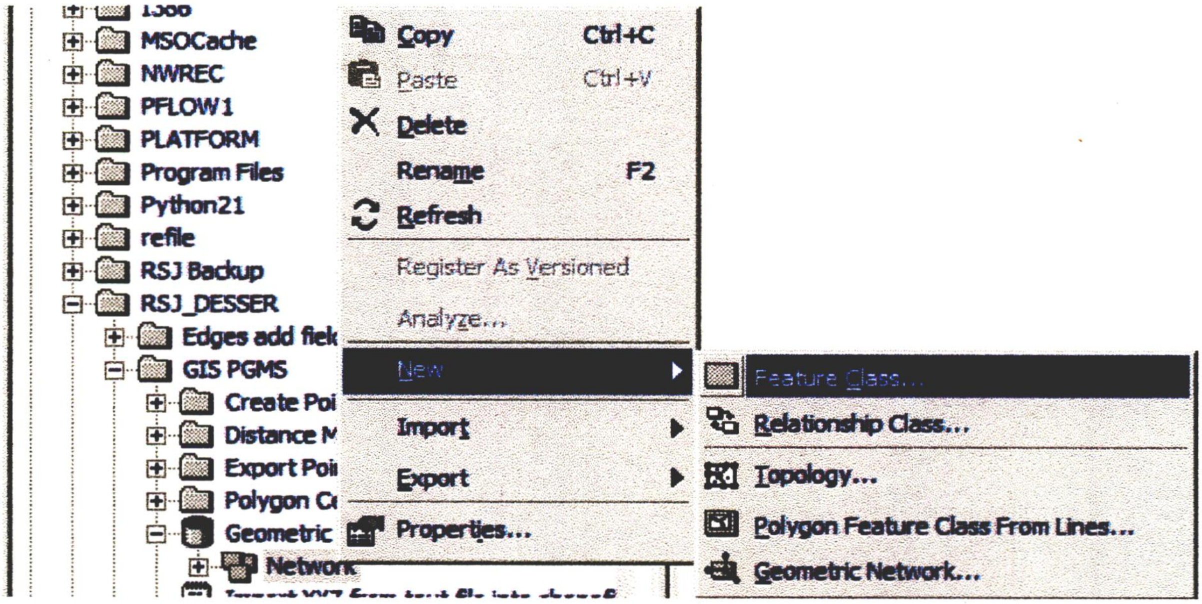


Fig 8.25 Creating New Feature Class

Give the name "Nodes". Once again right click on the "Feeder_Network" dataset, point to New and Click Feature Class as shown in Fig 8.25. Give the name "Edges". In this manner the Geometric Network consisting of Nodes and Edges is created.

Now add the Nodes and Edges feature class to the ArcMap. Click Editor and start editing the Nodes feature class.

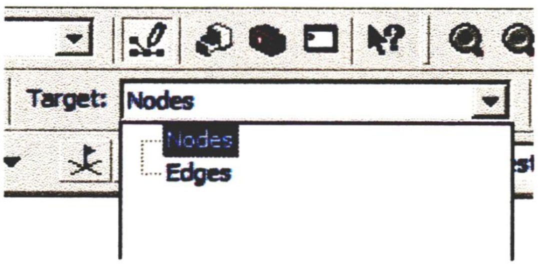


Fig 8.26 Editing the Nodes Feature Class

Start adding the points at the location of the load centers and complete it. The screen will look as shown in Fig 8.27.

Fig 8.27 Screen showing the Nodes

The attribute table for the Load Centers shape file is shown in Fig 8.28

Attributes of Nodes

OBJECTID*	SHAPE*	Enabled	AncillaryRole
1	Point	True	None
2	Point	True	None
3	Point	True	None
4	Point	True	None
5	Point	True	None
6	Point	True	None
7	Point	True	None
8	Point	True	None
9	Point	True	None
10	Point	True	None
11	Point	True	None
12	Point	True	None

Record: 0 Show: All Selected

Fig 8.28 Attribute Table of Nodes Feature Class

Now edit the Edges. Before the start of editing in the edges geometry, set the snapping criteria. Click Editor and select Snapping as shown in Fig 8.29.

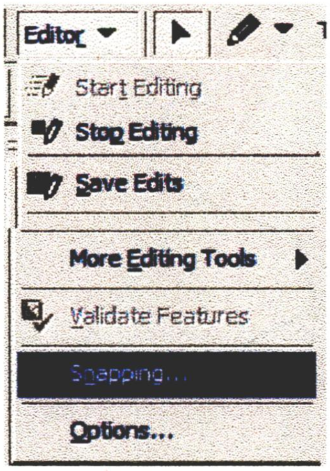


Fig 8.29 Method to Select Snapping

The window appears as shown in Fig 8.30 wherein one can specify the events to which snapping is to be applied.

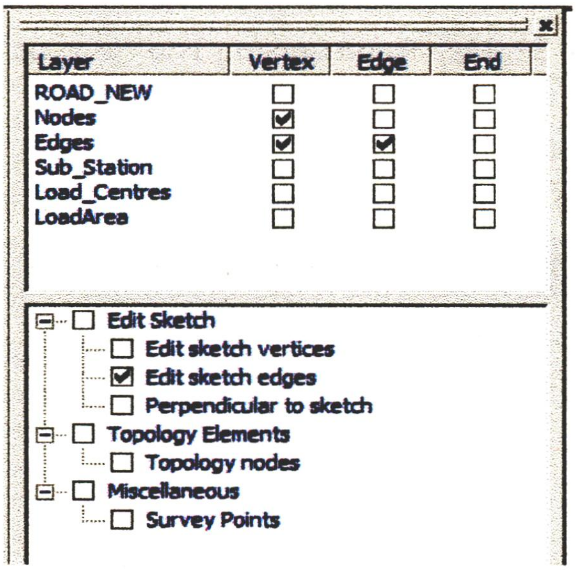


Fig 8.30 Defining Snapping Events

Tick the box in front of Nodes under vertex column and in front of edges under both vertex and edges column as shown in Fig 8.30. Also tick the Edit sketch edges. Thereafter draw all the possible edges along the roads. Stop editing and save the edits. The screen will look as shown in Fig 8.31.

The attribute table of the Edges Feature Class is shown in Fig 8. 33

Attributes of Edges

OBJECTID*	SHAPE*	Enabled	Length	SHAPE_Length
1	Polyline	True	256.12	256.12
2	Polyline	True	334.02	334.02
3	Polyline	True	309.13	309.13
4	Polyline	True	524.26	524.26
5	Polyline	True	368.39	368.39
6	Polyline	True	548.11	548.11
7	Polyline	True	280.32	280.32
8	Polyline	True	207.76	207.76
9	Polyline	True	399.74	399.74
10	Polyline	True	514.15	514.15
11	Polyline	True	645.15	645.15
12	Polyline	True	519.35	519.35
13	Polyline	True	388.22	388.22
14	Polyline	True	673.23	673.23
15	Polyline	True	272.28	272.28
16	Polyline	True	499.61	499.61
17	Polyline	True	848.81	848.81
18	Polyline	True	392.67	392.67
19	Polyline	True	443.85	443.85
20	Polyline	True	409.65	409.65

Record: 0 Show: All Selected Records

Fig 8.33 Attribute Table of Edges Feature Class

To run the Minimum Spanning Tree program we need to have the distance matrix. The program for calculating the distance matrix has been included as Macro in the ArcMap and an icon created as shown in Fig 8.34.

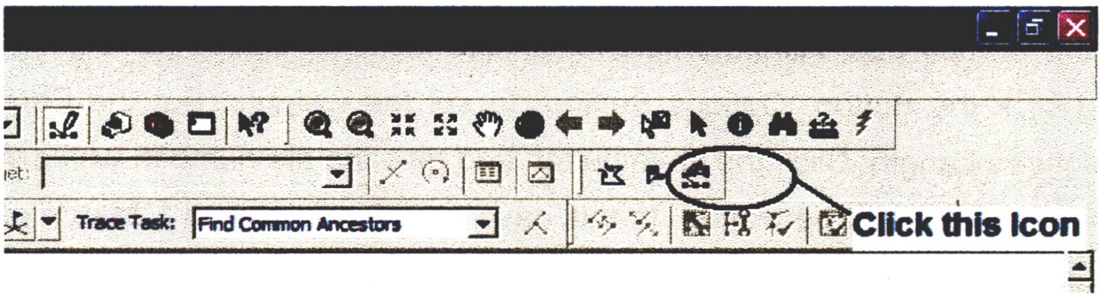


Fig 8.34 Icon to Run Distance Matrix Program

Click the icon to run the distance matrix program. The screen as shown in Fig 8.35 appears.

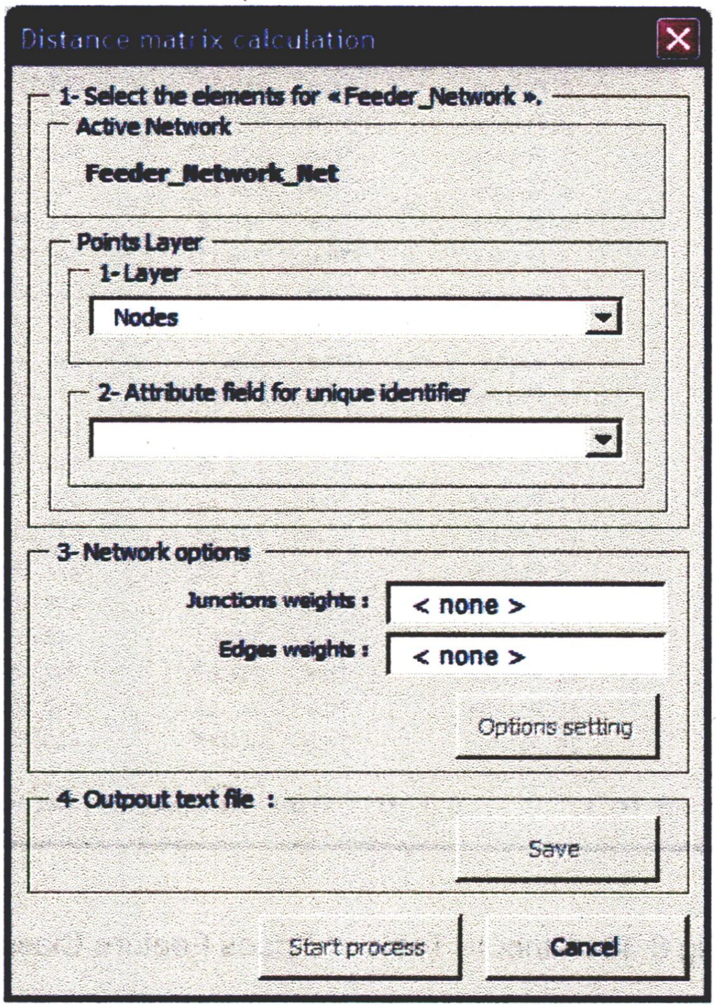


Fig 8.35 DistanceMatrix Program Screen

The program will run only when a geometric network is active in the ArcMap. The program automatically selects the active geometric network. In the Combo Box, Attribute field for unique identifier select the Object ID and click the Button "Options Setting" to set the weights. Set the Edges weight as Length. Click the save button and give the file name in which the distance data is to be written. In this case give Distance and "_Matrix" will automatically be added to the name. The distance matrix is written to "Distance_Matrix.txt" file and saved in the default directory.

The program to form the Minimum Spanning Tree (MST) has been written in C language since pointers have been used. The use of pointer in

Visual Basic is extremely difficult. The program is based on "Algorithm 422 Minimal Spanning Tree [H]" as presented in Appendix C. The program has been compiled and an executable file generated. The shortcut to this program is placed on the task bar as shown in Fig 8.36.

Fig 8.36 Shortcut to Run MST Program

As this program is run the Minimum Spanning Tree so generated is written to a text file named "Treeline.txt".

The next task is to add fields to the Edges Table to store the values of the Nodes "From" and "To" where the particular feeder is carrying the current, as also the field to store the type of the conductor selected for that feeder, the Branch Currents flowing in that feeder and finally the line losses in that particular feeder. The program for this task has been written in Visual Basic for Applications and can be run from the ArcMap with the help on an Icon. Select the Edges layer in the ArcMap and click the Icon as shown in Fig 8.37

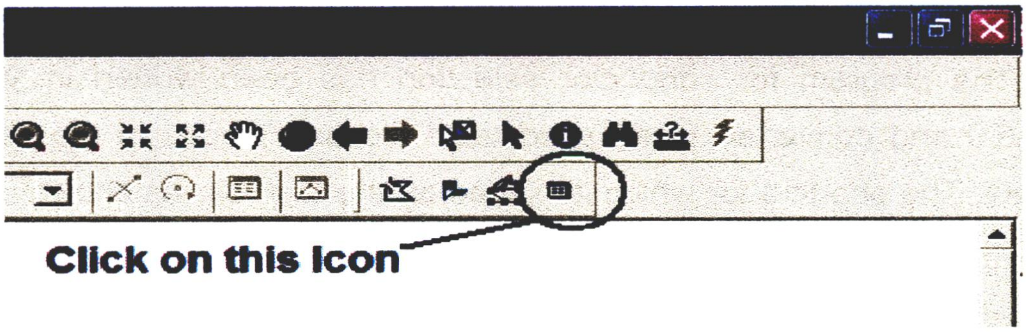


Fig 8.37 Icon to Run the Add Field Macro

As the icon is clicked, the screen as shown in Fig 8.38 appears.

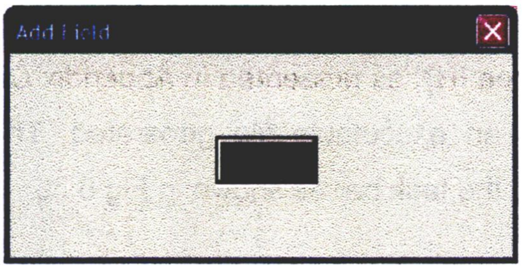


Fig 8.38 Screen for Adding Field to Edges Attribute Table

Click "Go" the new fields are created in the Edges Table. The new fields so created are namely NodeFrom, NodeTo, Conductor, BranchCurrent and FeederLoss as shown in Fig 8.39.

Attributes of Edges

OBJECTID*	SHAPE*	Enabled	Length	SHAPE_Length	NodeFrom	NodeTo	Conductor	BranchCurrent	FeederLoss
1	Polyline	True	256.12	256.12	<Null>	<Null>	<Null>	<Null>	<Null>
2	Polyline	True	334.02	334.02	<Null>	<Null>	<Null>	<Null>	<Null>
3	Polyline	True	309.13	309.13	<Null>	<Null>	<Null>	<Null>	<Null>
4	Polyline	True	524.26	524.26	<Null>	<Null>	<Null>	<Null>	<Null>
5	Polyline	True	368.39	368.39	<Null>	<Null>	<Null>	<Null>	<Null>
6	Polyline	True	548.11	548.11	<Null>	<Null>	<Null>	<Null>	<Null>
7	Polyline	True	280.32	280.32	<Null>	<Null>	<Null>	<Null>	<Null>
8	Polyline	True	207.76	207.76	<Null>	<Null>	<Null>	<Null>	<Null>
9	Polyline	True	399.74	399.74	<Null>	<Null>	<Null>	<Null>	<Null>
10	Polyline	True	514.15	514.15	<Null>	<Null>	<Null>	<Null>	<Null>
11	Polyline	True	645.15	645.15	<Null>	<Null>	<Null>	<Null>	<Null>
12	Polyline	True	519.35	519.35	<Null>	<Null>	<Null>	<Null>	<Null>

Fig 8.39 Attribute Table of Edges Feature Class

The program for conductor selection has been written in Visual Basic 6.0 and converted to an executable file and placed in the default directory. The shortcut for which is placed on the task bar as shown in Fig 8.40.

Fig 8.40 Shortcut to Run the Conductor Selection Program

As the shortcut is clicked the conductor selection program is executed and the result window appears on the screen as shown in Fig 8.41.

Conductor Description

Branch	Node From	Node To	Conductor Name
1	1	2	Wolf
2	1	8	Rabbit
3	2	3	Leopard
4	3	4	Mink
5	4	5	Ferret
6	8	9	Weasel
7	9	10	Squirrel
8	3	12	Rabbit
9	5	7	Gopher
10	7	6	Squirrel
11	12	11	Gopher

Fig 8.41 Result Window Conductor Selection Program

The Branch Number, Node From, Node To and the Conductor Name so selected are displayed on the screen. The program also writes the values of the edges used in the network to the Edges Table and writes the values of the corresponding Node_From, Node_To and Conductor Type to its attribute table as shown in Fig 8.42.

Edges : Table

OBJECTID	SHAPE	Enabled	Length	SHAPE_Length	NodeFrom	NodeTo	Conductor
1	.ong binary data	1	256.115012	256.115011674	1	2	Dog
2	.ong binary data	1	334.022347	334.022347228	2	3	Otter
3	.ong binary data	1	309.126573	309.126573059	3	4	Squirrel
4	.ong binary data	1	524.256397	524.256396663			
5	.ong binary data	1	368.393155	368.393155194	6	5	Squirrel
6	.ong binary data	1	548.114952	548.114951834			
7	.ong binary data	1	280.321815	280.321815140	7	6	Weasel
8	.ong binary data	1	207.756146	207.756145727	1	8	Dog
9	.ong binary data	1	399.73735	399.737349874	8	7	Ferret

Fig 8.42 Attribute Table of Edges Feature Class

The program for load flow analysis and capacitor placement has been written in Visual Basic 6.0 and converted to an executable file and placed in the default directory. The shortcut for which is placed on the task bar as shown in Fig 8.43.

Fig 8.43 Shortcut to Run the Load Flow Program

The database required for the execution of this program has been created using Microsoft Access. There are two tables which are used. Firstly the ACSR Data table which stores the data pertaining to the ACSR Conductor viz resistance, reactance etc as shown in Table 8.1.

ACSR DATA

Conductor Name	Resistance (ohm/km)	Reactance (ohm/km)	Impedance (ohm/km)	Area (mmsq)	Current Cap(Amp)
Squirrel	1.374	0.32	1.396	20.71	125
Gopher	1.098	0.31	1.1	25.91	148
Weasel	0.9116	0.308	0.953	31.21	160
Ferret	0.6795	0.298	0.738	41.87	190
Rabbit	0.5449	0.291	0.614	52.21	218
Mink	0.4565	0.285	0.536	62.32	236
Beaver	0.3841	0.2795	0.484	74.07	260
Racoon	0.3656	0.2765	0.464	77.83	270
Otter	0.3434	0.2752	0.437	82.85	281
Cat	0.302	0.2725	0.406	94.21	300
Dog	0.2745	0.2695	0.383	103.60	320
Leopard	0.2193	0.2625	0.34	129.70	375
Wolf	0.1844	0.241	0.31	154.30	455
Lynx	0.181	0.233	0.29	179.00	495
Panther	0.176	0.228	0.26	207.00	540

Table 8.1 ACSR Data Table

Second table stores the data pertaining to the conductor placement in a table named QC_Data. The table contains the sizes (Qc) in Kvar of the capacitors available in the inventory and their corresponding cost per Kvar (Cost/Kvar). The table is as shown in Table 8.2.

CAPACITOR DATA

Qc(Kvar)	Cost/kvar	Qc(Kvar)	Cost/kvar	Qc(Kvar)	Cost/kvar
150	0.5	1500	0.201	2850	0.183
300	0.35	1650	0.193	3000	0.18
450	0.253	1800	0.187	3150	0.195
600	0.22	1950	0.211	3300	0.174
750	0.276	2100	0.176	3450	0.188
900	0.183	2250	0.197	3600	0.17
1050	0.228	2400	0.17	3750	0.183
1200	0.17	2550	0.189	3900	0.182
1350	0.207	2700	0.187	4050	0.179

Table 8.2 Capacitor Data Table

The theory and the algorithms for the subroutines pertaining to various modalities of the program have been discussed in the preceding chapters. When the program is started with the help of short-cut from the task bar as in Fig 8.43 the screen as shown in Fig 8.44 appears.

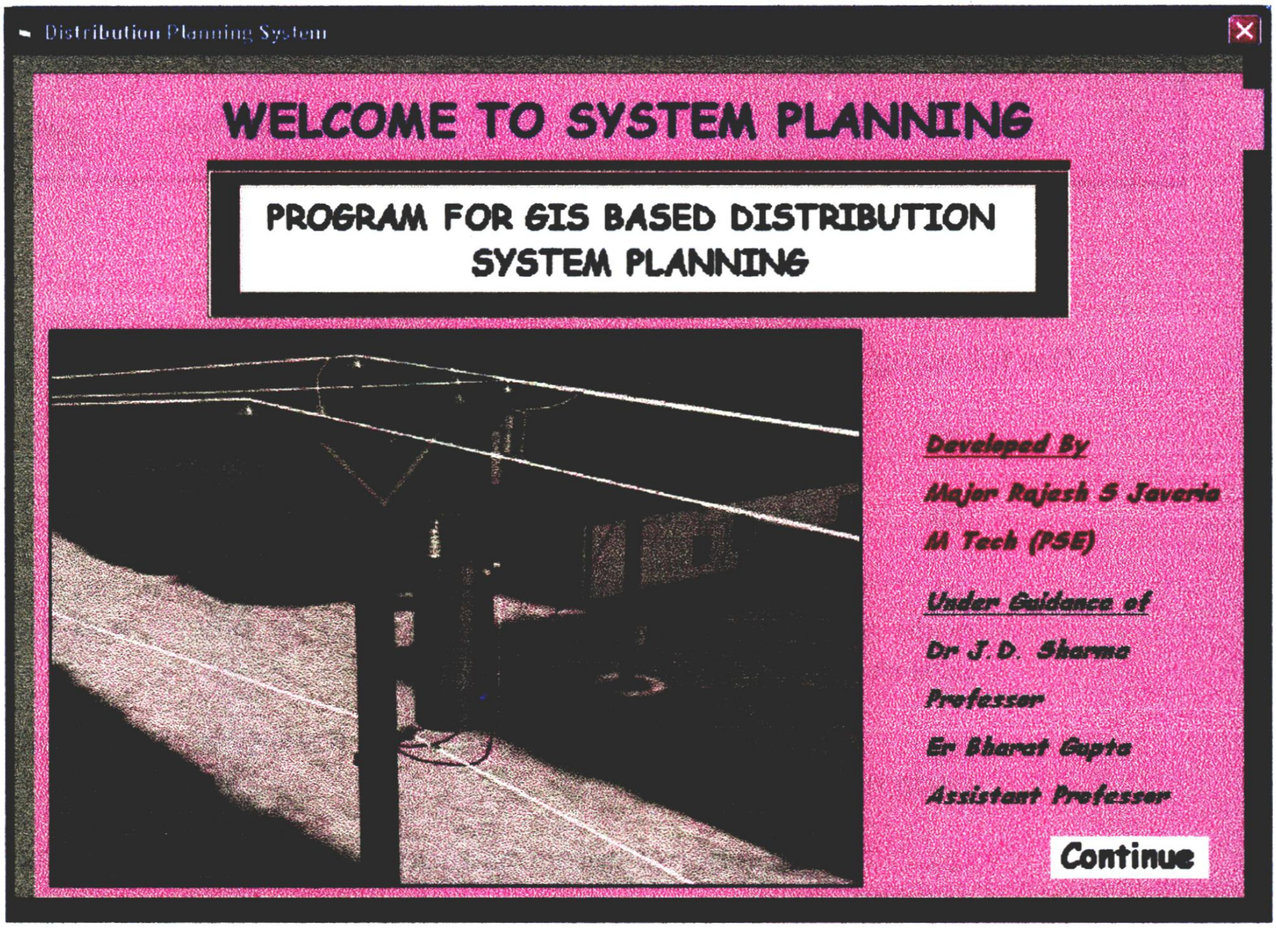


Fig 8.44 Start Page of The Program

The Program writes the values of the node voltage and angle, to the attributes table of the LoadAreas. The table when opened in the ArcMap will contain the values of Voltage and angle as shown in Fig 8.46.

Attributes of LoadArea

FID	Shape	Id	LdDensity	AREA	X-CENTER	Y-CENTER	LOAD	VOLTAGE	ANGLE
0	Polygon	2	6	65146.11	9273.57	11171.26	390.88	10.98	-0.07
1	Polygon	3	5.5	102909.6	9255.18	10891.97	566	10.95	-0.15
2	Polygon	4	4.5	104119.69	9558.93	10880.42	468.54	10.94	-0.3
3	Polygon	5	5	99452.19	9671.25	11153.85	497.26	10.89	0.06
4	Polygon	6	5	66805.67	9944.46	11328.99	334.03	10.92	0.02
5	Polygon	7	5.5	66455.6	9751.11	11497.32	365.51	10.94	-0.01
6	Polygon	8	4.5	138144.85	9388.62	11438.56	621.65	10.98	-0.03
7	Polygon	9	5	122284.02	9335.2	11782.48	611.42	10.94	0.01
8	Polygon	10	4.5	62401.8	9087.47	11670.66	280.81	10.93	0.02
9	Polygon	11	4	182473.08	8890.57	11331.11	729.89	10.88	-0.09
10	Polygon	12	4	154658.27	8870.68	10911.74	618.63	10.91	-0.14

Record: 1 Show: All Selected Records (0 out of 11 Selected.) Options

Fig 8.46 Attribute Table of LoadArea Shape File

The program also writes the values the Branch Current in amperes and feeder losses in watts in the attribute table of edges feature class. The attribute table is as shown in Fig 8.47.

Attributes of Edges

OBJECTID*	SHAPE*	Enabled	Length	SHAPE_Length	NodeFrom	NodeTo	Conductor	BranchCurrent	FeederLoss
1	Polyline	True	256.12	256.12	1	2	Dog	262.17	3.99
2	Polyline	True	334.02	334.02	2	3	Otter	222.87	4.71
3	Polyline	True	309.13	309.13	3	4	Squirrel	71.75	1.81
4	Polyline	True	524.26	524.26	<Null>	<Null>	<Null>	<Null>	<Null>
5	Polyline	True	368.39	368.39	6	5	Squirrel	52.72	1.16
6	Polyline	True	548.11	548.11	<Null>	<Null>	<Null>	<Null>	<Null>
7	Polyline	True	280.32	280.32	7	6	Weasel	88.05	1.64
8	Polyline	True	207.76	207.76	1	8	Dog	286.20	3.86
9	Polyline	True	399.74	399.74	8	7	Ferret	126.63	3.60
10	Polyline	True	514.15	514.15	<Null>	<Null>	<Null>	<Null>	<Null>
11	Polyline	True	645.15	645.15	<Null>	<Null>	<Null>	<Null>	<Null>
12	Polyline	True	519.35	519.35	<Null>	<Null>	<Null>	<Null>	<Null>
13	Polyline	True	388.22	388.22	8	9	Weasel	94.18	2.59

Record: 1 Show: All Selected Records (0 out of 20 Selected.) Options

Fig 8.47 Attribute Table of Edges Feature Class

To view the plot of the voltage profile click the "Voltage Profile" button on the result screen in Fig 8.45. The Voltage Profile window appears on the screen as shown in Fig 8.48.

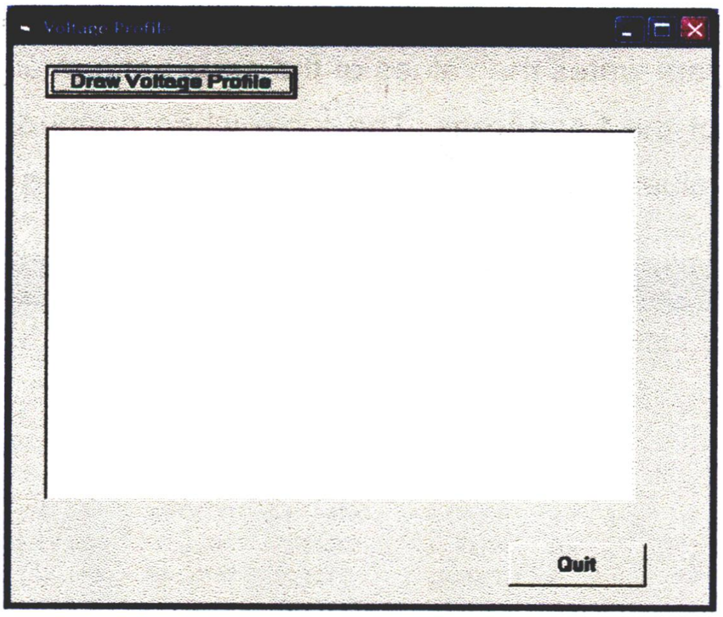


Fig 8.48 Draw Voltage Profile Window

Double click the Draw Voltage Profile button the plot of voltage in KV is drawn as shown in Fig 8.49.

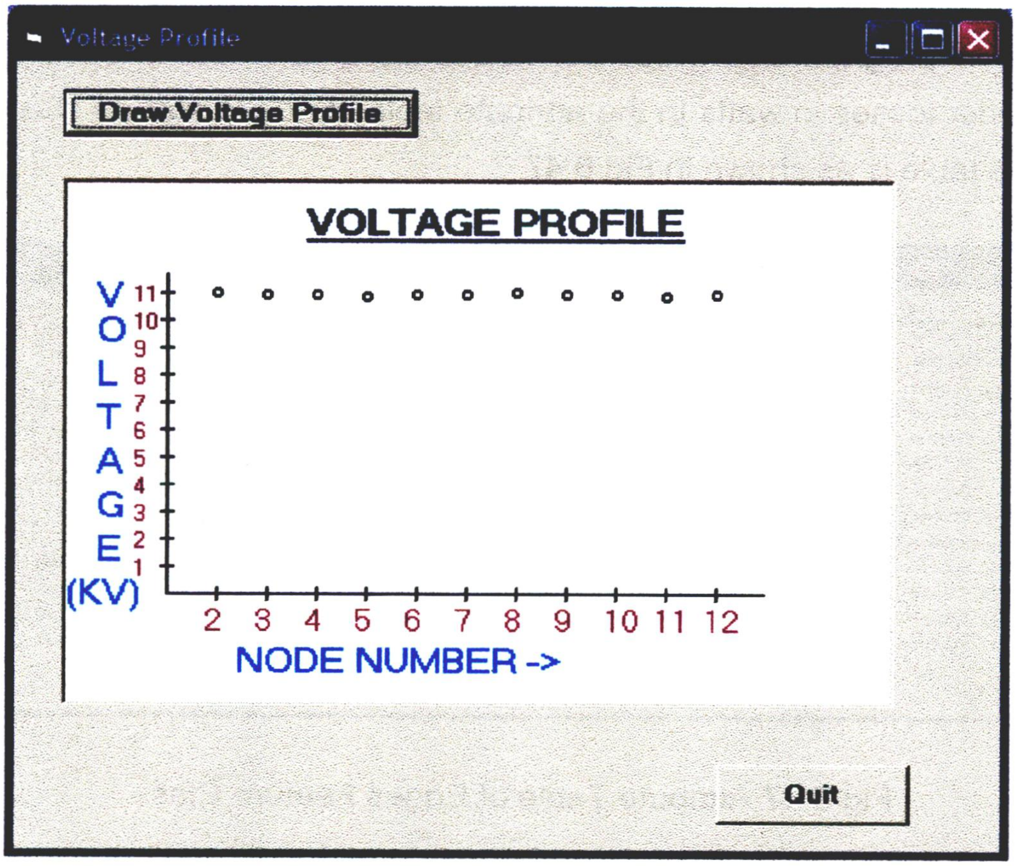


Fig 8.49 Plot Of The Voltage Profile

The voltage profile graph can also be plotted with the help of ArcMap tools. Click on Tools, point to Graphs and select Create. The screen appears as shown in Fig 8.50.

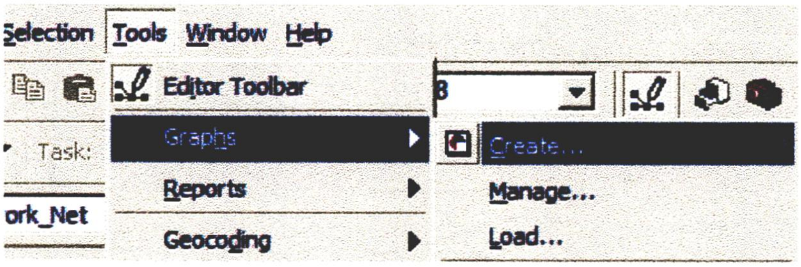


Fig 8.50 Selecting Create Graph

As you click Create, the window as in Fig 8.51 appears.

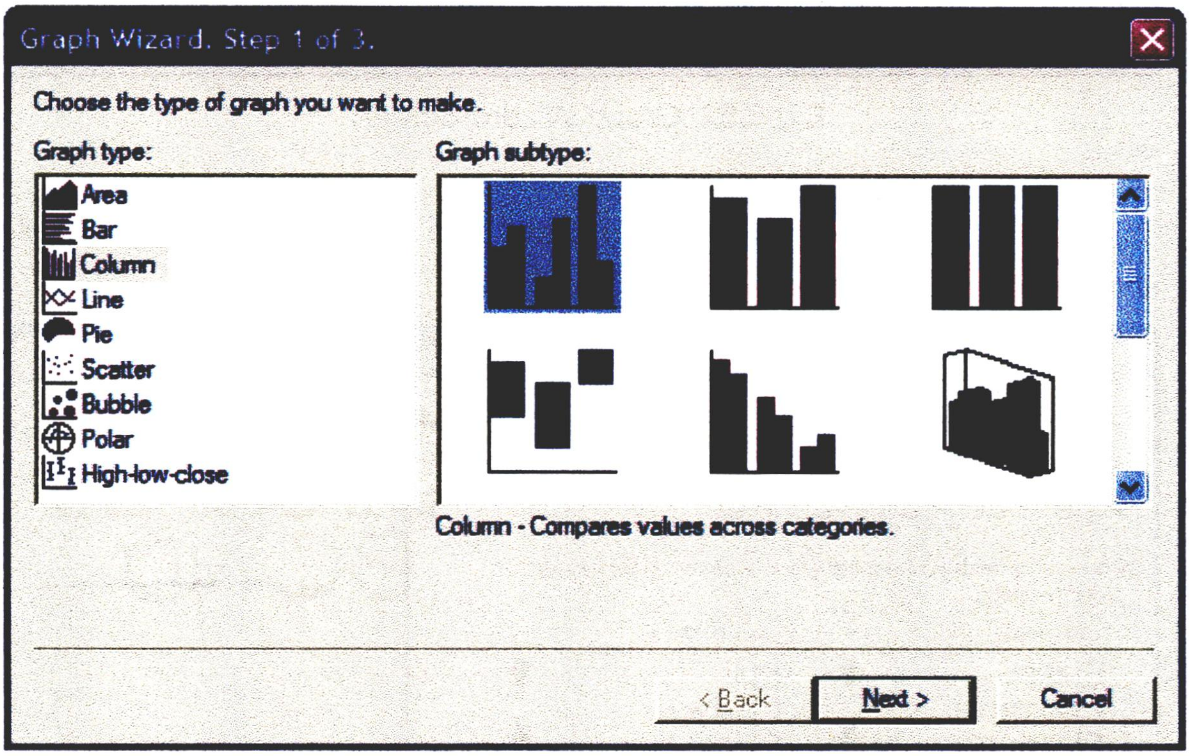


Fig 8.51 Graph Wizard Screen

In this window select the type of plot required for eg Bar, Pie, Column, Line etc. The Graph subtype also appears on the right. Any of the available options can be selected by the click of mouse.

To get a line plot select the Line option in the left window, the window as shown in Fig 8.52 appears.

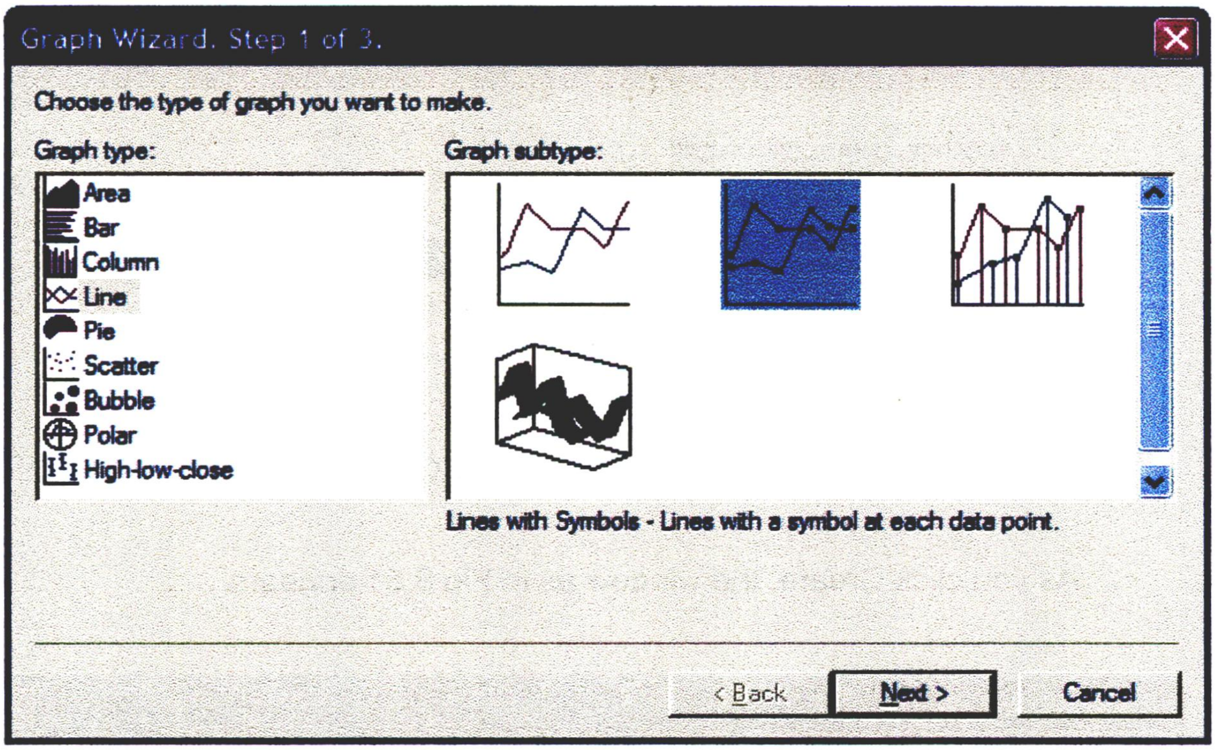


Fig 8.52 Graph Wizard Screen

Select the Graph subtype as desired and click Next. The window as shown in Fig 8.53 appears.

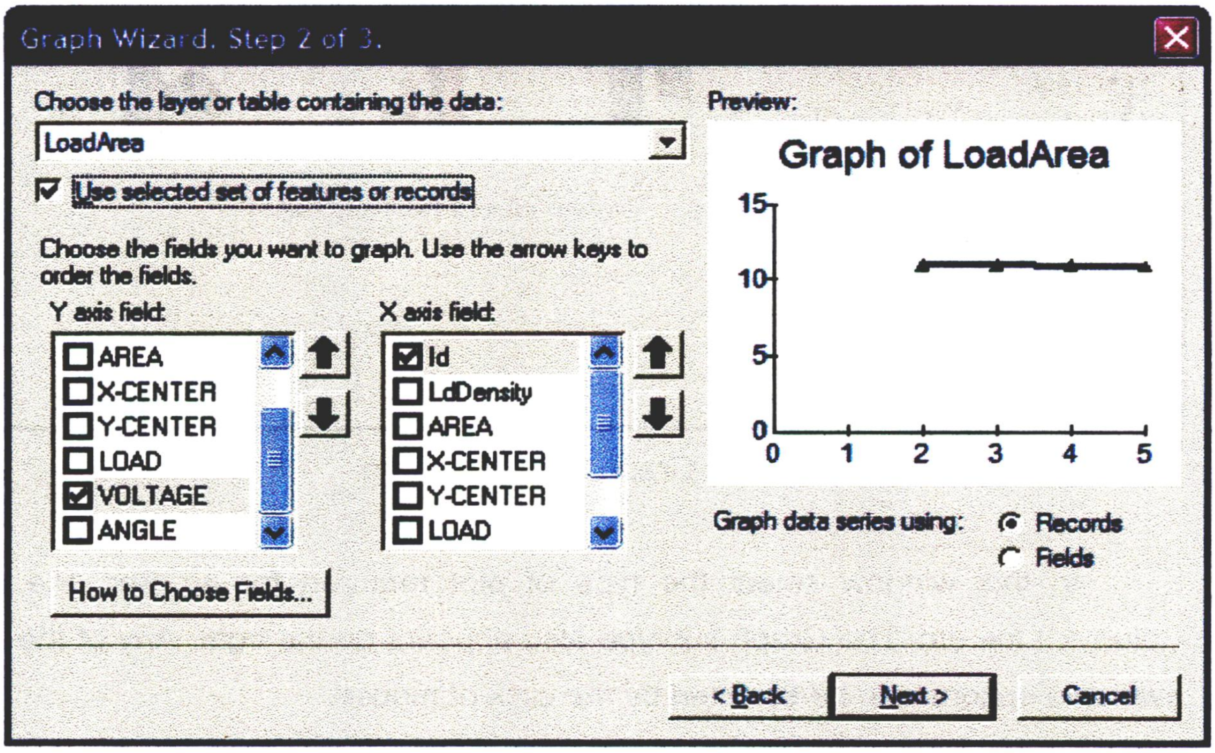


Fig 8.53 Graph Wizard Screen

In the combo box "Choose the layer or table containing the data" select the LoadArea layer since the values of voltage are written in that layer. Thereafter choose the field required to be plotted on the X and Y axis. In the Y axis select the Voltage field and for the X axis select the Id field. Click Next, the window as shown in Fig 8.54 appears.

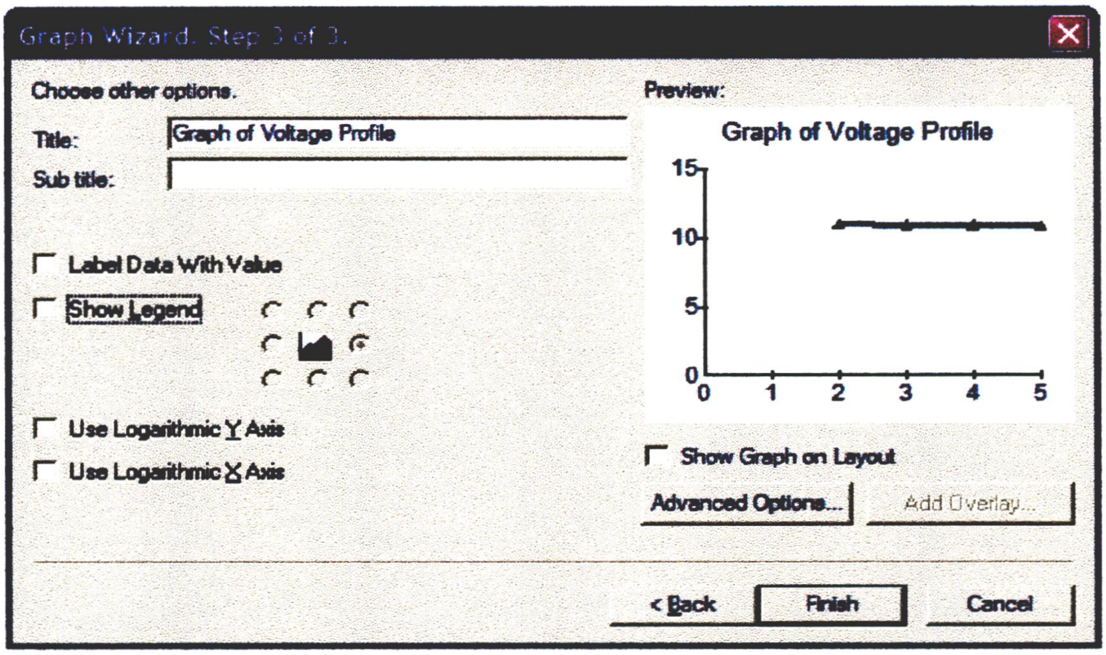


Fig 8.54 Graph Wizard Screen

On this window write the Title for the graph and the Advanced Options button can be clicked for adjusting the X axis, Y axis titles, font size, colour for display etc.

Finally click Finish. The graph is as shown in Fig 8.55 isdisplayed.

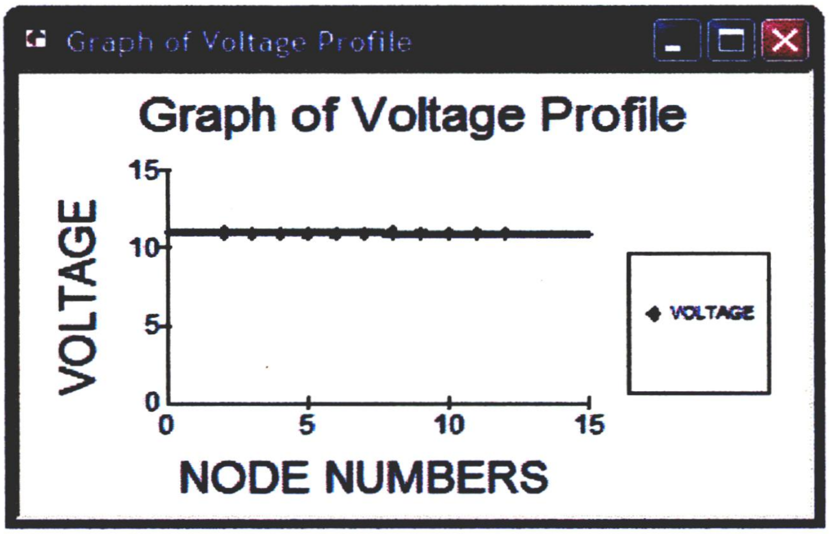


Fig 8.55 Graph of Voltage Profile

Folder SubStation Loc **Project Name** SStn.VBP

Form Name FrmSubStation

Input Polygon_Centroid_XY.txt and Load.txt files

Variables

X() – array to store the X Coordinate of the Load Centre.

Y() – array to store the Y Coordinate of the Load Centre.

Power() – array to store the load values read from Load.txt file.

Sum_Kva – summation of loads.

Kva() – array to store load demand at each load point.

L2X – summation of load square multiplied by X coordinate.

L2Y – summation of load square multiplied by Y coordinate.

L2 – Sum of load square.

X_Sub - X coordinate of Substation.

Y_Sub - Y coordinate of Substation.

Output X and Y coordinates of Substation are written to SubStnXY.txt in X,Y format.

5. **Minimum Spanning Tree**

Since the use of pointer in Visual Basic is extremely difficult, the program to form the Minimum Spanning Tree has been written in C language since using pointers. The program is based on "Algorithm 422 Minimal Spanning Tree [H]" as given in Appendix C. The program has been compiled and an executable file generated.

Folder MSTCPgm **File Name** Mst.C

Executable File Name Mst.exe placed in default directory.

Input Text file Distance.txt containing the array distance matrix.

Variables

in File handle for input file called Distance.txt.

out File handle for output file called treeline.txt.

graph 2D array used to store the edge weights of the graph.

npts number of points to be connected by the minimal spanning tree (MST)

buf1 temporary string buffer

*p character pointer used for the string tokenizer

n_mst number of edges in the MST

sum_mst -sum of the edge weights in the MST

min_span_tree -2D array output by function spantree(). It holds the "to" and "from" indices for each edge in the MST.

spantree Function

int spantree(double **graph, int **min_span_tree, int n, int p_num_of_edges, double *p_sum_of_edges)

Input variables for function

**graph	2D matrix representing the graph
n	the number of nodes in the graph

Output variables for function

**min_span_tree	2D matrix holding the station indices for each edge in the minimal spanning tree (MST).
*p_num_of_edges	number of edges in the MST.
*p_sum_of_edges	sum of all edge weights in the MST.

Output The output of the program is written to text file treeline.txt. The output format is number of edges in the MST in the first line, and thereafter from, to node numbers in columnar fashion. The program also writes the distance matrix array in a text file namely Ary13_VB.txt in a format which can be read by Visual Basic.

6. Conductor Grading Program

Folder Conductor Selection **Project Name** Conductor Gradation.VBP
Form Name FrmCondSelection

Input Reads the MST from the text file treeline.txt. It also reads the distance matrix from the text file ARY13_VB.txt. Reads the values of the Load from the LoadArea.dbf table and stores in the Power1 () array.

Variables

Ar_av()	Array to store the available conductor areas in mm^2
Area1 ()	Calculated area of conductor cross-section of the edge as per equation 5.6
Area()	The area of conductor cross-section of edges, which takes one of the discrete values of cross-section areas for the conductors available in the inventory
COST1	The cost to be minimized
VOL_DROP	Calculated value of voltage drop
Limit_drop	The maximum allowable voltage drop
RCV()	Calculated value as per equation 5.7
Cond_name()	Array to store the name of the conductor selected

Output The conductor so selected are displayed on the result screen and the values of N_From(),N_To() and Cond_name() are written to the attribute table of the Edges feature class.

7. **Load Flow Analysis and Capacitor Placement Program**

The program for load flow analysis and capacitor placement has been written in Visual Basic 6.0 and converted to an executable file and placed in the default directory. The database required for the execution of this program has been created using Microsoft Access. There are two tables, which are used. Firstly the ACSR Data table which stores the data pertaining to the ACSR Conductor viz resistance, reactance etc. Second table name is QC_Data, which contains the data pertaining to the conductor placement. The table contains the sizes (Qc) of the capacitors available in the inventory and their corresponding cost per kvar (Cost/kvar).

Folder Load Flow Single **Project Name** Load Flow Single.VBP

Form Name Form3

Representation of the Network

Input Reads the MST from the treeline.txt file.

Variables

EdgesThe number of edges in the network

N_From()Array to store the From node numbers

N_To()Array to store the To node numbers

Curr_Cap()Array to store the current carrying capacity for the edges

Length()Array to store the distance matrix

Dist()Array to store the length of the edge being used, in kilometer

nbusThe number of nodes

List()Node pointer for Linknet structure

inext()Branch pointer for Linknet structure

ifar()Node at the far or opposite end of the branch

Path()Array to store the edges forming the path

Str_Node()Array to store the nodes forming the path

Load Flow Program

Input Reads the values of resistance, reactance and current carrying capacity from the ACSR table in the ACSRData.mdb database. Also reads the load from the LoadArea.dbf table.

Variables

R() Array to store the value of resistance for the edges

X() Array to store the value of reactance for the edges

Z() Array to store the value of impedance for the edges

BIBCM The bus-injection to branch-current matrix

BCBVM The branch-current to bus-voltage matrix

DLF() The array formed by the multiplication of BCBVM() with BIBCM()

current() Current injected at node

Power() Load at the node

voltage() Node voltage
Delta_volt() Calculated value of voltage drop
Br_Curr() Branch current
C_Plr() Branch current in polar form
V_Plr() Node voltage in polar form
Power1 () Array to store the active power at node
P_Br() Array to store the active power for the edges
Q_Br() Array to store the reactive power for the edges
C_Act() Branch current in amperes
PLoss() Branch power loss in watts

Output The Branch current, Node voltage and Power so calculated are displayed on the result screen.

Capacitor Placement Program

Input Reads the values of capacitor size and the corresponding cost from the Qc_Data table in the QC_Data.mdb database.

Variables

Ir()Reactive component of branch current
Sum_Iri_Risummation of Ir()*R()
Sum_Risummation of Ir()
Ic()Calculated value as per equation 7.9
D_Sk()Cost reduction calculated as per equation 7.10
D_P_ds()Loss reduction calculated as per equation 7.11
Qck()Capacitor size calculated as per equation 7.7
Cap_size_final()The selected capacitor size
Cap_cost_final() The cost of the selected capacitor size

Output The values of the capacitors so selected are displayed on the result screen.

Writing Results to Database

Node Values The values of VOLTAGE and ANGLE ie V_Plr() are written to the attribute table of LoadArea shape file.

Feeder Values The values C_Act() and PLoss() are written to the attribute table of the Edges feature class.

8. Convert Text File into Shape File

The program utilizes the values of the X and Y coordinates written in the text file and converts them into a shape file. The program can be used for creating and importing only the shape files whose geometry is of type point. The text file in which the values are available can be browsed in the Open window and the name of the shape file to be created and the path can also be browsed in the Save As window. This program can also be utilized for generating three dimensional point shape file, in such a case the text file must contain X,Y & Z coordinates. The program has been incorporated in ArcMap as a macro and an Icon created on the toolbar.

Input Text file namely Polygon_Centroid_XY.txt for creating the load centers shape file and SubStnXY.txt for creating the Sub_Station shape file.

Variables pGxObj.FullName - The name of the text file
StrShpFile = .Name - Gets the name of the shape file to be created
strFolder = pShpObj.FullName - Gets the path where the file to be stored
strShapeFieldName - Stores the name of the field to be created
Set theCurrentIMap = theCurrentIMxDocument.FocusMap – Reads the active map
Set varlSpatial = theCurrentIMap.SpatialReference - Get this from the active map
Val_Xcoord - Stores the X coordinate of the point
Val_Ycoord - Stores the Y coordinate of the point
Val_Elevation - Stores the Z coordinate of the point, if exists else 0
pFeatureWorkspace – Creates a workspace
pFeatureLayer – The layer to be added to the active map
pMap - the active map
pMap.AddLayer pFeatureLayer – adds the layer to the active map

Output Creates the point shape file Load_Centres and Sub_Station.

Appendix B

REPRESENTATION OF NETWORK : LINK NET

In the development of any algorithm which deals with the network, a very important aspect involves efficient storage of the network information in the computer memory. This is particularly important for the analysis of large sparse networks which occur in the power systems studies. Often it will largely determine the computer memory requirements and may significantly affect the processing efficiency of the algorithm. A wide variety of methods have been used to store power system network information. Most of the structures have been developed for particular types of network algorithm and have a limited range of applications. However for a wide variety of network problems there are a number of common features which are desirable in the storage structure, these can be summarized as:-

- Use of small amount of computer memory.
- Processing of the network information should be facilitated, for example the branches and nodes connected to any given node should be easily scanned.
- The structure should perfectly reflect network changes, for example the addition and removal of branches.
- The structure should be simple and easy to program.

A distribution network has a typical tree structure, having the root node as being feeding node. Typical distribution system is shown in fig B.1, a similar system has been considered in this project work.

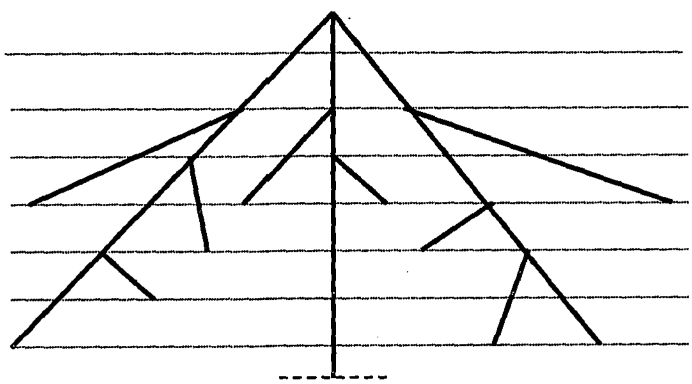


Fig B.1: Radial Distribution System – Tree Structure

The Link Net structure used in this project incorporates all the desired features listed above. The structure derives its name from linked list, which it applies to obtain some of these features. The Link Net is a general purpose structure for representing networks in a computer.

In this linking method it is assumed that nodes and branches in the network are numbered either manually or by the computer previously and put in data file accordingly. Typically in a power system network, the nodes are numbered manually and the branch numbering is left to the computer. The properties of the network are divided into node properties, branch properties and topological properties. The node properties and branch properties are stored in a standard fashion. For each node and branch property a one dimensional array is allocated and each position in the array is identified with the node or branch having the corresponding number.

The topological properties are represented by specifying the connection between the nodes and branches, assuming that the ends of each branch are numbered as follows:-

Ends of branch 1 are numbered 1 and 2, Ends of branch 2 are numbered 3 and 4 and so on. Thus the branch end numbers are derived from the branch number itself as :-

$$\text{END A} = f(\text{BRANCH}) = (2 * \text{BRANCH}) - 1 \quad (B.1)$$

$$\text{END B} = g(\text{BRANCH}) = (2 * \text{BRANCH}) \quad (B.2)$$

Conversely a branch number may be derived from either of its end numbers, using the expression

$$\text{BRANCH} = h(\text{END}) = (\text{END} + 1) / 2 \quad (B.3)$$

In this relationship, the integer round off is used to obtain the two to one mapping between branch ends and branches. The topology of the network can be defined by constructing a linked list of the branch ends which are connected to each Node.

For each node a pointer is defined as follows:-

LIST(NODE) = The first branch end on the list from the NODE.

For each branch a pointer is defined as follows :

NEXT(END) = The next branch end on the list END.

The last branch end on the list for each node is indicated when
NEXT(END) = 0.

LIST(NODE) and NEXT(END) pointers are sufficient to define the network topology uniquely. Thus the branches connected to any node can be directly obtained using the procedure given below.

Initialize END=LIST(NODE)
Then set BRANCH=h(END) AND END = NEXT(END)
Until NEXT(END) = 0

In the network computations, it is often necessary to obtain the nodes which are connected to a given node. This operation is facilitated by defining an additional pointer for each branch end as :

FAR(END) : The node at the far or opposite end of the branch.

The nodes connected to any given node can be obtained using the following procedure:

Initialize all LIST(NODE) equal to zero. Now follow the following procedure

NEXT(END A)=LIST(NODE A)
update LIST(NODE A)=END A
FAR(END A)= NODE B

Similarly, for the second end of the branch END B

NEXT(END B)=LIST(NODE B)
Update LIST(NODE B)=END B
FAR(END B)= NODE A

It may also be required to obtain the nodes at the end of a given branch. This can be obtained as follows :-

END A = f (BRANCH)
END B = g (BRANCH)
NODE A=FAR(END B)
NODE B=FAR(END A)

The pointers LIST(NODE), NEXT(END), FAR(END) form the framework of the Link-Net structure. This enables various network scanning operations to be performed very easily.

The Fig B.2 illustrates how the LINK NET structure can be built simply by adding each branch to the network.

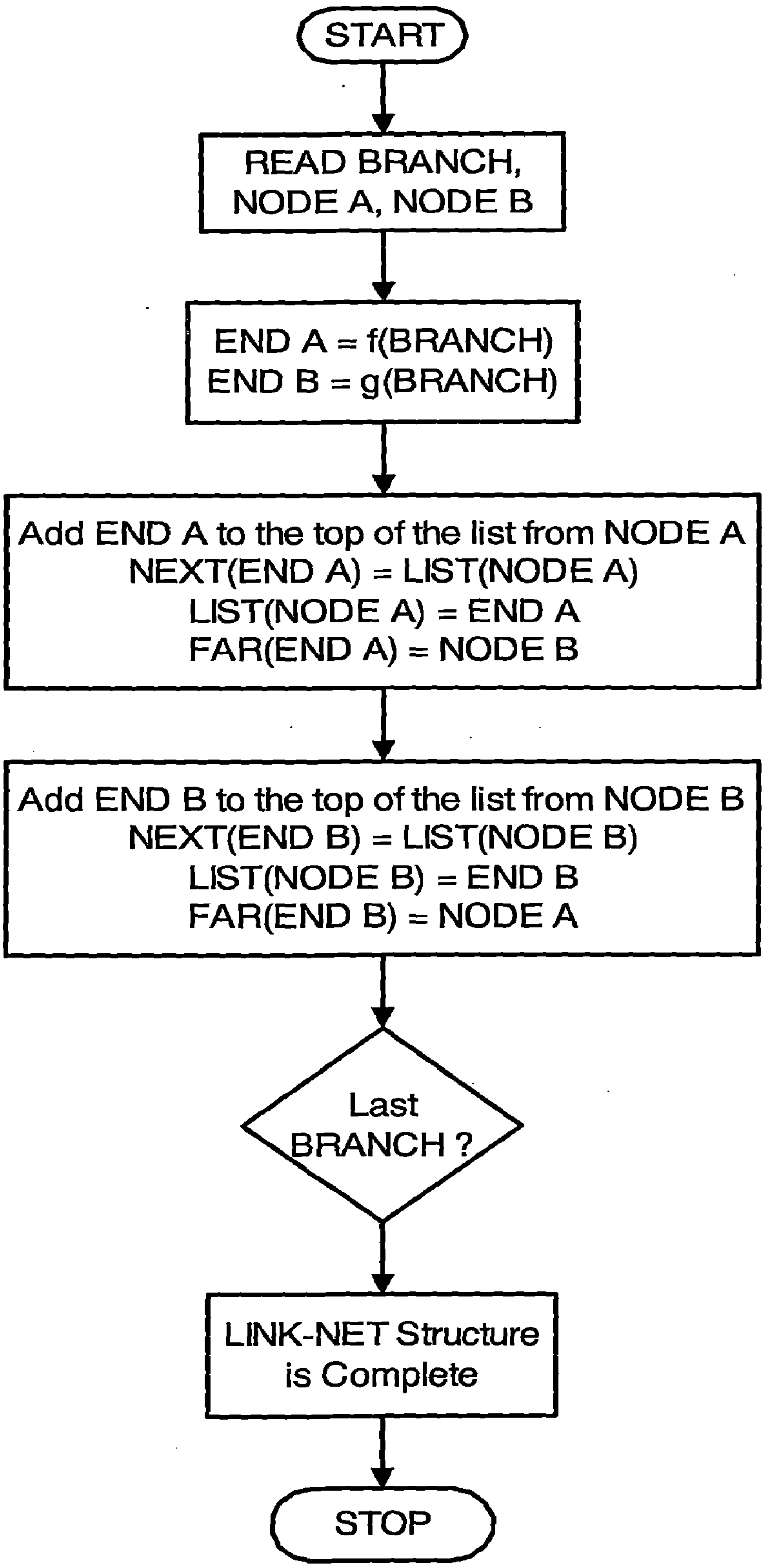


Fig B.2 : LINK NET STRUCTURE

Appendix C

Algorithm 422 Minimal Spanning Tree [H]

This algorithm generates a spanning tree of minimal total edge length for an undirected graph specified by an array of inter-node edge lengths using a technique suggested by Dijkstra. Algorithm is discussed in the succeeding paras.

The nodes of the graph are assumed to be numbered from 1 to N. The length of an edge from node I to node J is given by array element DM(I, J). If there is no edge from node I to node J, DM(I, J) is given a value larger than the length of the longest edge of the graph, say 10000. The diagonal elements of array DM are not used and may have any value. After execution of the algorithm, the edges of a minimal spanning tree are specified by pairs of nodes in array MST and the total edge length is given by CST.

The Dijkstra algorithm grows a minimal spanning tree by successively adjoining the nearest remaining node to a partially formed tree until all nodes of the graph are included in the tree. At each iterative step the nodes not yet included in the tree are stored in array NIT. The node of the partially completed tree nearest to node NIT(I) is stored in JI(I), and the length of edge from NIT(I) to JI(I) is stored in UI(I).

Hence the node not yet in the tree which is nearest to a node of the tree may be found by searching for the minimal element of array UI. That node, KP, is added to the tree and removed from array NIT. For each node remaining in array NIT, the distance from the nearest node of the tree (stored in array UI) is compared to the distance from KP, the new node of the tree, and arrays UI and JI are updated if the new distance is shorter.

The nearest node selection and list updating are performed N - 1 times until all nodes are in the tree.