SITING OF TRANSMISSION LINE USING GIS

A DISSERTATION

Submitted in partial fulfillment 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 "**SITING OF TRANSMISSION LINE USING GIS** ", submitted in partial fulfillment of the requirements for the award of the degree of **MASTER OF TECHNOLOGY** in **ELECTRICAL ENGINEERING** with specialisation in Power System Engineering in the Department of Electrical Engineering, Indian Institute of Technology, Roorkee, is an authentic record of my own work, carried out from July 2006 to June 2007, 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.

Dated : 15 May 2007

Place : Roorkee

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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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Dated : 15 May 2007

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ABSTRACT

The demand of power has increased manifold in the last few decades and thus there is requirement for developing power transmission systems to follow up with the rapid growth. In the site evaluation process for transmission line, it is necessary to carefully consider not only technical issues, but also the impact on natural environment, the influence on local communities, and various regulations. However, it is getting difficult to find the preferable site for a transmission line, because of the increasing cost of constructions, the increasing concern on environmental issues and the growing consciousness of land owners. To solve those problems, a computer system has been developed employing GIS technology.

The new methodology for automated route selection for the construction of new power lines, based on geographic information systems (GIS). It uses a dynamic programming model for route optimization. Environmental restrictions are taken into account together with all of the operating, maintenance, and equipment installation costs, including a new approach to the costs associated with the slope of the terrain crossed by the power lines. GIS platform is used for the selection of the minimum cost route as well as its economic corridor, where geographic data (installation, maintenance, operation costs, land use, etc.) and computing results are represented in raster format instead of vector format. The raster format allows adopting dynamic programming for all of the studied geographic areas.

The most Significant challenge for a transmission system and line designer is to achieve an economical design while meeting many diverse requirements and constraints. After recognition that a transmission facility is needed, a coordinated effort providing for this need is accomplished through long range transmission planning. When selecting a support structures, the design engineer will try to utilize available design to avoid the expenditures for a new tower family including the workshop drawings, especially in case of relatively short lines. From the technical point of view, a line route should be selected which avoid angle points, as far as possible, since they require considerably higher efforts and investments. A tower configuration as uniform

as possible should be selected. An easy access to the tower sites reduces compensation for land use and maintenance costs. Tower sites on exposed points of the terrain, such as rock noses, should be avoided although they offer advantages concerning the adjustments of the conductor catenary to the terrain.

In this dissertation, a Geographic Information System(GIS) application has been developed using MATLAB for the selection of optimal route and siting of the transmission line towers along the route so that overall cost of the project is minimum. Remote sensing is the most cost-effective source of information for updating a GIS and it is a valuable source of current land use/land cover data. This is done through satellite imagery, Arial photography etc. In this dissertation work satellite Imagery was taken as the data source for GIS. In this Integrated system between GIS and MATLAB has been designed. The GIS gives the complete profile of the pre selected routes. This profile is stored in the tabular form. Using the MATLAB the transmission line tower are sited which satisfies the design constraints so that the overall cost of the project is minimum.

The output obtained from the above algorithm which satisfy the constraints are plotted in three dimensional view in MATLAB. This output has also been interfaced with a GIS platform for easier display, analysis and assimilation. ArcView 3.0 has been used for developing the display of all the above data collected including development of attributes databases for the same. The data also specifically includes the latitudes and longitudes of each site locations.

CONTENTS

CHAPTER NO : 1

INTRODUCTION

In the last few decades, the electric power industries have been developing power transmission systems to follow up with the rapid growth of the power demand. On the other hand, the suitable site for new transmission lines has been getting restricted, because of development of rural areas and the growing concern over environmental issues. 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. This will help planners and engineers in the environmental and engineering analyses for transmission line siting. Power industry consequently has to keep track of numerous poles, circuits, power lines, and transformers. Information of location, voltage, and distribution of electricity of these facilities seem to be very overwhelming. However, with the use of GIS, information can be better organized on a computer system linking the database to map. A GIS as well can make the information easily updateable and accurate and hence can cater to the needs of maintaining large power infrastructure. GIS can effectively manage information on the distribution of electricity to customers and information describing the attributes of each customer such as location and electricity use. Electric companies are already finding GIS very useful in management of distribution.

Remote sensing is the most cost-effective source of information for updating a GIS and it is a valuable source of current land use/land cover data. This is done through satellite imagery, Arial photography etc. Remote Sensing is the science and art of acquiring information (spectral, spatial, temporal) about material objects, area, or phenomenon, without coming into physical contact with the objects, or area, or phenomenon under investigation. In remote sensing, information transfer is accomplished by use of electromagnetic radiation (EMR). EMR is a form of energy that reveals its presence by the observable effects it produces when it strikes the matter. The integration of image data into GIS has tremendously increased the capabilities of the GIS. Satellite Image which is the primary source of information are available in three formats (bip,bil,bq). This can be easily converted into DEM/ TIN through a software to be used in GIS. Remote sensing techniques has been utilized successfully in number of areas of application in routing, weather forecast, agriculture etc.

Geographic Information System (GIS) is a computer based information system used to digitally represent and analyse the geographic features present on the Earth's surface and the events (non-spatial attributes linked to the geographic feature under study) that taking place on it. Digital Terrain Modelling (DTM) is an important utility of GIS. Using DTM/3D modelling, landscape can be better visualized, leading to a better understanding of certain relations in the landscape.

Factors Making the GIS Powerful

- Revolution in Information Technology.
    - Computer Technology.
    - Remote Sensing.
    - Global Positioning System.
- Communication Technology.
- Rapidly declining cost of Computer Hardware, and at the same time, exponential growth of operational speed of computers.
- Enhanced functionality of software and their user-friendliness.
- Visualizing impact of GIS corroborating the Chinese proverb "a picture is worth a thousand words."
- Geographical feature and data describing it are part of our everyday lives & most of our everyday decisions are influenced by some facet of Geography

Planning Stages of a New Transmission Line

The demand of power has increased manifold n the last few decades, and thus there is requirement for developing power transmission systems to follow up with the rapid growth. On the other hand, the suitable site for new transmission lines has been getting restricted, because of development of rural areas and the growing concern over environmental issues. The transmission line projects consists of six stages, from conceptual planning to final completion. These six stages are as under :-

a) **Conceptual Planning.**
b) **Preliminary Planning.**
c) **Licences and Approvals.**
d) **General Circuit Performance.**
e) **Line and Station Performance.**
f) **Construction and Energization.**

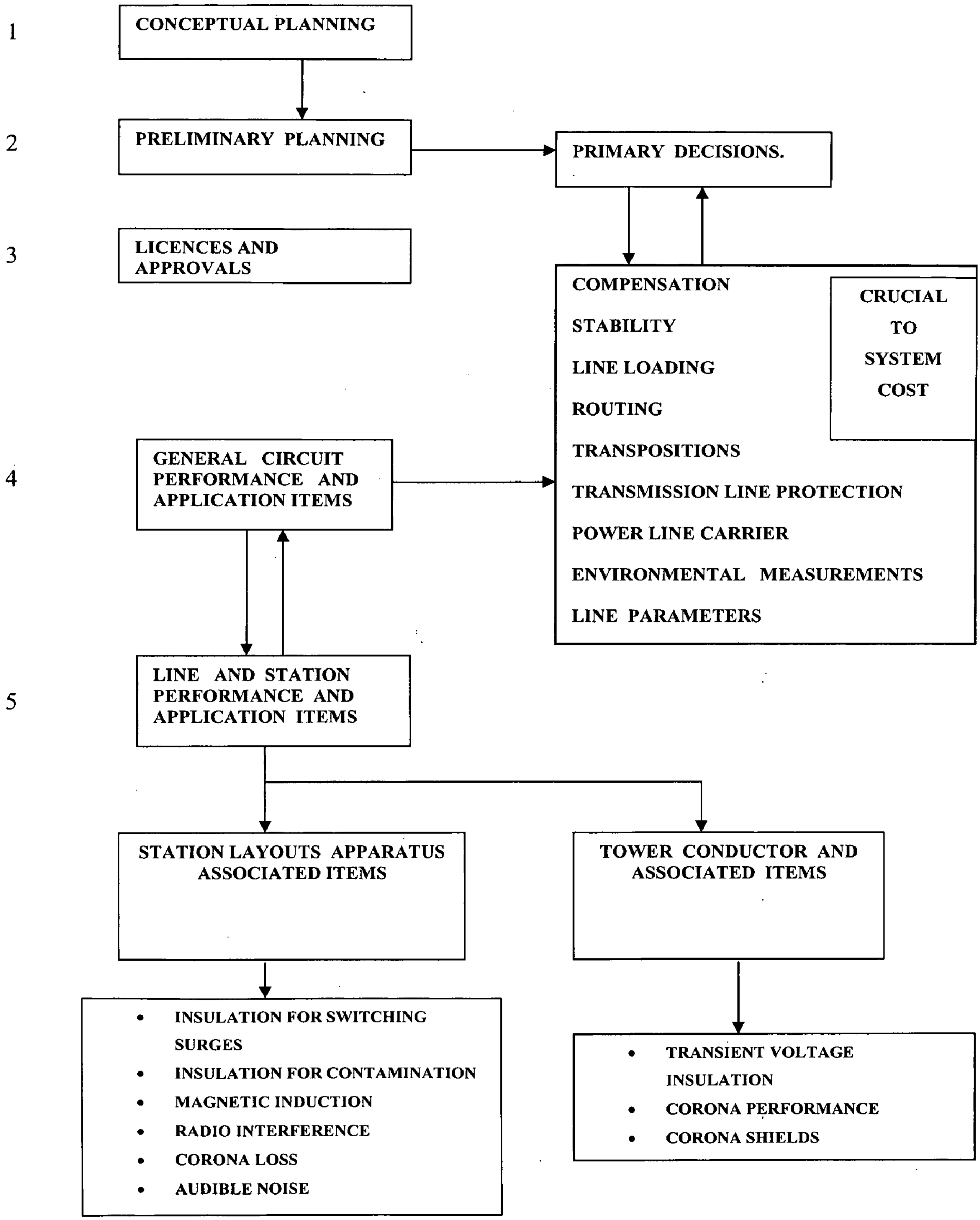
In practice, the exact sequence for a particular utility will depend on the design philosophy, organizational makeup, and the circumstances of a particular transmission project.

Conceptual Planning and Preliminary Planning. This is first two stages of planning for any transmission line project and during these stages four basic questions are addressed:-

a) When will the new transmission line needed ?
b) Where is more transmission needed?
c) How much transmission capacity is needed?
d) What type?

The above questions will help the planners to forecast approximately the transmission needs for next 15 to 20 years. It gives planners where to locate the new transmission capacity and how much will the load on the transmission line. Conceptual Planning will help deciding what type, whether to use ac or dc voltage type and overhead or under ground construction.

FLOW CHART : PLANNING STAGES



Primary Decisions Based on the answers to the basic questions in the first two stages four primary decisions are taken to be involved in a transmission line project , these are **capacity, voltage type, terminals and in-service date**. These primary decision are affected by the following three activities.

a) Preparing operating guidelines.

b) Making network performance studies for preliminary design and design decisions.

c) Making approximate network design studies for conceptual planning.

The five major dimensions of these are listed in the table given below:-

Table 1.1 : Transmission Planning Activities Each Year

	OPERATING GIUDES	**PREDESIGN AND DESIGN**	**CONCEPTUAL PLANNING**
Time Span	0-4 Years	4-8 Years	8-30 Years
Problems	Overload Voltage Power transfer Stability Limits Short circuit	Overload Voltage Power transfer Stability Limits Short circuit	Overloads Power transfer Stability Limits
Project Parameters	List of Operating restrictions for networks	Capacity voltage Terminals buses Target year	Capacity voltage Terminals areas Approximate year
Modal Size	Multi regional	Reliability Region	Power Pool
Analytical Methods	-------------------- -------------------- DC Power Flow AC Power Flow Transient stability Dynamic stability Short Circuit ----------------------	--------------------- --------------------- DC Power Flow AC Power Flow Transient stability Dynamic stability Short Circuit Economics	Linear flow estimation Distribution factors DC Power Flow AC Power Flow Transient stability -------------------- ------------------- Economics

The **Time Span** gives the time period of various activities. The conceptual planning takes the maximum time i.e. from 8 to 30 years. The **Problems** associated with preparing operating guidelines, design and conceptual planning are generally the same. The major problems which are of concern are overload, voltage problems, power transfer, stability, and short circuit problems.

A transmission line **Project** is define by four major parameters i.e. capacity, voltage type, terminals and in service target year. Capacity is initially is selected during conceptual studies and is finalized during the predesign phase. The voltage type for a line is estimated during the conceptual phase and finalized during the preliminary design phase. The location of the terminals i.e. the two substation is selected during the preliminary design phase. The target year of installation is estimated during the conceptual planning phase and is continually adjusted to meet budgetary, regulatory and the system requirements. The year of installation may not be known until the line actually goes into service. However, the year selected for installation is first set in the conceptual phase and than year for preliminary design work is calculated backwards, estimating the time required for construction, and for electrical and mechanical design of the line.

During the planning phase system planning organization will use at least three different **Modal sizes** for network transmission – planning studies. For conceptual planning , the modal will involve the power pool, for the preliminary planning phase the network modal involve the reliability region and for the operating guides for the next season or year a much larger modal, representing several reliability regions will be involved.

Overhead transmission of electric power has been along the years and will still continue one of the most important element of today's electric power systems. Power transmission from generating stations to industrial sites and to substations is the fundamental object of the transmission systems. This function is accomplished by overhead transmission lines that connect the power plants into the transmission networks, interconnect one utility with another, or deliver the electric power from various areas within the transmission network to the distribution substation, from which the distribution systems supply residential and commercial consumers. The planning activities of a new transmission system start years before the actual installation or expansion of the existing system.

The tower spotting consists primarily of matching the continues curve in which the conductor hangs with the discrete points, which are used to represent the ground profile. In solving for a point of tangency of the ground clearance curve with the discrete points, many factors must be considered. Two such factors are: tower heights (which hereafter will be represented as the distance from ground level to the lowest point of attachment of a conductor) and the required ground clearances. The curve in which the conductor hangs depends upon the tension in the conductor, which in turn, is dependent on the type of conductor as well as the temperature.

Whenever the survey data of a transmission line route is given and then out of available choice of towers of suspension type and of angle towers a dynamic programming algorithm is described which chooses and sites the towers (the location and angle of the angle towers being prescribed) in such a way that the overall cost of running the line from one end of the route to the other, subject to all the established design constraints, is a minimum. The basic algorithm uses Bellman's 'principle of optimality', the problem being considered as one of routing in a finite connected network. The Bellman principle of optimality states that an optimal policy must contain only optimal sub policies, and each optimal sub policy is independent of past optimal sub policies.

The quality of tower spotting of a transmission line determines directly the cost of the power line. In the early days all the tower spotting is done by hand. It is impossible for a designer to choose a best plan from thousands of plans in practical works. In the later years, some of the problems of tower spotting can be solved due to the development of computation methods and the rapid progress of computers. Dynamic programming is one of the best way to solve complicated tower spotting problem.

LITERATURE REVIEW

An extensive literature review was carried out for the purpose of understanding the various planning stages of a new transmission line project, basics of routing of a electric transmission line using GIS and once the optimal route is decided than methods to optimize the sites and heights of transmission line towers using dynamic programming.

Cláudio Monteiro *et. Al.* [1] discusses a new methodology for **automated route selection** for the construction of new power lines, based on **geographic information systems (GIS).** It uses a dynamic programming model for route optimization. Environmental restrictions are taken into account together with all of the operating, maintenance, and equipment installation costs, including a new approach to the costs associated with the slope of the terrain crossed by the power lines. The computing and visual representation capacities of GIS are exploited for the selection of economic corridors, keeping the total costs under a threshold imposed by the user. Intensive simulation examples illustrate the power and flexibility of the proposed methodology.

Tyeb Pervaiz *et. Al.* [2] Discusses the methodology for the selection of suitable route for a new transmission line project, the optimum path finding, the profile analyses, the engineering design of towers and wires, and the cost estimation using GIS.

G. Mitra *et. Al.* [3] When the survey data of a transmission line route is given and the choice of available towers are of suspension type and of angle towers a dynamic programming algorithm is described which chooses and sites the towers (the location and angle of the angle towers being prescribed) in such a way that the overall cost of running the line from one end of the route to the other, subject to all the established design constraints, is a minimum.

L Olbrycht *et. Al.* [4] A **dynamic programming algorithm** which chooses types, heights and sites of towers along a given transmission line route is described. On the basis of estimated data for the ground strength along the line path, and the criterion of minimum construction costs, a set of consecutive cheapest solutions of the problem is determined (i.e. the optimal and the required number of suboptimal solutions). It is proposed to submit the obtained set of solutions for further analysis based on some additional criteria and a more accurate survey of ground strength in tower locations already known. The analysis may prove that one of the suboptimal solutions is most advantageous.

Transmission line Reference Book Vol I and Vol II By EPRI was referred to study the aspects and the concepts related to **'Planning and Electrical Design of a Transmission Line'**. Basically there are six stages of planning a new transmission line project starting from conceptual planning to final completion. A new transmission line project is defined by four parameters i.e. capacity , voltage type , terminals and in service target year. The most Significant challenge for a transmission system and line designer is to achieve an economical design while meeting many diverse requirements and constraints.

Book on **'Overhead Power Lines'** by F.Kiessling and P.Nefzger was referred to study the concepts related to Overall Planning of a Transmission line Project and some basic aspects related siting of a Transmission Line i.e. finding out the location and height of electric Transmission Line Tower on a given route. The most Significant challenge for a transmission system and line designer is to achieve an economical design while meeting many diverse requirements and constraints.

CHAPTER NO : 3

TRANSMISSION SYSTEM PLANNING

The most Significant challenge for a transmission system and line designer is to achieve an economical design while meeting many diverse requirements and constraints. After recognition that a transmission facility is needed, a coordinated effort providing for this need is accomplished through long range transmission planning.

Long Range Transmission Planning

The transmission planning technique assumes that the ratings, locations and timing of future generating units have been established by generation expansion plans, with alternatives. An ultimate transmission system design, with alternatives is derived for a **Horizon Year** , usually it is 15 to 20 years. The Horizon Year Design becomes a goal for year by year additions.

The data required **for initial system** is voltage, terminal, equipment, location and capacity of each transmission circuit. For **new sites**, generating plants and load substation are described by name, location and size. Data for load forecasting are given by **year-by-year** at each location. Considerations for **right of way** includes land availability, economics and environmental considerations. The next items for study data are those associated with **normal and emergency tests** (power flow and stability), which detail the generation and load patterns and the circuit outages to be used in selecting circuits to form reliable network. Finally there is data for **design preferences** that indicate the voltages to study and their loading guides.

Horizon Year : In the Horizon Year planning phase, the need for new circuits, higher voltages, more substations and uses to be made of new right-of - way corridors is appraised.

Year- By –Year : The Horizon Year plans give direction to the incremental networks additions planned in a year by year analysis. Early years more thoroughly represented and tested.

Elements Of Long Range Transmission Planning

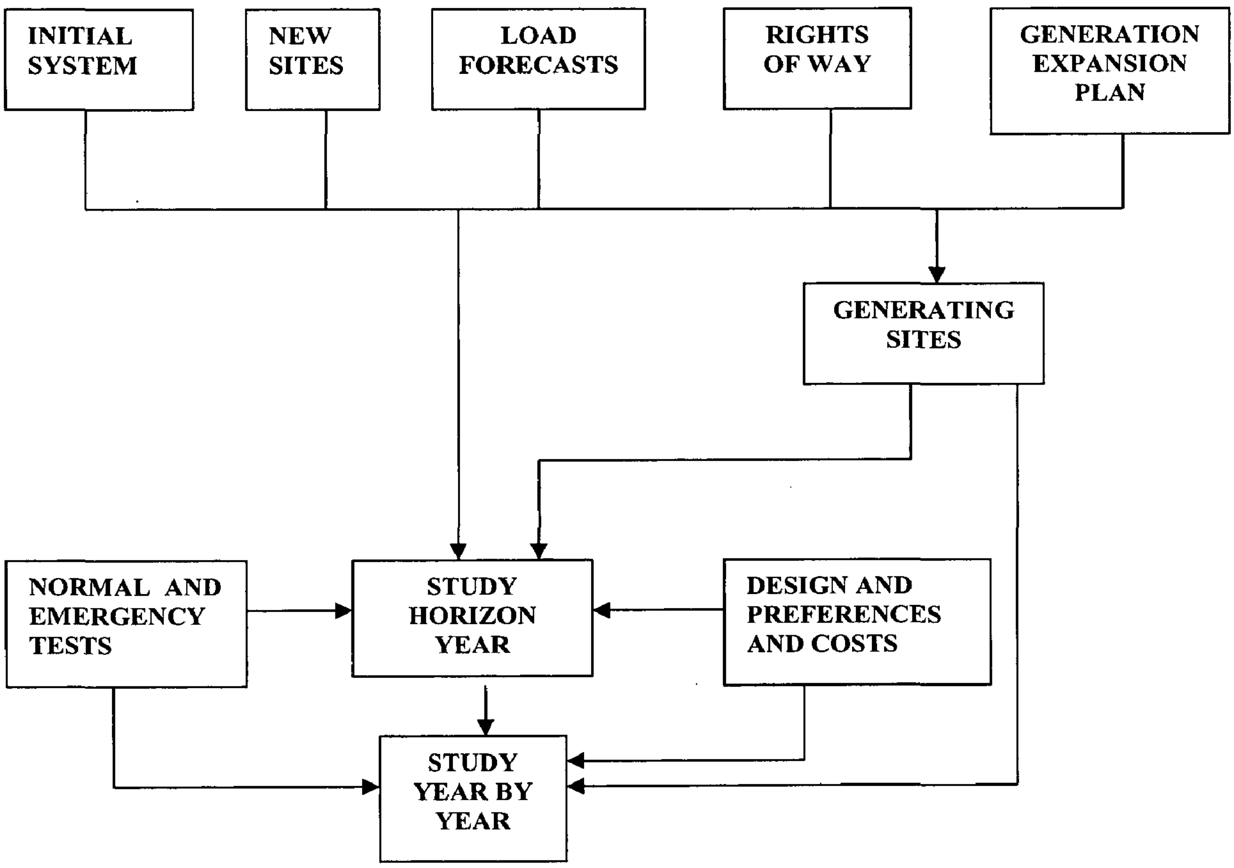


Fig 3.1

3.1. Transmission Line Routing

The Transmission line routing is the selection of a corridor for a proposed line based on optimizing engineering, environmental and economic criteria.

The determination of right of way locations for electric utilities is no longer the straight forward task now days as it used to be. A growing public concern for the environment has made corridor selection a complicated and highly sensitive tasks. Choosing the optimum transmission route requires the careful coordination of engineering, environmental and economic consideration. The best route, of course meets all electrical, mechanical and environmental requirements at the lowest cost.

During the line routing process, there will be numerous tradeoffs between some or all the important design factors. Therefore it is important that each major design factor needs to be evaluated with respect to its impact on the area over which the proposed line is to be routed. Sophisticated digital methods have been developed that use computer graphics to indicate optimum and alternate transmission routes. These are environmentally weighted according to their importance. For example, the geographical area under may have restraints concerning population density, transportation routes, preservation of natural habitats and areas of historical significance and thus will restrict the construction of transmission line. With help we can identify the paths of least environmental resistance.

There could be tradeoffs between environmental concerns and economics involved in corridor delineation. With the increasing cost of land the corridor length has become a crucial issue. Another factor contributing to line routing costs is the clearing methods used. If the optimum corridor has abundant vegetation, there will be additional costs involved in clearing and maintenance, especially if selective clearing method are employed. Corridors that are highly inaccessible may require special purpose access roads to be built, thus adding to the total costs. Studies for corridor selection must begin early in the planning of transmission line project. This will allow the optimum solution to be thoroughly documented, compared with alternatives, and presented in a convincing manner to the Government. Some of **design considerations** are listed below :-

Design Items

a) **Engineering Criteria**:-

(i) Right of way width determination.

(ii) Audible noise performance.

(iii) Radio interference

(iv) Television interference.

(v) Electric field induction

(vi) Magnetic field induction

(vii) Line configuration

b) **Environmental Criteria**:-

(i) Aesthetics (tower design)

(ii) Biological effects

(iii) Population density

(iv) Transportation routes

(v) Land use restraints

(vi) Preservation of natural habitats

(vii) Preservation of areas of historical significance

(viii) Type of terrain

c) **Economic criteria**:-

(i) Length of corridor

(ii) Clearing method

(iii) Corridor accessibility

(iv) Corridor maintenance

(v) Tower construction

3.2. Radio Interference and Audible Noise

EHV & UHV AC Transmission lines and electrical equipment produce electric & magnetic fields around their vicinity which are likely to produce various induction and biological effects when their levels exceed certain values. In addition to this, the electric field may initiate corona resulting in corona loss with associated interference nuisances like radio interference, audible noise etc. Transmission line planners should take these factors also into consideration at the design stage.

All electric power installations including overhead (OH) transmission lines generate electric and magnetic fields in their vicinity. AC conductors used for 220 kV and below are usually designed on the basis of current carrying capacity, whereas those for 400 kV and above have to take into account the electromagnetic fields produced by them. The design of EHV & UHV lines should also consider the consequences of the fields on objects and human beings when their levels are beyond certain limits. All electrical equipment in addition to these power lines, generates strong electric and magnetic fields depending upon the applied voltage and current flowing in the circuits. Any object or personnel present near or under these lines are subjected to these fields which produce various induction effects including induced voltages and spark discharges. Besides the induced effects, the fields are also likely to produce biological effects on animals and human beings. The harmfulness of the effects depends upon the magnitude of the induced voltages and currents. This necessitates the standardization of the maximum electric and magnetic fields that a transmission line can produce in the vicinity.

The maximum electric and magnetic fields produced from the power lines and the potential and field distribution within the vicinity of lines have become a very important parameter in designing these lines. The other important electrical effects of transmission lines besides the field effects is corona effect such as corona loss, radio, and television interference and audible noise. These effects create disturbance near transmission lines by interfering with radio and television signals. Although these noise levels are not harmful in terms of bio-physiological effects, its interference with radio, television signals may prevent clear reception. Radio and acoustic interference can potentially be troublesome at EHV & UHV range. Because of this, the corona loss, radio interference (RI), and audible noise (AN) also form as important parameters in designing transmission lines.

3.3. Electric field and Magnetic field Induction Effects

Measurements and calculations of electric and magnetic fields of transmission lines have increased in recent years. One reason for this is the public concern about possible health risks that the fields might cause. The electric and magnetic field (EMF) issue has become an area of increasing public concern. There is a heightened sensitivity among the public to the siting and construction of new, and the upgrading of existing electric facilities.

The increase in the demand of electrical energy has raised the operating voltage bf high voltage lines and as a consequence raised serious questions regarding potential health and environmental effects associated with the resultant higher levels of electric field intensity around these lines Public hearings and accompanying media exposure have evoked emotional responses on the part of the public and construction of the important high voltage transmission lines, especially those in the residential areas in the big cities, has been delayed.

AC electric and magnetic fields induce surface charges on humans and a weak current flows in the bodies of humans. This is one reason why there is a potential for electric and magnetic fields (EMFs) to cause biological effects. Recently, it has been suggested that if there is any harmful effect to health, induced currents may cause this effect. The amount of this current, even if a human directly beneath a transmission line, is extremely small. Currents from 50-60 **Hz** EMFs are weaker than natural currents in the body, such as those from the electrical activity of the brain and heart. The maximum body current induced by electric field from a transmission line is much greater than the body current or the body current density induced by the magnetic field.

Shielding

Electromagnetic field exposure is reduced if the areas occupied by people are shielded from the electric and magnetic field sources. Conceptually shielding methods from magnetic fields can be divided into:-

a) Shielding caused by induced currents.

b) Shielding obtained by modification of magnetic flux patterns using high permeability materials

c) Active shielding obtained by adding a magnetic field that tends to reduce the magnetic field present without shielding.

The application of field exposure techniques to existing facilities and equipment is much more difficult than for new constructions. Existing facilities and equipment in general have severe constraints which limit the choice of suitable field reduction options and offer a new set of engineering challenges.

Methods For Reducing Electromagnetic Fields

Apart from the obvious task of meeting existing regulations, if any, for the electric and magnetic fields at the edge of the right-of-way, transmission line electromagnetic field reduction may include:-

a) Inclusion of electric and magnetic field exposure, appropriately defined, among criteria for route selection.

b) Consideration of different design options and assessment of field exposure and cost for each option.

d) Design optimization to minimize the electric and magnetic fields at reasonable costs.

Different options to minimize the electric and magnetic fields have been conceptually developed, but for most of them effectiveness, cost, and practicality have not yet been evaluated. Methods for reducing the electromagnetic fields involve:-

(a) Distance,

(b) Conductor configuration,

(c) Phase arrangement,

(d) Split-phase,

(e) Current reduction,

(f) Shielding or active cancellation,

(g) Under grounding.

ROUTING OF OVERHEAD TRANSMISSION LINE USING GIS

A transmission line is one of essential infrastructures of the power supply system. In the site evaluation process for those facilities, it is necessary to carefully consider not only technical issues, but also the impact on natural environment, the influence on local communities, and various regulations. However, it is getting difficult to find the preferable site for a transmission line, because of the increasing cost of constructions, the increasing concern on environmental issues and the growing consciousness of land owners. To solve those problems, a computer system has been developed employing GIS technology.

The new methodology for automated route selection for the construction of new power lines, based on geographic information systems (GIS). It uses a dynamic programming model for route optimization. Environmental restrictions are taken into account together with all of the operating, maintenance, and equipment installation costs, including a new approach to the costs associated with the slope of the terrain crossed by the power lines. The computing and visual representation capacities of GIS are used for the selection of economic corridors, keeping the total costs under a threshold imposed by the user.

GIS platform is used for the selection of the minimum cost route as well as its economic corridor, where geographic data (installation, maintenance, operation costs, land use, etc.) and computing results are represented in raster format instead of vector format. The raster format allows adopting dynamic programming for all of the studied geographic areas. An original application of advanced dynamic programming optimization to raster data is carried out in an iterative way for the selection of the optimal route path. Another innovative process developed is a new directional routing formulation to model the additional routing costs caused by terrain slopes (that depend on the direction followed), as well as a two-directional approach to the routing problem (origins and destinations act as starting points of the routes in the first stages of the proposed methodology) for route path selection.

4.1 Data Structures Required

In this GIS raster structures is used instead of GIS vector data as the actual information of terrain (slopes, soil types, terrain costs, geographic restrictions, obstacles, etc.) is not suitably associated with nodes and lines, although it can be associated with small areas represented as polygons or elementary cells. This feature is a reason to optimize the paths directly in terrain-oriented formats ("GIS raster" structure) instead of using a synthetic network methodology. **GIS raster structures are basically a regular matrix of square cells where each cell represents an elementary area and position.** The detail of the geospatial analysis depends on the size of the elementary cell (resolution).

With this structure, the spatial analysis is based on matrix operations, where the matrix corresponds to a geographic coverage (terrain costs, terrain slope, soil types, and other aspects), and the information of each matrix element corresponds to numerical information associated with the corresponding location (cost of traversing the location, average slope surrounding the location, etc.). In GIS raster routing, all costs must be associated with terrain surface. When low resolution (e.g., cell area of 1x 1 km, that is, 1 km of resolution) is used, the costs of the sections of overhead lines, including conductors, insulators, and support structures are associated with a cell area of the map grid without specifying the location of the support structures (towers). This concept simplifies the routing process by assuming that the cost of the overhead transmission line components is uniformly distributed along the path (a cost per kilometer).

<u>**Cost Factor**</u>

The **cost** of each component is associated with the cell location that contains the geographic feature that causes the cost (e.g., road, lake, or river locations have an associated additional cost due to the insulator reinforcement and other elements).

There are basically two types of cost components associated with the routing of transmission line, and components are as under:-

a) Non Geographic Cost Component (NGC).

b) Geographic Costs Component

Non Geographic Cost Component (NGC). It is the component of the cost per kilometer is related to the equipment of the line and is independent of the geographic features. This Non Geographic cost component (NGC) is associated with the line that crosses the adjacent cells p_k and p_{k-1}, and leads to a straight line routing.

Geographic Costs Component This is the cost component which is mainly associated with terrain related costs. Various causes of this cost component are as under :-

a) Accessibility Costs.

b) Cost due to "specific characteristics" of the geographic area.

c) Terrain complexity cost.

d) Wind Speed cost.

e) Altitude cost.

f) Cost Due to Obstacles.

These **geographic costs** are modelled in the routing model (under a raster structure) as costs of crossing the cells. The geographic cost leads to non straight paths and, consequently, to additional costs associated with deviation towers. The costs due to direction changes are modelled in the routing algorithm. **Following information is required** about the cost factors discussed above, in this algorithm.

a) Information associated with **origins**, describing the location and the cost of departure from each origin cell.

b) Information about the **cost of crossing** an elementary cell $\mathbf{p_k}$, $\left(\mathbf{C}_{PK}^{TCC}\right)$, where most of the geographic costs are included.

c) **Direction change cost** $\left(\mathbf{C}_{PK,PK-1,PK-2}^{DCC}\right)$ stored in a geographic grid containing information about the additional cost if the direction changes at a particular point $\mathbf{p_{k-1}}$, between $\mathbf{p_k}$ and $\mathbf{p_{k-2}}$.

d) **Digital terrain model (DTM)** necessary to evaluate the costs associated with the local terrain slope $\left(S_{P_{K-1},P_{K-2}}\right)$ between the neighbouring cells $\mathbf{p_k}$ and $\mathbf{p_{k-1}}$. Crossing the same cell $\mathbf{p_k}$ (in different directions) toward different neighbouring cells $\mathbf{p_{k-1}}$ may result in different slope costs $\left(C^{SC}_{P_K,P_{K-1},}\right)$.

e) Information about **non geographic cost** $\left(C^{NGC}_{P_K}\right)$ associated with any cell $\mathbf{p_k}$.

4.2 Mathematical Problem Formulation

Dynamic Programming is used as a core optimization method for transmission line routing using GIS. Specific tools are design to manage and build spatial or geographic cost databases and are designed to embed DP into GIS.

Dynamic Programming is a suitable optimization technique for using with GIS raster structures (i.e., geographic coverage) in line routing. In Dynamic Programming terminology , GIS raster line routing is based on a set of elementary cells with links between neighbouring cells in a particular order (stage) along the path or route. Each cell maintains the record of an accumulated transition cost, evaluated at a particular point (state) of the calculation process along the path between the origin of the route and that cell. The optimal path between two locations (optimal decision policy) is the sequential aggregation of optimal elementary transitions or links (optimal decision policies that lead to new states of the following stages) between neighbouring cells from the origin to the end of the route.

Stage: The stage index (e.g. k) denotes the set of cells that must be crossed following the cheapest path from the origin(x_o,y_o) to the vertex $\mathbf{p_k}$ (i.e., the cell $(\mathbf{x_k},\mathbf{y_k})$).

State: The state t is an index in the computation sequence that represents the iteration number. It is associated with the accumulated cost $\mathbf{g_t(p_k)}$ to reach the cell $(\mathbf{x_k},\mathbf{y_k})$.

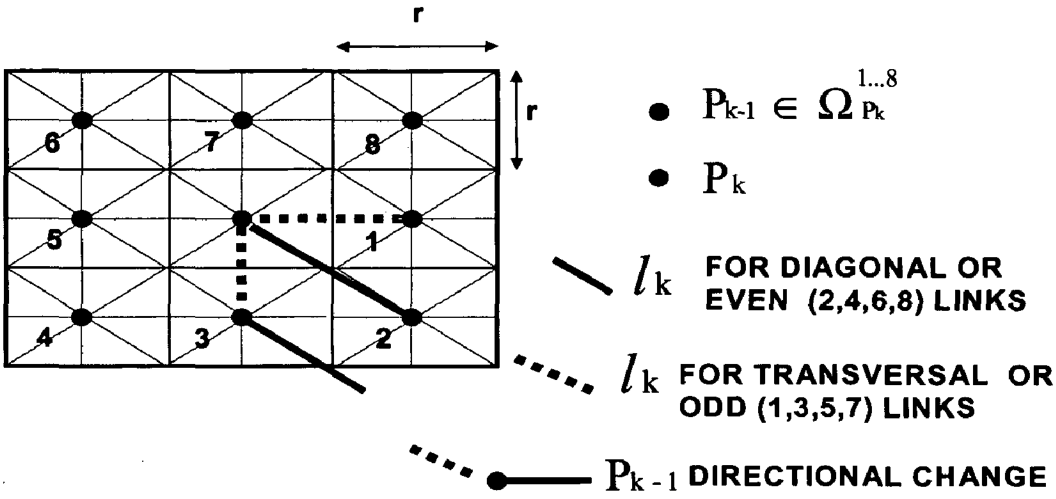


FIG. 4.1. DATA STRUCTURE ELEMENTS ASSOCIATED WITH LINKS.

First, let us define a discrete two-dimensional (2-D) space $\Omega = \{(x,y): x = 0,.....,H ; y = 0,.....,V\}$ that represents the GIS geographic coverage, where (x,y) represents the elementary cell (geographic location) that can be a vertex in a path. The set $P = \{p_o ,...,p_k ,....p_K \} = \{(x_o, y_o),...,(x_k,y_k),...(x_K,y_K)\} = \{l_1 ,....,l_k ,...l_K\}$ is the geographic path composed of k +1 vertices. Each vertex is a cell of coordinates (x_k,y_k) in the 2-D space Ω. The set of vertices creates a line by following a sequence of K stages labelled with the index k. The line segments l_k are the links between the vertices p_{k-1} and p_k. Adjacent stages must be necessarily associated to neighbouring cells in the space Ω. Thus, the space Ω is organized as a rectangular matrix where each cell can be linked to eight neighbouring cells $\Omega_{P_K}^{1....8}$, as shown in Fig 4.1.

In the computational process, the links that provide the optimal route (i.e., the minimum accumulated cost that links each cell with the origin) are saved in a directional grid coverage with a code in each cell with information on how to move to the origin. The assigned code is associated with the corresponding directions from one of the eight vertices p_{k-1} to the vertex p_k on the mariner's compass {(1,2,3,4,5,6,7,8) = (W,NW,N,NE,E,SE,S,SW)} as shown in Fig 4.1.

4.3 Calculation of Most Optimal Path Between Two Points

a) **Transition cost given** by $f(l_k)$ is initialized at the beginning of the computation. It is the cost that links two neighbouring cells.

b) Transition cost is calculated based on the elementary information associated and their relative position between the two cells. This cost is obtained from the following three cost component :-

(i) **Non Geographic Cost** $\left(C_{PK}^{NGC}\right)$, (NGCs) , independent of the position of the cell but dependent on its dimensions (i.e., the resolution of the raster).

(ii) **Slope costs** (SCs) $\left(C_{PK-1,PK-2}^{SC}\right)$, or costs associated with the local slope of the terrain between and (a geographic cost that also depends on the resolution).

(iii) **Terrain cross costs (TCC)** $\left(C_{PK}^{TCC}\right)$ and $\left(C_{PK-1}^{TCC}\right)$, with the remaining geographic costs associated with each particular cell of the grid when a specific power line crosses that cell. In the cost model, this part of the transition cost is shared between both cells.

(iv) Set a **Direction change cost (DCC)** $\left(C_{PK,PK-1,PK-2}^{DCC}\right)$, for each geographic location if the direction path changes between consecutive links.

c) **Calculation of transition cost:-** To calculate the transition cost the following mathematical expression are used:

$$C_{PK,PK-1}^{LU} = \left(C_{PK}^{NGC} + C_{PK,PK-1}^{SC} + \frac{C_{PK}^{TCC} + C_{PK-1}^{TCC}}{2} \right) \qquad \textbf{(1)}$$

$$f(l_k)_{\text{even}} = \sqrt{2}\, r\, C^{LU}_{PK,PK-1} + C^{DCC}_{PK,PK-1,PK-2} \qquad \textbf{(2)}$$

$$f(l_k)_{\text{ODD}} = r\, C^{LU}_{PK,PK-1} + C^{DCC}_{PK,PK-1,PK-2} \qquad \textbf{(3)}$$

d) **To calculate the accumulated cost $g_t(p_k)$** :- A stage **k** and a state **t** are associated with each cell (x_k,y_k) that can be a vertex of the route. The stage index **k** denotes the set of cells that must be crossed following the cheapest path from the origin $(x_0,y_0)$to the vertex p_k (i.e., the cell (x_k,y_k)). The state **t** is an index in the computation sequence that represents the iteration number; in our formulation, it is associated with the accumulated cost $\mathbf{g_t(p_k)}$ to reach the cell (x_k,y_k) in this iteration **t** by crossing all of the cells in the path. For each cell belonging to $\mathbf{\Omega}$, the accumulated cost $\mathbf{g_t(p_k)}$ for the stage **k** and the state **t** is given by the following expression :-

$$g_t(P_k) = g_{t,t-1}(P_{k-1}) + f(l_k) \qquad \textbf{(4)}$$

e) **Optimization Problem:-**

Let the cost of a line from origin to specific cell location corresponding to the stage k-1 is the accumulated cost be given by $g_{t,t-1}(p_{k-1})$ and the cost of linking stages k and k-1 is given by $f(l_k)$. Then according to **Dynamic Programming principle** the minimum accumulated cost is given by :-

$$^{*}g_t(P_k) = \min_{1\ldots 8}\left(g_{t,t-1}(P_{k-1}) + f(l_k)\right)$$
$$s.t. \quad P_{k-1} \in \Omega_{P_k} \qquad \textbf{(5)}$$

The minimum accumulated cost is computed along the Dynamic Programming optimization process, not only on the routing path but also on the whole geographic coverage. This means that the routing optimization is performed between the origin cell and the rest of the cells in the geographic coverage. The coverage of the minimum accumulated cost in each cell of the geographic GIS coverage allows to create cost isolines that show cost increases as functions of the distance to a selected origin.

f) **Optimal Path:** The path from the origin to each cell in the geographic coverage is stored in a **directional raster coverage**. For each cell, the code (1 to 8) represents the **'back'** link to the previous neighbouring cell. This coding defines a radial path structure that covers the whole region and allows to trace the path from any destination cell to the origin. This means that each p_k cell is linked to only one p_{k-1} cell although each can be linked to several p_k cells. Fig. 4.2 shows an example of this **directional raster coverage** which saves the directional codes to move from the origin (code 0) to each cell in a discrete 2-D space.

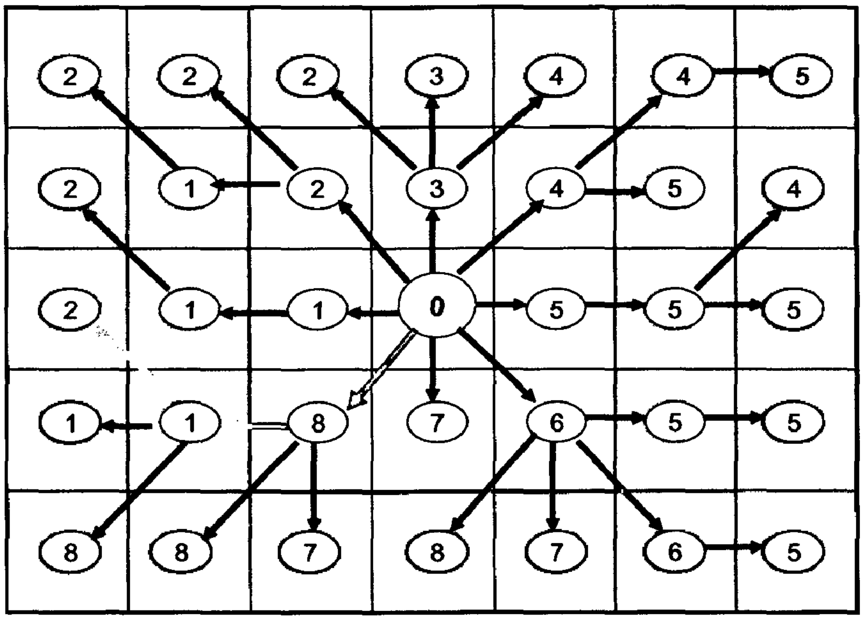


Fig. 4.2 Radial path structure for back-link path tracing.

For example in the above Fig 4.2 the directional raster coverage saves the directional codes to move from origin to any cell in the discrete space **Ω**. In order to move from origin (3,2) to the cell located at (0,2), the route followed is 0 → 8 → 1 → 2.

4.4 Dynamic Programming Algorithm

In order to get the correct results it very important to collect the correct cost data (both geographic and non geographic) for the construction of transmission line and arrange them into GIS practical spatial databases and map grid formats. The Dynamic Programming algorithm is as under:-

a) **Step 1:** Establish the resolution **r** of the studied area to create ($p_k \in \Omega$) cells of dimension **r**. Initialize the accumulation cost matrix with a simple initial state (for example, only the cost of "going out" the origin/origins, with "no data" in the rest of the cells). Digital terrain model (DTM) and non geographic costs $\left(C_{P_K}^{NGC}\right)$ are available.

b) **Step 2:** For each cell ($p_k \in \Omega$) for the state t.

c) **Step 3:** For each neighbouring cell $\left(P_{k-1} \in \Omega_{P_K}^{1...8}\right)$, for the state t if updated, or for the state t-1, otherwise.

d) **Step 4:** Compute the slope $\left(S_{p_k,p_{k-1}}\right)$ with the DTM.

e) **Step 5:** Compute the slope cost $\left(C_{P_K,P_{K-1},}^{SC}\right)$.

f) **Step 6:** Compute the terrain cross cost $\left(C_{P_K}^{TCC}\right)$ and $\left(C_{P_{K-1}}^{TCC}\right)$.

g) **Step 7:** Compute the direction change cost, if applicable $\left(C_{P_K,P_{K-1},P_{K-2}}^{DCC}\right)$.

h) **Step 8:** Compute the transition cost $f(l_k)$.

j) **Step 9:** Compute the accumulated cost $g_t(p_k)$.

k) **Step 10:** Go to following cell $\left(P_{k-1} \in \Omega_{P_K}^{1...8}\right)$. of the eight neighbouring cells (Cycle to 3).

l) **Step 11:** Select cell $\left(P_{k-1} \in \Omega_{P_K}^{1\ldots8}\right)$, with its code, as "back" link cell leading to the minimum of $\mathbf{g_t(p_k)}$, * $\mathbf{g_t(p_k)}$.

m) **Step 12:** In association with the minimum of $g_t(p_k)$, that is * $g_t(p_k)$ store the minimum cost path, for the state t and the stage k for the cell p_k.

n) **Step 13:** Go to following cell ($p_k \in \Omega$) in the geographic coverage. (Cycle to 2).

o) **Step 14:** Compare * $g_t(p_k)$ with * $g_{t-1}(p_k)$ for the whole coverage.

p) **Step 15:** Go to step 2 for a new iteration until no changes are identified in the whole coverage (checked in step 14).

The first step (1) is aimed at defining the resolution of the calculation grids, initializing the accumulated cost grid, and arranging data for subsequent calculations. Between steps 2 and 13, the computation of the accumulated cost grid is performed for each cell of the grid (only the origins are initialized), then the accumulated costs are calculated from the origin to every cell at each iteration. For steps 3 to 10, the algorithm computes the transition cost between a central cell and the eight neighbouring cells, including all of the cost components. In steps 11 and 12, the transition sequence between the neighbouring cells (which defines the path with the minimum cost) is selected as "back" link. In steps 14 and 15, the algorithm starts the following iteration and stops when no changes between iterations are detected. At previous iterations, cost paths can be selected by using other origins that do not lead to the global minimum cost path. When no changes are detected between successive iterations, we have reached the minimum accumulated cost path to each cell in the coverage and selected the "back" link cell leading to the least expensive path between the origin and the destination.

TRANSMISSION LINE TOWERS SITING

The most Significant challenge for a transmission system and line designer is to achieve an economical design while meeting many diverse requirements and constraints. After recognition that a transmission facility is needed, a coordinated effort providing for this need is accomplished through long range transmission planning.

The detail line design of a high voltage overhead line and the requirement for route selection are developed on the basis of an electric network analysis, defining the required starting and the terminal point of a transmission connection taking into account the generation and consumption load centres. The voltage level and required conductor cross section are as well determined by the existing network structure and requirements of load flow. The requirements on the supports to be used for a line project depend on the line voltage, number of circuits, conductor dimensions and arrangements as well as on climate, topographic, infrastructure or legal aspects.

When selecting a support structures, the design engineer will try to utilize available design to avoid the expenditures for a new tower family including the workshop drawings, especially I case of relatively short lines. From the technical point of view, a line route should be selected which avoid angle points, as far as possible, since they require considerably higher efforts and investments. A tower configuration as uniform as possible should be selected. An easy access to the tower sites reduces compensation for land use and maintenance costs. Tower sites on exposed points of the terrain, such as rock noses, should be avoided although they offer advantages concerning the adjustments of the conductor catenary to the terrain.

Though technical and economic criteria are important in the selection of support height and span lengths, evaluations of the visual impact may lead to the adoption of a supports on the longitudinal profile of the line. When crossing over the top of a hill or mountain, the use of lower supports rather than higher ones should be considered. While crossing flat landscape characterized by a wide visual field, it is preferable to use taller towers with longer span.

Main Components of Overhead Transmission Line

An overhead Transmission line is an important component of the electric Power System. The successful operation of overhead line depends to a great extent upon the mechanical design of the line. While constructing an overhead line, it should be ensured that mechanical strength of the line is such so as to provide against the most probable weather conditions. The main components of an overhead line are as under:-

a) Supports:- Supports may be poles or towers which keep the conductors at a suitable level above the ground.
b) Conductors:- Conductors carry electric power from sending end station to the receiving end station.
c) Insulators:- These are attached to the supports and insulate the conductors from ground.
d) Cross Arm:- They provide support to the insulators.
e) Miscellaneous items such as lightning arrestors, danger plates, and phase plates.

Supports

Tower or poles of overhead lines are parts of the supports and consists of tower or pole body, earth wire and cross arms. The transmission voltage, the number of circuits, the height of the supports and other aspects determine the support design and materials, whereby steel, reinforced concrete or wood are used. The supports dominate the aesthetic impact of an overhead line, govern the operational reliability and determine the necessary investment to a certain extent. The type of conductor attachment through the insulators at the supports depends on the task of the supports within the transmission system. At suspension supports, the conductors are fixed to suspension insulator sets. Some of the types of supports are as under:-

a) **Suspension Supports**: They carry the conductors in a straight line. During operation, they do not transfer conductor tensile forces to the supports and therefore can be designed relatively light-weight.

b) **Angle Suspension Supports**: Angle suspension supports serve as suspension supports for conductors where the line changes direction at line angle deflections.

c) **Angle Supports**: Angle supports carry the resulting conductors tensile forces where the line changes direction at the angle deflections. Contrarily to angle suspension supports, they are equipped with tension insulator sets.

d) **Strain and angle strain Supports:** Strain and angle strain supports carry the conductor tensile forces in line direction or in the resultant direction, respectively, and serve additionally as rigid points in the line.

e) **Dead – end supports :** Dead-end supports carry the total conductor tensile forces in the direction on one side. Frequently, dead-end are additionally loaded by the conductors leading to the substation portals.

Clearances

There are two types of electrical clearances in the design of overhead transmission line, these are internal and external clearances. The internal clearances refer either to conductor to conductor or conductor to tower air gaps in the lines. The external clearances are used for determining safety clearances between live conductors and the objects under or in the vicinity of the overhead line. The internal clearances are specified solely for the purpose of designing for an acceptable ability to withstand over voltages. The purposes of the external clearances is to avoid any hazard of flashovers to the general public, to persons carrying out activities in the vicinity of the over head power lines and to persons maintaining the power network.

5.1 Determination Of Support Locations And Height

The longitudinal profile of the terrain is obtained from the survey data, It is necessary to refer the registered data to known altitude at the beginning and the end of the line. The longitudinal profile forms the basis for the Tower Spotting. The clearances between the respective longitudinal profile and the catenary curve are used for planning of tower locations and heights. The longitudinal profile of the line route will contain all information relevant for the detailed line design such as type of terrain and utilization, crossed traffic roads, waters, railways is available. The next step, is to determine the support locations and the support types and heights. This step decides on the visual perception of the line and affects the investment for construction as well.

Even when the route has been finally selected, there are many possibilities for designing an overhead line between two given points, e.g. a large number of low towers with short spans or a few tall towers with long spans. In general, the terrain, the soil characteristics and land use within an overhead corridor change to a more or less great extent. That alternative should be selected, which complies with all technological and terrain conditions and involves the lowest investment.

The angle points along the selected route are fixed points for tower locations, only the height of angle towers is to be selected at the tower spotting stage. The terrain profile along and across the route determines the necessary tower heights, the investments necessary for foundations depend on the soil condition, the accessibility of the individual tower locations affects the efforts for construction, as well as for operation. The conductor sags between the attachments at the towers, change with conductor temperature and the ice load. Tower spotting must ensure that adequate clearances between conductors themselves and to objects crossed by the line are maintained under all conditions. The possible conductor suspension heights and permissible spans between two towers are determined by the geographical dimensions of the available tower types and their horizontal and vertical load capabilities.

An optimum tower spotting requires taking into account all investments for tower, insulator, accessories and foundations as precisely as possible. The same applies to the construction expenditures particularly in projects where access to tower sites is difficult. Attention has also to be given to the expenditures associated with land acquisition and compensation for tower locations and for real estates crossed by the conductors.

5.1.1 Manual Tower Spotting

In this method the route profile drawing and a template showing the catenary to the same scale as the profile drawing are used. In this sagging template is produced based on the sags related to the expected equivalent span (ruling span) and the maximum conductor temperature (Fig) In parallel to the ground curve, which is represented by the edge of the template , the conductor catenary is shown in a distance according to the stipulated ground clearance.. If the template touches the terrain, this parallel curve represents the conductor position and enables determining the conductor attachments points and checking the clearances to crossed objects.

In fig, the sagging template is presented in a position to determine the location and height of tower 2, assuming that tower 1 is fixed at location 1. While the sagging curve starts at the conductor attachment point at tower 1, the ground clearance curve touches the ground surface. The sagging template is adjusted such that its horizontal edge runs in parallel to the abscissa of the longitudinal profile. Therefore, its centre line is perpendicular to the horizontal abscissa. It is expedient to start tower spotting at locations where constraints on the free selection of a support site exist, e.g. at important crossings, fixed tower locations, angle points etc. While carrying out tower spotting, the engineer should take care of avoiding higher differences in the span lengths and tower heights. After preparing a preliminary tower spotting, the compliance with all technical stipulations, such as wind and weight span, relations of wind to weight span, geometric maximum span etc. need to be checked in detail. The quality manual tower spotting depends largely on the experience of design engineer.

5.1.2 Tower Spotting By Means of Data Processing

Tower spotting with the aid of data processing presumes, that the task can be performed analytically and digitally taking care of all relevant parameters. Optimizing the tower spotting can be included. In principle, the optimization of the tower spotting covers the whole line and can be carried out between its end points. In this method the quality and accuracy of the results do not depend on the design engineer's experience but solely on the extent of the calculations.

Tower spotting by computer program can be carried out using the **successive elimination method**. There, the line is divided into equidistant, steps between 5 and 20m long and each step of the profile is dealt with as a temporary end point for the purpose of tower spotting calculation. For each temporary end point, an optimum tower spotting is determined between the beginning of the line and the point currently being dealt with. Only the data of the optimum tower spotting calculated for each step need to be stored in the memory and to be given further consideration.

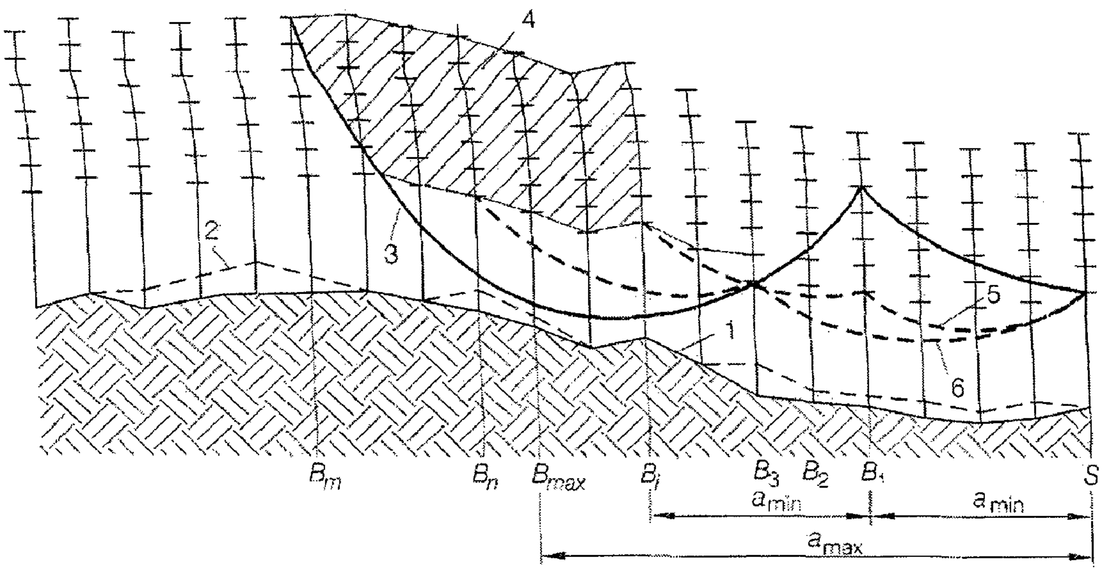


Figure 5.1: Tower spotting with location B_i considered as provisional end point. **1** centre line profile; **2** parallel profile; **3** ground curve of conductor sag, alternative with maximum height at location Bm;**4** range of technically possible tower locations and extensions with respect to location B_l and height alternative 4;**5** tower spotting with one intermediate tower between Sand B_i;**6** optimum tower spotting to B_n

The optimization process is visualized in **Figure 5.1** Starting at the tower S at the beginning of the line section to be spotted, each point of the profile in a distance between permissible minimum and maximum and span is considered as a possible tower site. The first acceptable location is $\mathbf{B_1}$, situated at minimum distance $\mathbf{a_{min}}$ from tower **S.** Then a conductor catenary line is established to the lowest height alternative of tower S and the clearances to ground are checked at all intermediate profile steps between the locations **S** and $\mathbf{B_1}$. It is obvious that for the minimum span minimum tower heights at both tower locations would be sufficient. Therefore, this solution would present the optimum and is the one kept in the memory correlated to the site B_1 and tower height considered there.

After processing all tower height alternatives at the location $\mathbf{B_1}$, the procedure continues with the location $\mathbf{B_2}$. There, again the only span length alternative is to the tower at the location **S** and the technically acceptable and least expensive height alternative is selected. This procedure is continued until a location corresponding to the maximum permissible span $\mathbf{a_{max}}$ will be reached. However, if the available maximum tower extensions at locations $\mathbf{B_i}$ and **S** were not enough to provide the required clearancé to ground or to obstacles, an alternative is checked with an intermediate tower location between the temporary end and **S.** In principle, such a solution can be implemented at location $\mathbf{B_i}$ in a distance of two times $\mathbf{a_{min}}$ from **S.** In this case, a tower spotting alternative assuming lowest tower heights at the involved tower locations considered would represent the lowest investment. This process is continued along the whole line section which is to be optimized. Only technically acceptable alternatives are subsequently included in the comparison of investment. For each temporary end point of the profile studied, only the solution representing the minimum investment is stored again characterized by the distance of the optimized. Thus, starting from each step currently considered as line end point, the most cost-effective height alternative and distance of the next tower is selected from technically acceptable solutions. For each point of the profile considered temporarily as an end point, this process is repeated for the terrain between the specified minimum and maximum span length towards the beginning of the line section. The most economic tower spotting is then assigned to the particular tower height alternative at the tower location considered as a line end point. This procedure is continued until the end of the line section to be spotted.

When arriving the end point, the optimum tower spotting can be obtained by retracing back the chain of optimum solutions towards the start point of the line section. In Figure 5.1, the tower spotting step is demonstrated, where the location $\mathbf{B_n}$ is considered as the current end point of the line. From Figure 5.1 it is obvious that the most economic tower spotting starting with the lowest extension at location $\mathbf{B_n}$ is that with one intermediate tower at location $\mathbf{B_3}$, since only one intermediate tower is necessary and the tower extensions are always the lowest possible. In Figure 5.1 this alternative is given the number 6.

5.2. Algorithm of siting of Transmission Line by Data Processing Method

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1. **Step 1 :** Prepare the data sheets containing the details of the available Towers with their heights and cost of construction and the data sheet of terrain profile where the tower spotting is required to be carried out.
2. **Step 2 :** The height, cost of construction and the location of the first Tower is initialised at the start point of the route. Minimum span and maximum span between the two Towers is also initialised in the beginning.
3. **Step 3:(Minimum And Maximum Span Constraints)** From the fixed start point the next Tower is spotted in the given span interval i.e. min span and max span. Between the start point and the minimum span, sag clearance is checked for all the available tower heights.

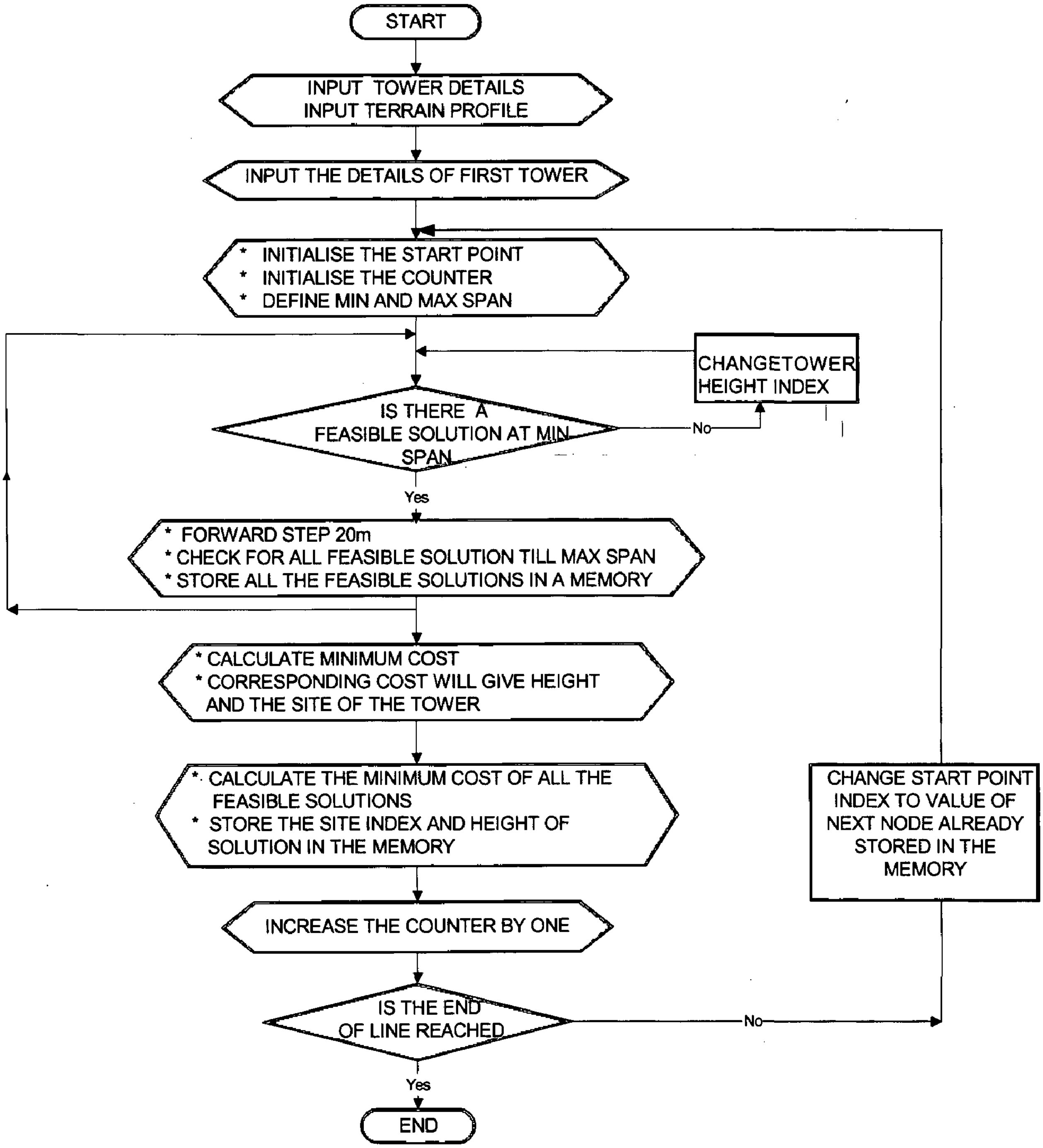
4. **Step 4 :** Now at a fixed forward step sag clearance is checked till the max span. At any node if the sag clearance is met than the cost of construction is calculated till that node and the value is stored in the memory. All the cost value is stored in the matrix.

5. **Step 5 :** Minimum cost value is calculated from the matrix of feasible solutions. The height and the site corresponding to the minimum cost is the most economical solution for the current node. This value of height and the site is stored in the memory for further calculations.

6. **Step 6 :** The Tower spotted will become the start point for siting the next Tower and the values of this Tower are initialised for the next calculations. The Step 3 repeated till the end point.

7 **Step 7 :** The above procedure is repeated till the finish point. In the end we get set of feasible solutions including corresponding costs between start point and the finish point. These feasible are plotted on a graph.

FLOW CHART


START
INPUT TOWER DETAILS
INPUT TERRAIN PROFILE
INPUT THE DETAILS OF FIRST TOWER
* INITIALISE THE START POINT
* INITIALISE THE COUNTER
* DEFINE MIN AND MAX SPAN
CHANGETOWER HEIGHT INDEX
IS THERE A FEASIBLE SOLUTION AT MIN SPAN
No
Yes
* FORWARD STEP 20m
* CHECK FOR ALL FEASIBLE SOLUTION TILL MAX SPAN
* STORE ALL THE FEASIBLE SOLUTIONS IN A MEMORY
* CALCULATE MINIMUM COST
* CORRESPONDING COST WILL GIVE HEIGHT AND THE SITE OF THE TOWER
* CALCULATE THE MINIMUM COST OF ALL THE FEASIBLE SOLUTIONS
* STORE THE SITE INDEX AND HEIGHT OF SOLUTION IN THE MEMORY
CHANGE START POINT INDEX TO VALUE OF NEXT NODE ALREADY STORED IN THE MEMORY
INCREASE THE COUNTER BY ONE
IS THE END OF LINE REACHED
No
Yes
END

5.3 Tower Spotting By Means of Dynamic Programming Methodology

Whenever the survey data of a transmission line route is given and then out of available choice of towers of suspension type and of angle towers a dynamic programming algorithm is described which chooses and sites the towers (the location and angle of the angle towers being prescribed) in such a way that the overall cost of running the line from one end of the route to the other, subject to all the established design constraints, is a minimum.

The basic algorithm uses Bellman's "**principle of optimality**", the problem being considered as one of routing in a finite connected network. The profile of the line route is divided into a fine grid of possible tower sites, and the elevation corresponding to each allowable tower height at each such test site forms a node of the network in which the routing algorithm is recurrently applied. Subject to the constraints imposed by ground clearance requirements, including the effects of side slope and of special offending structures, single and double span limits, and the weight-span to wind-span ratio, the algorithm determines that connection between one node and a preceding node of the mesh which minimizes the cost of the line up to the current node. In this way a family of solutions is generated linking the terminal tower at the beginning of the line to the set of possible towers at any test site, and when the end of the line is reached the overall optimum solution is selected and the corresponding linkage traced back to the origin.

Whenever the profile of a single straight line section is such that no solution is possible over this section using only suspension type towers, the program detects and monitors this situation. It then returns to a determined point on the line route from where it once again progresses, this time including the possibility of using an anchor tower at any subsequent test site.

5.3.1 Mathematical Problem Formulation

A_{hot} The parameter of the parabola in which the line is assumed to hang at 122° F, the statutory design temperature. Under ice and wind loading at 22° F it is A_{cold}

x The horizontal distance from the beginning of the line section.

$S_1(x)$ The maximum single span limit at x .

S_2 The maximum double span limit.

X_{test} An ordered set of test sites.

X_{tower} An ordered set of tower sites.

$x_{1,i}$ The distance from x_i to the lowest point of the span (x_i, x_{i+1}) at 22° F.

$x_{-1,i}$ The distance from x_i to the lowest point of the span (x_{i-1}, x_i) at 22° F.

z(x) The statutory clearance from the ground or any other object at x.

H_{tower} An ordered set of available tower heights.

d A horizontal displacement perpendicular to the direction of the line at x.

v(x) The elevation above sea level of the lowest conductor of the line at x.

u(x, d) The elevation above sea level of the ground or any offending structure at distance x and offset d.

C(x, h) The cost of erecting a tower of height h at site x.

The problem can now be formulated as follows. To choose an ordered set of tower sites

$$X_{tower} = \{x_i \mid n = 1,2, \ldots M, \text{ and } x_{i-1} < x_i\}$$

From an ordered set of test sites

$$X_{test} = \{x_j \mid j = 1,2, \ldots N, \text{ and } x_{j-1} < x_j\}$$

where $\mathbf{X}_{tower}$ C $\mathbf{X}_{test}$ in such a way as to minimize the cost function

$$\sum_{i=1}^{M} C(x_i,h_i) \tag{1}$$

where the tower height hi at x_i is selected from

$$\mathbf{H}_{tower} \quad \{H_k \mid k = 1,2,\ldots Q, \text{ and } H_{k-1} < H_k\}$$

If the foundation costs are neglected the cost function simplifies to

$$\sum_{i=1}^{M} C(h_i) \tag{2}$$

and this is to be minimized subject to the following constraints. where $x_0 = 0$ and ho is specified:

<u>Constraints</u>

(a) A maximum single span constraint

$$x_i - x_{i-1} \leq s_1(x_i), \; i = 1,2, \ldots M, \tag{3}$$

(b) A maximum double span constraint

$$x_{i+1} - x_{i-1} \leq s_2(x_i), \; i = 1,2, \ldots M-1, \tag{4}$$

(c) An uplift constraint which sets a limit on the possible angle of swing of the line under transverse wind loading

$$x_{i,1} + x_{-i,1} \geq W(x_{i+1} - x_{i-1}), \; i = 1,2, \ldots M-1, \tag{5}$$

W being a parameter of the line constants, and

(d) A statutory clearance constraint to conform with the British Standard Specifications for overhead transmission lines. Over ground with no side slope

let

$$u(x, 0) = u(x), \text{ so that for a span } (i, i + 1)$$

$$v(x) = A_{hot}(x - x_i)(x - x_{i+1}) \quad x \quad \frac{V_{i+1} - V_i}{X_{i+1} - X_i} \quad x \quad (x - x_i) \quad + v_i \qquad \textbf{(6)}$$

where $x_i \leq x \leq x_{i+1}$, $v_i = v(x_i)$ etc., and the actual clearance

$$v(x) - u(x) > z(x) \qquad \textbf{(7)}$$

5.3.2 Solution Technique

The non-linear constrained optimization problem is solved by **dynamic programming**. It is considered as a routing problem in a finite network to which the principle of optimality (Bellman, 1957) is applied.

Let

$$\mathbf{F(X_j, H_k)}, \qquad j = 1, 2, \ldots N; \text{ and } k = 1, 2, \ldots Q, \qquad \textbf{(8)}$$

be the cost (including the cost $C(H_k)$ of the current tower) of constructing a line from the unique starting node to the tower of height H_k at site X_j using an optimal policy. The solution space is a two dimensional rectangular grid of $(N + 1)Q$ nodes in which, for feasibility, not every node may be connected to every other node as given Fig 5.2.

The rule for assigning an optimal cost value $F(X_s, H_t)$ to any node (s, t) is to search for a linkage $(s, t) \rightarrow (j, k)$ satisfying the constraints of the problem and such that

$$\mathbf{F(X_s, H_t) = C(H_t) + \min F(X_j, H_k),} \qquad \textbf{(9)}$$
$$j = 0, 1, \ldots s - 1;$$
$$k = 1, 2, \ldots Q;$$

i.e. the minimum cost feasible linkage through a preceding node with determined optimal cost. This now specifies an optimal policy up to the node (s, t). Applying recurrence relation (9) repeatedly over the range t = 1,2, ... Q for s = 1,2, ... N successively [for s = 0, t is specified and $F(X_0, H_t) = C(H_t)$] a family of solutions is generated through to the end of each line section. It only remains to find

$$\min F(X_N, H_k), \qquad k = 1,2, \ldots Q,$$

and then to trace back to the origin those linkages which make up this overall optimum solution.

Whenever there is a side slope or an offending structure offset to the line route u(x, d) ≠ u(x, 0), and the appropriate critical clearance must be specially computed. Of course, it is only feasible to ensure that the statutory clearance is not violated at a discrete set of points, the clearance sites, along the line route, but provided these sites are sensibly chosen the likelihood of an invalid span being accepted can be ignored.

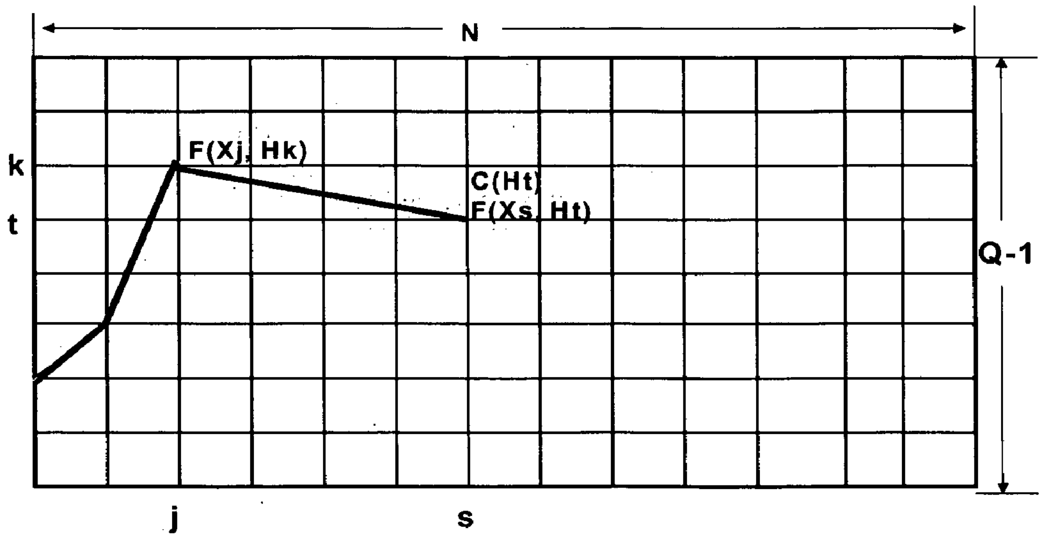


Fig : 5.2

5.4 Algorithm of siting of Transmission Line Using Dynamic Programming Method

1. **Step 1 :** Prepare the data sheet containing the details of the available Towers with their heights and cost of construction and the data sheet of terrain profile where the tower spotting is required to be carried out.

2. **Step 2 :** The height, cost of construction and the location of the first Tower is initialised in beginning at the start point.

3. **Step 3: (Single Span Constraint)** From the fixed start point the next Tower is spotted at the given single span distance. At this node sag clearance is checked for the tower of minimum height. If the sag clearance is not met increase the height of the Tower and check the clearance. Store all the feasible solutions in the memory.

4. **Step 4:** Now calculate the cost of construction between the nodes for all the feasible solutions. The minimum cost is calculated. The height corresponding to the minimum cost is the most economical solution for the current node. The value of height is stored in the memory for further calculations.

5. **Step 5 : (Double Span Constraint)** From the fixed start point the next Tower is spotted at the given double span distance. At this node sag clearance is checked for the tower of minimum height. If the sag clearance is not met increase the height of the Tower and check the clearance. Store all the feasible solutions in the memory.

6. **Step 6 :** Now calculate the cost of construction between the nodes for all the feasible solutions. The minimum cost is calculated. The height corresponding to the minimum cost is the most economical solution for the current node. The value of height is stored in the memory for further calculations.

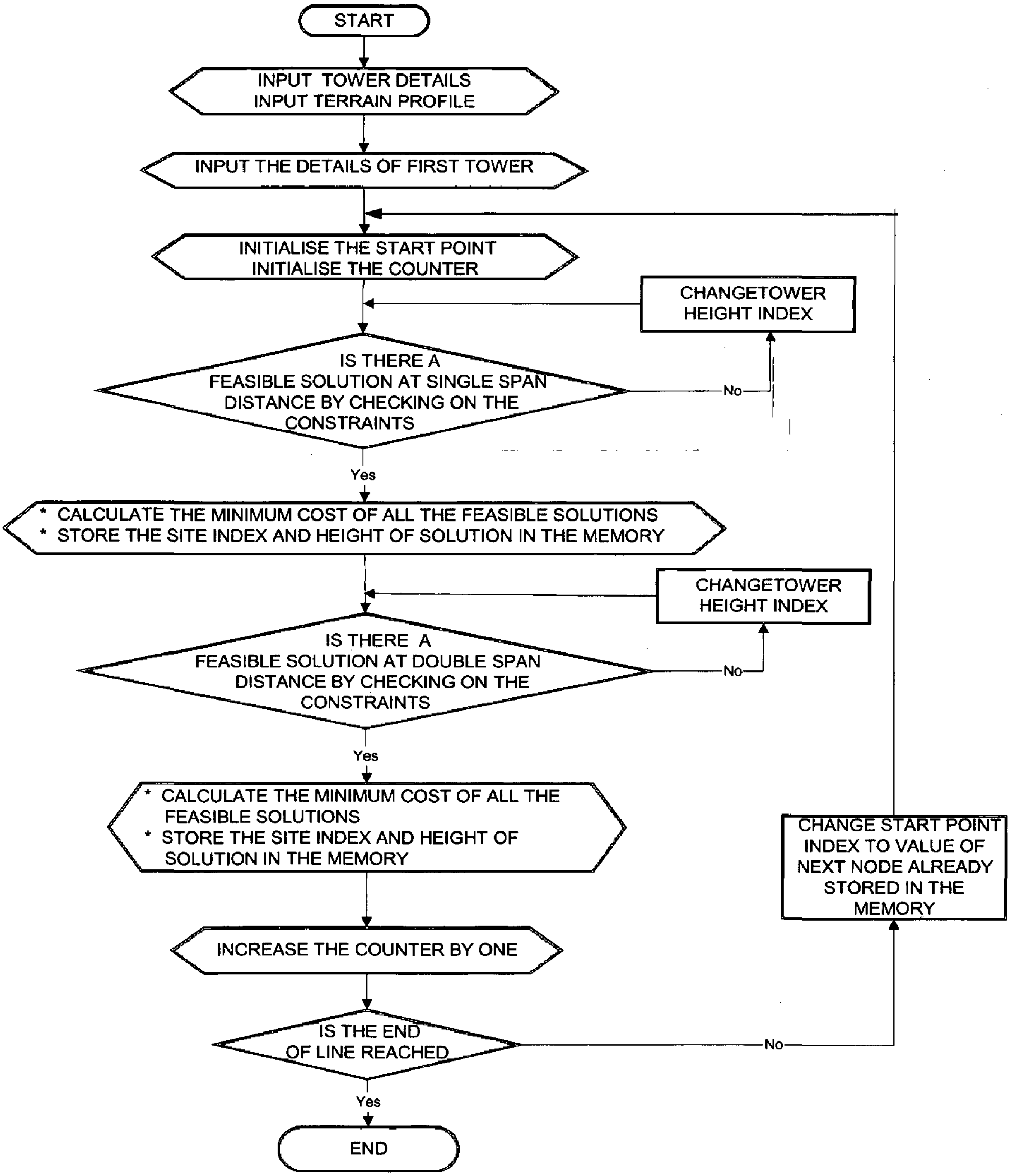
7. **Step 7 :** Move on to the next node already stored in the memory. Now this node becomes the start point. Repeat the above Step3 and Step 4 from this node.

8 **Step 8 :** The above procedure is repeated till the finish point. In the end we get set of feasible solutions including corresponding costs between start point and the finish point. These feasible are plotted on a graph.

9 **Step 9:(Dynamic Programming)** From the graph shortest path is calculated in term of the cost between start point and finish point using Dynamic Programming.

$$F(A) = \min (cost_1 + F(B), cost_2 + F(C))$$

FLOW CHART



START
INPUT TOWER DETAILS
INPUT TERRAIN PROFILE
INPUT THE DETAILS OF FIRST TOWER
INITIALISE THE START POINT
INITIALISE THE COUNTER
CHANGETOWER HEIGHT INDEX
IS THERE A FEASIBLE SOLUTION AT SINGLE SPAN DISTANCE BY CHECKING ON THE CONSTRAINTS
No
Yes
* CALCULATE THE MINIMUM COST OF ALL THE FEASIBLE SOLUTIONS
* STORE THE SITE INDEX AND HEIGHT OF SOLUTION IN THE MEMORY
CHANGETOWER HEIGHT INDEX
IS THERE A FEASIBLE SOLUTION AT DOUBLE SPAN DISTANCE BY CHECKING ON THE CONSTRAINTS
No
Yes
* CALCULATE THE MINIMUM COST OF ALL THE FEASIBLE SOLUTIONS
* STORE THE SITE INDEX AND HEIGHT OF SOLUTION IN THE MEMORY
CHANGE START POINT INDEX TO VALUE OF NEXT NODE ALREADY STORED IN THE MEMORY
INCREASE THE COUNTER BY ONE
IS THE END OF LINE REACHED
No
Yes
END

5.4.1 Example of Siting Of Transmission Line Tower Using Dynamic Programming

1. **Input Data :-** The Input Data sheet is prepared for checking the feasibility of a particular type of Tower.at the test site. The following type of data is required as the input.

a) **Tower Details :-** It includes the number of available type of transmission line tower with height and approximate cost of construction.

Ser No	Tower Type	Tower Height	Approx Cost of Construction
1	Tower 1	25	20000
2	Tower 2	30	28000
3	Tower 3	35	35000
4	Tower 4	40	45000

b) **Terrain Profile :-** Terrain profile includes the horizontal distance from the start point and elevation of the ground at every 20m interval.

Ser No	Site Location	Site Elevation
1	0	265
2	20	265
3	40	266
4	60	266
5	80	266
6	100	267
7	120	267
8	140	268
9	160	268

10	180	269
11	200	270
12	220	271

c) **Details of First Tower:-** The height, type and approximate cost of construction is initialised in the beginning. These details are used for further calculations of tower spotting.

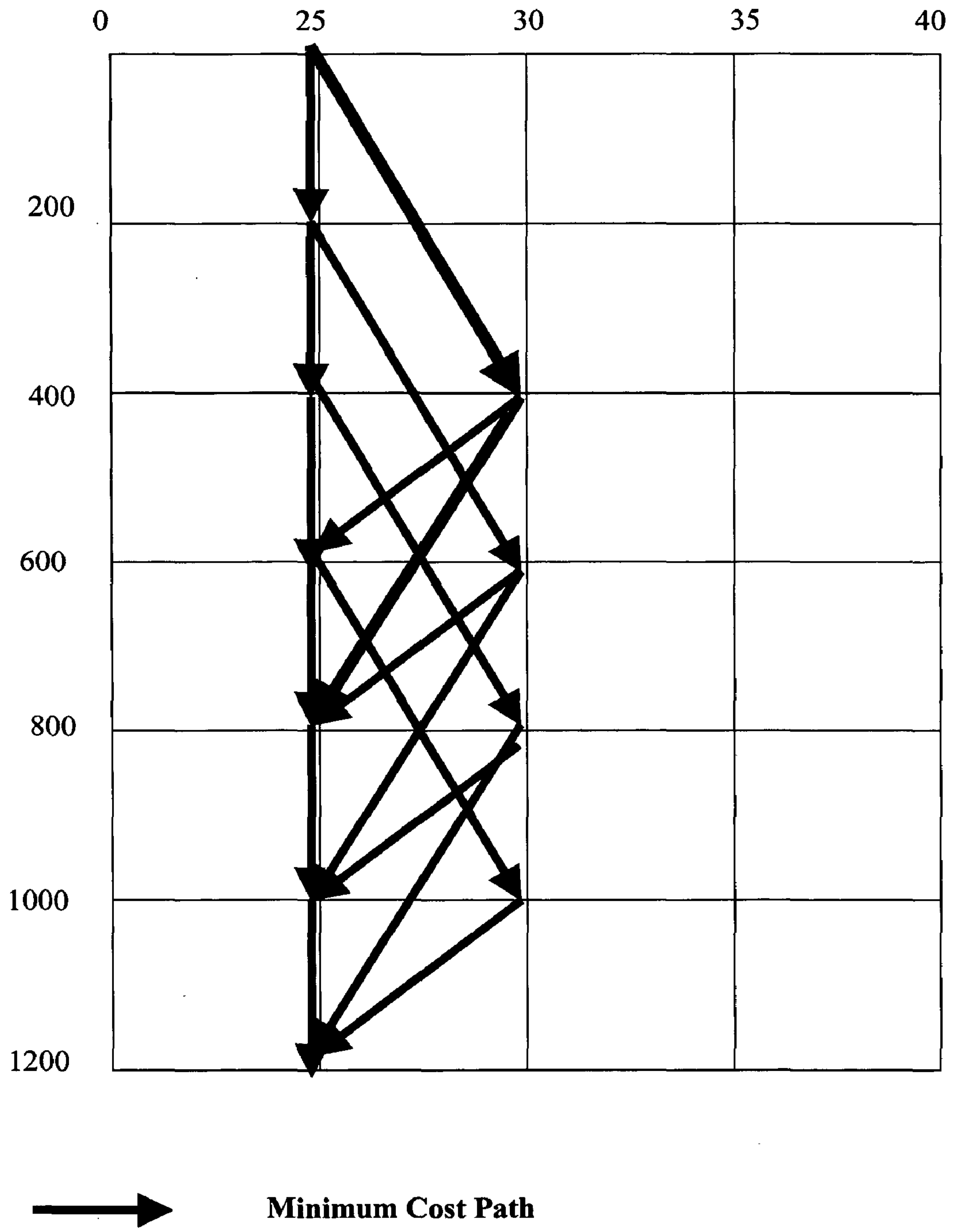
2. **Program:-** The above mentioned input data is read by the computer program. The program starts checking the feasibility of the next tower location starting from the start point and it checks the sag constraints at 200m and 400m. The result of the tower with minimum cost of construction is stored in the memory for further calculations. Once the calculation at first point is over now it checks at 200m, 400m,..... till the finish point. At every site location it checks the feasibility of tower at 200m and 400m from that point and minimum cost of the tower is stored in the memory. After the first point all the tower heights already stored in the memory are used for further calculations of tower spotting for that particular location. In the end the program displays all the feasible solutions of tower heights meeting the sag the constraints till the finish point.

3 **Dynamic Programming Method** :- Once all the possible solutions are obtained, the dynamic programming method is used to calculate the minimum cost path to reach the finish point from the start point. All

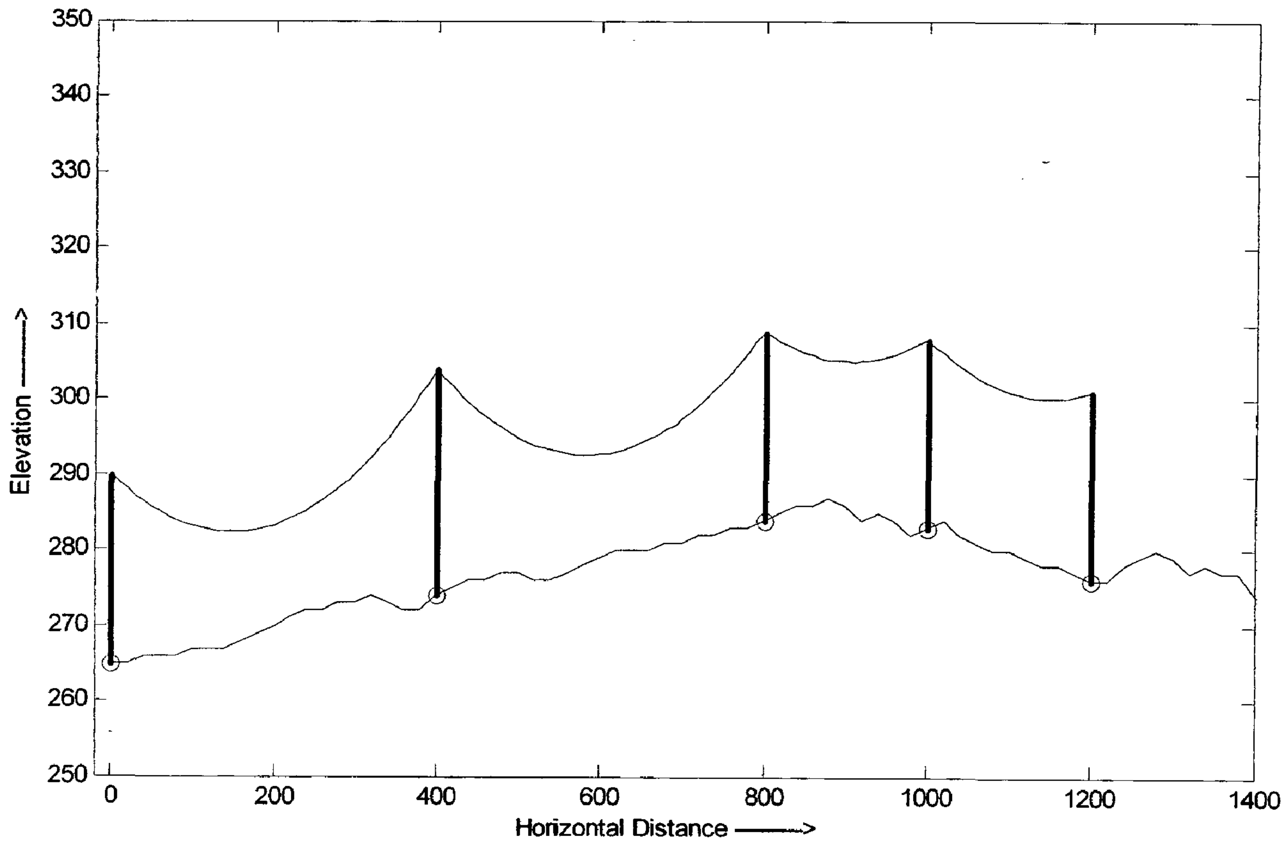
RESULT OF TOWER SPOTTING CALCULATIONS

SER NO	TOWER SITE	TOWER HEIGHT	COST
LOOP:1, START POINT : 0, TOWER HEIGHT:25			
1	200	25	60000
2	400	30	88000
LOOP:2, START POINT :200, TOWER HEIGHT:25			
3	400	25	60000
4	600	30	88000
LOOP:3, START POINT :400, TOWER HEIGHT:25			
5	600	25	60000
6	800	30	88000
LOOP:3, START POINT :400, TOWER HEIGHT:30			
7	600	25	68000
8	800	25	88000
LOOP:4, START POINT :600, TOWER HEIGHT:25			
9	800	25	60000
10	1000	30	88000
LOOP:4, START POINT :600, TOWER HEIGHT:30			
11	800	25	68000
12	1000	25	88000
LOOP:5, START POINT :800, TOWER HEIGHT:25			
13	1000	25	60000
14	1200	30	88000
LOOP:5, START POINT :800, TOWER HEIGHT:30			
15	1000	25	68000
16	1200	25	88000

DYNAMIC PROGRAMMING METHOD TO DETERMINE THE MINIMUM COST PATH



TOWER SPOTTING USING DYNAMIC PROGRAMMING METHOD



GEOGRAPHIC INFORMATION SYSTEM

A **geographic information system (GIS)** is a system for capturing, storing, analyzing and managing data and associated attributes which are spatially referenced to the earth. In the strictest sense, it is a computer system capable of integrating, storing, editing, analyzing, sharing, and displaying geographically-referenced information. In a more generic sense, GIS is a tool that allows users to create interactive queries (user created searches), analyze the spatial information, edit data, maps, and present the results of all these operations. **Geographic information science** is the science underlying the applications and systems, taught in degree programs at many universities.

Geographic information system technology can be used for scientific investigations, resource management, asset management, Environmental Impact Assessment, Urban planning, cartography, criminology, history, sales, marketing, and route planning. For example, a GIS might allow emergency planners to easily calculate emergency response times in the event of a natural disaster, a GIS might be used to find wetlands that need protection from pollution, or a GIS can be used by a company to find new potential customers similar to the ones they already have and project sales due to expanding into that market.

The most significant task in the design and development of a GIS is the survey of the existing network and creation of a background map. This is done by various state-of-the-art techniques like Global Positioning System (GPS). GPS helps to capture the latitude and longitudinal positions of various network facilities like the substations, HT poles, Distribution transformers, LT poles etc. and to collect the relevant attribute information of these assets. GPS and GIS help in improved management of Transmission and Distribution systems of utilities.

6.1 Definition of GIS

1) Computerized decision support systems that integrate spatially referenced data. These systems capture, store. retrieve, analyse and display spatial data.

2) An organized assemblage of computer hardware, software, spatial data and operating instructions designed for capturing, storing, updating, manipulating, analysing, and displaying all forms of geographically referenced information.

3) A manual or computer-based system for geographic data input, storage, manipulation, analysis, modelling and output. The system is used to improve geographic question-asking and problem-solving, and to enhance the overall geographic decision-making process

Components of GIS

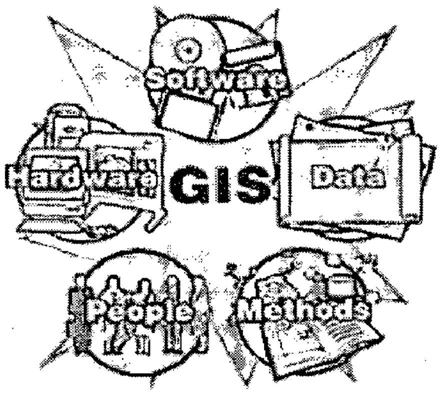


Fig 6.1 Components of GIS

Hardware

A GIS relies on a computer for storage and processing of data. The size of the computing system will depend on the type and nature of the GIS. A small scale GIS will only need a small personal computer to run on, while a large enterprise wide system with larger computers and a host of client machines to support multiple users.

Software

At a core of any GIS system lies the GIS software itself providing the functionality to store, manage, link, query and analyze geographic data. In addition to the core GIS software various other software components can be added to provide access to additional sources of data and forms of functionality.

Data

Data for a GIS comes in two forms geographic or spatial data, and attribute or a spatial data. Spatial data are data that contain an explicit geographic location in the form of a set of coordinates. Attribute data are descriptive sets of data that contain various information relevant to a particular location, e.g. depth, height, sales figures, etc. and can be linked to a particular location by means of an identifier, e.g. address, pin code, etc

Sources of spatial data include paper maps, charts, and drawings scanned or digitised into the system. Digital files imported from CAD or other graphics systems. Coordinate data recorded using a GPS receiver and data captured from satellite imagery or aerial photography.

Methods

GIS systems are designed and developed to aid the data management and decision support processes of an organization. The operation of any organization is based on a set of practices and business logic unique to that organization. While some organizations may use a GIS on an ad-hoc basis with each user formulating their own standards of work and methods of analysis others define their business logic into the GIS to streamline certain aspects of their operations. So the methodology applied is another factor for success of any GIS project.

People

The system users - those who will use the GIS to solve spatial problems - are most often people who are well trained in GIS, perhaps in a specific application of GIS. System operators are responsible for the day-to-day operations of the system, more often performing tasks that allow the system users to function efficiently. GIS suppliers are responsible for providing software support and updates of the software as new and improved methods are put into the system. The Data supplier could be either private or public. The private company may provide internally generated data or data obtained from public agencies modified to better fit needs expressed by the user community. Public agencies, primarily governmental agencies, provide data for large portions of the country. Application developers are generally trained programmers who will provide user interface to reduce the reliance on specialized GIS professionals to perform common tasks. GIS systems analysts are group of people specialize in the study of systems design.

Method of Storing Data in GIS

- A GIS stores a representation of the world in the form of layers connected by a common geographical frame of reference.
- Each of the features on a layer has a unique identifier which distinguishes it from the rest of the features on the layer and allows you to relate it to relevant information stored in external databases, etc
- This simple yet powerful mode of abstraction, a GIS allows us to capture only those elements of the world that are of interest to us. Different views and data about the world e.g., streets, soils, pipes, cables, vegetation, etc. can be captured and stored in the GIS over time to accommodate the needs of various different users and to reflect changes in the landscape over time.

A geographic information system supports several views for working with geographic information.

- **Geo database view:** A GIS is a spatial database containing data sets that represent geographic information in terms of a generic GIS data model (features, rasters, topologies, networks, and so forth).

- **<u>Geo Visualization view:</u>** A GIS is a set of intelligent maps and other views that shows features and feature relationships on the earth's surface. Various map views of the underlying geographic information can be constructed and used as "windows into the database" to support queries, analysis, and editing of the information.
- **<u>Geo processing view:</u>** A GIS is a set of information transformation tools that derives new geographic data sets from existing data sets. These geo processing functions take information from existing data sets, apply analytic functions, and write results into new derived data sets.

6.2 Digital Elevation Modal

A **digital elevation model** (DEM) is a digital representation of ground surface topography or terrain. It is also widely known as a digital terrain model (DTM). A DEM can be represented as a **raster** (a grid of squares) or as a **triangular irregular network**. DEMs are commonly built using remote sensing techniques, however, they may also be built from land surveying. DEMs are used often in geographic information systems, and are the most common basis for digitally-produced relief maps.

Older methods of generating DEMs often involve interpolating digital contour maps that may have been produced by direct survey of the land surface; this method is still used in mountain areas, where interferometry is not always satisfactory. Note that the contour data or any other sampled elevation datasets (by GPS or ground survey) are not DEMs, but may be considered Digital terrain models. A DEM implies that elevation is available continuously at each location in the study area.

Digital elevation models may be prepared in a number of ways, but they are frequently obtained by remote sensing rather than direct survey. One powerful technique for generating digital elevation models is inter ferometric synthetic apèrture radar; two passes of a radar satellite (such as RADARSAT-1) suffice to generate a digital elevation map tens of kilometers on a side with a resolution of around ten meters. One also obtains an image of the surface cover.

The quality of a DEM is a measure of how accurate elevation is at each pixel (absolute accuracy) and how accurately is the morphology presented (relative accuracy). Several factors play an important role for quality of DEM-derived products:

- terrain roughness;
- sampling density (elevation data collection method);
- grid resolution or pixel size;
- interpolation algorithm;
- terrain analysis algorithm;

6.2.1 Uses

Common uses of DEMs include:

- extracting terrain parameters
- modeling water flow or mass movement (for example avalanches)
- creation of relief maps
- rendering of 3D visualizations.
- creation of physical models (including raised-relief maps)
- rectification of aerial photography or satellite imagery.
- terrain analyses in geomorphology and physical geography

Differences between DEMs and DTMs

A digital elevation model — also sometimes called a digital surface model (DSM) generally refers to a representation of the earth's surface (or subset of this), including features such as vegetation, buildings, bridges, etc. The DEM often comprises much of the raw dataset, which may have been acquired through techniques such as photogrammetry, LiDAR, InSAR, land surveying, etc. A digital terrain model (DTM) on the other hand is (generally) a filtered version of this surface, and hence can be a post-processed version of what was originally a DEM. The DTM provides a so-called bare-earth model, devoid of landscape features. While a DEM may be useful for landscape modelling, city modelling and visualisation applications, a DTM is often required for flood or drainage modelling, land-use studies, geological applications, and much more.

Applications of DEMs

DEM's is be used in the generation of three-dimensional graphics displaying terrain slope, apsect (direction of slope), and terrain profiles between selected points. DEM's are used in combination with digital raster graphics (DRG's), digital line graphs (DLG's), and digital orthophoto quadrangles (DOQ's) to both enhance the visual information for data extraction and revision purposes and to create aesthetically pleasing and dramatic hybrid digital images. Non-graphic applications such as modeling terrain and gravity data for use in the search for energy resources, calculating the volume of proposed reservoirs, and determining landslide probability have also been developed.

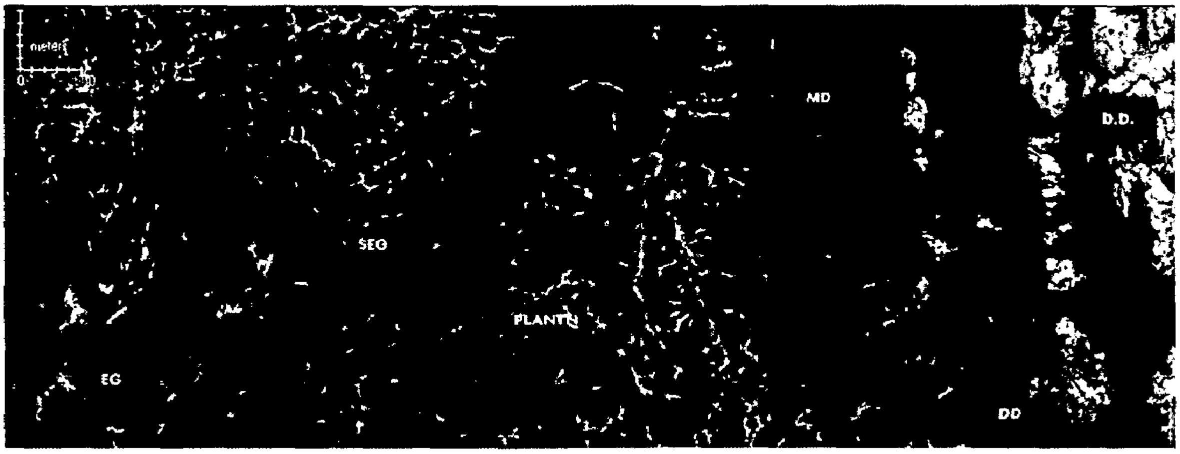
6.2.2 Triangulated Irregular Network (TIN)

A **triangulated irregular network (TIN)** is a digital data structure used in a geographic information system (GIS) for the representation of a surface. A TIN is a vector based representation of the physical land surface or sea bottom, made up of irregularly distributed nodes and lines with three dimensional coordinates (x, y, and z) that are arranged in a network of non overlapping triangles. TINs are often derived from the elevation data of a rasterized digital elevation model (DEM). An advantage of using a TIN over a DEM in mapping and analysis is that the points of a TIN are distributed variably based on an algorithm that determines which points are most necessary to an accurate representation of the terrain. Data input is therefore flexible and fewer points need to be stored than in a DEM with regularly distributed points. While a TIN may be less suited than a DEM raster for certain kinds of GIS applications, such as analysis of a surface's slope and aspect, TINs have the advantage of being able to portray terrain in three dimensions.

A TIN comprises a triangular network of points, known as mass points, with associated coordinates in three dimensions connected by edges to form a triangular tessellation. Three-dimensional visualizations are readily created by rendering of the triangular facets. In regions where there is little variation in surface height, the points may be widely spaced whereas in areas of more intense variation in height the point density is increased. A TIN is typically based on a Delaunay triangulation but its utility will be limited by the selection of input data points, well-chosen points will be located so as to capture significant changes in surface form, such as topographical summits, breaks of slope, ridges, valley floors, pits and cols.

6.3 Satellite Imagery

Satellite Image :- A picture of the earth taken from an earth orbital satellite. Satellite images may be produced photographically or by on-board scanner (eg MSS). Satellite imagery is similar to orthophotos, but are taken from a much higher altitude and their resolution is not as good as orthophotos. Satellite radar mapping is one of the major techniques of generating **Digital Elevation Models**. Satellite imagery is sometimes supplemented with aerial photography, which has higher resolution, but is more expensive per square meter. Satellite imagery can be combined with vector or raster data in a GIS provided that the imagery has been spatially rectified so that it will properly align with other data sets.



EG - Evergreen SEG - Semi evergreen MD - Moist Deciduous DD - Dry Deciduous PLANTN - Plantations

Fig 6.2 Satellite Image

Advantages

a) The satellites are always in the air and the resolution is lower, the imagery is much less expensive and more readily available just by ordering it from a distributor.

b) The satellite imagery that are have obtained contains an infrared version in addition to the natural colors version that allows an analysis of the vegetation and the imperviousness of the land surface.

Resolution and Data

The resolution of satellite images varies depending on the instrument used and the altitude of the satellite's orbit. For example, the Landsat archive offers repeated imagery at 30 meter resolution for the planet, but most of it has not been processed from the raw data. Landsat 7 has an average return period of 16 days. For many smaller areas, images with resolution as high as 10 cm can be available. Digital Globe's QuickBird satellite provides the world's highest resolution commercial satellite imagery. The 60 cm resolution of QuickBird's images allow objects on the ground as small as 60 cm across to be seen.

Uses of Satellite Imagery

Satellite images have many applications in agriculture, geology, forestry, biodiversity conservation, regional planning, education, intelligence and warfare. Images can be in visible colours and in other spectra. There are also elevation maps, usually made by radar imaging. Interpretation and analysis of satellite imagery is conducted using software packages like ERDAS_Imagine or ENVI. Satellite imagery are extensively used for DEM extraction, landscape modelling and GIS applications.

Land Use/Land Cover

Land is the most important natural resource on which the country's developmental activities are based. Land use information is critical for a variety of developmental activities - specially for watershed development, wasteland development, urban planning, highway routing, village transportation network planning, tourism planning and management, facility planning and other developmental activities. Land use is the way in which, and the purposes for which, human beings employ the land and its resources: for example, farming, mining, or lumbering. Land cover describes the physical state of the land surface: as in cropland, mountains, or forests.

Wasteland Mapping

The Satellite Image provide timely and accurate information on the location and extent of wastelands. There necessity of mapping wastelands which would enable identification of wastelands. This will help in selection of corridor for the siting of new transmission line.

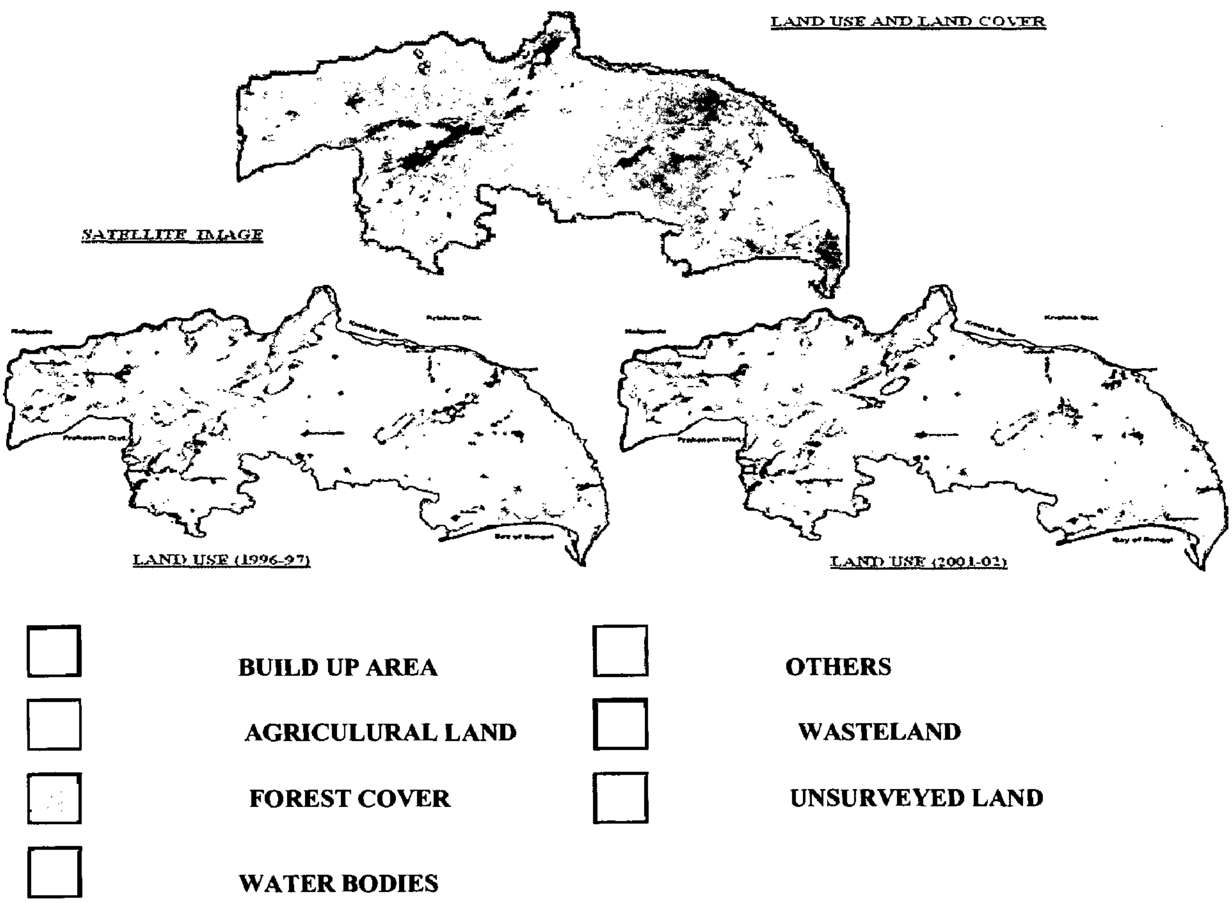


Fig 6.3 Land Use /Land Cover Using Satellite Image

CHAPTER NO: 7

PROGRAM : SITING OF TRANSMISSION LINE USING GIS

In this Dissertation work a GIS based package for **'Siting of Transmission Line'** has been developed. In this package **Integrated Software** has been developed in which the **Arc View 3.1** is used to manipulate, analyse the data and display the results and **Matlab Release 2006a** software is used to processing the data and calculation of various electrical parameters required for siting of Transmission Line and plotting the towers on the profile. The package has been made user-friendly by incorporating various help objects and GUIs.

7.1 Siting of Transmission line Towers Using Integrated Software

7.1.1 Adding Data Source in Arc View GIS 3.0

Start Arc View Find Arc View icon on the desktop, double-click it, and start Arc View.

Step 1 : Click "ok" for the first dialog box to start a new project.

Step 2: . It will then ask you if you would like to add a theme. Click "no".

Step 3 : You should now have a window titled "View1" and one behind it titled "Arc View GIS Version 3.1".

Step 4 : **(Adding Themes Into View Window)** Choose **View,** then **Add Theme** (or click on Add Theme icon:). Navigate to where the required data is stored. Choose the **Data Source Type: TIN Data Source** (see bottom left of navigation box). Select the data which is required for the analysis and than press **OK.** In this case **almoratin** data is selected for the siting the transmission line. Now the requisite data is loaded in the Arc View 3.1.

<u>Route Analysis using Extension 'Profile Extractor'</u>: Now 'tick' on the box where the data is loaded to make it active as shown in the fig 7.1 below. From the file menu add the extension 'profile extractor'. ⊟ dialog box appears on the main screen of the Arc View 3.1

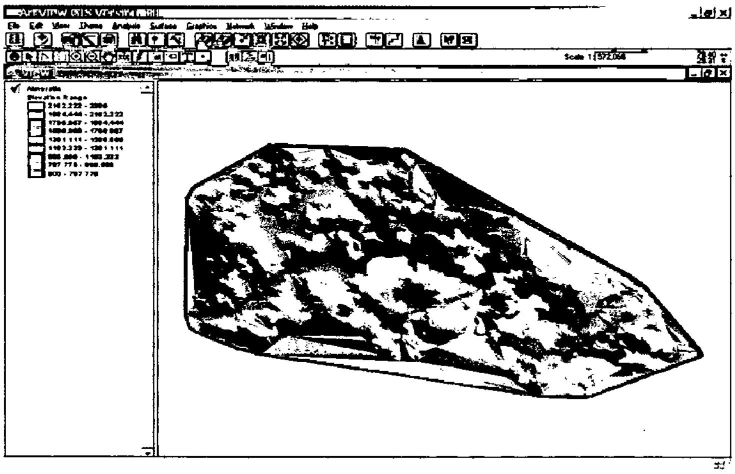


Fig 7.1 TIN Data with Profile Extractor Extension

With the help of Profile Extractor extension tentative route is plotted on the given TIN data source. The route is plotted along the terrain where there is minimum change in elevation avoiding the forest land, wet land, Water bodies, habitations etc so that the overall cost of construction is less.

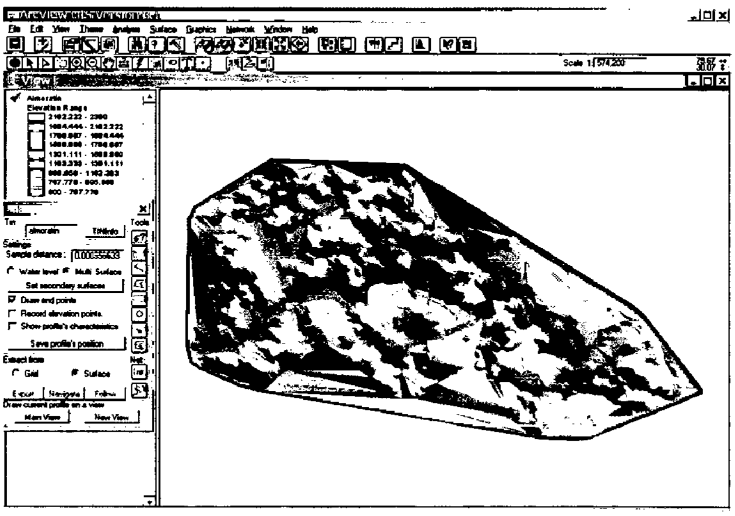


Fig 7.2 Use of Profile Extractor extension

Now using the various functions of this extension we can plot and study the ground profile of the area where the route has been selected. Complete profile of the route i.e. X-coordinate , Y-coordinate, horizontal distance and the ground elevation is stored in the tabular form as shown in the fig 7.3

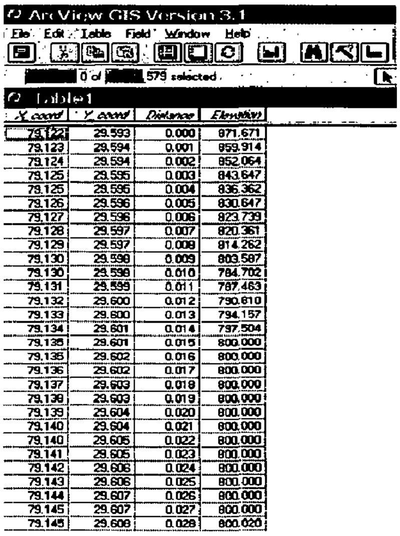

ArcView GIS Version 3.1

Table1

0 of 579 selected

X_coord	Y_coord	Distance	Elevation
79.122	29.593	0.000	871.671
79.123	29.594	0.001	859.914
79.124	29.594	0.002	852.064
79.125	29.595	0.003	843.647
79.125	29.595	0.004	836.362
79.126	29.596	0.005	830.647
79.127	29.596	0.006	823.739
79.128	29.597	0.007	820.361
79.129	29.597	0.008	814.262
79.130	29.598	0.009	803.587
79.130	29.598	0.010	784.702
79.131	29.599	0.011	787.463
79.132	29.600	0.012	790.810
79.133	29.600	0.013	794.157
79.134	29.601	0.014	797.504
79.135	29.601	0.015	800.000
79.135	29.602	0.016	800.000
79.136	29.602	0.017	800.000
79.137	29.603	0.018	800.000
79.138	29.603	0.019	800.000
79.139	29.604	0.020	800.000
79.140	29.604	0.021	800.000
79.140	29.605	0.022	800.000
79.141	29.605	0.023	800.000
79.142	29.606	0.024	800.000
79.143	29.606	0.025	800.000
79.144	29.607	0.026	800.000
79.145	29.607	0.027	800.000
79.145	29.608	0.028	800.020

Fig 7.3 Route Profile

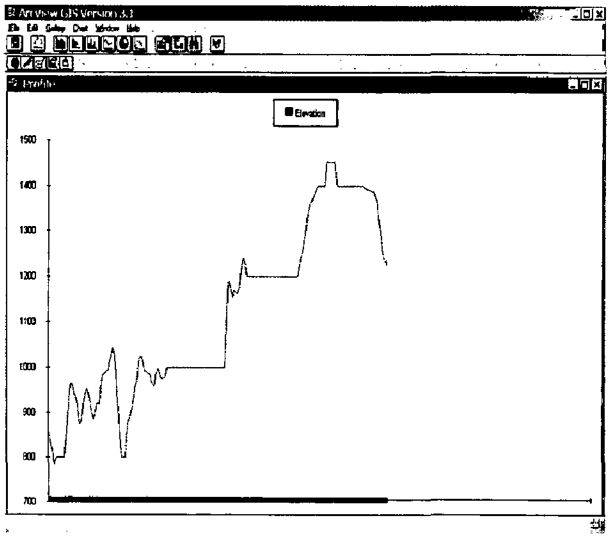


Fig 7.4 Ground Profile of the Route

7.1.2 Program In Matlab Release 2006a For Siting Of Towers

The profile of route is stored in the tabular form with the help of Arc View 3.1. This data is used in the Matlab for the siting of the Transmission Line . While performing the siting task both electrical and physical parameters of the transmission line are taken into account. In the program first the profile of the route is read and plotted. The 2 D and 3 D view of the profile will be shown in fig 7.5 and fig 7.6 respectively.

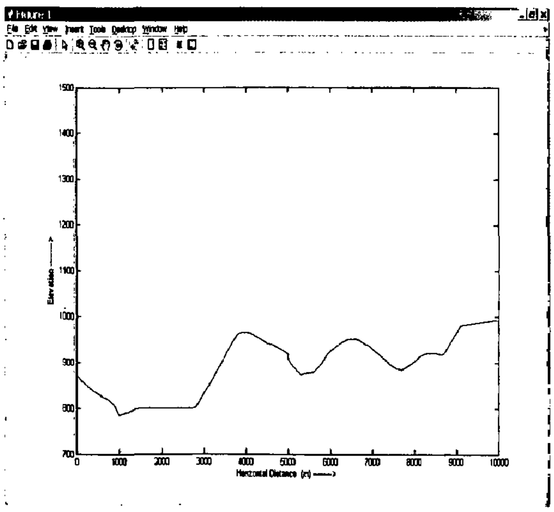


Fig 7.5 Two Dimensional View

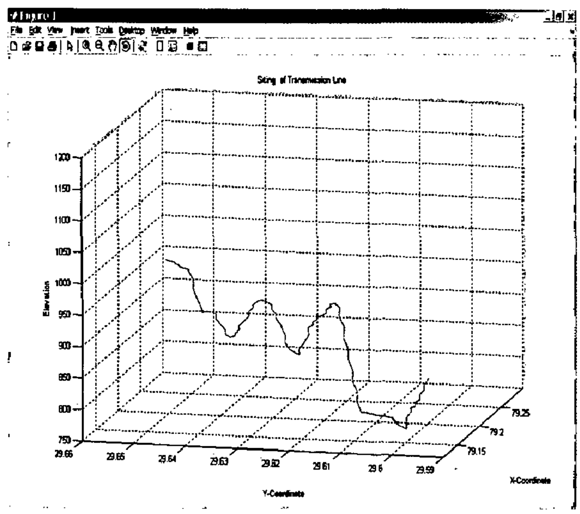


Fig 7.6 Three Dimensional View

The height and cost of construction of first tower is initialized in the beginning and is plotted on the profile. The first tower is the start point and the next tower is spotted at the location which satisfies electrical and physical parameters and also the cost of construction is minimum till that point including the cost of construction of tower at that location. While doing tower spotting the **sag constraint** is checked so that sag is not more than the minimum ground clearance required at the minimum point of the conductor between any two towers.

Once the tower location is fixed the details of this location is stored in the memory and the tower is plotted on the route profile. Now this location becomes the start point for the next tower location and this procedure is repeated till the finish point. The results of the tower spotting in two dimensional is as shown in fig 7.7.

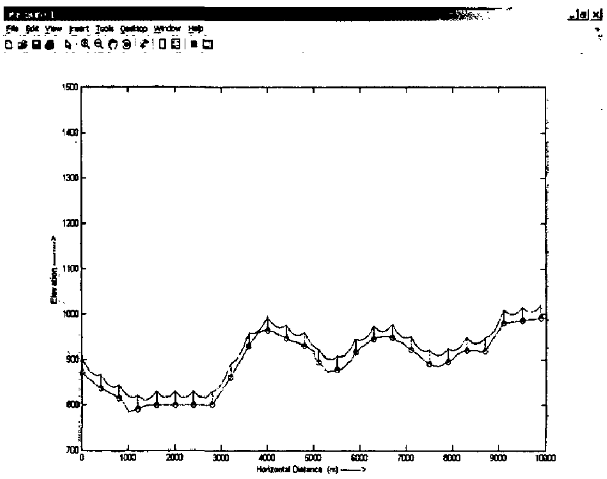


Fig 7.7 Tower Spotting in 2D View

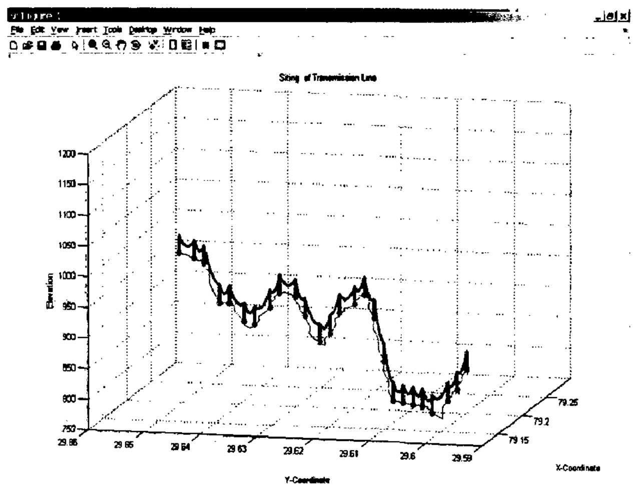


Fig 7.8 Tower Spotting in 3D View

7.2 Selection Of Best Route Using Integrated Software

a) The first step is to identify the start point or the location of generating stations and finish point or the load centers.

b) Next step is identify the possible route between the two locations. These routes are than marked with the help Profile Extractor extension in the GIS. The Arc View GIS now stores the profile of all the routes in tabular form. These values are later used siting of the towers and calculating the overall cost of the project. The entire theme of the routes is saved as project in the Arc View GIS as shown in fig 7.9 and fig 7.10 below.

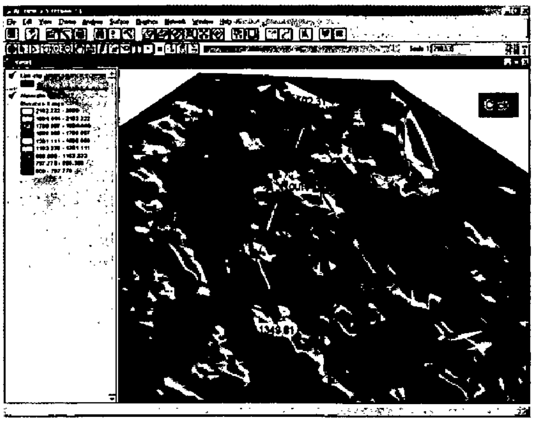


Fig 7.9 - Alternate Routes

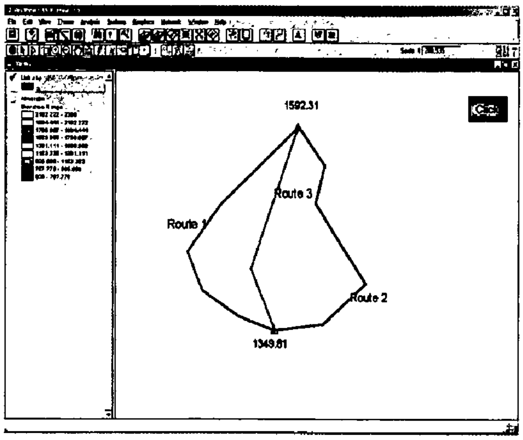


Fig 7.10

c) Each of selected route is being identified by a particular number. The GUI is created with help of MATLAB. The 'exe file' is formed to run the MATLAB portion of software and is executed using 'Hot Link' command in the Arc View GIS. Once click button of the project is clicked with the Hot Link, the exe file of Matlab starts running and GUI window (Fig 7.11) is opened for these selection of the route.

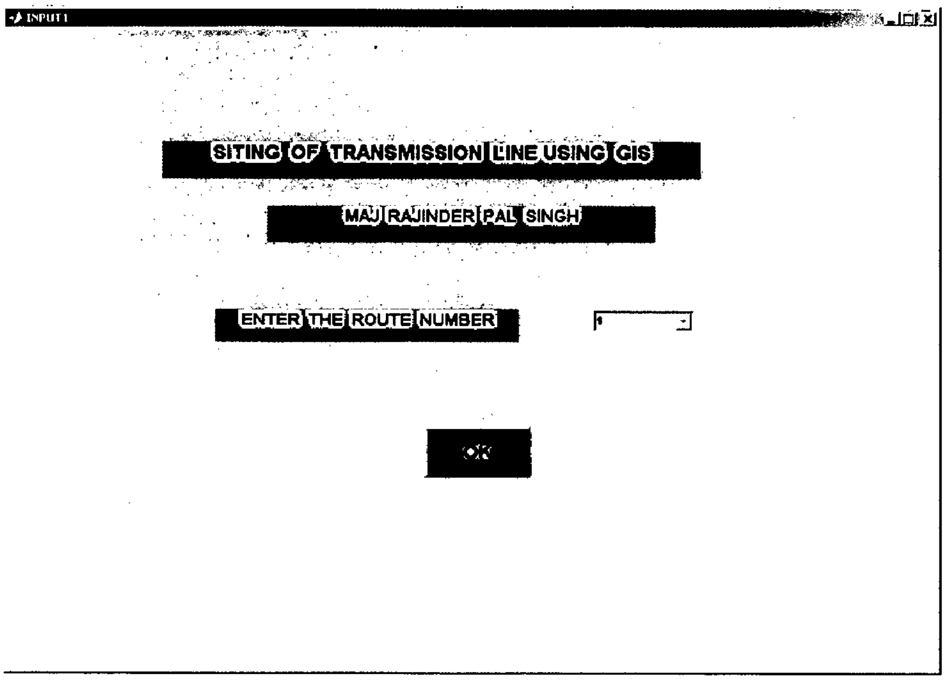


Fig 7.11 : Graphical User Interface

d) The route is selected and the result is displayed as graphical plot of the towers along the selected route and overall result of the project is stored in excel.

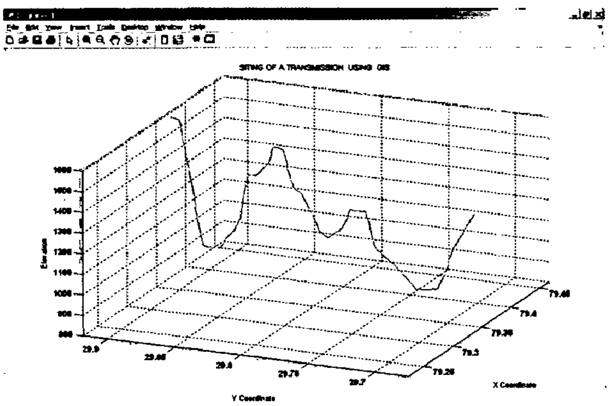


Fig 7.12 : Profile Plot

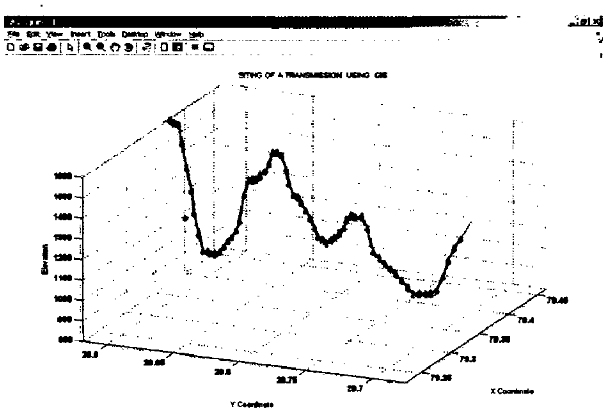


Fig 7.13 : Transmission Tower Plot

e) The result of the Integrated software is as shown below.

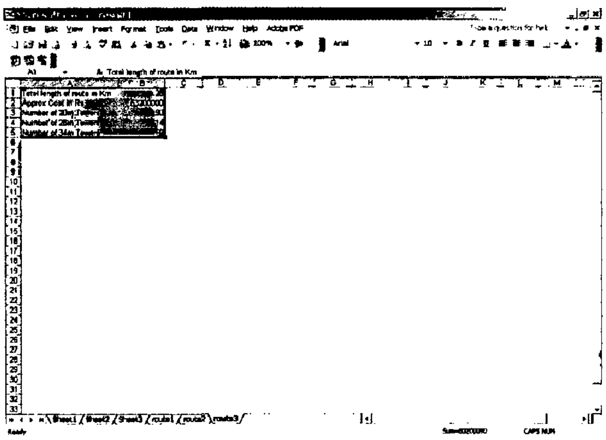


Fig 7.14 : Overall Result

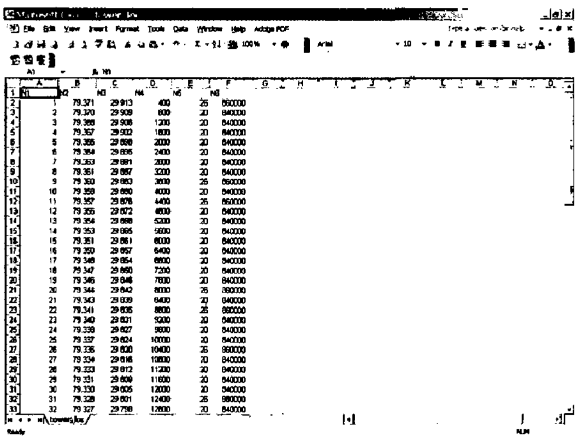


Fig 7.15 : Tower Sites

CHAPTER – 8

SAMPLE CASE STUDY

In order to demonstrate the effectiveness of the proposed approach developed in this work, a sample data of the Almora district was taken in the Triangulated Irregular Network (TIN) format as given at Figure 8.1 below. First the Satellite Image of the Area of interest was obtained which is than converted to Digital Elevation Modal (DEM)/TIN through a software. The TIN provides the complete information of Land Use and elevations. In the given area the locations of generating stations and the load centres is identified. These locations become the start point and the finish point of the proposed / new transmission line.

Fig 8.1 – Image of The Area Under Study In TIN Format

Using the Arc View GIS software the sample data source is added as a theme to perform the necessary analysis. All possible routes are marked between the start point and end point on the TIN data source using **Profile Extractor** Extension (Fig 8.2).

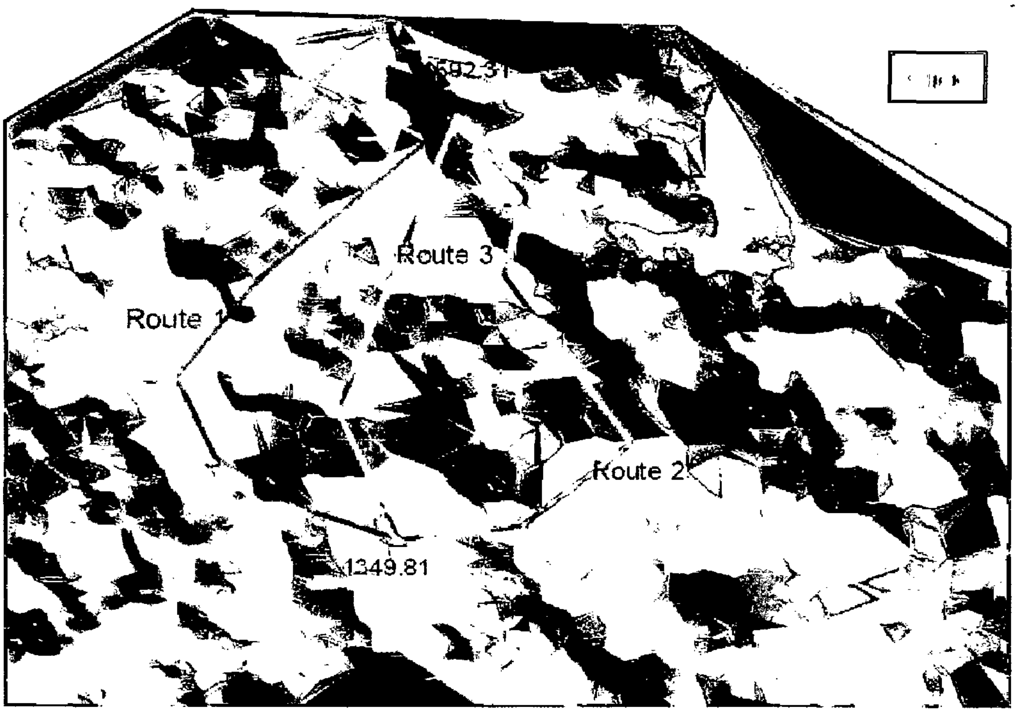


Fig 8.2 – All Possible Routes Plotted On The Data Source

The Profile Extractor Extension gives the profile of all the routes both in the form of graph as shown in fig 8.3 as well as in the form of a table as shown in fig 8.4.

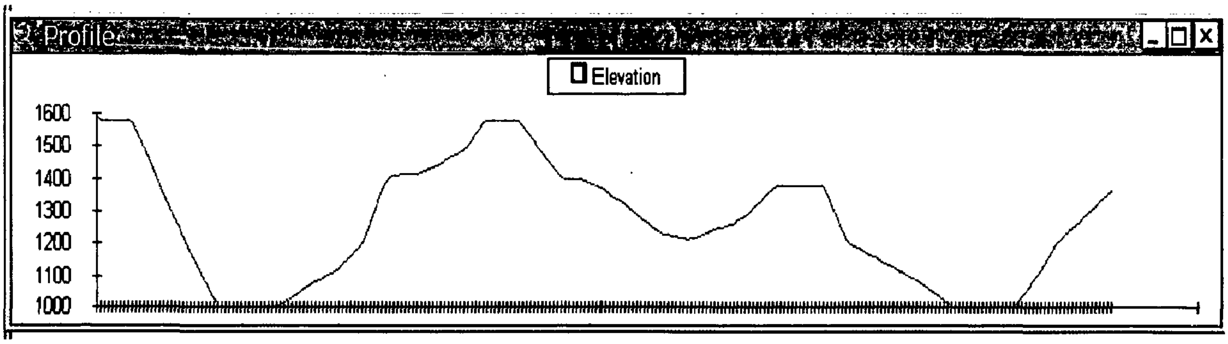


Fig 8.3 – Graphical Plot of the Route

The table as shown below gives the X Coordinate, Y- Coordinate, distance, and elevation of the route at regular interval. Similarly the profile all the routes is created and saved in the project.

Table1

X coord	Y coord	Distance	Elevation
79.374	29.916	0.000	1580.007
79.373	29.915	0.001	1580.000
79.372	29.915	0.002	1580.000
79.372	29.914	0.003	1580.000
79.371	29.913	0.004	1580.000
79.370	29.913	0.005	1580.000
79.369	29.912	0.006	1580.000
79.369	29.911	0.007	1572.637
79.368	29.911	0.008	1533.495
79.367	29.910	0.009	1494.302
79.366	29.909	0.010	1455.050
79.366	29.909	0.011	1415.802
79.365	29.908	0.012	1378.856
79.364	29.907	0.013	1342.739
79.363	29.907	0.014	1305.957
79.362	29.906	0.015	1269.765
79.362	29.905	0.016	1232.888
79.361	29.905	0.017	1196.639
79.360	29.904	0.018	1168.606
79.359	29.903	0.019	1140.883
79.359	29.903	0.020	1114.807
79.358	29.902	0.021	1088.910
79.357	29.901	0.022	1062.916
79.356	29.901	0.023	1037.907
79.356	29.900	0.024	1014.192
79.355	29.899	0.025	1000.000
79.354	29.899	0.026	1000.000
79.353	29.898	0.027	1000.000
79.353	29.898	0.028	1000.000
79.352	29.897	0.029	1000.000
79.351	29.896	0.030	1000.000
79.350	29.896	0.031	1000.000
79.350	29.895	0.032	1000.000
79.349	29.894	0.033	1000.000
79.348	29.894	0.034	1000.000
79.347	29.893	0.035	1000.000

Fig 8.4 – Profile of Route

After adding all the profiles of the routes in the project, the software for siting the Transmission line tower is run from the Arc View GIS itself through the Matlab exe file. The algorithm for siting of Towers is carried out for all the routes individually through Graphical User Interface (GUI).

8.1. Algorithm of Siting of Transmission Line Towers

1. **Step 1 :** Data sheets containing the details Towers heights and cost of construction is prepared and the data sheet of terrain profile is prepared using the GIS.

2. **Step 2 :** The height, cost of construction and the location of the first Tower is initialised at the start point of the route. Minimum span and maximum span between the two Towers is also initialised in the beginning.

3. **Step 3:(Minimum And Maximum Span Constraints)** From the fixed start point the next Tower is spotted in the given span interval i.e. min span and max span. Between this span interval sag clearance is checked for all the available tower heights. Wherever the sag constraint is met the cost of construction is calculated till that node and this value is stored is stored in the memory.

4. **Step 4 :** At a fixed forward step sag clearance is checked till the max span. All the cost values are stored in the memory.

5. **Step 5 :** From all the feasible solutions minimum cost value is calculated. The height of the tower and the site corresponding to the minimum cost is the most economical solution for the current node. This value of height and the site is stored in the memory for further calculations.

6. **Step 6 :** The tower location and height calculated above will become the start point for siting of the next Tower location.

7 **Step 7 :** The above procedure is repeated till the finish point. In the end we get set of feasible solutions including corresponding costs between start point and the finish point. These feasible are plotted on a graph as shown in fig 8.5and fig 8.6. The final solution is the most economical solution.

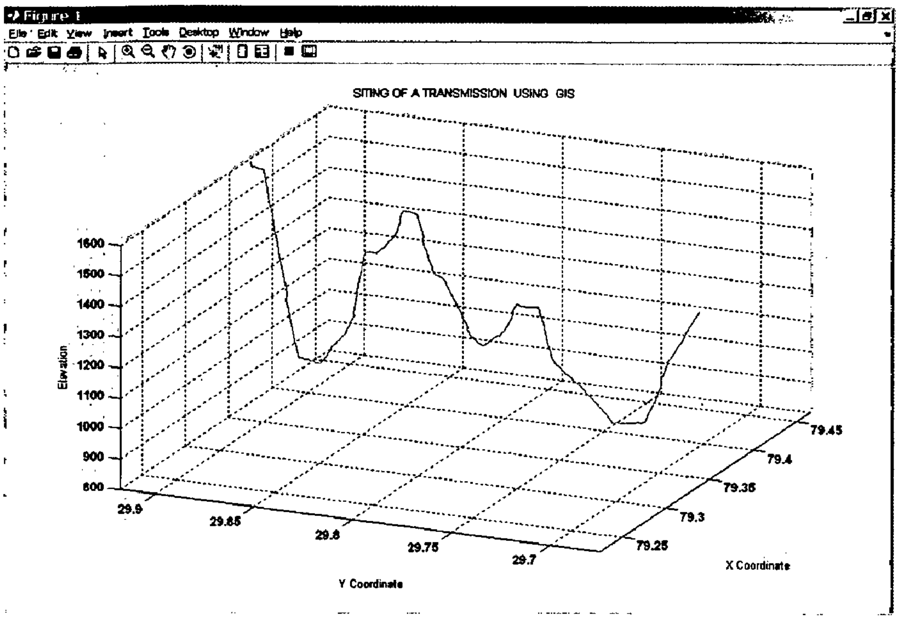


Fig 8.5 – Route Profile Plot in 3 Dimensional

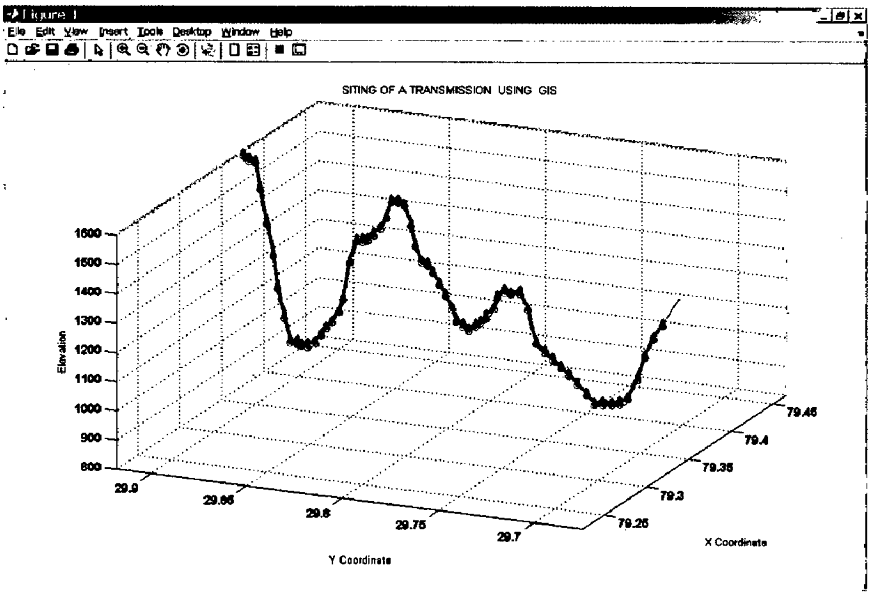


Fig 8.6- Final Tower Locations on the Route

Result

The tower spotting is carried out for all the routes identified on the TIN data source. The final output is the Total Length of the route, approximate cost of construction of the transmission line and total numbers of each type of towers for each route. Thus on comparing the individual results we get the most economical path between the start point and the finish point. The most economical route is Route No 3. Final result is as shown in the table 8.1

Table 8.1- Comparative Result

Route 1	
Total length of route	37.2 Km
Approx Cost	Rs 76860000
Number of 20m Towers	62
Number of 26m Towers	31
Number of 34m Towers	0
Route2	
Total length of route	36.6 Km
Approx Cost	Rs 75520000
Number of 20m Towers	65
Number of 26m Towers	26
Number of 34m Towers	0
Route3	
Total length of route	26 Km
Approx Cost	Rs 53200000
Number of 20m Towers	50
Number of 26m Towers	14
Number of 34m Towers	0

In this dissertation, a Geographic Information System(GIS) platform based algorithm has been developed in MATLAB for Optimal route selection for the siting of a new transmission line. The advantage of this method is that with help of GIS we can obtain the ground profile of the tentative routes and most economical route can be selected for new transmission line. Before the actual physical survey on ground is carried out the accurate location in terms of latitudes and longitudes and the height of the towers are known which satisfies the constraints. Thus this methodology will help the planners in saving precious time and man hours required for initial ground survey.

CONCLUSION

The use of digital computer as a planning and design tool has helped the transmission engineer in number of applications such as calculations of minimum clearance required for the conductors, automatic plotting of transmission line towers etc. The quality of tower spotting of a transmission line determines directly the cost of the power line. In the early days all the tower spotting is done by hand. It is impossible for a designer to choose a best plan from thousands of plans in practical works. In the last few years, the problems associated tower spotting have been solved due to the development of computation methods and the rapid progress of computers. Dynamic programming is one of the best way to solve complicated tower spotting problem.

This is the new methodology of automated optimal routing for new overhead electric power lines at the transmission and sub transmission levels that can be easily extended to the primary distribution level. The methodology is useful for the automated selection of the most economic route to build new lines. The method is also useful for the creation of power-line economic corridors. These corridors are feasible routing areas that link two particular points (origin and destination of the electric line) and keep associated line costs below a limit value determined by the planner; moreover, they also include multiple suitable economic routing alternatives for new power lines. The line costs considered are the operating, maintenance, and investment costs for a given electrical conductor size.

A GIS-based application has been developed for transmission line siting. This system supports from the planning phase to the engineering design phase and provides total solution for the siting process. The GIS data format used in this methodology is the raster format for input values (associated costs: terrain, slopes, obstacles, infrastructures, maintenance, etc.) as well as for computational results (minimum cost paths and economic corridors). Other innovate processes are the additional routing costs due to terrain slopes depending on the direction followed by the electric line. This new methodology has been developed to build overhead electric power lines, it can be easily extended to other line routing problems, such as power underground distribution feeders, and takes advantage of the processing and viewing capabilities of GIS.

Remote Sensing is the science and art of acquiring information about material objects, area, or phenomenon, without coming into physical contact with the objects, or area, or phenomenon under investigation. Remote sensing is the vital source providing the latest and up to date information which in turn becomes the start point for the GIS for various types analysis and applications. The integration of image data into GIS has tremendously increased the capabilities of the GIS. Remote Sensing provide the data through satellite imagery, Arial photography etc. Satellite Image is available in three formats (bip,bil,bq) which can be easily converted into DEM/ TIN through a software to be used in GIS. Remote sensing techniques has been utilized successfully in number of areas of application in routing, weather forecast, agriculture etc.

Geographic Information System (GIS) is a computer based information system used to digitally represent and analyse the geographic features present on the Earth' surface and the events (non-spatial attributes linked to the geographic feature under study) that taking place on it. Digital Terrain Modelling (DTM) is an important utility of GIS. Using DTM/3D modelling, landscape can be better visualized, leading to a better understanding of certain relations in the landscape. The two major advantage of using the GIS for siting of transmission line firstly the most optimal route can be identified without actual survey on ground and secondly the actual location and height of the towers can be spotted on the selected route. Based on the above result approximate cost of project of the new transmission line can be estimated. This methodology will save tremendous amount of time and effort during the planning stages.

REFERENCES

[1] Cláudio Monteiro, Ignacio J. Ramírez-Rosado, Pedro J. Zorzano-Santamaría, L. Alfredo Fernández-Jiménez, **GIS Spatial Analysis Applied to Electric Line Routing Optimization**, IEEE Transactions on Power Delivery, vol. 20, no. 2 pp.934-942, April 2005.

[2] Tyeb Pervaiz, **GIS Application for Power Transmission line Siting,** http://www.gisdevelopment.net/application/utility/power/utility.

[3] Mitra,, G and Wolfenden, K, **A computer technique for optimizing the sites and heights of transmission line towers - a dynamic programming approach**, Computer. Journal. No 4 (1968) pp 347-351.

[4] L Olbrycht, **Algorithm for the Design of Overhead Transmission lines** 0010-4485/81/050265-05 IPC Business Press, vol. 13 no 5 pp. 265–269, Sep . 1981.

[5] Chris Coulston, Robert Weissbach, **Routing transmission lines via Steiner Trees,** 0-7803-7989-6/03©2003 IEEE, pp 1576-1579.

[6] N A. West, B. Dwolatzky, A.S. Meyer, **Terrain–Based Routing of Distribution Cables,** IEEE Computer Applications in Power, ISSN 08959156/97/1997 IEEE , pp. 42–46, Jan 1997.

[7] Nicholas G. Boulaxis and Michael P. Papadopoulos, **Optimal Feeder Routing in Distribution System Planning Using Dynamic Programming Technique and GIS Facilities,** IEEE Transactions on Power Delivery, vol. 17, no. 1,pp. 242-247Jan 2002.

[8] R.E Kennon and D A Douglass, **EHV Transmission Line Design Opportunities for Cost Reduction,** IEEE Transactions on Power Delivery, vol. 5, no. 2,pp.1145-1152 Apr1990.

[9] Lin Zheng, **The Application of Dynamic Programming Theory for Optimization of Transmission Line Tower Spotting, IEEE tencon'93 / Beijng ,** pp. 466– 467.

[10] Leslaw Olbrycht, **A Contribution to the Methods of Optimizing the Spotting of Transmission Line Towers,** Electric Power Systems Research, 0378-7796/82/0000-0000/, pp. 163 – 171 Jan 1982.

[11] Min-Yuan Cheng), Guey-Lin Chang, **Automating utility route design and planning through GIS,** 0926-5805r01r$ - see front matter q2001 Elsevier Science B.V, pp. 507–516, 30 August 2000.

[12] Miguel Vega, He'ctor G. Sarmiento, **Image Processing Application Maps Optimal Transmission Routes,** IEEE Computer Applications in Power, pp. 47–51, **April** 1996.

[13] A.Luchmaya, B.Dwolatzky, A.S.Meyer**, Using Terrain Information in an Electrification Planning Tool,** 0-7803-7285-9/01/$17.00 (C) 2001 IEEE, pp. 456–460.

[14] N.C Rowe and R.S Ross, **Optimal Grid-Free Path Planning Across Arbitrarily Contoured Terrain with Anisotropic Friction and Gravity Effects,** IEEE Trans. On Robotics and Automation, vol. 6, No 5 pp. 540–553, Oct. 1990.

[15] Transmission line Reference Book Vol I and Vol II By EPRI

[16] F.Kiessling and P.Nefzger , Book '**Overhead Power Lines'** , Oct 2002