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Role of GIS in Distribution Power Systems

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***Abstract*—With the prevalence of computer and development of information technology, Geographic Information Systems (GIS) have long used for a variety of applications in electrical engineering. GIS are designed to support the analysis, management, manipulation and mapping of spatial data. This paper presents several usages of GIS in power utilities such as automated route selection for the construction of new power lines which uses a dynamic programming model for route optimization, load forecasting and optimizing planning of substation's location and capacity with comprehensive algorithm which involves an accurate small-area electric load forecasting procedure and simulates the different cost functions of substations.**

***Index Terms*—Geographic information systems (GIS), optimal location and capacity, power distribution planning, route selection, spatial load forecasting.**

I. Introduction

THE ability to consume and control energy is one of the initial contributions to the development in our life all over the years. The use of GIS in power system has greatly enhanced the efficiency in energy sector. Proximity to the furthest customer and high cost to invest capital, are the reasons that make the distribution system as an important part of electrical utility, which endeavor to improve the reliability of general power system [1]. Problems of planning in distribution system can be solved by using new methods and specific techniques. Complexity of electrical distribution system and necessity of accurate up-to-date information of the network assets is a reasonable intention for introducing new method of information technology. GIS software breakthrough technology which help utilities discover new things about their investments and risks, reduce the cost of manual maintenance of the maps, and allows the simultaneous assessment of technical, financial, and environmental factors. GIS have been proven to be a workable system to connect database information such as billing, material account, distribution analysis and outage reporting in power utility. Geographic Information Systems (GISs) are now being used widely for the mapping and modeling of utility network systems. Utilities use network models to monitor and analyze their distribution systems. Network analysis conclude network tracing which selects a particular path through the network based on user's criteria, network routing which determines the optimal path that has the shortest and the fastest distance and minimum cost and network allocation which deals with the designation of portions of the network [2]. The electrical network are mapped on a suitable scale over the base map and with the help of suitable GIS software changes in the network can be updated in less time and more accurate on a periodic basis [3]. In near future, GIS will be a powerful tool to restructure industry for making an effective investment decision about its substructure. The most important usages of GIS in distribution system are optimizing electric line routing, suitable sites for locating new feeders, optimal design and choice of substation location and capacity, load distribution and load forecasting.

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II. Geographic Information System

GIS is a powerful tool which can be defined as integrated sets of data, hardware, software and processes designed as a computer system for gathering, managing, mapping and analyzing spatial data. GIS is one of the most important new technologies which consider growth opportunities for fault analysis, optimization of networks, load forecasting, cost estimation and selection of suitable areas and etc. GIS which has been proven to be a workable system, allows the utility engineer to design and focus on the real issues rather than trying to understand the data, also analyze power system networks in less time, more economically and more accurately. Database which is the most important asset of an organization plays a central role in the operation of planning, can be divided into two main various data types: spatial data that describe the location and the shape of geographic features and spatial relationship of map features. Attribute data known as descriptive information of the map features. The two most frequently used GIS models of spatial data are raster and vector. Vector data are based on co-coordinating the system where geographic object is represented by points, lines and polygon. Vector data are more suitable for features that have discrete boundaries such as roads. Raster data consists of a regular grid of cells or pixels where each cell has an individual value that in the coordinate system the cell size indicates distance and geographical position of objects. Each set of cells constitute a layer which called coverage and several thematic layers can logically constitute a complete database .The raster data model is the most suitable format for arithmetic operations among cells. A mathematical procedure called topology is used for representing spatial relationships among the objects. GIS software and hardware are used as tools for storing, analyzing, interpreting, updating, displaying information, professional's designs and maintaining the system.

III. Optimal Line Routing

The manual design of a new electric power line with traditional methods includes the restrictions such as scale measurements, high cost, time-consuming, low speed, elimination of information, lack of information and efficient tools. The design process can be divided into two sub-processes: the first, concerning line routing or equipment placement determination and the second, concerning sizing of all the elements. The manual design is much harder to handle, compared with automatically design which is an engineering task that optimizes the equipment installation and maintenances costs and satisfies a given set of spatial, technical, and economical constraints [4]. Line routing is based on spatial logic and needs the ability to distinguish among different geometric shapes and objects. Equipment sizing, after line routing is next straightforward process. In last decades, GIS were defined as the suitable computer platform to develop automated routing of underground residential distribution systems [5]. At the first approaches of line routing using GIS, vector format was used and the different features were shown as lines or polygons [4]. For distribution system, planning raster format is used which references spatial data according to a grid of cells and each cells represents a geographic position and involves a value of interest. A GIS platform is used for minimizing cost routing considered its economic corridor where geographic data are represented in raster format instead of vector format. Because the actual terrain information can be associated with small areas represented as polygons or elementary cells instead of nodes and lines, the paths optimize in GIS raster structure which is basically a regular matrix of square cells where each representing an elementary geographical area and position with equal characteristics. This structure based on matrix operations which a GIS coverage (of terrain costs, terrain slope, soil types, or coverage of other aspects), and the element of each matrix corresponds to alphanumerical information associated with the corresponding geographical location [4], [6]. In this structure, all costs which associated with the cell location must be associated with terrain surface. Several geographic costs can be described as:

1) Accessibility costs
2) Costs due to specific characteristics of the geographic area
3) Terrain complexity cost
4) Wind speed cost
5) Altitude cost
6) Cost due to obstacles[4].

The incurrence of some economic costs which are not geographically dependent, in the path routing process is important because of the influences of their relative value in the overall installed line cost [6]. In process of path selection, decreasing the sensitivity to the geographical characteristics and obtaining a straighter path depend on the relation of non geographical cost (like line equipment) which should be included in the raster GIS coverage, to the geographical cost components. These variables influence the costs related to usage of terrain, the installation of equipment in each location, recompensation and transposition of obstacles, special additional costs associated with environmental and social requirements [6].

A. Line Routing With Dynamic Programming

This part explains Dynamic programming (DP) which is a suitable optimization technique for using with GIS raster structures for power-line routing as the core optimization method. In DP terminology, GIS raster line routing is defined as a set of elementary cells with links between neighboring cells in a particular stage along the path. The optimal object in this process is minimizing the cost in line routing the optimal path between two locations is got by moving successively from neighboring cells based on Bellman principle of optimality and maintaining an optimal ”back-link cell path” from the origin to the end of the route which stored in directional raster coverage. For minimizing the cost geographic and non geographic data should collect and arrange in spatial databases in raster format. After this process they can be performed by the designed DP algorithm [4] and [6].

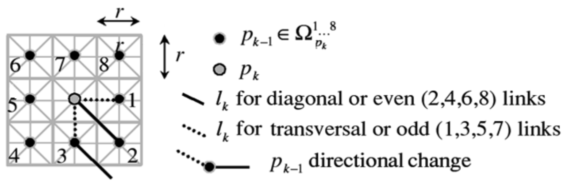

Fig. 1. Date structure elements associated with links.

Bellman’s principle optimality is a fundamental statement and a useful tool for solving dynamic problems which states that an optimal policy must contain only optimal sub policies and a policy for the remaining stages must be independent of the policy adopted in previous stages. It breaks a dynamic multi-period optimization problem into simpler sub problems in a recursive manner at different points in time. It identifies a collection of sub problems and tackling them one by one and at last the solution is optimal [7].

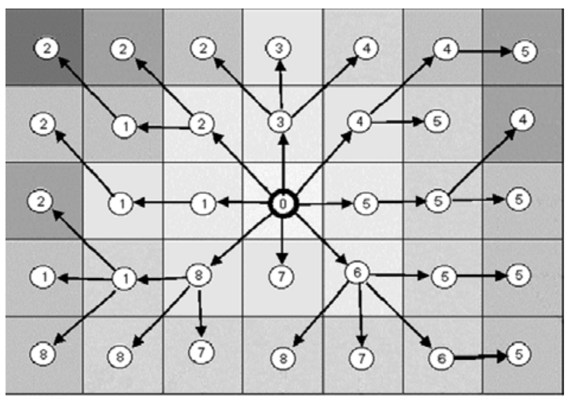

Fig. 2. Radial path structure for back - link path trancing

The optimal cost is computed on the whole geographic coverage in addition to the routing path which results the routing optimization between the origin cell and the rest of the cells in the geographic coverage.

B. Selecting Routing With Power -Line Corridors

Economic corridors are elongated areas which define the geographic bounds of potential optimum or near-optimum paths .Line corridors show the sensitivity of the electric power-line routing to cost-associated geographic aspects and give a visual idea of the geographic uncertainty of the routing. The economic corridor routing methodology assesses the additional costs related with a path deviation from the optimal path.

1) The optimal paths that connect each cell of the area with the origin A in terms of economic costs are calculated in the first step, as shown on the left side of Fig.3. The optimal ”back” line that links the point C (C represents a generic location) with the origin A is represented as the black line; and the other black line represents the optimal ”back” line that links the point B with the origin A. Note that the accumulated cost isolate in the background: clearer areas have lower associated accumulated costs than darker ones.
2) In the second step (in the middle of Fig. 3), the previous step is repeated but using B as the origin instead of A. The optimal ”back” line that links the point A (accumulated cost h_{min}) with the origin B (null accumulated cost h_{min}) passes through the same locations as the optimal ”back” line obtained in step 1) that links the point B (accumulated cost) with the origin A (null accumulated cost).
3) In the third step (on the right side of Fig. 3), the geographic coverage obtained in two previous steps are added to obtain the cost of the electric power-line path between A and B passing through C. These cell locations with costs lower than or equal to h_{max}) define the economic corridor. Cell locations with the value h_{min}) define the optimal path [4].

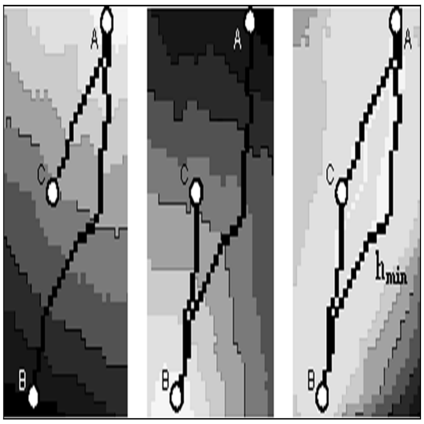

Fig. 3. Path computation

IV. OPTIMAL LOCATION AND CAPACITY OF SUBSTATION

Distribution system planning contains the sitting of Substations, the routing of feeders, and many other Decision-variables which affect both the locations and amounts of capacity attachments. Distribution system planning (DSP) is a complex and indefinite systemic scheme for spatial load forecasting (SLF). Spatial load forecasting which is suitable for comprehensive distribution planning besides of forecasting the amount of future load growth, also predicts the location of load increment. To perform spatial load forecasting techniques GIS technology provides an excellent platform which merge distribution system data with land-use and development data [3] , [8] and [9].

A. Spatial Load Forecasting

Load forecasting is an important subject of DSP which is resulted the precision of the whole planning work. Load forecasting is consisting of whole power, classified loads, load curve and load distribution. Forecasting the demand and the distribution of the load in power domain is the first step of spatial load forecasting [3]. This process is done in this way: at first the whole capacity of load forecasting should be considered. For accomplishing this total power supply area should be divided into several sufficiently small areas based on the Geographic location which includes a number of demand points that indicate different customer loads. Each section gathers spatial data and forecasts the future load growth for every small area. Gathering spatial information can be performed on the geographic information system (GIS) Platform. With considering the different characteristics of electric-use and land-use of consumer and forecasting the spatial land-use distribution, SLF Can easily be done. To forecast load growth of the geographical area served by substation, the model which translates the land use into a system-load forecast, uses data such as current land use, transportation infrastructure, mountain slopes and urban centers and then location of new load additions which expected is determined [10]. Therefore, the steps of SLF are shown in Fig. 4. Allocate the growth of demand or electric-use of customers computed in system forecast for the total area among the small areas is the Objective of spatial load forecast. The future system can then be planned from these load forecasts. Forecasting future load centers, prioritizing projects, identifying substation property requirements and obtain budgeting approval while minimizing risk are the usages of Forecast results [11] the basic purpose of optimization process in distribution planning is to ensure that the demand growth with its rates and high load densities, can be controlled rather to minimize the cost required for construction and operation of the distribution system [12].
Based on the results of spatial load forecasting, in each area during each step of the design, the load density and points of consumer power can be confirmed. It also presents appropriate decision-making for the geographic location, time and capacity which put into running of each substation to provide the demand of load growth in planning process and minimize the cost of investment and maintenance. Because of being unknown the geographic location, power-supply scope, capacity and the time that put into running of each substation, the combination methods are used [3].

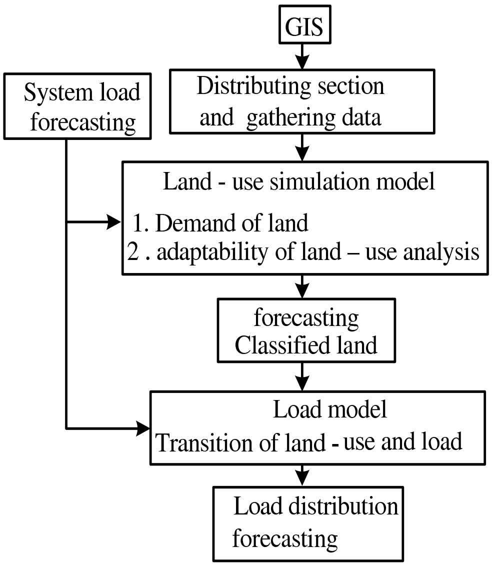

Fig. 4. Steps of SLF

B. The Mathematical And Network Flow Models

Cost for each piece of equipment is divided into two parts: fixed and alterable costs. Fixed cost includes cost required for the purchasing and construction of the equipment and iron loss in independent of the flux passing through the component and the other, represents the portion of the cost which depends on flux passing and relates to copper loss of substation. In total-cost formulation, existing substations and a piece of equipment which is not installed have no fixed cost [3].

$$\sum_{i=1}^{N}\sum_{j\in Ji} w_j \times d_{ij}$$

$$min\ Z = \sum_{i=1}^{NSF}(hF_i \times x_i + hV_i \times f_i) + \sum_{i=1}^{NSU}(hV_k \times f_k) + r$$

$$\sum_{j\in Ji} W_j \leq S_i \times e(S_i) \times \cos\phi \qquad (i = 1, 2, ..., N)$$

$$f_k \leq x_k \times c_k \times \cos\phi \qquad (k = 1, 2, ..., NSF)$$

$$f_k \leq c_k \times \cos\phi \qquad (k = 1, 2, ..., NSU)$$

$$f_k \geq 0 \qquad (k = 1, 2, ..., N)$$

$$x_k \geq 0 \text{ or } 1 \qquad (k = 1, 2, ..., NSF)$$

Where

NSU: Number of substations utilization

NSF: Number of substations future $N = NSU + NSF$

f_i: The load magnitude of substation

c_k: The capacity of the number k substations

S_{xi}: x_i is equal to 1,if substation I is built during the current stage, or x_i is equal to 0

w_j: The load magnitude in load point j

J_i: Gather of the load point substation I supplies the power for

d_{ij}: The distance of line from substation I to load point j

S_i: The capacity of the No. i substation

$e(S_i)$: Utilization rate of the number No. i substation

$\cos\phi$: Power factor

r: Fee coefficient of network wastage

$\sum_{i=1}^{N}\sum_{j\in Ji} w_j \times d_{ij}$ approximately indicates network loss and investment

We can adjust each block area to make load of each one, equal to each block [3]. The network flow model is shown in Fig.5.

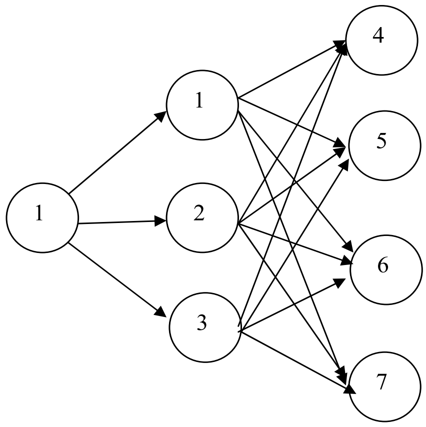

Fig. 5. The network flow model

V. Conclusion

The two main goals of this paper which are discussed are a new methodology of automated optimal routing for new power lines by dynamic programming (DP) and economic corridors which include suitable economic routing alternatives for new power lines. The other one is optimizing substation's location and capacity. Proper application of optimization methods to distribution system design can reduce the time required in design and improve the quality and cost of the resulting. According to the results, these algorithms are very efficient and have been successfully implemented in utilities Worldwide.

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