ABSTRACT

The conventional method of Transmission Line Routing is based on expert judgment, making it sub-optimal, subjective and biased. This paper introduces, elaborates and implements a new method of Transmission Line Routing based on Geographic Information System, which not only eliminates the biasedness during routing but also helps to maintain the balance between conservation and development. Transmission Line Routing using GIS tools of spatial sciences involves identification of factors affecting transmission line route such as land-use data, settlements, roads, slope etc. and preparation of several parameters sets by specifying different weight/cost index values to each of these factors and their subcategories, based on different priority for different factors. Modified Dijkstra (A*) algorithm implemented in python computer program was used to calculate the least cost path from start point to end point on the combined weighted raster for each of the parameter sets. The least-cost path represented the transmission line route alignment in this case. Lastly, a case study based on the implementation of GIS concept of routing a 400 kV Transmission Line of over 70 km has been presented. The study shows that GIS-based transmission line routing is a flexible and effective method of tracing the routes.

Keywords: Transmission line routing, least cost path, geographic information system.

1. Introduction

High voltage (HV) transmission lines are used for bulk power transmission from a generating station to a distant substation or between substations. The route for a transmission line project is developed in a sequential phase starting with many potential routes and narrowing to a single option.

The conventional method of transmission line routing is entirely a subjective process and the final route depends on the expertise of the designer. Even though the routing is carried out with focus, and shorter routes may hit upon the goal, the task becomes successively difficult with the increase in the length of the line. Thus, the route might not be optimized in terms of route length and cost.

An alternative to this is the use of Analytical Hierarchical Process (AHP) and geographical information system (GIS) tools for quantification of the relative cost (also referred to as weights) of each unit of land in the problem domain from the perspective of transmission line routing and with respect to the different optimization criteria, and the subsequent use of routing algorithm to find the least cost route within the discretized problem domain (between two specified points).

2. Literature Review

A similar technique for transmission line routing was carried out successfully in Kenya at 132 kV transmission level [1]. In [1], Analytical Hierarchy Process (AHP) was used to provide weightage to the transmission line route affecting parameters in a qualitative manner. This paper illustrates and distinguishes these factors quantitatively through weight values (or cost indices) assigned manually.

Routing a transmission line is not only an engineering problem but also includes socio-economic, environmental and safety issues [2] and as such, the developed model of the transmission line routing also helps to maintain the trade-off between development and environmental conservation aspect.

3. Objectives

The main objective of the study was to attempt a synthesis of expert judgement and mathematical optimization for the transmission line routing problem. While the use of expert judgement in assessing the suitability or relative cost of running a transmission line through a unit of land is quite accurate, maintaining the same level of objectivity in routing a line over a long distance becomes an intractable problem. The present study tries to use concepts from Analytical Hierarchical Process and classical path optimization to produce a transmission line route that is optimal with respect to several different criteria.

4. Methodology / Model Analysis

A. Study Area

The 400 kV transmission line connects Rasuwagadhi substation at Minrakhu village, Rasuwagadhi of Rasuwa district to proposed substation at Ratmate (Galchhi) of Nuwakot district.

The impact area in which the route alignment can pass is identified considering the start and endpoints of transmission line. For the sake of simplicity and effectiveness, unsuitable areas for transmission line route are avoided after a thorough study of the maps. For instance, to overcome the downside of high elevation, the areas with elevation values greater than 2500 m are eliminated from the processing extent while preparing the datasets.

B. Factors Affecting the Route and their Sources

Sentinel 2 image of 10 m spatial resolution was processed in digital remote sensing domain to get the land use map while buildings and roads were extracted from Open Street Map. Moreover, slope map was generated from the contour lines obtained from topographic maps (Spatial resolution: 20 m) prepared by the Survey Department of Government of Nepal, which also accounts as the data source of Langtang National Park. In addition, the data of transmission lines of 132 kV and 220 kV, within our area of interest were obtained from Nepal Electricity Authority.

C. Optimization Methodology

Initially, the layers/rasters of different aforementioned factors that guide the route, were prepared. The rasters were then combined (summed up) to come up with a single raster consisting of composite weight values. In this raster, the cells with least value lead the way for the most preferred route whereas cells with highest value are least preferred. Then the computer program was used to identify the route (interconnected cells) which yielded the lowest sum of composite weight values from the source (powerhouse or substation) to destination (substation).

For optimal path calculation, A* path searching (APS) algorithm was used because of its optimal efficiency compared to many other paths searching algorithms. Before the raster could be fed into the algorithm for pathfinding, it was preprocessed by using the GDAL python library. General line cost, tower cost and elevation cost were calculated in the preprocessing phase and then, were fed into the path searching algorithm.

In addition to the three costs, starting and ending points were also given to the APS. Then, beginning from the start point, the neighbors of the current cell within the predefined angular and distance limits were calculated. At each cell, node traversal cost to the neighboring node and the heuristic function- defined by the Euclidean distance between given and destination cell coordinates determined the next cell with least cost that was to be chosen for consideration in the next iteration. This cycle repeated until the current cell was equal to the destination cell. When calculating the node traversal cost, each of the general line costs, tower placement cost and the elevation had equal weights and, therefore, when one of the components bore a significantly higher cost, it led to the overall node traversal cost to be higher. In case of multiple destination points, APS was run with the same input parameters except for the end cells. The end result was the series of coordinates that when graphed created a line from start to the end, thus, creating the least cost path.

D. Parameter Set Optimization

To optimize the process of route generation, multiple sets of weight were prepared where different values of weights were assigned for different categories of the parameters. The alignment with an edge over others in maintaining the trade-off between development aspect and conservation aspect was selected as the final route, which at the end, was chosen through manual judgement.

5. Limitations

The spatial resolution of parameters such as elevation data that impact the design considerations of transmission line, if improved, could have delivered a better result. Also, if the inputs used are of better quality and additional features including sag calculation can be incorporated into the algorithm, the approach used here can become an indispensable tool for a transmission line designer.

6. Conclusions

The current study has tried to utilize concepts from Analytical Hierarchical Process and classical path optimization to produce an optimized transmission line route. The methodology followed has tried to use expert judgement where it works the best for assessing the priority and weightage of criteria and used an algorithmic approach for determining the optimal solution based on the initial expert input. While the information used as inputs were low in resolution, the generated route is a viable one and will be selected for the next phase of design. The methodology adopted here is a scalable one as opposed to the traditional method of route selection.

7. Key References

[1] Gill, Ramandeep Singh. "Electrical Transmission Line Routing Using a Decision Landscape Based Methodology." MS Thesis.

[2] Korir, J. K. and M. M. Ngigi. "The Use of GIS in High Voltage Transmission Line Routing in Kenya: A Case Study of 132 kV Kilimambogo-Thika-Kiganjo Line." *African Journal of Geogrpahy and Regional Planning* (2015): 208-217.

[3] Monteiro, Claudio, et al. "GIS Spatial Analysis Applied to Electric Line Routing Optimization." *IEEE Transactions on Power Delivery* (2005).

[4] Schmidt, Andrew J. "Implementing a GIS Methodology for Siting High Voltage Electric Transmission Lines." *Saint Mary's University of Minnesota University Central Services Press*. 2009.

8. Appendices

The workflow adopted in the study is shown in Figure 1.

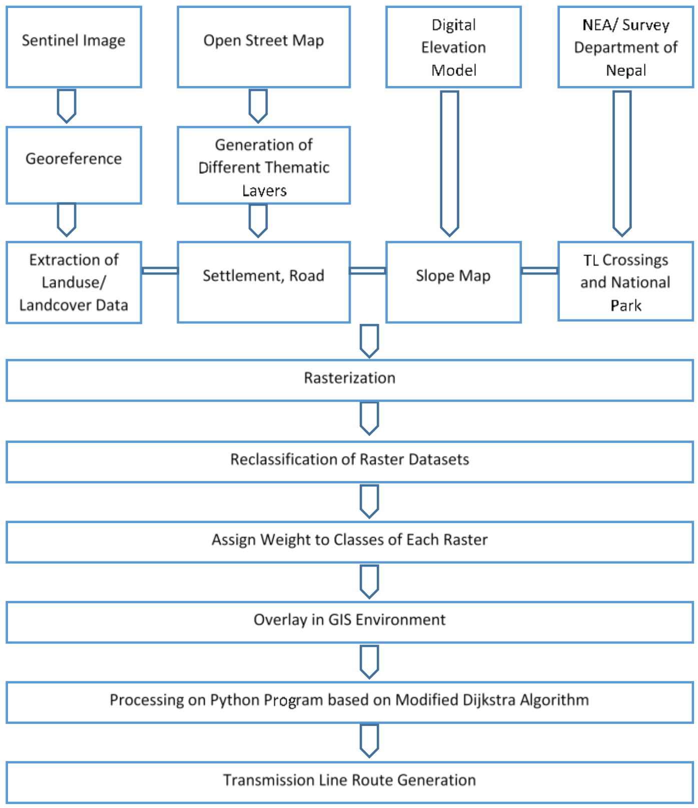

Figure 1: Workflow of the study

The different parameters considered and the respective weights assigned to each of these parameters are presented in Table 1.

Table 1: Weights Assigned to Different Parameters Considered for Transmission Line Routing

Category	Subcategory	Weight Values for Transmission Line
Distance from Building	Less than 50m	1000
	50m to 100m	500
	100m to 200m	150
	More than 200m	100
Distance from Road	Less than 50m	500
	50m to 200m	100
	200m to 500Km	200
	500m to 1Km	300
	More than 1Km	400
Distance from River	Less than 50m	500

Category	Subcategory	Weight Values for Transmission Line
	More than 50m	0
Landuse	Landslide	600
	Agriculture	200
	Barren	100
	Riverbank	500
	Dense Forest	400
	Scattered Forest	200
Slope	0° to 20°	100
	20° to 30°	200
	30° to 40°	400
	More than 40°	1000
National Park	Yes	300
	No	0
Existing Line (with ROW)-132	Yes	200
	No	0
Existing Line (with ROW) - 220	Yes	250
	No	0

The map showing the location of the study area along with a sample of the cost-raster is shown in Figure 2.

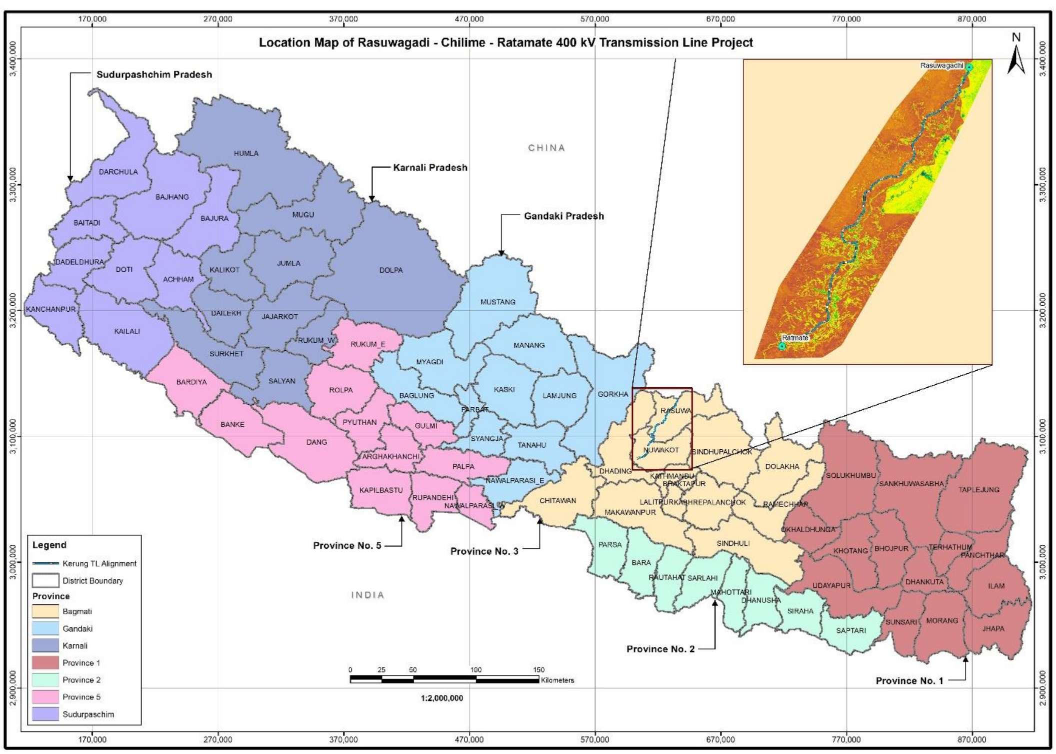

Figure 2: Location Map of Kerung Transmission Line along with the Combined Weight Raster for Least Cost Path Optimization