COST OPTIMIZATION OF POWER TRANSMISSION LINES IN HILLY AREAS

A THESIS

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by

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ABSTRACT

Global electricity demand in the developing countries is expected to triple by 2030, as it will rise by over 4% per year. The share of global electricity demand in developing countries is expected to be 43% in 2030. To meet this increase in demand, a capital investment of US $16.4 trillion globally and US $5 trillion in developing countries is required for the development of power sector. Electricity sector of India has undergone radical development in the past decade, particularly with the Electricity Act 2003 coming into force. The industrial and economic development in the country poses a continuous ever increasing demand for electricity. The peak demand in India has been projected as about 200 GW and 284 GW in 2017 and 2021, with corresponding energy requirements of 13, 54,874 and 19, 04,861 million units respectively. With an installed capacity of 258 GW, the present peak demand is about 135 GW and the peak demand met is 129 GW with an average deficit of about 10%. One of the major reasons for not meeting the peak demand is the lack of proper transmission infrastructure. Transmission lines play a vital role in the successful and stable operation of the power system network. The present transmission and distribution corridor length in India is about 89, 70,112 circuit kilometers.

To meet the ever rising energy demand, the generation and transmission capacity additions are to be planned and executed simultaneously. Most of the power is generated from conventional power stations utilizing fossil and nuclear fuels, which are probably located away from the load centers due to environmental constraints. The most convenient means of transporting electrical energy in such a scenario is the use of transmission lines. The design and construction of these lines is a very complex process as several design parameters having complex interactions among themselves and in terms of their effect on overall system cost has to be selected. Any delay in constructing new transmission lines will under utilize the generation facilities and investment. Construction of transmission lines involves heavy investment and hence, a careful analysis needs to be carried out at the planning stage in order to take investment decisions. There is a need for assessing and optimizing the cost of these lines based on scientific principles as compared to those adopted conventionally based on availability of standard designs and line designer’s experience. Also, the extension of grid to remote energy sources has to be done to fully exploit the generation diversity and to take advantage of the dispersed generation resources. Uttarakhand, a Himalayan state in India has rich source of renewable energy generation particularly small hydro power (SHP) as well as conventional large hydropower. There is an immediate requirement for constructing a power

evacuation system of the order of 6,000 to 6,500 MW of ongoing generation projects in various river basins of the state. Development of transmission lines in this region will help in grid extension to these energy resources as well as in meeting the peak power demand.

Literature survey reveals that earlier studies were conducted on design and planning, optimization of transmission line components such as conductor and tower and economic analysis of transmission lines. The uncertainties involved in transmission lines planning and construction are becoming larger and larger and certainly new methods need to be developed for analysis. Based on the literature review, following research gaps are identified.

i) Very few studies are available in the literature to find out the capital investment for construction of power transmission lines. For successful execution and timely commissioning of the power transmission lines, it is essential to predict the cost involved.
ii) Methodologies or models are not available in the literature for optimizing the capital cost of power transmission lines.
iii) It is found that a two stage procedure has been reported which involves designing the transmission lines in two stages independently. Design of conductor in the first stage and design of other components in second stage. There is a scope for modification in this methodology.
iv) Most of the earlier researches were concentrated on only one component i.e. conductor and very few studies were available on other components and cost influencing parameters.

Based on the literature review and identified gaps in research as discussed above, it is found that lot of studies were carried out to analyze the cost for power transmission lines. However, no study has been reported on cost analysis specifically for transmission of power in hilly regions. In India lot of hydropower potential exists in hilly regions, where the economics for developing large and small hydro power plants is very much dependent on the availability of transmission lines. Therefore, there is a need to analyze and optimize the transmission line costs in hilly areas. Keeping this in view, the present study is proposed with the following objectives,

i) To select hilly region representing different terrain conditions in order to identify different parameters of transmission lines.

ii) To work out the design of transmission line components for the selected region.

iii) To determine and analyze the costs of the components.

iv) To investigate the sensitivity of the site conditions on the cost.

v) To establish the correlations for cost influencing parameters in terms of their design variables and optimize the costs under different conditions.

In order to achieve the above mentioned objectives, an attempt has been made to develop a methodology for cost assessment of transmission lines so as to determine the techno-economic viability for investment decision before undertaking detailed investigations. The cost of transmission lines is site specific based on conditions prevailing en route in which the line traverses. The basic components of transmission lines are broadly categorized into three parts (i) electrical (ii) mechanical and (iii) civil. Electrical components consist of conductor, earthwire and insulators. Tower and accessories form the mechanical components, while foundations form the major civil component. In the present study, tower, conductor and energy losses are considered as major cost influencing parameters to carry out detailed cost analysis.

The line design is influenced by a number of factors which depend on terrain, geographic and atmospheric conditions of the region in which the line operates. The design of a transmission line is highly site specific and is carried out based on the guidelines provided by various national and international standards. Based on the conditions existing in the selected region, three phase double circuit high voltage lines in the order of 132 kV, 220 kV and 400 kV were considered for evacuation of power generated from proposed hydro power generating stations and other renewable energy sources. The design of tower was carried out using tower design and analysis software. For a given set of input design parameters, a set of loading conditions applicable on the tower are generated. Based on the standard galvanized steel member sections available commercially, towers were designed for minimum weight which are capable of providing the specified electrical clearances and withstand the applicable loadings and allowable stresses. The cost of transmission line towers depends on the weight of structural steel required for fabrication of towers and the total number of towers in a given line length. It has been identified that transverse load, longitudinal load, vertical load, height of the tower and base width are the major design parameters affecting the tower weight and hence, correlations for tower weight were obtained in terms of these variables.

The cost of the conductor depends on the weight of conductor, circuit kilometer length, number of circuits, number of phases and number of sub conductors per phase. Conductor weight is dependent on its diameter and the circuit kilometer length depends on span, unit weight of conductor and conductor tension. Hence, correlations have been developed for estimating conductor weight and conductor tension in terms of its diameter. The cost of energy losses depends on the resistance of the conductor and the current flowing through it. Correlations for conductor resistance have been developed in order to estimate the amount of energy losses occurring on the line annually and its corresponding cost. The data obtained from the correlations were compared for accuracy with the data obtained from manufacturers/power transmission utilities. A maximum deviation of ±3% has been found for 132 kV and 220 kV transmission line tower weights. The maximum deviation for 400 kV transmission line tower weight is observed to be within ±5% and for conductor parameters the maximum deviations of ±10%, ±8% and ±5% are found for conductor weight, tension and resistance respectively.

The total cost of transmission line has been computed based on the correlations developed for quantities of major items and the prevailing rates. Genetic Algorithms (GA) based technique has been employed to work out the optimum cost for the lines under consideration. The total cost of the transmission line project depends on the cost of tower, cost of conductor, cost of energy losses and cost of miscellaneous items and other indirect cost. Establishment related cost including engineering design, audit and account, indirect charges, tools and plants, preliminary expenses on report preparation, survey and investigations were considered under miscellaneous and indirect costs. The total cost as computed is validated from the cost data collected from the existing transmission line projects. A maximum deviation of ±10% has been found for the total transmission line cost for 132 kV and 220 kV transmission lines and for 400 kV transmission lines, it is observed that the deviation between the computed total transmission line cost and actual cost as per data collected is within ±5%.

Keeping in view the importance of cost management and decision making, economic analysis was carried out for the transmission lines to determine life cycle cost (LCC) using net present value (NPV) analysis and interval mathematics. A methodology for performing cost breakeven analysis considering right of way costs as reference is evolved to determine the point of economy indifference in the transmission lines for various available alternatives. LCC studies involve significant amount of technical and economic input data obtained from various reliable sources. However, the data obtained is highly uncertain and the effect of these uncertainties cannot be directly included in the study process, resulting in inaccurate solutions. Interval mathematics provides an effective solution for handling uncertainties in input data. The input parameters are expressed as interval numbers whose ranges include the uncertainties in those parameters. The computations can be performed entirely in interval form, which carry the uncertainties associated with the data throughout the analysis. The final outcome is a solution range in interval form, consisting of all possible solutions due to the variations in input parameters.

It has been observed from the base case results that the life cycle cost of 220 kV line is approximately 50% higher than a 132 kV line providing nearly 2.6 times more power carrying capacity and the life cycle cost of a 400 kV line is 70% and 135% higher, providing 4 and 10 times more power carrying capacity as compared to 220 kV and 132 kV lines respectively. From the uncertainties case results, it has been found that the minimum and maximum deviation for cumulative present worth is varying between - 4.2% to + 10.5% with respect to base case, for all the lines under study.

In order to meet the ever increasing power demand, it becomes inevitable for generation and transmission utilities to expand their infrastructure. In this regard, the present study focuses on cost optimization of power transmission lines in hilly areas. Uttarakhand state in India is selected for carrying out the transmission line design. Correlations have been developed for transmission line cost influencing parameters in terms of their design variables and are verified for accuracy by performing error analysis and observing key regression performance indicators. Based on the developed correlations, a mathematical model has been formulated to optimize the cost. Genetic algorithm optimization technique has been employed for cost optimization, which evaluates the minimum cost with simultaneous selection of optimum design parameters. Economic analysis has also been performed to investigate the sensitivity of various economic and market parameters on transmission line cost. The correlations developed and the cost optimization methodology employed for constructing overhead power transmission lines can be used by the line designers and developers for investment decision.