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Optimal costing of overhead power transmission lines using genetic algorithms

Srinivasa Kishore Teegala *, Sunil Kumar Singal

Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand 247667, India

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ABSTRACT

In the era of ever increasing power demand and deregulation of the power industry globally, it becomes extremely essential for transmission utilities to strengthen their infrastructure for accommodating the changes posed by deregulation and transfer reliable power to consumers. 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 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. In the present study, an attempt has been made to develop a model for cost assessment and optimization of overhead power transmission lines using genetic algorithms. The results obtained from genetic algorithm optimization technique have been compared with that of interior point method based classical optimization technique. Correlations based on regression analysis were developed for cost influencing parameters of the transmission line in terms of the line design variables and are used in constructing the mathematical model for cost optimization. The developed model is capable of optimizing the cost while simultaneously selecting the optimum design variables influencing the cost of the line. The proposed methodology can be used by transmission line designers and developers to determine techno-economic viability for investment decision before undertaking detailed investigations.

Introduction

Global electricity demand is expected to double by 2030, growing at an annual rate of 2.4%. This growth is more in developing countries, where electricity demand will rise by over 4% per year and is expected to triple by 2030. The share of global electricity demand in developing countries is estimated to be 43% in 2035 [1]. An investment of US $40 trillion in cumulative investment in energy supply is essential to meet the world's projected energy demand over the period 2014-2035. Economic and population growth, rise in living standards and shift from rural to urban living account for majority of new electricity demand. The high energy demand also calls for high capital investments for the development of power sector infrastructure comprising predominantly generation facilities and transmission and distribution (T&D) networks. To meet this growth in energy demand, capital investments required for the development of power sector infrastructure are expected to be US $16.4 trillion over 2014-2035 globally, at an annual average of US $740 billion per year. Nearly 58% of this investment is made for development of power plants and 42% is allocated for T&D systems. Of the total 3.2 million kilometers of planned addition of transmission lines at a cost of US $1.7 trillion over the period 2014-2035, 5% of this investment serves for integrating new renewable energy sources [2].

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 [3]. 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

* Corresponding author. Tel.: +91 9290464573.
E-mail address: srinivasakishoret@gmail.com (S.K. Teegala).

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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 [4].

The cost of transmission lines is site specific based on conditions prevailing en route in which the line traverses. 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 [5]. Transmission line design and construction in hilly regions is more complex and costlier as compared to plain regions due to inhospitable site conditions, higher cost of transportation, bigger foundation volumes and higher quantum of steel for towers in addition to short working seasons. Hence, in the present study, 400 kV three phase double circuit transmission lines employing twin moose ACSR conductor operating in Uttarakhand, a Himalayan state in India was selected to demonstrate the effectiveness of the proposed model and methodology. The selected region is a hilly region with rich sources 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 6,000–6,500 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 mitigating the peak power demand faced by the country and increase power system efficiency due to larger proportion of hydro-thermal mix [6].

Transmission line cost components

The construction of transmission lines is a complex task based on several technical, geographical, regulatory and other factors involving huge capital investment. The degree of reliability and security plays significant role in enhancing the total cost. Certain factors like right of way (RoW), land cost, labor cost, and raw material costs are highly volatile based on market conditions introducing a significant level of uncertainty in estimation of the capital investment for transmission lines [7]. The structure geometry which depends on rated line voltage, cross section of the conductor and power losses occurring over the operating life of the line can be considered as the major parameters for estimating the transmission line cost [8].

Tower

The transmission line structures employing latticed type steel towers constitute about 35–40% of the total line cost. The cost of the tower depends on the tower weight and total number of towers [9]. The tower weight is related to tower geometry which in turn is determined by various electrical and mechanical parameters such as loadings, spacing's and clearances. The total number of towers for a given length of a line is dependent on the span. The span between the towers affects the loads on towers. The longer the span, the magnitude of vertical, transverse, and longitudinal loads acting on the tower increases, resulting in more tower weight and vice-versa. However, increase in span length decreases the total number of towers required for a given length of transmission line.

Conductor

Aluminum conductor steel reinforced (ACSR) conductors are commonly used for transfer of power in overhead lines. ACSR conductors constitute upto 20% of the total line cost. For a given amount of power transfer, the cost associated with selection of the conductors is such that it increases as the size of the conductor increases, while transmission losses decrease. The minimum and maximum limit on conductor sizes are governed by radio interference levels and tower weight required to withstand the loads respectively. An increase in the number of conductors in a bundle decreases the energy loss while increasing the conductor cost [10]. The overall cost of the conductor depends on the total circuit kilometers for a given length of transmission line, which in turn depends on size(weight), number of phases and number of subconductors in a phase.

Losses

Energy loss during transmission occurs mainly due to resistance of the conductor. A minor amount of energy loss occur due to corona phenomenon, which is negligible for the present lines under consideration, but, due importance has to be given to these losses at higher voltage levels in the order of 765 kV and above [11]. Energy losses occur over the entire economic operating life of the line. The cost associated with energy losses depends on the resistance of the conductor and the current flowing through it. The resistance depends on the conductor size and material while; current flow can be computed by integrating the square of the current from a typical annual load duration curve. The present value of cost of energy losses can be determined by using continuous discount formula.

Development of correlation based cost model

The process of developing correlations starts with the collection of tower, conductor and load data required for this purpose. The data set is then screened to detect outliners which have unreasonable variations. The parameters on which the tower, conductor and energy loss cost depends are identified. These are weight of steel required for constructing the tower and weight and resistance of conductor. The cost of these components form a substantial part of the total transmission line investment cost and needs careful analysis for achieving technical and economic efficiency [12].

Methodology

In the present section, methodology for obtaining correlations for the cost influencing parameters is discussed. The dependent variable (cost influencing parameter) is generally related to its independent variables (design parameters) in linear form. "Least Squares" method has been used to calculate a straight line that best fits the data. It can also be combined with other functions to calculate the statistics for other types of models that are linear in the unknown parameters, including polynomial, logarithmic, exponential, and power series. The initial expression for dependent variable is

$$D = a\,I^b \tag{1}$$

where D is the dependent cost influencing parameter, I is the independent design variable and a and b are constants of regression analysis. Applying logarithms on both sides of Eq. (1)

$$\log D = \log(a\,I^b) = \log a + b\,\log I \tag{2}$$

Carrying out a variable change

$$Z = \log D$$

$$X = \log I$$