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Economic Analysis of Power Transmission Lines using Interval Mathematics

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Abstract – A major portion of the capital costs in the present day power transmission systems are due to the cost of equipment and construction process. Transmission utilities in the recent years are drawing greater attention towards performing life cycle costing studies for cost management and decision making. However, the data involved in these studies are highly uncertain and the effect of these uncertainties cannot be directly included in the study process, resulting in inaccurate solutions. Interval mathematics provides a method for including these uncertainties throughout the cost analysis and provides final solution range in the form of intervals. In this regard, it is essential and extremely important that significant research has to be carried out in understanding the principles of life cycle costing methodology and its applicability to cost analysis of transmission lines along with uncertainties involved in the cost assessment process. In this paper, economic analysis of power transmission lines using interval mathematics has been studied. Life cycle costing studies are performed using net present value analysis on a range transmission lines used in India and the results are analyzed. A cost break even analysis considering right of way costs was carried out to determine the point of economy indifference.

Keywords: Overhead, Underground, Transmission line, Life cycle costing, Interval mathematics, Net present value analysis, Breakeven analysis

1. Introduction

Transmission lines play a vital role in the successful and stable operation of the power system network. The design of these lines is a very complex aspect as several design parameters have to be selected. These design parameters have complex interactions among themselves in terms of their effect on overall system cost [1]. A change in conductor design parameter such as diameter and configuration affects the tower loadings and foundation design which further influences the construction process and the total system cost. Life cycle costing (LCC) methodology proves to be a powerful tool in helping the decision maker for selecting a particular design configuration among the various available alternatives [2]. LCC studies require a large amount of data for analysis from transmission utilities which are subjected to varying degrees of accuracy. The most often encountered difficulty is the high degree of uncertainty present in the data used for LCC studies. It is impossible to include all the effects of uncertainties and their impact on the final outcome of the study, but with the help of interval mathematics, uncertainties can be included to some extent. An advantage offered by interval mathematics is the ability to compute guaranteed bounds on the range functions defined over interval domains.

In this study, the applicability of interval mathematics for life cycle costing analysis for typical overhead and underground transmission lines has been presented. The results of the analysis provide an insight to the costing aspects which help in evaluating the construction, operation and maintenance strategies of the lines and also, in decision making among the available alternatives. Comparative analysis and breakeven point range determination was performed to identify the point of indifference in the economy. In this regard, the paper is organized as follows. Section 2 deals with LCC significance and evaluation process. Section 3 presents modelling of uncertainties using interval mathematics concept. Section 4 introduces the transmission line LCC model along with details of cost components and finally, section 5 deals with economic analysis consisting of LCC analysis and cost breakeven analysis for the transmission lines under consideration followed by conclusions.

2. LCC Significance and Evaluation

Life cycle costing is the process of economic analysis to assess the cumulative cost of a project over its life time. The primary objective of life cycle costing is to provide input for decision making in any or all phases of a project's useful life. The preparation of LCC models must identify costs that may have a major impact on the LCC or may be of special interest for that specific project and also identify

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costs that may only influence the LCC to a very small extent. A typical transmission line project's total life mainly includes planning and design stage, implementation stage, operation stage and replacement stage. Most of the electric power utilities follow a standard cost management process, in which only the technical and economic feasibility of the transmission line project for completing the construction and to start up operation is considered. This phenomenon reflects the investment cost only to a certain extent i.e. the design and construction phase of the project. Even though this phase has a major share of the total line investment, but cost of line losses, faults, repair times, operation and management costs must also be considered in evaluating the total LCC of the project. The LCC method provides a clear demarcation between the planning and design stage, construction stage and operation and maintenance stage which allows access to cost information transparently for cost analysis and for future operation and maintenance management of the project. The use of LCC methodology for transmission line projects helps in promotion and application of new technologies, environmental conservation, and infrastructure management, improving overall level of engineering, transmission network security and reliability. It also improves the economic efficiency of the investment by maximizing the returns over the entire life cycle [3]. The evaluation process aims at analyzing the following categories

2.1 Project

Transmission lines are designed to transfer power as economically as possible while meeting the safety, security and reliability requirements. Transmission line projects are to be executed in compliance with the environmental conditions and local regulations prevailing in the region where the lines are to be constructed. The factors significantly influencing the design, construction and operation of these lines are right of way (RoW), weather conditions, conductor material and configuration, insulator design, tower geometry and designs, foundations and environmental considerations [4]. LCC method provides various costs occurring in different phases of the project and helps in quantitative assessment of the costs effectively over a range of available technical solutions [5].

2.2 Economics

The construction and operating costs of a transmission line are spread over a long time frame and the life cycle costs are subjected to macro-economic and social factors. Investment, project life cycle, inflation, discount rate, interest rate, escalation etc. are the important macro economic factors which affect the project life cycle cost. Computation of various economic factors over the useful life of the project is necessary for performing LCC analysis. However, keeping in view the complexity of economics, economic indicators using existing data of similar projects can be used for qualitative and quantitative analysis. The typical costs involved in a transmission line project for performing LCC analysis are construction costs, operation and maintenance costs and cost of energy losses. A sensitivity analysis can also be performed after LCC analysis by varying some key parameters individually to analyze their effect on life cycle costs. This information will be helpful in improving the LCC management process, performance and effectiveness [6].

2.3 NPV analysis

The application of LCC to evaluate the cost of transmission line involves some macro-economic factors which depend on the country's economy and changes from time to time. Net present value (NPV) analysis is a widely accepted form for LCC evaluation which helps in analyzing alternatives for capital cost estimation. NPV can be defined as the present value of cash flows. The analysis is conducted for a pre-determined time span and discounted to the present cash flows with a discount rate. NPV can be calculated by,

$$NPV = \sum_{n=1}^{t} \frac{CF_n}{(1+\mathrm{i})^n} \tag{1}$$

Where n is the operating lifetime, i is the discount rate and CF_n is the cash flow in the n^{th} year. The uncertainties associated with predicting changes in future interest and inflation rates should be taken care in applying NPV analysis for LCC studies. NPV uses the concept of time value of money which states that value of money at present and future is not the same [7]. The present and future values of money can be calculated by the formulae given in Eqs. (2) and (3) respectively

$$PV = FV(1+i)^{-n} \tag{2}$$

$$FV = PV(1+i)^{n} \tag{3}$$

Where, PV is the present value of money, FV is the future value of money, i is the discount rate and n is estimated life of the project. The value $(1+i)^{-n}$ and $(1+i)^{n}$ are referred as present value factor (F_{PV}) and future value factors (F_{FV}) respectively.

3. Modelling Uncertainty using Interval Mathematics

Uncertainty is a major concern for electric utilities in planning and decision making. Modelling of uncertainty in system planning was presented by probabilistic distribution and "unknown but bounded" approaches by Burke et al [8]. Probabilistic approach considers probability distributions to be assumed for all the uncertainties. Uniform distribution is preferred for this approach as no particular distribution is well known and all values are assumed to be uniformly probable between given limits. Uniform distribution is also known as rectangular distribution due to its shape. Confidence intervals can be defined based on a known distribution and also, the means by which confidence intervals vary with transformations.

In "Unknown but bounded" approach, upper and lower limits on the uncertainties are assumed without a probability structure. Interval mathematics provides a tool for the practical implementation and extension of the unknown but bounded concept. As there are no probability distributions, the computation of confidence intervals is not possible. The unknown but bounded concept does not directly address sensitivity analysis. In this approach, sensitivity analysis can be performed by assigning interval bounds to any or all of the input parameters and the effects on the final interval result can be analyzed. The method was based on performing simulations frequently for a range of input variables. Simulation results are integrated into functions that yield nonlinear relationships between input and output variables. These functions are used to evaluate the effects of uncertainties and sensitivities of particular decisions. This form of sensitivity analysis is local sensitivity analysis.

Interval mathematics concept helps in avoiding this process by directly involving all the possible parameter variations from the beginning of the analysis and their effect on the solution at every stage of the process can be analyzed. This type of sensitivity approach is global sensitivity analysis [9]. The uncertainties connected with utility economic analysis can be effectively analyzed, if 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 through the analysis. The final outcome, which is also in interval form, consist all possible solutions due to the variations in input parameters. The set of axioms providing rules for basic interval arithmetic operations are as follows [10, 11].

If [a, b] and [c, d] are two interval numbers subjected to the condition $a \leq b$ and $c \leq d$ then,

$$[a, b] + [c, d] = [a + c, b + d]$$
$$[a, b] - [c, d] = [a - d, b - c]$$
$$[a, b] * [c, d] = [\min(a*c, a*d, b*c, b*d), \max(a*c, a*d, b*c, b*d)]$$
$$[a, b] / [c, d] = [a, b] * [1/d, 1/c],\ 0 \neq [c, d]$$
$$\begin{aligned} [a, b]^n &= [a^n, b^n] \text{ if } a > 0 \text{ or n is odd} \\ &= [b^n, a^n] \text{ if } b < 0 \text{ and n is even} \\ &= [0, \max(a^n, b^n)] \text{ if } a < 0 < b \text{ and n is even} \end{aligned}$$

The disadvantage of using interval mathematics is the algebraic structure which has the probability of producing large bounds in the resultant solution. These bounds depend on the calculation procedures and the input data. Precautions should be taken to keep the resultant solution interval width to a minimum. Significant studies were performed in the past using interval mathematics for modelling uncertainties in electric power utilities [12-13]. Transmission line analysis using interval mathematics for inductance calculation purpose was presented in the literature [14]. Modelling and optimization of power flows in electric power transmission and distribution networks using interval analysis was described by earlier researchers [15-19]. Application of uncertainty analysis for various applications in distribution systems such as compensation studies, feeder sizing and loss reduction were discussed in the literature [20-23]. Reliability analysis of transmission and distribution systems to evaluate uncertainty using interval mathematics was presented by earlier researchers [24-25]. From the previous research, it is evident that significant work has been carried out in applying interval mathematics to various areas in power systems for analysis, but very few literatures is available on economic analysis aspects.

4. Transmission Line LCC Model

The transmission line LCC model helps in accessing the total cost of ownership of the project from the beginning to the end of its operational life covering various stages like design, construction, operation and maintenance, and repair of the line [7]. Each transmission line project is unique and depends on the geography, regulations and local conditions. The factors which influence the life cycle costs also vary from project to project. The typical transmission line life cycle cost model incorporating various stages is given by Eq. (4)

$$C_{LC} = C_{CI} + C_{OM} + C_{EL} \tag{4}$$

where, C_{LC} is life cycle cost, C_{CI} is capital investment cost, C_{OM} is operation and maintenance cost and C_{EL} is cost due to energy loss.

4.1 Capital costs

The capital investment (C_{CI}) for a new transmission line consists of cost of structures, conductors, civil works, engineering, administration and management. The factors influencing the costs are RoW, local regulations, land rights and issues, construction material and labour cost escalations etc. Out of these, RoW and land rights are highly variable and site specific. Based on the data collected from the utilities the various cost components of the lines which make up the capital investment are summarized in Table 1. All costs are expressed in INR/km (1 US$= 63 INR). The capital investment cost for constructing the lines can be assigned to one or more years before the line

Table 1. Capital costs

Costs↓ / Voltage →	132 kV	220 kV	400 kV
OHTL			
Site work	155128	535210	915294
Towers and foundations	1249964	3856246	6462529
Conductor & Hardware	533627	1261048	1988470
Earthwire & Hardware	30548	164409	298270
Accessories	175642	684361	1193082
Construction	208643	692556	1176470
Sales tax	94142	287753	481364
Project management	253007	792750	1332494
UGTL			
Site work	3102540	3723048	4343556
Ducts	5999822	7199786	8399750
Cable & Hardware	6403524	8324581	10245638
Compensating equipment	366576	439891	513206
Accessories	878205	1053846	1229487
Construction	417286	500743	584200
Sales tax	686718	849675	1012633
Project management	1888474	2266168	2643863

is energized [26]. In this study, it is assumed that all the capital costs occur in the construction starting year. RoW costs are not included in capital investment. The cost assumptions used in this paper for calculation purposes do not refer to any specific project and are merely rough approximations, which helps in demonstrating the methodology.

4.2 Operation & maintenance costs

O&M costs (C_{OM}) are estimated as a percentage of the total capital investment. O&M of the line is essential to supply power to the consumers reliably and economically and is generally a preventive measure [27]. The O&M expenses include charges of personnel for operating and controlling the line according to schedule, personnel deployed for inspection of the line as part of routine maintenance activity, labour cost for tree removal on RoW, general repairs and replacement of damaged items due to adverse climate conditions, live line maintenance activities, testing of cable joints, verifying soil conditions, online monitoring and other necessary activities to keep the line in proper operating condition. The factors which impact the O&M costs are age of the line, weather conditions and length of the line. In the present study, the O&M costs are assumed as 1.5% and 0.15% of C_{CI} for OHTL and UGTL respectively. The Present Value (PV) of the annual O&M costs is given by

$$PV\ of\ C_{OM} = \frac{(1+i)^n - 1}{i(1+i)^n} C_{OM} \tag{5}$$

4.3 Energy loss costs

The cost of energy losses (C_{EL}) reflects to the cost of resistive electrical energy loss occurring in a line during operation. Some of the important factors which influence the losses in the line are line length, conductor parameters, loading of the line, loss factor, load growth and voltage level. The PV of the annual cost of energy loss is given by

$$PV\ of\ C_L^n = \frac{(1+i)^n - 1}{i(1+i)^n} C_L^n \tag{6}$$

The initial cost of losses is computed according to the formula given in Eq. (7)

$$C_{IL} = 3 \times I^2 \times R \times C_{IE} \times L_f \tag{7}$$

where, C_{IL} is the initial cost of losses, I is the peak load current in amperes, R is the resistance of the conductor in Ω/km, C_{IE} is the incremental cost of energy in INR/kWh and L_f is the loss factor. The cost of losses for any year during the useful life can be calculated using Eq. (8)

$$C_L^n = C_{IL} \times C_{EE} \times L_g \tag{8}$$

where, C_L^n is the cost of losses for any year ‘n’, C_{IL} is the initial cost of losses, C_{EE} is the energy cost escalation and L_g is the load growth.

5. Economic Analysis

5.1 LCC analysis

In this section, LCC analysis using NPV method has been carried out for 132 kV, 220 kV and 400 kV transmission lines. The lines considered are single circuit overhead transmission lines (OHTL), constructed with steel lattice structures employing Aluminium Conductor Steel Reinforced (ACSR) conductors and underground transmission line (UGTL) employing Cross Linked Poly Ethylene (XLPE) cables. The useful life of the lines is considered to be 35 years as it is consistent with the practice by most of the transmission utilities. The calculations performed are classified into three broad categories namely, base case, uncertainties case and breakeven analysis. The following necessary assumptions made in the analysis which reflect the current conditions in the transmission scenario of the country [28].

Economic data assumptions:
Capital recovery factor – 13%
O&M escalation factor – 4%
Load growth – 3%
Energy cost escalation – 1.5%
Discount rate – 8%
Incremental energy cost – 0.3 INR/kWh
Loss factor – 0.4
Depreciation – 5.7%

Overhead line data:

Voltage level, kV – 132, 220, 400

ACSR Conductor, mm – 30/7, 54/7, 54/7

Resistance, Ω/km – 0.14, 0.06885, 0.25595

Line current, A – 260, 420, 720

Underground cable data:

Voltage level, kV – 132, 220, 400

XLPE Cable, mm2 – 185, 400, 1000

Material – Al, Al, Cu

Resistance, Ω/km – 0.164, 0.0778, 0.0176

Line current, A – 289, 420, 671

5.1.1 Base case

Base case deals with the life cycle cost calculations using NPV analysis without uncertainties involved in the parameters. NPV analysis is carried out for the lines under consideration and the final life cycle costs are estimated. The calculations for a 400 kV OHTL based on NPV analysis is shown in Table 2. From Table 2, it is observed that the cumulative present worth of a 400 kV transmission line is INR 31316248 per km. Similar analysis is performed for other lines based on the collected data and the cumulative present worth of the lines over their useful life is summarized in Table 3. The variation of cumulative present worth of OHTL and UGTL with respect to useful life is shown in Fig. 1 and Fig. 2.

Table 2. NPV analysis of 400 kV OHTL

Year	Present value factor	Capital costs	Energy loss costs	Operation & maintenance costs	Deprecia-tion	Present value	Net present value
1	0.93	1666886	45640	192479	435955	2340960	2340960
2	0.86	1543413	45418	184780	403662	2177273	4518233
3	0.79	1429086	45116	177389	373761	2025351	6543584
4	0.74	1323228	44738	170293	346075	1884334	8427918
5	0.68	1225211	44291	163481	320440	1753423	10181341
6	0.63	1134455	43780	156942	296704	1631880	11813221
7	0.58	1050421	43211	150664	274725	1519022	13332243
8	0.54	972612	42589	144638	254375	1414215	14746458
9	0.50	900567	41920	138852	235533	1316871	16063329
10	0.46	833858	41207	133298	218086	1226450	17289779
11	0.43	772091	40457	127966	201931	1142446	18432224
12	0.40	714899	39674	122848	186974	1064394	19496618
13	0.37	661943	38861	117934	173124	991862	20488480
14	0.34	612911	38024	113216	160300	924451	21412931
15	0.32	567510	37166	108688	148426	861789	22274720
16	0.29	525472	36291	104340	137431	803534	23078254
17	0.27	486548	35402	100167	127251	749367	23827621
18	0.25	450508	34502	96160	117825	698995	24526616
19	0.23	417137	33595	92314	109097	652143	25178759
20	0.21	386238	32684	88621	101016	608559	25787318
21	0.20	357627	31771	85076	93533	568008	26355325
22	0.18	331136	30858	81673	86605	530273	26885598
23	0.17	306608	29949	78406	80190	495153	27380751
24	0.16	283896	29044	75270	74250	462460	27843211
25	0.15	262867	28146	72259	68750	432022	28275232
26	0.14	243395	27256	69369	63657	403677	28678910
27	0.13	225366	26377	66594	58942	377279	29056188
28	0.12	208672	25509	63930	54576	352687	29408875
29	0.11	193215	24653	61373	50533	329774	29738650
30	0.10	178903	23812	58918	46790	308423	30047072
31	0.09	165651	22985	56561	43324	288521	30335593
32	0.09	153380	22174	54299	40115	269968	30605561
33	0.08	142019	21379	52127	37143	252668	30858230
34	0.07	131499	20602	50042	34392	236534	31094764
35	0.07	121758	19841	48040	31844	221484	31316248

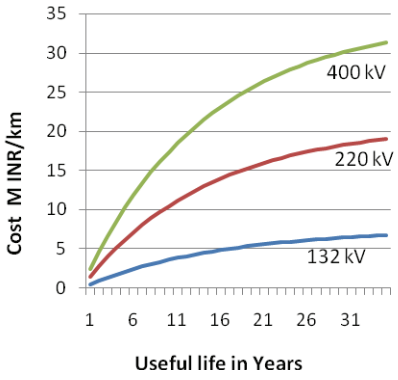

Fig. 1. Results for OHTL

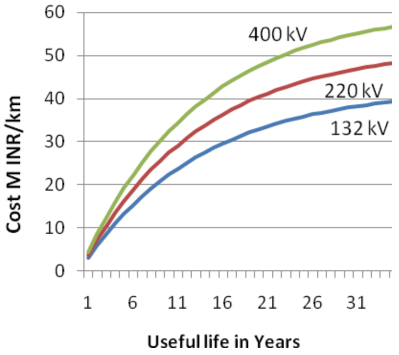

Fig. 2. Results for UGTL

From Table 3, Fig. 1 and Fig. 2, it is observed that the life cycle cost of 220 kV OHTL is approximately 65% higher than a 132 kV OHTL providing nearly 2.5 times more power carrying capacity and the life cycle cost of a 400 kV OHTL is 56% and 85% higher, providing 3.5 and 8.5 times more power carrying capacity as compared to 220 kV and 132 kV OHTL respectively. It is also observed that the life cycle costs of underground lines are much higher compared to overhead lines and this is mainly due to high capital costs in case of underground lines. The life cycle cost of 220 kV UGTL is nearly 19% more than a 132 kV UGTL and can carry 2.5 times more power. The life cycle cost of a 400 kV UGTL is 14% and 31% higher, providing 3 and 7 times more power carrying capacity compared to 220 kV and 132 kV UGTL respectively. Overall, the life cycle costs of UGTL are two to six times more than OHTL.

5.1.2 Uncertainties case

In this section, uncertainties are introduced in the input economic parameters and used for calculating life cycle costs in the form of intervals. These intervals consist of a

Table 3. Present worth of costs

Voltage Level (kV)	Present Worth INR/km					
	Base Case		Uncertainties Case			
	OHTL	UGTL	OHTL		UGTL	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
132	6650669	39379625	5945141	7781742	37475262	41593903
220	18996176	48323753	17677889	20896690	46114135	51046963
400	31316248	56790660	29402220	33957287	54532447	59241018

Table 4. Data for breakeven analysis

Voltage Level (kV)	Width (m)	C_{TL} (M INR/km)	Base Case	Uncertainties Case	
			Overall Cost (M INR / km)	Overall Cost Lower Bound (M INR / km)	Overall Cost Upper Bound (M INR / km)
OHTL					
132	27	0.027 CL	6.6506+0.027 CL	5.9451+0.027 CL	7.7817+0.027 CL
220	35	0.035 CL	18.9961+0.035 CL	17.6778+0.035 CL	20.8966+0.035 CL
400	52	0.052 CL	31.3162+0.052 CL	29.4022+0.052 CL	33.9572+0.052 CL
UGTL					
132	3	0.003 CL	39.3796+0.003 CL	37.4752+0.003 CL	41.5939+0.003 CL
220	4	0.004 CL	48.3237+0.004 CL	46.1141+0.004 CL	51.0469+0.004 CL
400	8	0.003 CL	56.7906+0.008 CL	54.5324+0.008 CL	59.2410+0.008 CL

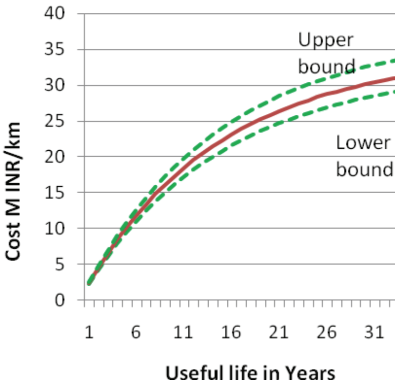

Fig. 3. Variation of NPV within bounds with useful life for 400 kV OHTL.

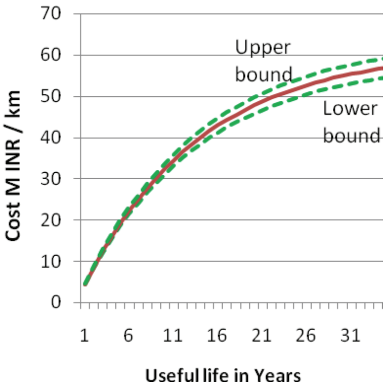

Fig. 4. Variation of NPV within bounds with useful life for 400 kV UGTL.

range of real numbers for each parameter. The interval range can be computed by assuming a deviation of ±0.5 from the base value for capital recovery factor and ±0.25 for O&M escalation factor, load growth, energy cost escalation and discount rates. NPV analysis was carried out using mathematical analysis package "PTC Mathcad Prime 3" for the entire range of transmission lines and the interval bounds of the cumulative present worth are summarized in Table 3. The software package allows direct implementation of interval mathematics according to a set of user defined formulae developed for NPV calculations. Fig. 3 and Fig. 4 illustrate the variation of life cycle costs within the lower and upper bounds with respect to useful life for 400 kV OHTL and UGTL respectively. Similar graphs can be obtained for other transmission lines under study. From the results summarized in Table 3 the minimum and maximum deviation for cumulative present worth with respect to base case is computed and found to be −10.6% to +17% for OHTL and −4.8% to +5.6% for UGTL.

5.2 Break even analysis

Break even analysis helps to determine the breakeven cost for the capital investment made for a specific project. It is defined as the cost at which the investment for OHTL and UGTL becomes equal. A forward breakeven analysis procedure cannot be adopted for comparison of OHTL and UGTL as the difference in capital cost is huge and increases exponentially with respect to useful life for both types of the lines. Alternatively, it can be shown that breakeven point can be determined by considering the cost of land as reference used for construction of these lines. The total cost of land can be computed by the following Eq. (9)

$$C_{TL} = A_T \times CL \quad INR \qquad (9)$$

where, C_{TL} is the total cost of land in INR, A_T is the total area in m^2 for the required RoW and CL is the per unit land cost in INR/m^2. The value of per unit land cost is dependent on the local real estate market conditions and thus, is highly dynamic in nature.

The total area per kilometre for the required RoW width W, can be computed by multiplying the RoW width W with a unitary kilometre length of corridor, and can be expressed by Eq. (10)

$$A_T = W \times 10^3 \text{m}^2 / \text{km} \tag{10}$$

The total cost of land per kilometre of required RoW width can then be expressed by Eqs. (11) and (12)

$$C_{TL} = W \times 10^3 \times CL \quad INR / \text{km} \tag{11}$$

or

$$C_{TL} = W \times 10^{-3} \times CL \quad M\ INR / \text{km} \tag{12}$$

Table 4 presents the data regarding required RoW widths for the transmission lines under consideration and overall investment including cost of land as a function of per unit land cost for base case and uncertainties case. Breakeven analysis of 400 kV transmission lines for the base case and uncertainties case is illustrated in Fig. 5 and Fig. 6 respectively. Similar analysis is performed for other lines based on the collected data and the results are summarized in Table 5.

The breakeven costs signify the point of indifference in economy. The breakeven range in the uncertainties case is less well defined due to uncertainties in market conditions, indicating its sensitivity to modest variations in market parameters.

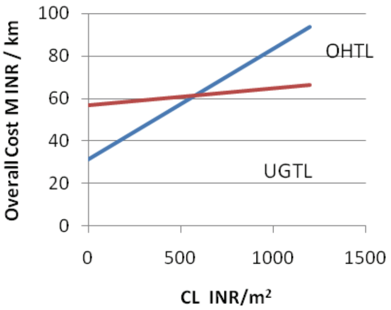

Fig. 5. Overall Cost per km as function of CL for 400 kV lines

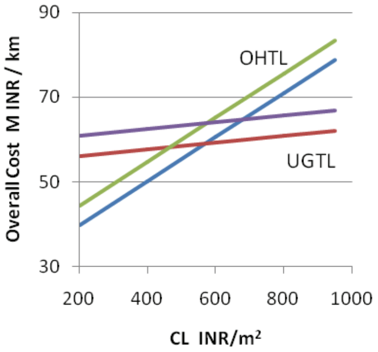

Fig. 6. Range of Overall Cost per km as function of CL for 400 kV lines

Table 5. Results of Breakeven analysis

Voltage Level (kV)	Breakeven Cost (INR/m^2)		
	Base Case	Uncertainties case	
		Lower Bound	Upper Bound
132	1200	1250	1450
220	900	820	1070
400	550	450	650

6. Conclusion

In this study, the significance and applicability of life cycle costing method to transmission lines has been presented in detail. The methodology is implemented on 132 kV, 200 kV and 400 kV overhead and underground transmission lines using NPV analysis and the present worth of the lines is determined. The transmission line cost components and the various factors which affect these costs are discussed. Based on the LCC, a comparative analysis is performed for entire range of OHTL and UGTL and the results are summarized. Energy loss cost calculations and operation and maintenance costs play a major role in influencing the total life cycle cost of the line especially at higher voltage levels and also signify considerable scope for losses reduction and improvement in maintenance strategies. Life cycle costing analysis can be considered as a useful tool for considering changes in macro-economic conditions posed by regulatory bodies on transmission line projects.

Further, interval mathematics technique is applied to the entire range of transmission lines under consideration for evaluating the life cycle costs. It includes uncertainty in the input parameters considered for LCC evaluation throughout the analysis and the output which is in the form of interval ranges is presented. Breakeven analysis is performed considering overall cost as a function of per unit land cost for OHTL and UGTL to determine the point of indifference in economy. The major advantage of this method is that sensitivity calculations are performed along with LCC analysis and do not depend on other methods of analysis.

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