Estimation and Analysis of Costs for Electrical Power Transmission Lines in Iraqi Projects

Wadhah A. Hatem¹, Kadhim R. Erzaij²
¹Baquba Technical Institute, Middle Technical University, Baghdad, Iraq
²College of Engineering, University of Baghdad, Baghdad, Iraq
Email: kadhim1969@yahoo.com, wadhah1970wadhah@gmail.com,

Abstract: With the increased demand for energy and lack of organised strategies in the generation sector, the challenges in this sector in Iraq still negatively affect macro-economic aspects. It is necessary to support the infrastructure of the electrical industry to cover any rising energy demands and the required related transfer process to reliably meet consumer demands. In this paper, the cost of energy-line transfer elements was considered with the aim to optimise the cost of capital. As the majority of economic energy studies have found, power transmission lines that use project management methodologies and scientific predictions for cost achieved reasonable financial savings in capital costs. Improving the process of designing and planning electrical power transmission lines is a complex issue due to diverse factors affecting the established costs. The primary goal of this study is to prepare a cost model of electrical Iraqi projects, including the local required factors related to the implementation costs based on the intensive review of the design areas of power transmission lines and the challenges of erecting and operating these lines. The possible steps and computation model are established to overcome the calculation challenges, where procedures are suitable to the terrain and the local requirements for economic transportation lines.

1. Introduction

Transmission lines in the energy sector play a vital role in efficient and stable energy delivery of power in the transmission network. One of the most important reasons for not benefiting from electric power generation is the delay in establishing power transmission lines. Accordingly, transportation lines must be planned and implemented simultaneously with the generation sector, which ensures the rational use of the substantial required capital. The aim is to provide transportation lines with minimal capital to gain the greatest possible economic efficiency.

Most electricity forecasting refers to the expected global increase in demand based on the assumption of an annual growth rate of 2.4%. In developing countries, this rate is likely to increase to over 4% annually, globally increasing the demand for electric power to an estimated 43% by 2030 [1]. The increase in energy demand requires considerable financial capital to develop energy infrastructure. To keep pace with the growth in energy demand, the amount of capital investment in the developing energy infrastructure is estimated at $11 trillion globally and $5 trillion for developing countries. The average annual investment rate is expected to increase from $450 billion to $630 billion [2].

The design of the power transmission line depends on the identification and appropriate selection of data and parameters because these are very complex aspects. These parameters consist of complex interactions that directly affect the total cost of the transmission-line system. This paper aims to
address issues related to optimal economic planning for establishing power transmission lines with a detailed review of all aspects related to planning, design, modelling, and economic analysis.

2. Literature Review

The following table comprises the most relevant studies on cost estimating, design, transportation losses, and so on.

Table 1. Previous studies of transportation lines

| Authors          | Contributions                                                                                                                                                                                                 |
|------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Adam et al. [3]  | Discussed the features of design and construction of overhead lines above 132 kV, envisaging the importance of load and strength assessment using statistical means to define the reliability of the system. Important aspects are discussed in detail concerning transmission-line construction via loadings, conductor properties, insulators, insulation levels, tower structures, tower foundations, construction methods depending on terrain, and problems encountered during the design and construction stages. |
| Orawski [4]      | Presented design considerations with various design parameters and construction aspects of overhead transmission-line engineering. The need to calculate the present-day worth of different solutions that consider the cost of the losses and capital invested was emphasised. The conclusions from the study indicate that, according to the CIGRE WG22 report, future changes in design would be based on static and dynamic conductor ratings, meteorological data for system operation, effective use of right of way (ROW), government policies, assessment of the condition and expectancy of aged lines, component diagnostics, and diagnostic techniques. |
| Peyrot et al. [5]| Developed an integrated computerised model, providing three-dimensional access to the entire line and its ROW. The model provides a complete illustration of the topography under the line, cables, insulators, and structures in all spans. The objective of the integrated and interactive environment for the given topographic data in electronic form is to enable the designer to perform the complete line engineering and acquire all the requisite documents for its construction. |
| Picard et al. [6]| Developed a knowledge-based system consisting of a record of tower configurations and allied parameters to assess transmission-line costs for various alternating current (AC) voltage levels subjected to environmental constraints. |
| Ilić et al. [7]  | Presented a survey article defining and evaluating transmission capacity, providing economic incentives and the means of increasing the incentives in the changing electric power industry. |
| Sabharwal [8]    | Proposed a procedure incorporating transmission and distribution costs in the electricity supply cost to the rural load centres, which includes the capacity and operating costs of generation, transmission, and distribution. |
| Fenton & Sutherland [9] | Presented a methodology for the optimum design of transmission lines, considering the uncertainties in both environmental loads and structural resistance to achieve acceptable reliability at a reasonable cost. |
| Hanson et al. [10]| Presented relative advantages and disadvantages as well as cost comparisons for upgrading existing transmission lines. The case study of four transmission-line projects that were upgraded with an increase in the number of conductors, conductor size, and voltage level with modifications in the tower structure showed that the lines were upgraded successfully with satisfactory performance. |
at 50% to 60% of the cost of the new transmission lines.

Mooney [11] Developed a technique to economically justify transmission-line transposition. The technique is based on cost comparisons of the transposition towers and line losses for a transposed and un-transposed line over the useful life of the line. Procedures for computing three-phase line losses under unbalanced conditions and the net present value of the line losses were presented.

3. Methodology
In this paper, a mathematical model is presented to calculate the capital costs for electrical projects concerning the features of power transmission lines and transportation infrastructure. This was done by calculating the specific costs of transportation equipment and expected costs of the right of passage to the land. Then, the costs were calculated and adjusted to determine the costs of developing the model according to the terrain of the different regions with adjustments to factors that include the type of terrain and other factors.

3.1. Transmission-Line Construction
Transmission-line construction is an arduous and complex task that requires considerable effort in the development of a coordinated plan to implement power transmission lines, which include many individual tower sites at a time. The methodology of constructing the line differs from other construction methodologies, but the changes from site to site according to the terrain and conditions surrounding it should also be considered. Effective planning and management of electrical projects are critical in developing and achieving the required quality and in maximising the economic benefits with the environmental requirements, which reduces environmental damage. Figure 1 shows the flowchart of the transmission-line construction steps.

The establishment of energy transmission lines requires considerable capital because several factors are involved in establishing these lines, including technical, geographical, organisational, and other factors. In addition to the degree of reliability and security stability, which have a key role in increasing the total cost, additional factors include the right of way (ROW) and cost of the land, which varies from one transmission line to another according to the type of land, its owners, its geographical location, the market, labour and material costs, and economic standards. This variation leads to a high level of uncertainty in estimating the cost of capital required to construct the transmission lines [12].

Usually, power transmission lines take a long time to establish due to many regulatory issues, including environmental impact studies, the participation of the project owner, and the justification and treatment of various other factors that include licences and approvals that are required by institutions and regulatory agencies to implement transmission-line construction. The restrictions imposed by the regulatory agencies differ from country to country according to the regional geographic and environmental standards, but most of these countries deal with common advantages in obtaining these approvals and licences [13,14].

1. Feasibility studies, approval and statutory clearances
2. Surveying, trail-pit marking, profiling
3. Building access roads, clearing, and right of way
4. Pit making, excavation, construction of foundations
5. Stub setting, tower erection
6. Stringing of conductor and earth wire
7. Residue work, inspection and commissioning of lines

Figure 1. Transmission-line construction steps.
3.2. Capital Costs of the Electrical Transmission Line

Generally, the capital cost of electrical transmission consists of three main elements. Moreover, each element can be branched to sub-elements as illustrated in Figure 2.

**Figure 2.** Elements of capital costs of the electrical transmission line.

3.2.1. Cost indices

Many cost indicators reflect the annual price and cost developments for electrical projects. The consumer price index (CPI) is the most important cost indicator for electric utilities. In the United
In the United States, the Handy-Whitman Electric Utility Index includes transportation lines. The importance of the Handy-Whitman Electric Utility Index is due to the following factors:

- It accurately reflects the electrical industry and all its components (generation, transmission, transfer stations, etc.).
- It has been in use since 1912 to allow the extraction of indicators of annual cost increases.
- The primary authorities accredited in the electricity industry, the most important of which are the US Department of Energy and the Electricity Regulatory Authority, have approved this index.
- The index includes increases in the prices of labour, materials, land, equipment, and so on.

Regarding the Handy-Whitman indicator for transmission lines, the evolution of increases in the costs of transmission-line projects during the period from 1968 to 2012 is shown in Figure 3. In addition, Table 2 and Figures 4, 5, and 6 explain several aspects of the Iraqi electrical transmission lines.

![Figure 3. Increases in costs of transmission-line projects over time by index.](image)

In Figure 4, the Handy-Whitman Index for overhead line connectors displays the information for antenna connectors and towers.

![Figure 4. Handy-Whitman Index for overhead line connectors.](image)
Figure 5. Number of transmission lines in Iraq.

Figure 6. Total line length in Iraq.

Table 2. Transmission lines in Iraq

| Year | Voltage (KV) | Number of transmission lines | Total line length (KM) |
|------|--------------|------------------------------|------------------------|
| 2010 | 132          | 388                          | 12608                  |
|      | 400          | 48                           | 4353                   |
| 2011 | 132          | 391                          | 12073                  |
|      | 400          | 48                           | 4356                   |
| 2012 | 132          | 418                          | 12870                  |
|      | 400          | 48                           | 4458                   |
| 2013 | 132          | 502                          | 13358                  |
|      | 400          | 53                           | 5716                   |
| 2014 | 132          | 451                          | 13295                  |
|      | 400          | 59                           | 4593                   |
| 2015 | 132          | 461                          | 13187                  |
|      | 400          | 63                           | 4945                   |
| 2016 | 132          | 923                          | 23088                  |
|      | 400          | 70                           | 6271                   |
| 2017 | 132          | 495                          | 11882                  |
|      | 400          | 61                           | 5505                   |
| 2018 | 132          | 425                          | 11567                  |
|      | 400          | 65                           | 4306                   |
3.3 First: Materials and costs

3.3.1. Tower costs

The cost of towers is related to the price of steel and the specification type of tower formation. It also depends on tower height. Table 3 and Figure 7 show the material costs and prices for the supply of towers for the voltage of 132 kV (for double circuit) and 400 kV (for single circuit; prices are without installation).

Table 3. Tower costs for 132 kV and 400 kV

| No | Voltage (kV) | Tower weight (kg) | Tower type | Price in Iraq $/unit | Price in USD/unit |
|----|--------------|-------------------|------------|----------------------|------------------|
| 1  | 132          | 6402              | Suspension tower 2S2 +3 | 9285          | 27700            |
|    |              | 14400             | Tension strength 2T2 +3 | 21655         | 83100            |
|    |              | 16777             | Terminal tower 2E2 +3  | 25230         | 48474            |
|    |              | 9220              | Suspension tower XA (+6+0) | 14580     | 31850            |
| 3  | 400          | 19154             | Tension strength XC (+6+0) | 28685       | 95550            |
|    |              | 24447             | Terminal tower XD (+6+0) | 38030         | 55736            |

Figure 7. Costs of materials for towers.

3.3.2. Other item costs

The following figures display prices for supplies, which include connectors, accessories, and other add-ons (e.g. earth, insulators, floor cables, and spacers) for a voltage of 132 kV for a double circuit and 400 kV for a single circuit (prices are without installation). Conductor costs depend on the price of aluminium because most of the connections are made of aluminium. Figure 8 shows the difference in the price of conductors in Iraq and the United States by voltage type.

Figure 9 illustrates the difference in the price of the land in Iraq and in the US according to voltage type. The price of land depends on the price of wire and the voltage type because the type of wire differs according to the voltage type. The voltage type with 132 kV contains only OPGW, whereas the voltage of 400 kV contains OPGW in addition to working.

Insulator prices vary according to voltage and tower type (i.e., suspended or tension) and the load strength of the cable. Figure 10 shows the difference in the price of the insulators in Iraq and the US according to the type of voltage and load strength.
Figure 8. Conductor costs.

Figure 9. Ground costs.

Figure 10. Insulator costs.
3.4. Second: Installation Costs

3.4.1. Tower installation costs

Tower installation costs generally constitute 15% to 30% of the total cost. The cost of installing 1 kg of a tower is estimated at one dollar as illustrated in Table 4.

Table 4. Installing towers costs

| No. | Voltage (KV) | Tower weight (kg) | Tower type | Assembling | Installation | Price in Iraq $/unit | Price in USD/u nit |
|-----|--------------|------------------|------------|------------|---------------|---------------------|-------------------|
| 1   | 132          | 6402             | Suspension tower 2S2 +3 | 1458       | 1042          | 2500                | 3661              |
|     |              | 14400            | Tension strength 2T2 +3 | 3125       | 1458          | 4583                | 10983             |
|     |              | 16777            | Terminal tower 2E2 +3   | 3333       | 1667          | 5000                | 6408              |
|     |              | 26230            | 2SP2                  | 4167       | 2500          | 6667                | NA                |
|     |              | 15132            | 2R2                   | 3333       | 2500          | 5833                | NA                |
|     |              | 14189            | 2K2                   | 2083       | 1250          | 3333                | NA                |
| 2   | 400          | 9220             | Suspension towerXA (+6+0) | 2083       | 1042          | 3125                | 4550              |
|     |              | 16006            | XB (+0,+6)            | 2917       | 1250          | 4167                | NA                |
|     |              |                  | XB (+12,+18)          | 5000       | 6667          | 11667               | NA                |
|     |              |                  | XB (+24,+30,+36)      | 6667       | 10000         | 16667               | NA                |
|     |              | 19154            | Tension strength XC (+6+0) | 3333       | 1459          | 4792                | 13650             |
|     |              |                  | Terminal tower XD (+6+0) | 3750       | 1667          | 5417                | 7962              |
|     |              | 24447            | XE                    | 3750       | 1667          | 5417                | NA                |
|     |              | 20100            |                       |            |               |                     |                   |

3.4.2. Other item installation (conductor stringing costs)

The conductor cost is directly related to its size. The per-kilometre conductor cost in terms of the design variables can be computed by obtaining the relation between the conductor weight and diameter [15] [16]. Table 5 and Figure 11 show conductor stringing costs.

Table 5. Conductor stringing costs

| Conductor stringing                                                                 | Voltage | Cost $/km |
|-------------------------------------------------------------------------------------|---------|-----------|
| Acts as a connecting line using phase wires with OPGW & DORKING including transferring materials from the project site to work site, laying wires, hanging pulleys and insulators, installing all attachments, returning rollers and wire scraps to the project site. This includes the price of machinery, tools, workers, and space. | 132 kV  | 6667      |
|                                                                                     | 400 kV  | 5000      |

Figure 11. Conductor stringing cost.
3.5. Third: Other Costs

Civil engineering costs include preparing the ground for the line and foundations. Table 6 and Figures 12, 13, 14, 15, and 16 explain many aspects of the electrical project costs, such as the excavation costs, painting by bitumen and filling costs, reinforcement costs, template work costs, and concrete costs.

Table 6. Other installation costs

| Tower type | Excavation with ground-water withdrawal $/m³ | Painting by bitumen, filling, and compaction with tower site levelling $/m³ | Template work $/tower | Reinforcement $/tons | Concrete $/m³ |
|------------|---------------------------------------------|-------------------------------------------------|----------------------|---------------------|--------------|
| 132 kV     |                                             |                                                 |                      |                     |              |
| 2S2        | 4.2                                         | 4.6                                             | 437.5                | 1042                | 139          |
| 2T2        | 4.2                                         | 1.5                                             | 604                  | 1083                | 140          |
| 2E2        | 4.2                                         | 1.3                                             | 625                  | 1083                | 140          |
| 2SP2       | 4.2                                         | 1.3                                             | 667                  | 1083                | 140          |
| 2R2        | 4.2                                         | 2.7                                             | 646                  | 1083                | 140          |
| 2K2        | 2.2                                         | 1.8                                             | 562.5                | 1083                | 139          |
| XA         | 4.2                                         | 6.4                                             | 437.5                | 1042                | 139          |
| XB         | 4.2                                         | 3.5                                             | 521                  | 1083                | 139          |
| XB (high)  | 4.2                                         | 2.4                                             | 792                  | 1083                | 141          |
| 400 kV     |                                             |                                                 |                      |                     |              |
| XB         | 4.2                                         | 2.4                                             | 792                  | 1083                | 141          |
| XC         | 4.2                                         | 2.6                                             | 646                  | 1083                | 141          |
| XD         | 4.2                                         | 1.9                                             | 667                  | 1083                | 141          |
| XE         | 4.2                                         | 3.8                                             | 646                  | 1083                | 138          |
| Tower in the US | 6 | 2 | 60 | 2800 | 182 |

Figure 12. Excavation cost.

Figure 13. Painting by bitumen and filling costs.
3.6. Mathematical Model Method

These models were developed based on studies using technical, financial, and economic information about transmission lines created with the aim of developing a model to link the basic costs (per unit of length) and other elements of capital costs. Line costs were studied and analysed for varying voltages, single or dual circuits, and AC or DC. Multiple options are analysed regarding tower type, connectors, and line lengths. Furthermore, the construction of new connection (or re-conductor) lines was considered. The study and analysis of different line locations were also considered.

The following criteria were considered from the capital cost perspective:

1. Voltage class
   - AC - 132 kV and 400 kV (single and double circuit)
2. Line characteristics
   - Conductor type
   - Pole structure
   - Length of line
3. New construction or re-conductor
4. Terrain type
5. Location

The foundations for deriving the mathematical model for two lines with the coefficients for different variables [17] are shown below.

### 3.6.1. First: Baseline transmission cost

#### Table 7. Available costs approved for lines

| Line no. | Line description     | Supply cost $/km | Implementation cost $/km | Total basic capital costs $/km |
|----------|----------------------|------------------|--------------------------|--------------------------------|
| L1       | 132 KV double circuit| 94755            | 141878                   | 236633                         |
| L2       | 400 KV single circuit| 94755            | 141878                   | 236633                         |

### 3.6.2. Second: Developing parameters for conductors

Based on the basic costs in fourth, transactions were entered to consider the changing conductors and changing line costs as shown in Table 8.

#### Table 8. Changing line costs

| Connector Type | L1 | L2 |
|----------------|----|----|
| ACSR           | 1  | 1  |
| ACSS           | 1.08 | 1.08 |

### 3.6.3. Third: Tower structure transactions

Cost-change coefficients were entered when the tower structure changed, as shown in Table 9.

#### Table 9. Cost-change coefficients

| Connector Type | L1 | L2 |
|----------------|----|----|
| Lattice        | 0.9 | 0.9 |
| Tubular Steel  | 1  | 1  |

### 3.6.4. Fourth: Coefficients of the change in total line length

Whenever the line length increases, the average cost per kilometre is reduced (Table 10).

#### Table 10. Coefficients of the total length change

| Length          | L1 | L2 |
|-----------------|----|----|
| Longer than 15 km | 1  | 1  |
| 3–15 km         | 1.2 | 1.2 |
| Less than 3 km  | 1.5 | 1.5 |

### 3.6.5. Fifth: Line development transactions instead of creating a new line (re-conductor)

The line developing concept is to replace the connectors of the existing old line instead of creating a new line to increase the capacity (this means not changing towers and insulators). The methods, assumptions, and costs of developing an existing and operating line are shown in Table 11.
Table 11. Costs of developing existing and operating lines

| No. | Conductor voltage | Conductor no. | Costs |
|-----|-------------------|---------------|-------|
| 1   | 132 KV            | + 2 conductors per phase | + conductor cost is (55%) of total capital cost |
| 2   | 400KV             | + 3 conductors per phase | + conductor cost is (55%) of total capital cost |

3.6.6. Sixth: Terrain coefficients
The least expensive areas in terms of development costs are flat areas, and the most expensive are critical areas (forested). Table 12 shows the coefficients of the adjusted cost factor for five regions in Iraq.

Table 12. Coefficients of adjusted cost factor for regions

| No. | Area Type         | Zone 1 | Zone 2 |
|-----|-------------------|--------|--------|
| 1   | Desert            | 1      | 1      |
| 2   | Flat              | 1      | 1      |
| 3   | Farmland          | 1.1    | 1.1    |
| 4   | Forested          | 1.15   | 1.15   |
| 5   | Gradient hills, rolling hills | 1.25 | 1.25 |
| 6   | Wetlands          | 1.25   | 1.25   |

3.6.7. Seven: Right of way (ROW) costs
This aspect covers land acquisition costs in which the ROW line will be built if purchased. The cost of land may reach 4% of the total line cost, which includes implant compensation and agricultural crops and trees. It is necessary to derive transactions for the right of traffic (line forbidden), technical information about the width of the land for each effort (the required area can be calculated), and the purchase price of the land (dollars per square metre) in the line area, and the path information is required.

3.6.8. Eighth: Mathematical model
Considering the information and data shown above, the mathematical model developed for use in Iraq is as follows:

\[
TLC = [(BTC) \times (CC) \times (SC) \times (ReC) \times (TC) \times Number of kilometres] + [ROWC \times Number of kilometres],
\]

\[
ROWC = (ROW \frac{acre}{kilometre}) \times (land cost/acre),
\]

where

- \( TLC \) = Transmission-line cost
- \( BTC \) = Base transmission cost
- \( CC \) = Conductor coefficient
- \( SC \) = Structure coefficient
- \( ReC \) = Re-conductor coefficient
- \( TC \) = Terrain coefficient
- \( ROWC \) = Right of way cost
Table 13. Summary of cost estimates for each kilometre and the coefficients according to variables

| Cost category     | 132 kV double | 400 kV single |
|-------------------|---------------|--------------|
| Base cost $/km    | 236633        | 236633       |
| **Conductors**    |               |              |
| ACSR              | 1             | 1            |
| ACSS              | 1.08          | 1.08         |
| **Complications** |               |              |
| Lattice tubular steel | 1          | 1            |
| **Line length**   |               |              |
| Longer than 15 km | 1             | 1            |
| 3–15 km           | 1.2           | 1.2          |
| Less than 3 km    | 1.5           | 1.5          |
| **Line lifetime** |               |              |
| New               | 1             | 1            |
| Line development Re-conductor | 0.55      | 0.55        |
| **Project area terrain** |         |              |
| Desert            | 1             | 1            |
| Flat              | 1             | 1            |
| Farmland          | 1.1           | 1.1          |
| Heavy farmland    | 1.15          | 1.15         |
| Slope hills 2%-8% | 1.15          | 1.15         |
| Mountains over 8% slope | 1.25      | 1.25        |
| Wetlands          | 1.25          | 1.25         |

4. Conclusion
The results reflect the adequacy and success of applying the estimation producer supported by the equations to determine and predict the estimated costs of constructing several electrical transmission lines. The conclusion is summarised as follows:

- The mathematical model assists decision-makers in determining the costs of establishing electric power transmission lines and implementing future projects.
- Research and development in transmission projects promotes the economic development of Iraq’s electric power and energy industry.

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