Research on the Technical Reliability of the Overhead Transmission Lines Based on the Life Cycle Technology

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Abstract. Based on the actual operating conditions of overhead transmission line, the safety and reliability of overhead transmission line is researched using the life cycle technology. Taking a 220kV overhead transmission line as an example, various parameters at different life stages are measured and analyzed, and finally the technical scheme most conducive to ensuring safe and reliable operation of the overhead transmission line is obtained. The research results provide a reference for the power company to ensure the safety of the power system operation and stimulate the innovation of power technology.

Keywords: overhead transmission line, life cycle technology, various parameters.

1. Introduction

The power industry is an important basic industry and public utility that supports the development of the national economy and society. It plays an important role in promoting the economic development of our country and ensuring the basic national economy and people's livelihood. In order to ensure the sustained rapid development of the economy of our country and society, the construction of the power grid must also meet the strong needs of the sustained economic development of our country and the continuous improvement of people's living standards. The scale of assets and the number of equipment have increased significantly. These equipments are large in number, diverse in variety, and huge in capital, occupying a very high proportion of the total assets of power companies. At present, the life-cycle management mode adopted by the power grid production technology transformation project fully adapts to the current development situation of the power grid. Many problems such as short service life of power equipment, low use efficiency, large investment in technology transformation, and high operation and maintenance costs have been gradually improved and implemented. Asset life-cycle management is not only a realistic need for grid companies to improve the quality and efficiency of grid assets, but also an important strategic measure for grid companies to achieve sustainable development.

This paper takes the overhead transmission line technical renovation project as an example, and calculates the full life cycle cost of the overhead transmission line before and after the technical transformation through the front-to-back comparison method.
2. Life Cycle Cost Technology

2.1. Overview of Life Cycle Cost Technology
Life cycle cost (LCC) refers to the entire cost of a system or equipment to purchase and maintain its normal operation during the entire life cycle, including the sum of direct, indirect and other related costs required for the design, research and development, development, manufacturing, use, maintenance and warranty of the equipment during its life cycle until its retirement.

The meaning of life-cycle cost management of power systems: It is a management mode that makes the equipment or system's owning cost the lowest on the basis of meeting the reliability requirements and includes the management of the entire life cycle of the design, selection, procurement, operation, maintenance, update and retirement of equipment or systems.

Asset life cycle management is essentially the application of systems engineering theory to asset management. Asset life-cycle management takes assets as the research object. Starting from the overall goal of the system, it takes overall planning into consideration for the planning, design, procurement, construction, operation, maintenance, technical transformation, and retirement of assets.

2.2. Life Cycle Cost Model
The life cycle cost model is as follows.
\[ \text{LCC}\text{=}\text{CI}\text{+CO}\text{+CM}\text{+CF}\text{+CD} \]

\( \text{CI} \) is the initial input cost, which refers to the sum of all costs and expenses before the power project is put into production, including equipment purchase costs, construction engineering costs, installation engineering costs, demolition engineering costs, and other costs.

\( \text{CO} \) is the operating cost, including equipment energy consumption and usual inspection costs, periodic comprehensive maintenance, operating labor costs and other operating costs.

\( \text{CM} \) is the cost of inspection and maintenance, which mainly includes two parts: routine power failure inspection and live inspection.

\( \text{CF} \) is the cost of failure loss, which refers to the cost of loss due to power failure caused by failures and emergency defects. The cost of failure loss is divided into two parts, namely the cost of emergency defect power loss and the cost of failure power failure.

\( \text{CD} \) is the cost of decommissioning disposal, including demolition costs, transportation costs, warehousing, tendering and other related costs.

The time period of the initial cost of the overhead transmission line renovation project and the future cost are different. All the initial costs of the project occur in the base year of the research cycle. Future costs may occur at any time between the base year and the end of the research cycle. The operation time and equipment material life cycle of the two schemes before and after the transformation are different. The annual value calculation is a balance between the initial cost and the future cost, which is applicable to the comparison of different life cycle schemes. To accurately calculate the project cost of two different life cycles before and after renovation, this paper analyzes the expenses that have occurred or will be incurred into the expenses of each year in the research period, and the net annual value method (NAV) is used to calculate the results.

3. Application examples of the life cycle management technology of the overhead transmission line reconstruction project

3.1. Project overview
A 220kV overhead transmission line is the regional backbone power grid, which shoulders important power supply tasks and supplies power to users in factories and communities in the area. The line was put into operation in December 1993 and has been in operation for 25 years. Due to the long operating time, the original cement poles, iron parts, pull wires, and ground wires were severely corroded, and some cement poles were severely weathered and had cracks, which had poor ability to withstand natural disasters.
Due to the upgrading of some towers in the early stage, the vertical distance between the two sides of the existing tower became smaller, the wind deviation of the insulator did not meet the electrical distance of the tower body, and the safety distance to the crossing and crossing objects was insufficient in some sections. The low pole call height makes the operation safety of the line channel poor, and makes the line channel operating environment very bad.

After preliminary technical evaluation and analysis, the length of the section to be reconstructed on this line is 4.174km, with 10 bases for straight towers and 2 bases for corner towers, for a total of 12 bases. The circuit adopts a single loop design. The conductor cross-section is 300 mm² and adopts 2 × LGJ-300 / 40 double split steel core aluminum stranded wire. 2 ground wires are erected on the ground wire bracket, and the OPGW is 24 cores, and the shunt ground wire uses GJ- 50 steel strands.

3.2. The calculation of life cycle cost

Based on the technical description of the overhead transmission line, the life cycle cost model is used to analyze the life cycle cost of the line reconstruction project.

The decision of this project mainly revolves around two schemes: "Continue operation of the original line" and "Implementation of line transformation on the original channel". In this section, the full life cycle cost of these two schemes is calculated based on the actual operating data of a 220kV overhead transmission line. The original line is considered based on the remaining service life of 5 years, and the new line after reconstruction is considered according to the 30-year life cycle. It is calculated from the start of the project. When the service life is reached, the residual value is considered at 5% of its material cost. The project is calculated using the annual value method. At full life cycle cost, the discount rate is calculated at 7%.

(1) The initial input cost (CI)

For projects or equipment with different life cycles, the annual value comparison method should be used when analyzing and evaluating the life cycle of the asset, that is, converting the life cycle cost of the asset into an annual value. The annual value calculation formula is as follows:

\[
AV = \frac{P \times i(1+i)^n}{(1+i)^n - 1} \quad (1)
\]

In (1), P represents the initial input cost, i represents the interest rate, and n represents the number of interest-bearing periods.

If the original line is not modified, it can be considered for five years. After the modification, the life of the line is 30 years. Based on this, the initial input cost before and after the line transformation is shown in Table 1.

Table 1. Comparison of initial input cost before and after overhead transmission line transformation (annual value)

| Evaluation index                  | Cost/yuan |
|-----------------------------------|-----------|
| Before transformation: original line | 0         |
| After transformation: new line    | 75358     |

(2) The operating cost (CO)

According to the basic constituent elements and operating characteristics of overhead transmission line, combined with the work content that occurs during the actual operation of overhead transmission line, the operating cost is divided into five tasks: line inspection, periodic comprehensive maintenance, ground excavation, pole inspection, and ground resistance test. The costs before and after the transformation are measured separately. The specific calculations are as follows:

line inspection. Each person patrols 5 km per day, and the labor fee is 59 yuan per day. The normal line patrols once a month for the whole line.

2) periodic comprehensive maintenance. The main work content is the inspection of the climbing tower, the bolt tightening of the tower, the sporadic supplementary bolts, the ladder, the foot nail line,
the anti-vibration hammer inspection and the bolt tightening, the earth excavation, the grounding device inspection, the adjustment of the position, the site cleaning and restoration. Grounding resistance measurement of tower, grounding body connected to high-altitude down-conductor, disassembly, material and tool transportation, etc. After the new line is put into operation, periodic comprehensive maintenance is carried out every 5 years, and the periodic comprehensive maintenance cost is estimated based on the integrated unit price of 6,966 yuan / km.

3) ground excavation. The grounding excavation is determined according to the measurement results of the grounding resistance. If necessary, sampling and excavation will be carried out. Excavation will not be considered in the first 10 years, and then 20% of the annual sampling will be considered for excavation. The 220 kV line is calculated based on the excavation length of 12 m per pole and 24 m per tower, and the cost of ground excavation is estimated at a comprehensive unit price of 23 yuan / m.

4) pole inspection. In the first year, the whole pole will be checked once, and in the next 12 years, the pole will not be considered. After that, one third of the samples will be checked every year. Boarding inspection cost.

5) ground resistance test. The whole line is measured once in the first year, and then the periodic test is carried out every 5 years, and 20% of each sample is taken for measurement. The cost of the ground resistance test is estimated according to the integrated unit price of 53 yuan / base.

The operating cost measured according to the above parameters is shown in Table 2 below.

Table 2. Comparison of operating cost before and after overhead transmission line transformation (annual value)

| Evaluation index                      | Cost/yuan |
|---------------------------------------|-----------|
|                                       | Before transformation: original line | After transformation: new line |
| remaining service life                 | 5         | 30         |
| line inspection                        | 591       | 591       |
| periodic comprehensive maintenance    | 6978      | 5815      |
| ground excavation                      | 15898     | 10598     |
| pole inspection                        | 1552      | 1025      |
| ground resistance test                 | 127       | 144       |
| the total operating cost               | 25146     | 18173     |

(3) The cost of inspection and maintenance (CM)

According to the basic components of the overhead transmission line and the actual work content during the daily operation and maintenance, the operating cost is divided into replacement of grounding device, replacement of anti-vibration hammer, replacement of identification plate, replacement of anti-bird device, replacement of insulator, repair of damaged guide/ground wire, adjust the guide and ground line sag, and replacing, shifting and raising of towers. The costs before and after the transformation are measured separately. The specific calculations are as follows:

replacement of grounding device. The line will be destroyed due to external forces such as construction quality or farmland cultivation. In the early stage of commissioning of the new line, 1 base pole tower needs to be maintained for the grounding device every 5 years. Later, as the operating time increases, the grounding body corrosion increases, and the grounding device for 2 base pole towers needs to be replaced every 2 years. Estimate the replacement cost of the grounding device based on the comprehensive unit price of 3730 yuan per base.

2) replacement of anti-vibration hammer. As the years of operation of the line increase, the anti-vibration hammers gradually appear defects such as corrosion, slippage, and drop. The number of defective anti-vibration hammers increases stepwise with time. Count the number of replacement shock hammers every five years. Estimate the replacement cost of anti-vibration hammer according to the comprehensive unit price of 160 yuan per piece.
3) replacement of identification plate. With the increase of the operation period, the signs of line poles, forbidden climbing, and hues will gradually be damaged and lost, and the number of signs that need to be replaced will increase with time. Estimate the replacement cost of signage according to the comprehensive unit price of 200 yuan per block.

4) replacement of anti-bird device. With the increase of operating years, the bird-preventing device gradually appears damaged and falls, and the number of devices to be replaced increases. Estimate the replacement cost of bird-proof devices according to the comprehensive unit price of 150 yuan per piece.

5) replacement of insulator. According to the experience of overhead transmission line operation, the synthetic insulators are replaced as a whole in 8 to 10 years. During the period, 1 to 3 replacements are performed every 3 years due to lightning strikes, flashovers, etc., and the replacement cost of the insulators is estimated based on the comprehensive unit price of 2421 yuan per piece.

6) repair of damaged guide/ground wire. Due to external force damage and vibration, the loss of the ground wire needs to be repaired. It is considered to occur once every 10 years. The probability of stock breakage increases when it runs to 30 years. According to the occurrence of 2 times, the ground damage repair cost is calculated according to the comprehensive unit price of 2610 yuan per place.

7) adjust the guide and ground line sag. As the running time of the line increases, after considering 20 years of operation, the four guides and ground sags need to be adjusted, and the adjustment cost of the guide and ground sags is estimated based on the comprehensive unit price of 6257 yuan per place.

8) replacing, shifting and raising of towers. As the running time of the line increases, the operating environment of the line deteriorates, and the tower may have serious defects such as tilt, crossover change, and insufficient distance. The tower needs to be replaced, displaced, and upgraded. It is not considered 10 years before the new line is put into operation, and one base every 5 years is considered from 11 to 25 years, and one base is considered to be renovated every five years in the last five years. The cost of pole replacement, displacement, and reconstruction is estimated according to the comprehensive unit price of 350,000 yuan per base.

The cost of inspection and maintenance measured according to the above parameters is shown in Table 3 below.

Table 3. Comparison of the cost of inspection and maintenance before and after overhead transmission line transformation (annual value)

| Evaluation index                      | Cost/yuan | Before transformation: original line | After transformation: new line |
|---------------------------------------|-----------|--------------------------------------|-------------------------------|
| remaining service life                |           | 5                                    | 30                            |
| replacement of grounding device       |           | 3730                                 | 2735                          |
| replacement of anti-vibration hammer  |           | 5760                                 | 3360                          |
| replacement of identification plate   |           | 720                                  | 420                           |
| replacement of anti-bird device       |           | 540                                  | 315                           |
| replacement of insulator              |           | 43094                                | 22031                         |
| repair of damaged guide/ground wire   |           | 2506                                 | 870                           |
| adjust the guide and ground line sag  |           | 2503                                 | 834                           |
| replacing, shifting and raising of towers |       | 350000                                | 93333                         |
| the total cost of inspection and maintenance |       | 408853                                | 123898                        |

(4) The cost of failure loss(CF)

The cost of failure loss of the overhead transmission line is measured from four aspects: damaged wire, damaged ground wire, damaged insulator, and inverted tower (bending) failure. The costs before and after the transformation are measured separately. The specific calculations are as follows:
1) damaged wire. According to the statistics of O & M data of overhead transmission line, the single-kilometer fault rate of line conductors in this area is 0.02% in 1-10 years, 0.06% in 10-20 years, 0.18% in 21-25 years, and 0.59% in 26-30 years. The main failures include lightning strikes, shedding caused by high winds, loose strands, crane trips, line dropouts, line aging, corrosion and fracture, etc. The cost of damaged conductors is estimated at a comprehensive unit price of 25,600 yuan per place (path length 350m).

2) damaged ground wire. According to the statistics of the operation and maintenance data of overhead transmission line, the failure rate of single-km damaged ground lines in this area is 0.02% in 1-10 years, 0.06% in 10-20 years, 0.18% in 21-25 years, and 0.59% in 26-30 years. The main failures include lightning strikes, shedding caused by strong winds, loose strands, crane tripping, line disconnection, and line aging, rust and fracture, etc. The cost of ground damage is estimated based on the integrated unit price of 5467 yuan per place (path length 350m).

3) damaged insulator. According to the statistics of the operation and maintenance data of overhead transmission line, the failure rate of single-kilometer insulators in this area is 0.09% for 1-10 years, 0.27% for 10-20 years, 0.8% for 21-25 years, 2.68% for 26-30 years. The cost of damaged insulator is estimated based on the integrated unit price of 2950 yuan per bunch.

4) inverted tower (bending) failure. According to the statistics of O & M data of overhead transmission line, the single-kilometer failure rate of inverted tower (bending) in this area is 1 to 10 years 0.0006%, 10 to 20 years 0.0017%, 21 to 25 years 0.0051%, 26 to 30 years 0.017%. The actual situation determines the repair plan, which is mainly divided into "newly built tower foundation and tower body" and "use the original foundation to replace the tower body". The cost is estimated based on the integrated unit price of 42000 yuan per base.

The cost of failure loss measured according to the above parameters is shown in Table 2-4 below.

**Table 4.** Comparison of the cost of failure loss before and after overhead transmission line transformation (annual value)

| Evaluation index            | Cost/yuan |
|-----------------------------|-----------|
|                            | Before transformation: original line | After transformation: new line |
| remaining service life      | 5         | 30         |
| damaged wire                | 360       | 87         |
| damaged ground wire         | 77        | 18         |
| damaged insulator           | 1328      | 316        |
| inverted tower (bending) failure | 171    | 41         |
| the total cost of failure loss | 1936     | 462        |

(5) The cost of decommissioning disposal (CD)

The life-cycle decommissioning disposal cost is based on the equipment used in the project reaching the decommissioning period or the equipment that is seriously damaged and needs to be replaced in advance. The residual value is reused or directly scrapped. The residual value of the reusable equipment is the remaining life / design life * Equipment purchase fee, the residual value of scrapped equipment is generally calculated based on 5% of the original equipment value.

The life-cycle decommissioning disposal cost of this overhead transmission line is shown in Table 4 below.

**Table 5.** Comparison of the cost of decommissioning disposal before and after overhead transmission line transformation (annual value)

| Evaluation index            | Cost/yuan |
|-----------------------------|-----------|
|                            | Before transformation: original line | After transformation: new line |
| the cost of decommissioning disposal | -614     | -7456    |
(6) Life cycle cost

According to the calculation process and results of the above five cost items, the full life cycle cost before and after the project transformation can be obtained. The specific costs are shown in Table 6.

**Table 6. Comparison of the life cycle cost before and after overhead transmission line transformation (annual value)**

| Evaluation index | Before transformation: original line | After transformation: new line |
|------------------|-------------------------------------|-------------------------------|
| CI               | 0                                   | 75358                         |
| CO               | 25146                               | 18173                         |
| CM               | 408853                              | 123898                        |
| CF               | 1936                                | 462                           |
| CD               | -614                                | -7456                         |
| LCC              | 435321                              | 210435                        |

It can be seen from the table that the annual value of the full life cycle cost before the transformation of the line is 435,321 yuan and the annual value of the full life cycle cost after the transformation is 210435 yuan. After renovation, the life cycle cost is lower than before renovation, the transformation effect is remarkable, and the overall benefit is better. At present, the line is at the end of its life, with high maintenance costs and frequent failures. In order to eliminate the hidden dangers of the operation safety of the line, improve the reliability of the line power supply and the safe and stable operation of the power grid, save the cost of daily operation and maintenance, and reduce the loss of faults, it is necessary to implement transformation.

4. Conclusion

This article applies the concept and method of life cycle cost management, specifically divides the cost according to the characteristics of overhead transmission line, and calculates the full life cycle cost of overhead transmission line before and after transformation, respectively, to provide support for the application of full life cycle theory to company resource management practices. The following conclusions were obtained:

(1) Although the cost of overhead transmission line transformation is high, operation and maintenance costs often occupy a greater proportion in the entire life cycle of overhead transmission line. Therefore, it is necessary to provide an economic basis for various decisions by establishing a full life cycle cost model for overhead transmission line.

(2) Overhead transmission line often have an economic life, that is, the service time when the cost annuity is the smallest, and the time conditions for the retirement or technical transformation decision of the overhead transmission line fully take into account.

(3) In practice, the technical transformation of overhead transmission line in power companies is divided into a variety of situations, and the contents of technical transformation are also different, so specific analysis needs to be made for specific contents.

(4) When the capital investment of the overhead transmission line technical transformation plan, the service time of the line before and after the technical transformation, or the content of the overhead transmission line technical transformation are different, the selection of the technical transformation plan of the overhead transmission line is different, and a specific analysis needs to be made for the specific situation.

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