Cost calculation method and application of GIS equipment in substation based on asset life cycle management theory

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ABSTRACT

With the continuous advancement of the construction of smart grids, new situations, new demands and new development models have put forward higher requirements for substations, which are important supporting nodes of the power grid. In this paper, the implementation of asset life cycle management in substation engineering projects is to conduct overall and entire process management of all stages and activities in the asset life cycle of substation engineering projects. Starting from the overall project, reflecting the requirements of the entire life cycle of the project, it not only includes the goals of the construction period, but also pays more attention to the operation phase of the project, and highlights the overall efficiency and benefits of project management. Life cycle cost theory can indeed achieve good effects such as reducing the life cycle cost of substation engineering and improving reliability.

Keywords: *Asset life cycle management, substation, maintenance cost.*

1. INTRODUCTION

Life cycle cost management (LCC) was originally a typical engineering economic evaluation method [7]. Asset life cycle management (LCAM) originated from life cycle cost management. The engineering planning and design stage determines the construction and operation of the project. Stage direction [13]. Power companies attach great importance to life cycle management, and formulate asset life cycle management strategies through asset management plans, such as British NG Company, New Zealand Ashburton Power Company, etc. Facing an increasingly complex business environment, world-renowned power transmission and distribution companies have introduced advanced asset management concepts and methods to achieve economical, safe and stable operation of power grid assets, while meeting the requirements of multiple stakeholders and promoting the sustainable and healthy development of the company. Many internationally renowned power companies such as British NG Company, French EDF Energy Company, and Singapore Power Company have introduced the concept of life cycle management, and have carried out a lot of fruitful work in this field.

Since the equipment works in different supply areas, its load and geographical environment have a greater impact on its operation status, and the uneven product quality provided by suppliers also has a greater impact on the operation and maintenance workload. The material cost, labor cost, safety cost and insurance compensation brought about by emergency repair are difficult to collect and apportion to each equipment one by one. It is necessary to verify the rationality and accuracy of the current LCC calculation method through long-term pilot projects.

Asset life cycle management is an internationally recognized advanced management concept, and its core is the optimal comprehensive benefit of safety, efficiency and cost. The company's power grid physical assets are large in scale, and it is urgent to use the concept and method of the whole life cycle to carry out power grid asset management and continuously improve operational efficiency. Asset life cycle management is a strong support for improving the quality and efficiency of the company's asset operation, the core content of building a modern equipment management system, and the only way to improve equipment quality. This paper preliminarily establishes the LCC scheme comparison

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and selection mechanism, clarifies the factors of equipment LCC cost collection, selects pilot projects, calculates and analyzes the LCC cost difference of different design schemes of the put into operation, formulates the LCC comparison and selection template of the power grid construction project design scheme, and increases the technical economy of equipment. Comparison and selection of dimensions such as life and operation and maintenance cost change analysis, to assist in the demonstration of the plan. At the same time, taking GIS equipment as the starting point, and at the same time, in order to reduce the influence of different dimension factors on the calculation results of the whole life cycle of the equipment, the typical data of substations with different general design schemes but the same construction effect are selected to study the influence of indoor and outdoor construction on GIS equipment. Based on the influence of its life cycle cost, the optimal construction conclusion is drawn, and then by further expanding the research on the dimensions of factors affecting the life cycle cost of equipment, a set of general calculation, design, comparison and selection of application schemes based on equipment LCC is determined.

2. METHODS AND THEORIES OF ASSET LIFE CYCLE COST MANAGEMENT

2.1 Definition of LCC management

Life cycle cost management is based on the long-term economic benefits of the equipment/system or project, and comprehensive consideration of the entire process of equipment/system or project planning, design, manufacturing, purchase, installation, operation, maintenance, transformation, update and scrap. A management concept and method that minimizes the life cycle cost under the premise of meeting performance/reliability [12].

LCC management is based on considering the entire life cycle of the asset and the loss caused by system or equipment failure. The final benefit can be summarized as a management method of financial cost and output [3]. Therefore, LCC management is the foundation and technical means of LCM. The related content concepts and calculation formulas of asset life cycle cost from a quantitative point of view provide clear quantitative comparison results for asset life cycle management and help it achieve the goal direction [5].

LCC can be expressed as (1):

$$LCC = CI + CO + CM + CF + CD \tag{1}$$

In the formula: LCC is the life cycle cost; CI is the investment cost; CO is the operating cost; CM is the maintenance cost; CF is the failure cost; CD is the decommissioning disposal cost. Failure cost CF is composed of direct failure cost and indirect failure cost. Direct failure cost is the direct economic loss caused by multiple failures of the system. It usually refers to the loss of power outage, which can be expressed by the cost of supply interruption (UEC).

The life cycle cost of the main wiring of the substation is shown in (2)(3)(4):

$$LCC = CI + K_1 \times (CO + CM + CF) + K_2 \times CD \tag{2}$$

$$K_1 = (1+r)^{-n} \tag{3}$$

$$K_2 = (1+r)^{-a} \tag{4}$$

K1 represents the present value conversion coefficient of the operating year, r represents the annual interest rate, n represents the year, and n changes from 0 to a, a represents the calculated life of a year, and K2 represents the present value conversion coefficient of the calculated life.

Where CI, CO, CM, CF are expressed as (4)(5)(6)(7):

$$CI = \sum_{i=1}^{M} f(s_i) + l \times c_l \tag{5}$$

In the formula, CI represents the cost of building a new substation, f(si) represents the initial investment cost of the i-th component of the substation, and M represents the total number of components in the substation. l indicates the total length of the transmission line, and indicates the project cost per unit length of the line, including purchase costs, installation and commissioning costs, etc.;

$$CO = \sum_{tr \in TR} (p_{tro} + \rho^2 p_{trk}) \tau_{\max} C_{price} \tag{5}$$

CO represents the operating cost of the substation, which mainly includes two parts, one is the cost of personnel inspections, and the other is the cost of equipment energy consumption. Since the labor costs of different substation main wiring schemes are not much different, this article is omitted and only considers the energy consumption of the transformer. Cost, ptro, ptrk, τmax , ρ represent the no-load loss rate, load loss rate, annual maximum loss hours and load rate of the tr-th transformer, and Cprice represents the current electricity price.

$$CM = \delta CI + UEC_{jw} \tag{6}$$

CM represents the maintenance cost of the main wiring of the substation, where δ is the maintenance cost conversion coefficient, and UECjw is the power outage loss caused by the maintenance cost. This article will further discuss overhaul and maintenance issues later;

$$CF = UEC_{sub} + UEC_{sys} \tag{7}$$

UECsys represents the power loss cost of other load nodes in addition to the system node where the substation is located, UECsub represents the power loss cost of the system node where the substation is located,

CD represents the cost of decommissioning disposal, which can be calculated by the following formula (8)(9)(10):

$$CD = C_{cl} - C_{cz} \tag{8}$$

$$C_{cz} = CI \times V_{cz} \tag{9}$$

$$C_{cl} = CI \times V_{cl} \tag{10}$$

Ccl is the decommissioning treatment fee, Ccz is the residual value at the time of decommissioning, vcz is the residual value conversion coefficient, and vcl is the scrap conversion coefficient. Because the residual value of the line is low when it is decommissioned, it can be offset against o'wequipment and environmental processing costs.

2.2 Calculation of maintenance cost for main wiring of substation

Inspection and maintenance can be simulated in two ways. The first method is to assume that inspection and maintenance are regarded as a random event. In the other method, inspection and maintenance are pre-arranged time [4]. Both methods have their own advantages and disadvantages. In order to reflect the unknown situation of the long-term planning of the system, this article adopts the first method.

The cost of overhaul and maintenance mainly includes two types, one is the cost of periodic disassembly and overhaul (overhaul), and the other is the cost of various types of periodic overhaul and maintenance (minor overhaul) [14]. The maintenance costs are detailed into material costs, labor costs, and other costs. In order to simplify this part of the calculation, this article adopts the method that most power supply companies currently determine the maintenance costs of power supply equipment based on the annual total cost plan and take the percentage of the initial investment. In addition, in addition to the above costs, the maintenance cost should also include the cost of power outage loss in the substation caused by the maintenance and the cost of social power outage. Therefore, the maintenance cost in this article includes various maintenance costs and power outage loss costs.

2.3 Calculation of Failure Cost in Asset Life Cycle Cost

The key to the influence of reliability on the LCC model is to consider the penalty cost under multiple failures of the system, that is, the cost of failure. In addition, the sum of operation and maintenance costs and failure costs after the construction of the substation is completed and put into operation will be greater than its initial investment [2]. Therefore, it is necessary to study and calculate the cost of failure in more detail, in order to take into account economy and reliability, and to ensure the scientificity and accuracy of the selection of the main wiring scheme of the substation. The cost of failure discussed in this article is mainly reflected in the loss of benefits of power companies and the losses to society caused by failures and blackouts. The following introduces and analyzes several methods of calculating the cost of failure: according to the lack of power, the lack of power, the duration of the lack of power and the frequency of the lack of power, as shown in formula (11).

$$UEC = \sum_{i=1}^{N} (K_w \times P_i + K_e \times E_i) \tag{11}$$

In the formula, Kw and Ke represent the unit power shortage and the coefficient of loss per unit power shortage, which are related to the size of industrial users. Pi and Ei represent the i-th power shortage and power shortage.

The electricity production ratio is the ratio of the gross national product of a certain period to the electric energy consumed in that period. It represents the national income that a unit of electric energy can create. From a monetary point of view, the loss caused by a power outage is described in the formula (12) Shown.

$$UEC = \sum_{C_i \neq 0} C_i \times p_i \times 8760 \times R \tag{12}$$

In the formula, R represents the ratio of electricity production, and the unit is yuan/kWh. EENS represents the expected value of insufficient power of the reliability index, which refers to the average value of power outages of power users caused by the power supply cannot meet the load demand. Ci represents the amount of load reduction. pi represents the probability of load reduction.

The estimated cost of outage based on insufficient expected value is shown in formula (13)

$$UEC = \sum_{C_i \neq 0} C_i \times p_i \times 8760 \times C_{price} \tag{13}$$

In the formula, Cprice represents the electricity price of the system.

Because the calculation of the failure cost is related to the country's power development, domestic power

demand, economic development in different regions, and relevant national laws and regulations, it is difficult to quantify it in detail [15]. In addition, the lack of necessary basic information also affects to calculate the cost of failure, in order to better reflect the impact of shortcomings and at the same time reflect the impact of reliability, this paper adopts the electricity production ratio method.

2.4 Cost trial

The initial cost is obtained from the original value of the equipment in the ERP system, and the annual initial cost is calculated using the double balance depreciation method, which is consistent with the financial calculation method.

The operation and maintenance cost is calculated by multiplying the standard operation quota (people, materials, machines) by the number of operations" to calculate the annual operation and maintenance cost of each equipment from 2015 to 2019.

The maintenance cost is calculated by multiplying the standard operation cost (manpower, material, machine) by the number of operations. The daily maintenance and test costs of each equipment from 2015 to 2019 are calculated. The ERP system is used to sort out the actual equipment types and quantities in the overhaul project. The overhaul cost is apportioned according to the original value of the equipment assets, and the overhaul cost of a single GIS equipment is collected.

The failure cost and the maintenance cost are apportioned and collected in the same way

The operating years of the selected sample substations in this paper are all over 40 years. Except for the data of operation and maintenance, maintenance frequency and other historical data, other historical data cannot be traced to the source. The company's overhaul operation and maintenance standard cost system revision results, using the standard operation quota multiplied by the operation frequency to collect the cost of each year. The results are shown in Table 1.

Table 1 Equivalent annual cost conversion table

Years	Cost	Years	Cost	Years	Cost	Years	Cost
T1	4.97	T11	10.73	T21	23.17	T31	50.02
T2	5.37	T12	11.59	T22	25.02	T32	54.03
T3	5.80	T13	12.52	T23	27.03	T33	58.35
T4	6.26	T14	13.52	T24	29.19	T34	63.02
T5	6.76	T15	14.60	T25	31.52	T35	68.06
T6	7.30	T16	15.77	T26	34.05	T36	73.50
T7	7.89	T17	17.03	T27	36.77	T37	79.38
T8	8.52	T18	18.39	T28	39.71	T38	85.73
T9	9.20	T19	19.87	T29	42.89	T39	92.59
T10	9.94	T20	21.45	T30	46.32	T40	100.00

The estimated operating cost this time is mainly composed of inspection cost and operating cost. By collecting samples of the frequency of routine inspections, comprehensive inspections, lights-out inspections, special inspections, professional inspections and various switching operations every year after the substation is put into operation, combined with Hubei. The revision results of the company's maintenance, operation and maintenance standard cost system collect the annual operating costs.

With the growth of the life cycle, the annual cost of maintenance, etc. of the two substations is on the rise. The annual cost of the failure of the two substations is on the rise. With the increase of the life cycle, the number of equipment failures increases, and the loss cost caused by the power failure also increases; secondly, the upward trend of outdoor substations is more obvious than that of indoor substations. The reason is that with the service life with the increase of, the probability of outdoor substation failure is more frequent. The full life cycle cost comparison is shown in Figure 1.

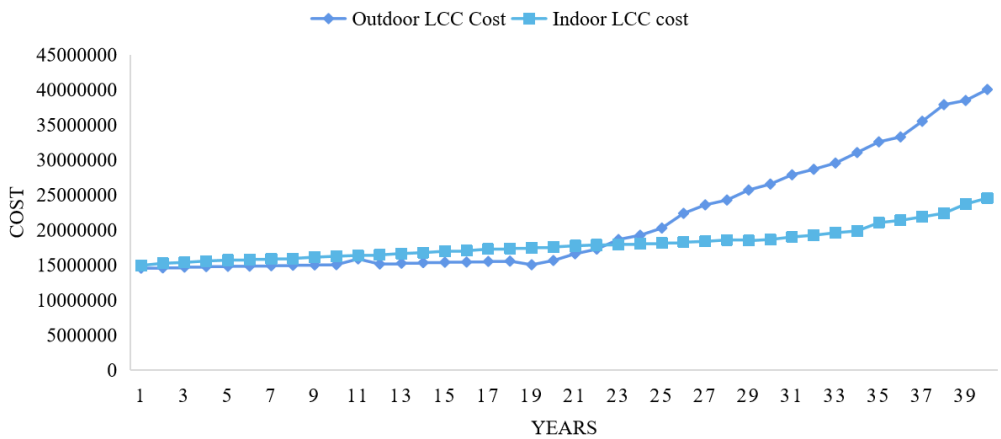

Figure 1 Comparison of full life cycle costs

According to Figure 1, it can be seen that the life cycle cost of the sample substation increases with the increase of the commissioning time. The annual cost of indoor substations has always been higher than that of outdoor substations. After about 20 years of operation, the annual cost of indoor substations has become lower than that of outdoor substations. This is because although the initial investment cost of indoors is high, the costs of operation, maintenance, and faults are lower than those of outdoor, and as the life cycle increases, the cost advantages of operation, maintenance, and faults are more obvious.

3. METHOD FOR SELECTING MAIN WIRING OF GIS EQUIPMENT IN SUBSTATION BASED ON LCC

3.1 Component reliability model of main wiring in substation

The components involved in the reliability assessment of the main wiring of the substation include transformers, circuit breakers, isolating switches, bus bars, etc. Transmission lines and transformers transmit power between the two end nodes of the element. If a fault occurs, the adjacent circuit breaker will operate, and the relevant circuit breaker needs to be disconnected during repair, which is defined as an extended fault. The isolation switch model is similar to the above components. Therefore, their reliability models can adopt a four-state model, including: normal operation state N, expanded fault state S, fault repair state R, and planned maintenance M state. Figure 2 is a four-state model diagram.

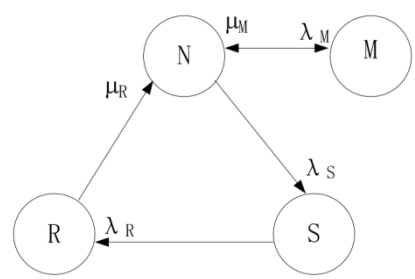

Figure2: Four-state model of transmission lines, transformers and isolating switches

Circuit breakers generally have 7 states [9], including normal state N, planned maintenance state M, forced maintenance state m, misoperation state f, grounding or insulation fault state i, refusal operation state st, and post-fault repair state r. By simplifying the circuit breaker model, introducing the concepts of repair state (R state), expanded fault state (S state), and F-type fault state, an equivalent five-state model is obtained, as shown in Figure 2. It is an extended fault. The isolation switch model is similar to the above components. Therefore, their reliability models can adopt a four-state model, including: normal operation state N, expanded fault state S, fault repair state R, and planned maintenance M state. Figure 3 is a four-state model diagram.

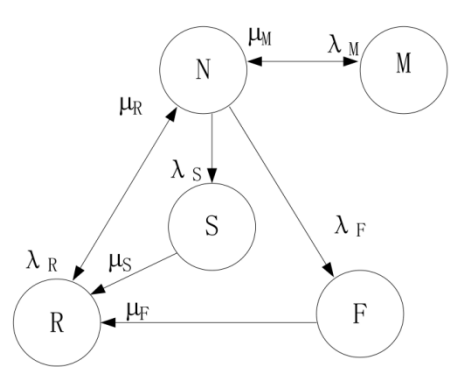

Figure 3: Five-state model

Suppose the probability of normal operation state, planned inspection state, repair state, expanded fault state

and relay protection refusal state are: PN, PM, PR, PS and PF respectively. λF is the relay protection rejection rate, μF is the relay protection rejection transfer rate.

The bus without switching operation can be in normal working state N, expanded fault state S and planned maintenance state M. The model can be shown in Figure4.

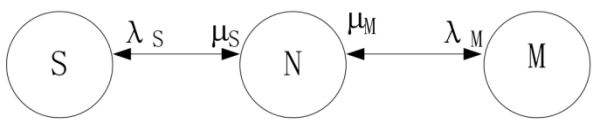

Figure 4: Three-state model of non-switching operation bus

This paper considers that the main wiring failure cost of the substation involves system failure states including forced outage, planned overhaul and forced outage, planned outage and partial failure outage, which belong to the independent outage model, and the affected outage belongs to the related outage model. Forced outages occur randomly; partial failure outages means that certain components can be derated when the system fails [1]. For example, when there are two main transformers in a substation, when one transformer is scheduled for maintenance or fault repair, the load required for the outgoing line can be transmitted from the other main transformer. According to relevant regulations, the other main transformer needs to transmit 70% of the total load, so it will cause a part of the load to be lost at the outlet end.

3.2 Component reliability model of main wiring in substation

At present, the literature on the selection of the main wiring of the substation either ignores the calculation of the failure cost, or considers only the calculation of the load loss of the substation after the component failure, without considering the constraints that must be met, such as the node voltage amplitude, The upper and lower limits of generator output and the settings to ensure that thermal power units reduce shutdowns, etc. [10], the load reduction of the substation will redistribute the power flow distribution of the power grid, which may cause the load reduction of other nodes. Therefore, the failure cost of the substation discussed in this article should not only consider the load loss of this node, but also the load reduction loss of the entire network. This involves the redistribution of the power flow of the entire network. This article establishes the objective function to minimize the load reduction of the entire network to calculate the impact on the entire network after the failure of the main wiring element of the substation. There are currently two methods for calculating the optimal power flow of the power grid, one is DC power flow, and the other is AC power flow. The following article discusses and analyzes the characteristics of the two methods.

In this paper, the nonlinear primal dual interior point algorithm is used to solve the above-mentioned AC optimal power flow model through MATLAB programming. A simple study and analysis of IEEE's 5-node system illustrates the impact of substation fault load reduction on other load nodes. The reference power is 100MW, as shown in Figure 5.

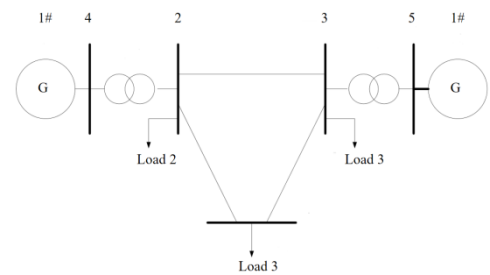

Figure 5: Non-linear 5-node system structure diagram

The simulation research and analysis of the non-linear 5-node system are carried out, and it is concluded that the load reduction of other nodes caused by the flow congestion must be considered [6]. Because the cost of maintenance and failure is of great significance in the cost of each stage, it has a direct impact on enterprises and users, and the indirect impact on society that is difficult to count. Therefore, this chapter analyzes the calculation methods of maintenance cost and failure cost in detail, and proposes A model with the minimum load reduction of the entire network as the objective function is established, and the AC optimal power flow model is solved by MATLAB programming using the non-linear primal-dual interior point algorithm.

4. CONCLUSIONS

Based on the whole life cycle cost management of assets, this paper starts from the whole life cycle of the system or equipment, considers the long-term benefits, seeks the optimal total cost and benefit, and realizes the organic combination and comprehensive optimization of the reliability and economy of power assets.) to analyze and compare the current reliability analysis methods. In order to realize the organic combination of reliability and economy, this paper adopts the method of risk assessment to calculate the reliability index, combines technical economics and quantitative economics, and comprehensively considers The probability of failure and the resulting loss, from the perspective of risk, deal with the safety analysis of the system, and provide technical and method support for the calculation of maintenance costs and power outage costs in failure costs [11].

The purpose of establishing the optimization model is to not only consider the cost of power outage in the substation, but also consider the power outage loss of other load nodes that may be caused by the outage of the substation due to factors such as line congestion, minimizing downtime of thermal power units and node

voltage limits; Life cycle cost management starts from the entire life cycle of the system or equipment, organically combines economy and reliability, and seeks the optimal management method of LCC, which can better meet the current power market requirements for equipment lean management [8].

Power grid construction is systematic and long-term. The costs incurred in the operation and maintenance stage account for a large proportion of the whole life cycle cost of the power grid system. The rationality of the construction plan directly affects the economy and reliability of the power system construction and operation stages. It is the most critical stage in project life cycle management. Therefore, on the basis of asset life cycle analysis, comprehensively consider the relationship between safety, cost, and efficiency, and establish a safety, cost, and efficiency evaluation model for the distribution network planning scheme. And the whole life cycle management evaluation index system has important practical significance. Relying on the development of life cycle management work, it is possible to obtain excellent asset quality and optimize operation and maintenance costs, so that the goal of the overall life cycle cost of power grid infrastructure projects can be reduced, and corporate assets can achieve higher operating efficiency. It can be predicted that the application of the whole life cycle management theory to the decision-making of infrastructure projects is the future development trend.

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