Research on Design Scheme Comparison of Power Grid Infrastructure Project based on Equipment LCC

Guanglei Huang[1,a*], Tao Wang[2,b], Shuyao Chen[1,c], Tian Mao[2,d], Jiangnan Li[1,e]

{l15897554402@163.com[a], w.t18@mail.scut.edu.cn[b], 1435200069@qq.com[c], tianmao7658@126.com[d], x18871136145@163.com[e]}

Shenzhen Power Supply Company China Southern Power Grid ,Shenzhen 518067, China[1]
Electric Power Research Institute China Southern Power Grid ,Guangzhou 510530, China[2]

Abstract. With the deepening of power system reform, there is a corresponding evolution in power grid equipment, as an important core management object of the enterprise, faces higher requirements for the refinement of cost accounting and the lean value management, that is, the degree of precise investment needs to be deepened. In this context, this paper examines the cost consumption of substation equipment, encompassing the entire lifespan from construction to retirement, with a focus on the equipment itself. so as to construct various indicators that can accurately and objectively reflect its life cycle cost. Finally, combined with the actual example, 110 kV outdoor aviation road substation and 110 kV indoor Gusaoshu substation are selected for example verification, additionally, the paper compares the disparities in each sub-index of the life cycle cost among various types of substations, and the effectiveness of the method is demonstrated.

Keywords: Substation; refinement; life cycle cost.

1 Introduction

As the electric power system reform advances, changes in power grid equipment become more pronounced [1-2], since January 1,2019, the power grid equipment, as an important core management object of the enterprise, is facing higher requirements for the refinement of cost accounting and value management [3-4]. Therefore, in order to ensure the economic benefits of power system planning and operation and achieve better economic benefits, power grid enterprises must continue to make breakthroughs and innovations in future work, and use more objective, effective and accurate measures to carry out the construction of power grid infrastructure and its maintenance and upgrading [5-6]. This requires that with the continuous increase of power supporting investment, the degree of precise investment needs to be deepened. In the project feasibility study and initial design stage, the best investment project review and decision-making should be made, and the preliminary work should be done in equipment selection and procurement.

At present, the evaluation method based on life cycle cost (LCC) [7-10] is widely used in the traditional planning scheme of power grid substation. Reference [11] constructed the corresponding substation LCC prediction model based on GA optimized least squares support vector machine, but the predicted results of the model are closely related to the setting of the

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parameters of the basic example, and have great prediction uncertainty. Reference [12] selected the significant features that can reflect the whole life cycle index of substation as the basis through neural network, and carried out multiple training to solve the problem of poor prediction accuracy and low objectivity. Based on LCC theory, References [13-15] derived a planning method for substation location and capacity considering the optimal comprehensive benefits. Based on the LCC theory, Reference [16] constructed a theoretical model of the outage cost of the distribution network. The operation cost model captures the combined impact of outage frequency, duration, and power on outage expenses. For the above research, the index value is often only obtained in the historical statistics of the operation process after the completion of the power grid infrastructure, and it is difficult to accurately predict in the power grid planning and construction stage, so the scheme is difficult to reflect the objectivity of the economy.

As the LCC modeling division becomes more and more refined, the amount of calculation increases, the manpower and material resources are huge, and the cost division will also be affected by human subjectivity [17-28], which reduces the objectivity of the LCC mathematical model [19-20]. Based on LCC theory, this paper constructs a more comprehensive and refined mathematical model of substation life cycle cost. The index construction of the model is no longer based on the future forecast data [21-22]. Therefore, this paper constructs a LCC model that can accurately and objectively estimate the substation, and then improves the practicability of LCC estimation. The cost management concept of the whole life cycle of the equipment serves the equipment selection, reduces the cost of later maintenance and replacement equipment, and provides an effective reference for the promotion of the power system reform and the precise investment of the power grid in the design and selection.

2 The establishment of asset life cycle management index evaluation system

According to the use of the invested funds [23-24], the equipment cost is categorized into initial investment, operation, maintenance, fault, and scrap costs [25]. Under the guidance of the whole life cycle concept, the comparison model of LCC equipment selection scheme is obtained.

2.1 Life cycle cost planning model

In this paper, the whole life cycle cost is used as the cost index, and the formula is:

$$C = C^{\mathrm{I}} + C^{\mathrm{O}} + C^{\mathrm{M}} + C^{\mathrm{F}} + C^{\mathrm{D}} \tag{1}$$

In formula (1)： C is the annual value of the whole life cycle cost in the cycle planning; C^{I}, C^{O}, C^{M}, C^{F}, C^{D} are the annual values of initial investment cost, running cost, maintenance cost, fault cost and decommissioning cost in the planning cycle in Fig. 1.

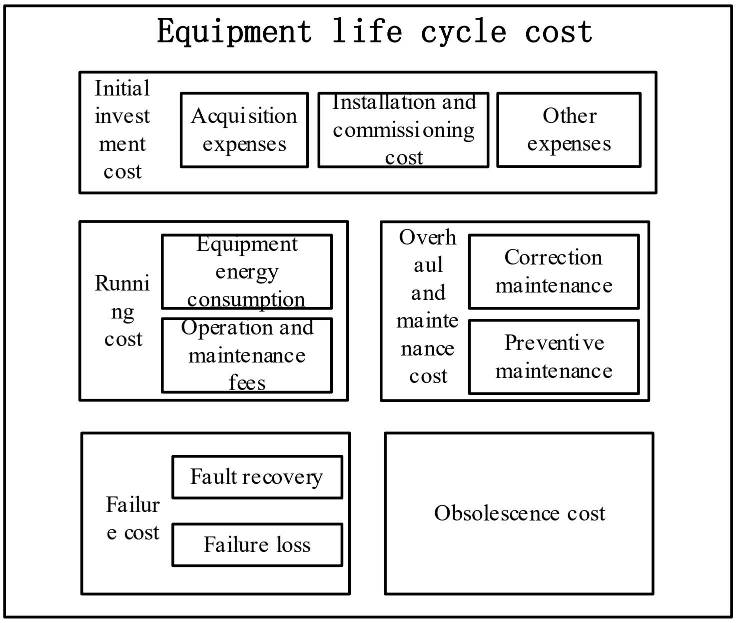

Fig. 1. Composition of each sub-index of equipment life cycle cost

(1) Initial investment cost C^{I}

The initial investment cost C^{I} refers to the one-time cost to be paid before the project is officially put into operation during the construction, transformation and commissioning period. The initial investment cost of the traditional theory mainly includes purchase cost, installation and commissioning cost and other costs.

$$C^{\mathrm{I}} = (c_{1,2} + \alpha_1 + \alpha_2)\frac{\gamma(1+\gamma)^T}{(1+\gamma)^T - 1} \tag{2}$$

In formula (2): $c_{1,2}$ represents the initial investment cost of indoor and outdoor stations, where c_1 is indoor station and c_2 is outdoor station; α is the equipment disposal fee; γ is the discount rate; T is the life cycle planning period.

(2) Running cost C^{o}

Running cost C^{O} refers to the sum of all the costs generated by the equipment during the life cycle operation, mainly including equipment energy consumption, daily operation and maintenance costs, the specific formula is as follows:

$$C^{\mathrm{O}} = \frac{\gamma(1+\gamma)^T}{(1+\gamma)^T - 1} \bullet \sum_{t=1}^{T} \frac{m_2 + m_3}{(1+\gamma)^t} \tag{3}$$

$$m_2 = \Delta P_{\max} \times T_{\max} \times \eta \times M \tag{4}$$

In formula (3) and (4), m_2 is the energy consumption of equipment, including the energy consumption cost of equipment body and auxiliary equipment; m_3 for the daily operation and maintenance costs, including the daily inspection needs of the inspection equipment, material costs; $\Delta P_{\max}$ is the power loss generated at the maximum load; $T_{\max}$ is the maximum load loss time; η operation main supply rate; M is the average electricity price.

(3) Maintenance cost C^M

The maintenance of the line mainly includes periodic maintenance [26-28]. Periodic maintenance costs include labor and material costs required for periodic maintenance [29-30]. Substation is calculated according to different time periods of minor repair and overhaul.

The maintenance cost of equipment level C^{M} mainly includes the correction maintenance cost of single equipment fault is $p_1 \times x$ and the preventive maintenance cost of single equipment is $p_2 \times x$. The specific formula is as follows:

$$C^{\mathrm{M}} = \frac{\gamma(1+\gamma)^T}{(1+\gamma)^T - 1} \sum_{t=1}^{T} \frac{p_1 \times x_i + p_2 \times y_i}{(1+\gamma)^t} \tag{5}$$

In formula (5): p_1 is the frequency of equipment corrective maintenance; x is the maintenance cost of each equipment; p_2 is the frequency of equipment preventive maintenance; y is the maintenance cost of each equipment.

(4) Fault cost C^{F}

Equipment-level fault cost C^{F} is the cost of fault recovery and fault loss caused by the failure of a single power equipment during the operation of the power grid.

$$C^{\mathrm{F}} = \frac{\gamma(1+\gamma)^T}{(1+\gamma)^T - 1} \sum_{t=1}^{T} \frac{S K_{\mathrm{d}} t_{\mathrm{g}} \psi p \cos\varphi + \varepsilon C_{\mathrm{jx}}}{(1+\gamma)^t} \tag{6}$$

In formula (6): S is the maximum capacity of the distribution transformer; K_d is the electricity price conversion coefficient, $K_d = 15$; t_g is the outage time of the accident; ψ is the equipment load rate; ε is the equipment accident rate; C_{jx} is the cost of the maximum troubleshooting, taking 3 % of the equipment purchase cost.

(5) Decommissioning cost C^{D}

Decommissioning cost C^{D} refers to the costs caused by the demolition and disposal of the assets formed by the equipment infrastructure investment when the equipment life cycle is limited. This cost is related to the initial investment cost.

$$C^{\mathrm{D}} = C^{\mathrm{I}}(\mathrm{c-b}) \tag{7}$$

In formula (7): c denotes the residual rate; b is the proportion coefficient of management cost of scrapped assets.

3 Study on comparison and selection of planning schemes

Taking GIS equipment as the starting point [31-35], The study focused on a substation with various design options yielding similar construction outcomes [36-37]. It aimed to analyze how the indoor and outdoor construction of Gas Insulated Switchgear (GIS) equipment affects its life cycle cost. Through this investigation, an optimal construction approach was identified. By broadening the scope of factors influencing the equipment's life cycle cost, a comprehensive set of practical application strategies was established. These were derived through calculations, designs, and thorough comparisons of equipment Life Cycle Costs (LCC) in Fig.2.

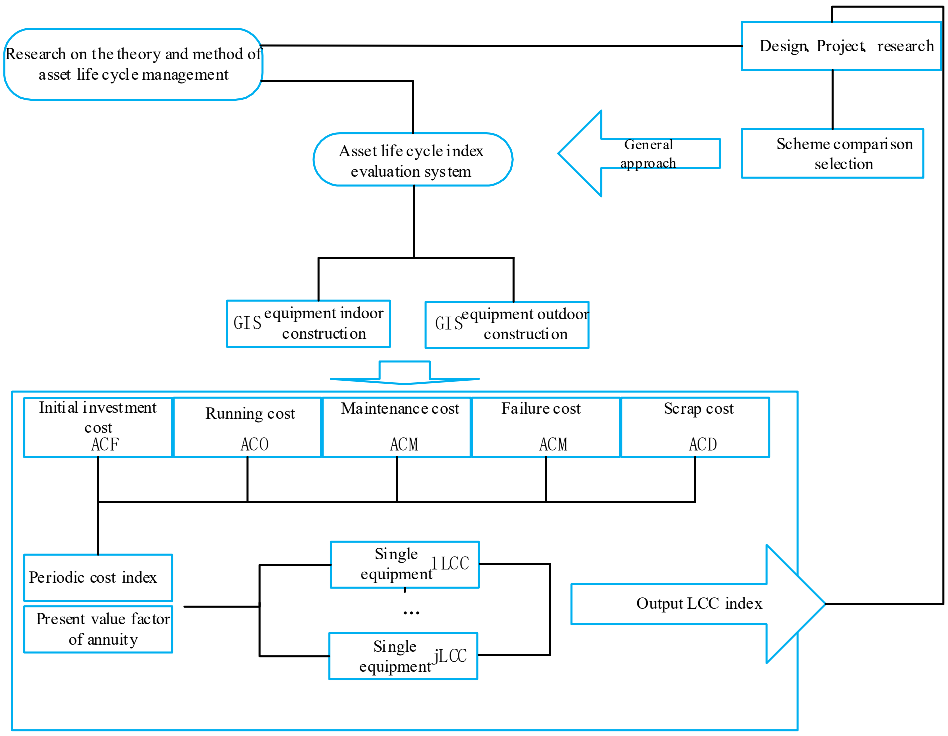

Fig.2. Construction comparison scheme

Based on the chosen research approach, which involves examining substations with varied design schemes but consistent construction outcomes, the focus is on understanding how the indoor and outdoor construction of GIS equipment influences its life cycle cost [38-41].

This paper directly selects the typical substation of GIS indoor and outdoor construction with 40 years or more of operation time as the statistical and analysis sample data, traces the actual annual operation and maintenance cost of GIS equipment for 40 years, and estimates the

40-year LCC cost of typical substation of GIS indoor and outdoor construction in the way of cumulative cost [42-44]. Through the analysis of multiple sets of sample data, the LCC cost of GIS indoor and outdoor construction for 40 years is obtained, and the optimal construction scheme is finally obtained [45].

4 Example analysis

4.1 Practical example analysis

Through the statistical analysis of 225 110 kV indoor and outdoor GIS stations in Hubei, it is concluded that 110 kV outdoor aviation road substation and 110 kV indoor Gusaoshu substation have the above characteristics in Table 1, among which:

Scheme 1: 110 kV Outdoor Aviation Road Substation, construction capacity of 2×50 MVA, 110 kV outgoing line for 4 times, 10 kV outgoing line for 24 times, high and low voltage bus connection form for single bus section, and put into operation for more than 40 years.

Scheme 2: 110 kV indoor Gusaoshu substation, construction capacity of 2×50 MVA, 110 kV outgoing line for 4 times, 10 kV outgoing line for 24 times, high and low voltage bus connection form for single bus section, and put into operation for more than 40 years.

Table 1 Basic situation of outdoor station and outdoor station

Substation type	Prefecture city	The voltage level of the power station (kV)	Transformer capacity	Date of commissioning	The number of outgoing lines (time)
Aviation Road Station (Outdoor)	A	110kV	2×50	1981	High pressure: 4 times Low pressure: 24 times
Gusaoshu Station（indoor）	B	110kV	2×50	1981	High pressure: 4 times Low pressure: 24 times

4.2 Analysis of effect

1) Comparative analysis of initial investment cost

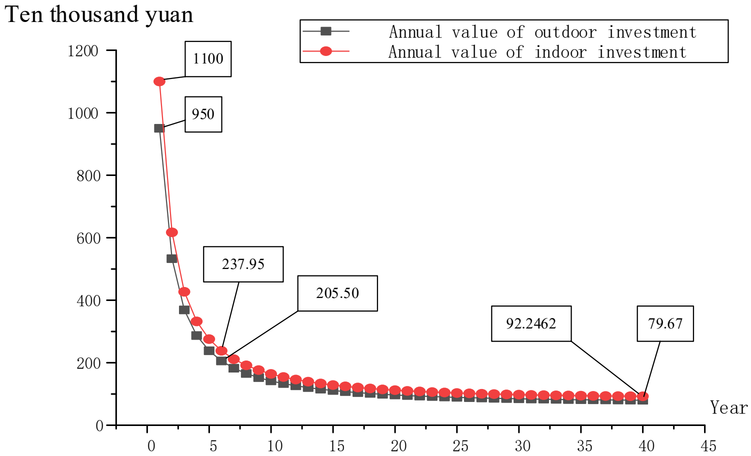

Fig. 3. Comparison of initial investment cost of indoor and outdoor stations

In fig. 3 above, the annual initial investment cost for the outdoor and indoor substations exhibits a 1.5 million yuan difference; in the sixth year, the annual value of the initial investment cost of outdoor substation and indoor substation is 2.055 million yuan and 2.3795 million yuan respectively, and the gap between the two is reduced to 324.5 thousand yuan. In the fourth decade, the annual initial investment cost for outdoor substations was 796,700 yuan, while for indoor substations, it was 922,500 yuan, respectively, and the gap between the two was the smallest at 125,800 yuan. It can be seen from fig. 3 With the growth of the life cycle of the substation, the annual value of the initial investment cost of the two substations is declining. The reason is that the initial investment cost remains unchanged. As the number of year increases, the cost allocated to each year will become less, and its economic benefits will be more obvious. Furthermore, it is evident that the annual initial investment cost of the indoor substation surpasses that of the outdoor substation. The reason is that the current value of the initial investment cost of the indoor substation is higher than that of the outdoor substation. In the case of the same life cycle, and the annuity present value coefficient is constant, so the annual value of the investment cost of the indoor substation will always be higher than that of the outdoor substation.

2) Comparative analysis of running costs

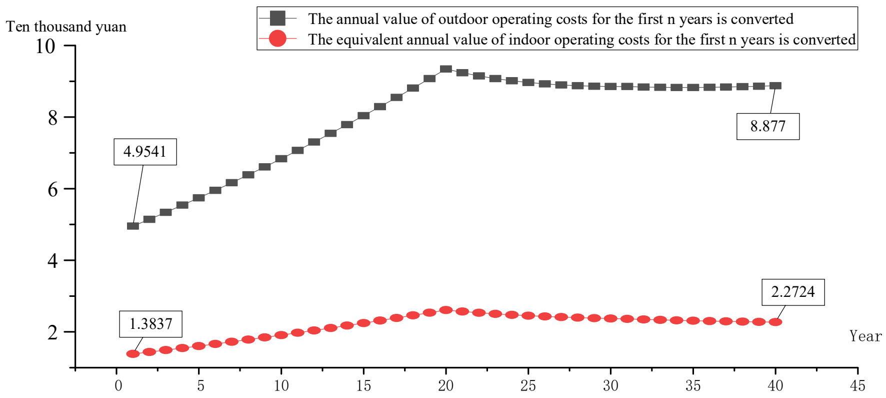

Fig.4. Comparison of operating costs of indoor and outdoor stations

Fig.4 indicates that the annual operation cost of outdoor substations surpasses that of indoor substations. And the first year the gap between the two is: 357.04 million yuan, the fourth decade the gap between the two is: 660.46 million yuan. As the life cycle progresses, the operational costs for both substations escalate. This is primarily attributed to expenses associated with equipment energy consumption and routine operation and maintenance. As the life cycle extends, these costs gradually mount.

3) Comparative analysis of maintenance cost

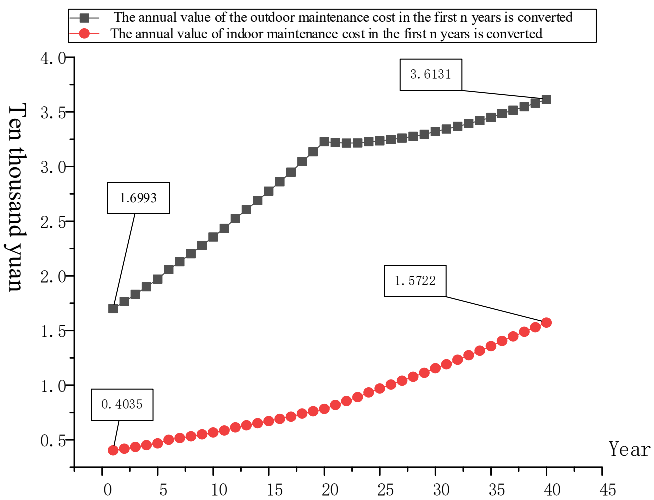

Fig. 5. Comparison of maintenance costs of indoor and outdoor stations

As depicted in fig. 5, the annual maintenance costs for both substations rise with the extended life cycle. This is due to the heightened frequency of equipment failures and the subsequent increase in maintenance expenses. Additionally, the upward trend in maintenance costs is more pronounced for outdoor substations compared to indoor substations. This is attributed to the higher likelihood of failures occurring in outdoor substations compared to their indoor counterparts.

4) Comparative analysis of fault cost

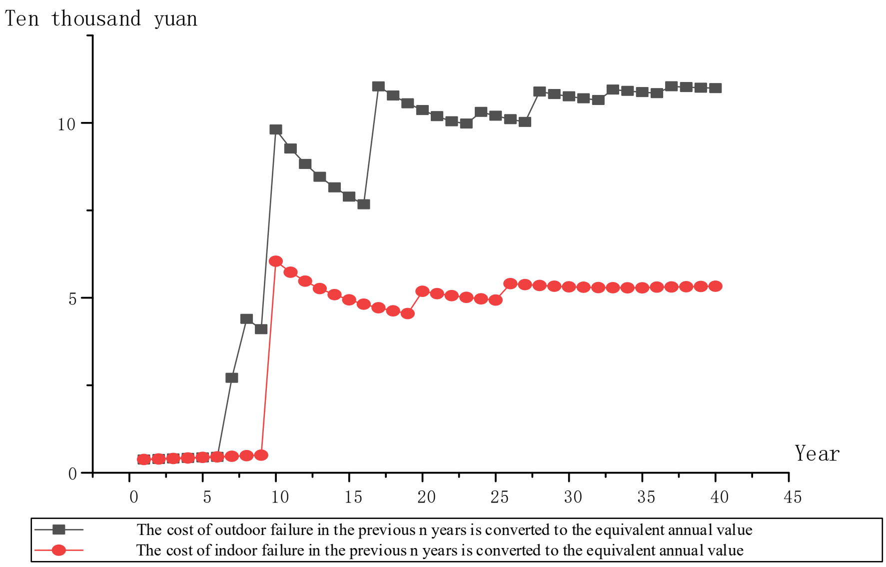

Fig.6. Comparison of failure cost of indoor and outdoor stations

Fig.6 highlights four distinct upward trends in the annual fault cost of outdoor substations, and the annual value of the fault cost increases to 271.17 million yuan in the seventh year. In the eighth year, the annual value of its failure cost increased to 439.79 million yuan; in the 10th year, its failure cost increased to 980.72 million yuan, and in the 17th year, its failure cost increased by 11.0383 million yuan. For the annual value of outdoor substation fault cost, there are three rising trends, and the annual value of fault cost increases to 604.36 million yuan in the 10th year. In the 20th year, the annual value of its failure cost increased to 51.859 million yuan; in the 26th year, the outdoor substation was overhauled, and its fault cost increased to 540.45 million yuan. As the life cycle progresses, the annual costs for both substations increase. This is attributed to the rising number of equipment failures and the resulting costs incurred due to power outages. Additionally, the upward trend in costs is more pronounced for outdoor substations compared to indoor substations. This is because the probability of failure in outdoor substations increases with the extended service life. According to the results of data collection and the empirical data provided by the on-site operation and maintenance personnel, in the life cycle, the outdoor substation is damaged.

5) Comparative analysis of scrap disposal cost

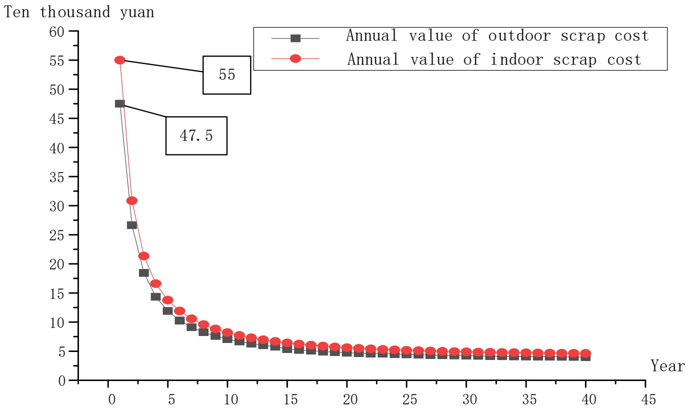

Fig.7. Comparison of the scrapping cost of indoor and outdoor stations

It can be seen from fig.7 that the trend of the annual value of the scrap cost of outdoor substation and indoor substation is consistent with the initial investment cost. In the fourth decade, the gap between the two was the smallest at 62.89 million yuan.

6) Comparative analysis of life cycle cost

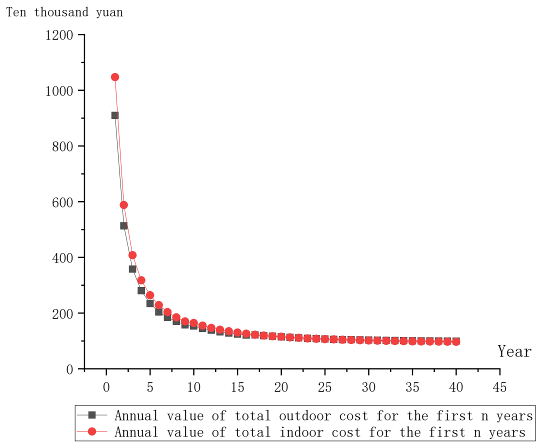

Fig.8. Comparison of life cycle cost of indoor and outdoor stations

According to Fig.8, it can be seen that the longer the operation time of indoor and outdoor stations, the lower the annual value cost of the whole life cycle, and the more economic significance. In the first 22 years, the annual cost of the whole life cycle of the indoor substation has been higher than that of the outdoor substation, but the gap is gradually decreasing. In the 22nd year, the difference between the annual cost of the indoor substation and the total cost of the outdoor substation is minimal, at 0.0114 million yuan. Moving into the 23rd year, the total annual cost of outdoor substations surpasses that of indoor substations, with a gap of 0.01243 million yuan. Beyond the 23rd year, the life cycle cost of the outdoor substation consistently exceeds that of the indoor substation. Fig.8 illustrates that between the 22nd and 23rd years, the life cycle costs of the indoor and outdoor substations intersect. By the 40th year, the gap widens to 2.3563 million yuan.

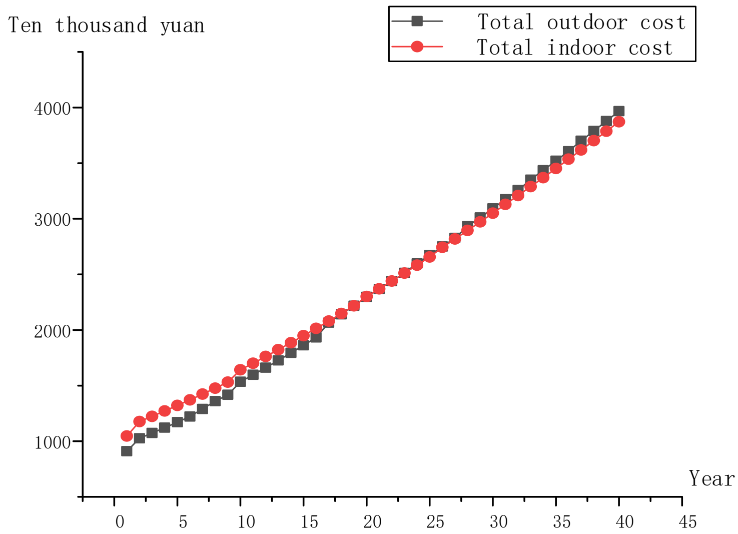

Fig.9. Comparison of cost differences between indoor and outdoor stations

For indoor aviation road substation and outdoor Gusaoshu substation, the total cost of indoor substation is higher than that of outdoor substation, and the initial gap of total cost is 1.376339 million yuan. In the fourth decade, the cycle cost of outdoor substation is higher than the total cost of indoor substation, and the life cycle cost gap is: 942.51 million yuan in Fig.9.

5 Conclusion

From the perspective of engineering practice, this paper constructs a more comprehensive and precise mathematical model of substation life cycle cost. Combined with practical examples, 110 kV outdoor aviation road substation and 110 kV indoor Gusaoshu substation are selected for simulation verification. The following conclusions are obtained through case analysis:

(1) Through the analysis of the example, it can be seen that the economic benefit of the cost of the outdoor station is better in the initial construction period. However, with the extension of the planning period, the difference between the initial investment cost of the indoor and outdoor station begins to shrink, and the difference between the operation, maintenance and maintenance costs begins to gradually expand.

(2) The model in this paper optimizes the material procurement strategy from the perspective of cost optimization, improves the quality of network equipment, reduces the increase of operation and maintenance workload and the cost consumption of operation and maintenance caused by

the quality of equipment, effectively improves the efficiency of asset management, and meets the requirements of quality and efficiency.

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