An optimization calculation method of transformer operating cost

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Abstract

In this paper, based on the theory of life cycle cost (LCC), the LCC of transformer was analyzed, and the life cycle cost calculation model of transformer was established. For calculating the cost of transformer loss, in order to make the final calculation results more accurate, the correction coefficient of electricity price is considered to improve the calculation model. Then, in order to reduce the loss of the transformer operation and save cost, the load rate of transformer is combined with efficiency to get the optimal load rate, so as to calculate the operating loss of transformer. Finally, these two improvement scheme were proved through the calculation and contrast analysis of examples.

Keywords: power transformer; life cycle cost; correction coefficient of electricity price; optimal load rate

1 Introductions

With the continuous development of construction power grid construction in China, the investment of electric power equipment is also in constant growth. Power transformer as one of the key equipment in the power system, its investment accounts for a large proportion in power equipment investment and the LCC of power transformer is getting more and more attention. Thus, the reasonable management of power transformer LCC is the guarantee of power system economic operation [1-3].

Power transformer LCC is generally divided into five parts, such as original investment cost (CI), operation cost (CO), maintenance cost (CM), fault loss cost (CF) and disposal cost (CD). Through investigation, analysis and summary of power transformer, the calculation models of these five parts were built. Then, through the calculation of five parts, the total cost of power transformer LCC is decided. In this paper, the loss cost in operation cost was researched [4].

Firstly, the calculation model should be built. Different types of expense contained in power transformer operation cost were introduced in reference [5, 6], which has a certain reference value.

For the loss cost calculation in power transformer operation cost, Wu Guowei and Zhou Hui et al [7] had built the calculation model, and added unite electricity price to get the loss cost of power transformer operation. Based on the former research, the annual load factor was added by Xia Chengjun and Qiu Guihua et al [8] to improve the calculation model and make the result more accurate. Since the accuracy of the calculation will have a significant impact on the final result of LCC, so it should be as comprehensive as possible to consider all the details of the parameters.

Since July 2012, the ‘ladder electricity price’ police was implemented in China. Meanwhile, different electricity price strategy was developed due to different period such as ‘peak, flat, valley’. Article mentioned above all had ignored the influence of electricity price coefficient (different price due to different period), and this would affect the calculation accuracy of the final result.

On the other hand, as the load rate of power transformer has a significant impact on the loss of the transformer operation, so it could be used to reduce the operation loss so as to achieve the purpose of cost saving. Zeng Wenyuan [9], Yang Jie and Yang Huiyu [10] only focused on the calculation of load coefficient but did not apply it on the optimization of the operation cost of the transformer.

Based on the above background, the correction coefficient of electricity price was added to improve the calculation model of operation cost of power transformer. Then, in order to reduce the operation cost, the efficiency and optimal load rate were considered to modify the operation cost. Finally, these two improved methods were verified through example calculation and analysis.

2 Life cycle cost

2.1 LCC AND ITS DEVELOPMENT

Life cycle cost is from the perspective of economic benefit of long-term economic investment, comprehensively considers the total cost such as equipment and investment projects planning, design, acquisition, installation, ope-

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ration, inspection, maintenance and even the disposal. The LCC analysis method distinguishes all types of cost in the whole life cycle, and uses the method of statistics to establish cost model and fee estimate equation.

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LCC originated in the Swedish railway system in 1904. In 1947, the value analysis method of LCC established in American was the start of the technical and economic analysis. But LCC officially got attention was in the latter half of the twentieth Century. Because of the need to improve and enhance the performance of weapon equipment, which not only greatly increased the purchasing cost but also greatly increased the use and maintenance cost, which had become a heavy burden of military expenditure. Thus making the lowest maintenance cost, was the basic starting point of LCC. In the 1960s, the United States began a systematic study of LCC and put forward that the LCC assessment should be conducted in the procurement of weapons and equipment to control military [11,12]. From the beginning of the 1970s, LCC concept was gradually used in the aerospace, defense, energy, engineering and other fields. At that time, companies which could maturely apply LCC, mainly concentrated in United States and Europe [13]. They not only successfully applied LCC concept in military aircraft, laser guided missiles and other high-tech weapons, but also in the power system. Only a few developed countries applied LCC technology in power system. In the United States and Sweden, it was mainly used for nuclear power and power transmission and distribution lines [14]. And in Japan, Canada, Australia, France, there were only sporadic reports and documents. LCC was advanced and prospective in electric power system. The United States firstly applied LCC management method to nuclear power plants, because the reliability of nuclear power plant construction must be taken priority. On this basis, the LCC technology was promoted to the generator, transformer, low voltage power distribution system and instrument system. Sweden and other European countries combined LCC and sustainable development, and applied it to green energy power system with considering the environmental cost [15]. Thus, LCC had a trend of being gradually applied in the electric power system.

3 LCC model of transformer

3.1 ANALYSIA OF LCC

Transformer LCC contains the cost produced from equipment planning, purchasing, installation, operation, inspection, maintenance until the disposal. Mainly divided into five parts such as original investment cost (CI), operation cost (CO), maintenance cost (CM), fault loss cost (CF) and disposal cost (CD)[7,8].

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

In the formula: CI-- original investment cost； CO-- operation cost； CM -- maintenance cost； CF-- fault loss cost； CD-- disposal cost.

3.2 THE ESTABLISHMENT OF LCC MODEL

3.2.1 Original investment cost(CI).

Transformer original investment costs include the purchase cost of the equipment, transportation cost, labour cost, land cost and other cost.

$$CI = C_{\mathrm{gz}} + \mathrm{C}_{rg} + C_{qt} \ , \tag{2}$$

In the formula: C_{gz} is the purchase cost of the equipment, C_{rg} is labour cost, C_{qt} is the total of other cost.

3.2.2 Operation cost(CO).

Transformer operation cost is the total costs in the process of transformer operation, which contains Loss cost, labour cost, environmental cost and other cost.

$$CO = C_{cs} + C_{sh} + C_{qt} , \tag{3}$$

In the formula: C_{cs} is the test cost before transformer operation, C_{sh} is total cost of loss cost in the transformer operation, C_{qt} is other cost which contains labour cost and environment cost.

3.2.3 Maintenance cost (CM).

Transformer maintenance cost contains overhaul cost and minor repair cost. Transformers will usually conduct an overhaul about 5 years after installation and operation. Then, the overhaul will be conducted once every 10 years and minor repair every year.

$$CM = C_{\mathrm{dx}} + C_{\mathrm{xx}} , \tag{4}$$

In the formula: C_{dx} is overhaul cost, C_{xx} is minor repair cost.

3.2.4 Fault loss cost (CF).

Fault Loss Cost is the loss cost from lack of electricity or power outage caused by transformer failure, which contains fault maintenance cost and fault loss cost.

$$CF = C_{\mathrm{jx}} + C_{\mathrm{ss}} , \tag{5}$$

In the formula: C_{jx} is fault maintenance cost, C_{ss} is fault loss cost.

3.2.5 Disposal cost (CD).

Disposal cost mainly contains scrap cost and salvage value of the transformer. Scrap cost is labour and equipment cost when transformer scraps, transportation cost and environment cost when transformer disposes, etc.,

$$CD = C_{bf} - C_{cz} , \tag{6}$$

In the formula: C_{bf} is scrap cost, C_{cz} is salvage value.

3.3 IMPROVEMENT OF LCC MODEL

The operation loss of the transformer occupies a large proportion in the transformer LCC, so accurate calculation and reduction of operation loss has great significance of LCC management.

Among five LCC models above, original investment and disposal cost can be decided directly, but other three models can only be calculated and even estimated. As the existing calculation models of operation loss have all ignored the coefficient of electricity price, which has made the calculation of operation loss not accurate enough.

Thus, in order to make the calculation result more accurate, the correction coefficient of electricity price was added in this paper to improve the calculation model of operation loss. Meanwhile, in order to reduce the loss of the transformer operation and save cost, the load rate of transformer is combined with efficiency to get the optimal load rate, so as to calculate the operating loss of transformer.

3.3.1 Correction coefficient of Electricity Price.

At the time of calculating operation loss of transformer, the electricity price will be added to convert calculation results into electric charge. The formula is:

$$C_{sh} = 8760 \times \left(P_0 + \eta^2 P_k\right) \times \omega \times A, \quad (7)$$

In the formula: P_o is the no-load loss of transformer, P_k is the load loss of transformer, η is load rate of transformer, ω is annual load factor, which take the value of 0.618, A is unite electricity price.

However, due to the ‘period decoupled price’, ‘ladder price’ and other fluctuation factors of electricity price, the annual electricity price will not be a fixed price but changes over time. If this point is not taken into consideration, then the calculation results are not consistent with the actual and also not accurate.

In order to solve this situation, the correction coefficient of electricity price was added in this paper to improve the calculation model. The formula is:

$$C_{sh} = 8760 \times \left(P_0 + \eta^2 P_k\right) \times \omega \times A \times \lambda, \quad (8)$$

3.3.2 Optimal load rate of transformer.

In the loss of distribution network, the loss of transformer has occupied over 60%. The electricity loss of transformer has occupied more than 4% of power generation in China. Thus, reducing the loss and making economic operation of transformer has become an important issue of common concern of departments such as power generation, power supply and electricity sector. The transformer economical operation is on the basis of ensuring the safe operation of the transformer and transmission power, then makes full use of existing equipment, adjusts the load and improve the operating conditions through optimal operation mode, so as to make the transformer operating in the low state of power loss. The traditional concept is that efficiency will be the highest when the loading rate is between 0.7 - 0.8, but the actual operation situation is not like this [9,10].

Based on the above condition, how to reduce loss, save energy and control operation loss on the guarantee of transformer efficiency is an important job in power system.

The load rate of transformer has a great influence on the loss of the operation, so the reasonable choice of load rate is important. In this paper, on the guarantee of efficiency, the optimal load rate was decided and the operation loss was also calculated.

The formula is:

$$\lambda = P_S \Big/ \left(P_S + \Delta P_0 + \eta^2 \Delta P_K\right), \quad (9)$$

The load rate of transformer has a great influence on the loss of the operation, so the reasonable choice of load rate is important. In this paper, on the guarantee of efficiency, the optimal load rate was decided and the operation loss was also calculated.

In the formula: ΔP_o is no-load power loss of transformer, ΔP_k is load power loss of transformer, η is load rate.

When the transformer load loss and no-load loss are equal at a load rate, the efficiency is highest, and the load rate is called as the optimal load rate.

It equals as:

$$\Delta P_0 = \eta_1^{\,2} \Delta P_k, \quad (10)$$

$$P_0 + KQ_0 = \eta_1^{\,2}\left(P_k + KQ_k\right), \quad (11)$$

$$\eta_1 = \sqrt{\Delta P_0 / \Delta P_k}, \quad (12)$$

The η_1 is optimal load rate

The formula of transformer operation is:

$$C_{\text{sh}} = 8760 \times \left(P_0 + \eta^2 P_k\right) \times \omega \times A \times \lambda, \quad (13)$$

Take the optimal load rate into formula, the loss of transformer on the optimal operation state can be calculated.

In conclusion, the improved calculation formula of operation is:

$$CO' = C_{cs} + C_{sh}' + C_{qt}, \quad (14)$$

The improved LCC model of transformer is:

$$LCC' = CI + CO' + CM + CF + CD, \quad (15)$$

4 The example analysis

In order to verify the above two kinds of improved schemes, this paper had calculated compared and analyzed the results which were before and after the improvement [16,17].

4.1 OPERATION COST WITHOUT CONSIDERING THE COEFFICIENT OF ELECTRICITY PRICE

(1) Without considering the coefficient of electricity price, the calculation formula is:

$$C_{sh} = 8760 \times \left(P_0 + \eta^2 P_k\right) \times \omega \times A, \quad (16)$$

In the formula: P_0 is non-load loss, which takes the value of 200kW, P_k is load loss, which takes the value of 750kW, η is load rate, which takes the value of 80%, ω is annual load factor, which takes the value of 0.618, A is unite electricity price, which takes the value of 0.6 Yuan/kWh, the result C_{sh1} was about 2.21 million Yuan.

(2) With Considering the coefficient of electricity price, the electricity price due to different period is (Take the price of 2012 in Chongqing as an example) :

a. Flow period (In May and November each year) :
Flat (11: 00-19:00) 0.8444 Yuan/kWh; Peak (7:00-11: 00, 19:00-23:00) 1.2397 Yuan/kWh; Valley(23:00-7:00)0.4491 Yuan/kWh;

b. Wet period (From June to October each year)
Flat: 0.76534 Yuan/kWh; Peak: 1.1211 Yuan/kWh; Valley: 0.4095 Yuan/kWh;

c. Dry period (From January to April, and December each year) :
Flat: 1.0025 Yuan/kWh; Peak: 1.4768 Yuan/kWh; Valley: 0.5281 Yuan/kWh.

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The calculated result C_{sh2} was about 3.79 million Yuan.

So, whether to consider the price coefficient will make a larger difference between two calculation results (about 42%). Obviously, when considering the volatility of price coefficient, the calculated result will be more accurate and practical.

4.2 THE LOSS COST WITH CONSIDERING THE OPTIMAL LOAD RATE

The 10kV S9 series distribution transformer was selected, the rated capacity is 10kVA, non-load loss ΔP_0 is 1.70kW, and load loss ΔP_k is 10.30 kW. The optimal load rate was calculated from formula (13), and the calculated result was about 1.75 million Yuan.

Without considering the optimal load rate, the load rate was traditionally taken the value of 70%, and the calculated result C_{sh4} was about 3.07 million Yuan.

Thus, whether to consider the optimal load rate will make a larger difference between two calculation results of operation loss cost of transformer (about 43%). Apparently, When considering the optimal load rate, the loss of operation will be greatly reduced.

5 Conclusions

In this paper, based on the theory of LCC, the LCC of transformer was analyzed, and the life cycle cost calculation model of transformer was established. The correction coefficient of electricity price was added to improve the calculation model and the load rate of transformer was combined with efficiency to get the optimal load rate, so as to calculate the operating loss of transformer. Finally, these two improvement scheme were proved through the calculation and contrast analysis of examples. The conclusions are as follows:

(1) Through adding correction coefficient of electricity price to improve the calculation model: When considering the volatility of price coefficient, the calculated result will be more accurate and practical.

(2) Through adding the optimal load rate to calculate the operating loss of transformer: When considering the optimal load rate, the loss of operation will be greatly reduced.

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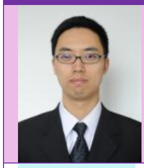

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