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Cost Comparison Based on Transformer Operating State Under Two Kinds of Inspection Strategies

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Abstract. Based on the analysis of traditional state maintenance strategy and big data-based state maintenance strategy, this paper builds a transformer state duration simulation model based on Monte Carlo method and builds an annual cost model based on the running state of the transformer. Finally, a typical case is selected to simulate a time series of 8760 hours of transformer operation under two operational inspection strategies, and the annual cost is calculated separately. The example shows that the annual cost of the transformer is lower under the big data-based inspection strategy.

1 Introduction

Electricity is the lifeblood of the country's economic strategic energy relations and social development [1]. Transformers play a key role in the power system. They have always been the focus of operation and maintenance of substation equipment. Scientific and reasonable transportation inspection strategies can improve the safety and reliability of transformer operation and reduce the cost of operation and maintenance.

In the early days of maintenance of transformers, the most common in China is planned maintenance. Although the planned maintenance has provided a guarantee for the safe and reliable operation of the equipment to a certain extent, there are also shortcomings such as "under-repair" and "overhaul", which will result in waste of resources. The traditional state maintenance refers to the state maintenance combined with planned maintenance, which is the mainstream trend of today's maintenance. The state maintenance is to check the operation of the equipment through the state evaluation of the equipment, the maintenance time is more flexible, and the maintenance content is more specific and detailed [2]. However, due to the numerous factors affecting the state of the equipment, it is difficult to find potential faults during the state maintenance evaluation, resulting in inefficient equipment fault detection.With the development of science and technology, state-based maintenance based on big data has been generated. Based on the data mining analysis method and the advanced fault characteristics of the equipment historical data analysis device, the equipment abnormality warning is issued by real-time analysis of the equipment status data [3], and timely discovery The early signs of potential failures, the judgment of the severity of the fault location and the development trend [4], brought great convenience to the maintenance work.

Based on the characteristics of two kinds of transportation inspection strategies, this paper constructs the Monte Carlo simulation model and annual cost calculation model of transformer state duration, and selects the example to analyze the annual running time series and annual cost of the transformer under two transportation inspection strategies.

2 Simulation model of each state duration of transformer based on Monte Carlo method

2.1 Division of transformer operating state

The operation of the transformer for a long period of time can be regarded as an alternating cycle of "run-stop-run" (as shown in Fig.1).

Fig. 1 Transformer working state diagram

In the figure, $MTTF_i$ and $MTTR_i$ are the values of the trouble-free working time $MTTF$ and the outage duration $MTTR$ of a plurality of random variables, respectively.

2.2 Transformer sequential Monte Carlo simulation model

A two-state model is used to simulate the duration of each state of the transformer (as shown in Fig. 4)..

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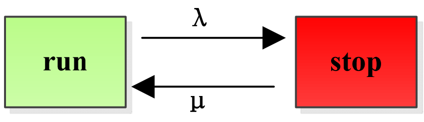

Fig.2 Transformer state transition diagram

Assuming that the failure rate of the transformer is λ, the repair rate is μ, and the probability density function of its fault-free operation duration *MTTF* and outage duration *MTTR* is subject to an exponential distribution.Based on the sequential Monte Carlo simulation, the random number is generated by the inverse transformation method, so the random variables m, r can be obtained by the following formula:

$$m = -\frac{1}{\lambda} \times \ln \xi_1 \tag{1}$$

$$r = -\frac{1}{\mu} \times \ln \xi_2 \tag{2}$$

In the formula, ξ_1 and ξ_2 are random numbers uniformly distributed in the interval [0, 1].

The steps to simulate the different state durations of a transformer based on the Monte Carlo method are as follows:

1) The number of simulation years is 10 years. Assume that the running state is 1, and the outage state is 0. At the beginning, the transformers are all running.

2) Under the condition of a time span of 1 year (8760 hours), the durations of the current states of different transformers are sampled according to formulas (1) and (2). Fig. 3 is a time series of transformers under different inspection strategies for a period of time.

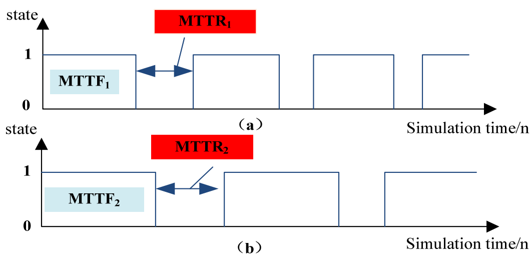

Fig.3 Timing diagram of the timing state of the transformer

3)Repeat step 2) in the simulation process so that we can obtain the state transition process of the transformer under a certain inspection strategy within the total simulation time. The simulation ends until the simulation time is greater than 10 years or the variance coefficient is less than the convergence condition.

4) Calculate the cost corresponding to the 10-year state sequence (hourly) of the transformer under different operational inspection strategies, and solve the expected cost per hour of transformer operation under different operational inspection strategies.

2 Annual average cost model based on transformer operating status

The operating state of the transformer can be divided into available and unavailable. The durations of the two states of the transformer are different under different operational inspection strategies. Therefore, the costs in different states (as shown in Fig.5) are also different. The average annual cost of the transformer is:

$$E(C) = \left[\sum_{t=1}^{10}\left(C_1^t + C_2^t + C_3^t + C_4^t + C_5^t + C_6^t\right)\right]/10 \tag{3}$$

In the formula, t is the number of years the equipment is operated; 10 is the total operation of the equipment for 10 years; C_1^t is the operation and maintenance cost of the t-year of the equipment operation; C_2^t is the operation loss cost of the t-year of the equipment operation; C_3^t is the t-year of the equipment operation Maintenance cost; C_4^t is the fault disposal cost of the t-year of equipment operation; C_5^t is the estimated grid power purchase cost in the t-year of equipment operation; C_6^t is the estimated grid power loss cost of the equipment in the t- year.

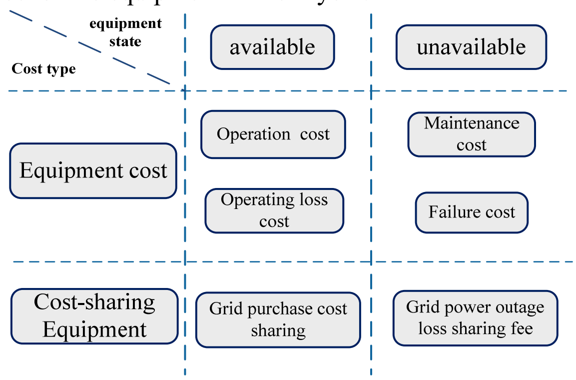

Fig.4 Cost and classification of transformers under different conditions

The cost of the device itself is calculated as follows:

(1)When the transformer is in the available state, it needs to perform operation and maintenance (daily inspection, live test, cleaning and maintenance), etc. The operation and maintenance cost is: all available time of the transformer in one year (h) multiplied by the operation and maintenance cost per unit hour.

(2) When the transformer is in the available state, the operating loss cost C_2 generated by the transformer load loss is expressed as:

$$C_2 = \sum_{T_F=1}^{8760} T_F \times S \times \eta \times \beta \times p \tag{4}$$

In the formula, T_F is the available time of the transformer; $\sum_{T_F=1}^{8760} T_F$ is the sum of the available time of the transformer in one year; S is the transformer capacity and the unit is kWA; η is the average load ratio of the transformer; β is the loss factor of the

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transformer; p is the catalogue price per unit hour and the unit is ￥/kWh.

(3) When the equipment is in an unavailable state, the maintenance cost is: all the unavailable time (h) of the transformer in one year multiplied by the unit hour maintenance cost.

(4) When the equipment is in an unavailable state, the fault disposal cost is: all the unavailable time (h) of the transformer in one year multiplied by the unit hour fault disposal cost.

The cost of equipment allocation is calculated as follows:

(5)When the equipment is running, it will generate revenue. Therefore, it is necessary to share the purchase cost of a part of the grid, as follows:

$$C_5 = \sum_{T_F=1}^{8760} T_F \times q_{load} \times p_{buy} \times \xi \qquad (5)$$

In the formula, q_{load} is the unit load value of the power supply area, the unit is kWh; p_{buy} is the unit purchase cost of the power supply area and the unit is ￥/kWh; ξ is the contribution rate of the transformer in the power supply area, taking 2%.

(6)When the transformer is faulty, it may cause the power grid to lose power. Therefore, the transformer needs to share the cost of power failure loss of some power grids, as follows:：

$$C_6 = \sum_{T_R=1}^{8760} T_R \times P_{chain} \times P_{GDP} \times Q \times \xi \qquad (6)$$

In the formula, T_R is the available time of the transformer; $\sum_{TR=1}^{8760} T_R$ is the sum of the available time of the transformer in one year; P_{chain} is the probability of power failure of the grid caused by the chain reaction of the transformer failure; P_{GDP} is the unit GDP of the transformer Cost and the unit is ￥/ kW; Q is the transformer unit time power loss kW / h; .

3 case analysis

3.1 Raw data

This section selects a main transformer currently being put into operation in the substation of Haitu District, Shangyu City, Zhejiang Province as the analysis object.The account information and parameter information of the transformer are shown in Table 1 and Table 2, respectively.

According to the historical operation experience, the failure rate of the state maintenance strategy and the transformer based on the big data state maintenance strategy are 0.0057 times/h and 0.0042 times/h, respectively; the repair rate is 0.0945 times/h and 0.1012 times/h.

Table 1 Main transformer account information of Haitu Substation

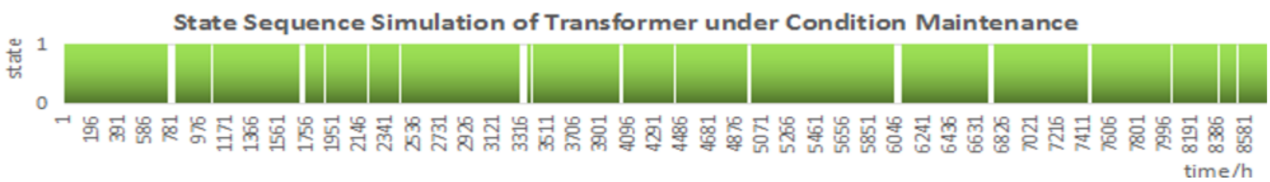
model	SSZ9-40000/110
Manufacturer	Nanjing Power Transformer Co., Ltd
Voltage ratio	(110±8*1.25%)/37/10.5
Joingroup label	YNyn0d11
Date of operation	2001.08.15

Table 2 Main transformer cost information of Haitu Substation

Cost type	data
Transformer capacity (kW)	40000
Unit maintenance cost (￥/h)	389.694
Unit failure repair cost (￥/h)	1887.602
Unit electricity GDP cost (￥/h)	22.44
Electricity loss per hour (kW/h)	706
Transformer average load rate	60.00%
Transformer loss factor	6.60%
Unit hour load in the power supply area（kWh）	29284.4
Power purchase unit unit purchase cost (￥/ h)	0.24
Transformer power supply contribution rate	2%

3.2 Simulation analysis

(1)The transformer state simulation under two maintenance strategies is shown in Fig.5 .It can be seen that compared with the traditional state maintenance strategy, the transformer operation time is longer and the unavailable time is shorter under the big data-based state maintenance strategy.



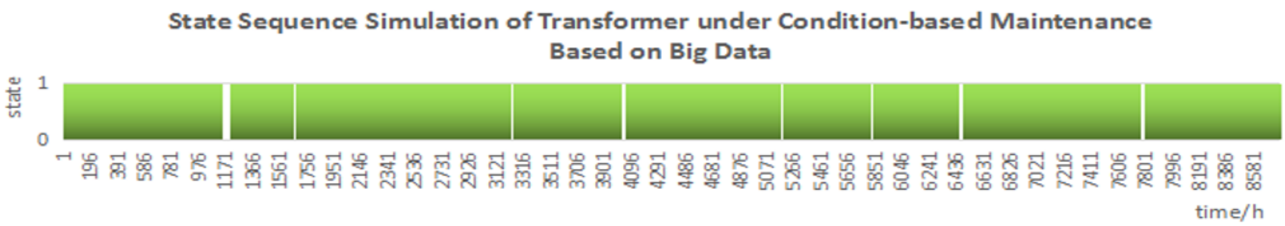


Fig.5 Simulation sequence diagram of the 8760 hourly hourly operation of the equipment under two maintenance strategies

(2)The annual cost average based on transformer status under the two maintenance strategies is shown in Table 3.It can be seen that compared with the traditional state maintenance strategy, the annual available cost of the transformer is increased under the big data-based state maintenance strategy, and the annual unavailable cost is reduced, but the annual total cost is reduced.

Table 3 Annual cost averages based on transformer status under two maintenance strategies

Maintenance strategy	Equipment cost(￥)				Cost-sharing Equipment (￥)		Sum (￥)
	Operation cost	Operating loss cost	Maintenance cost	Failure cost	Grid power outage loss sharing fee	Grid purchase cost sharing	
Condition maintenance	78639.668	257618.4	196016.082	949463.806	0	1160759.467	2644091.192
Maintenance based on the state of big data	78973.008	258710.4	182376.792	883397.736	0	1166194.703	2569652.639

(3)The average cost per hour of transformer operation under the two maintenance strategies is shown in Fig.6. State based on the large data maintenance equipment operating cost per hour under Means 200 ￥, while the traditional operating device state maintenance cost per hour average at 400 ￥; Overall, devices based on big data-based status maintenance strategies cost less per hour.

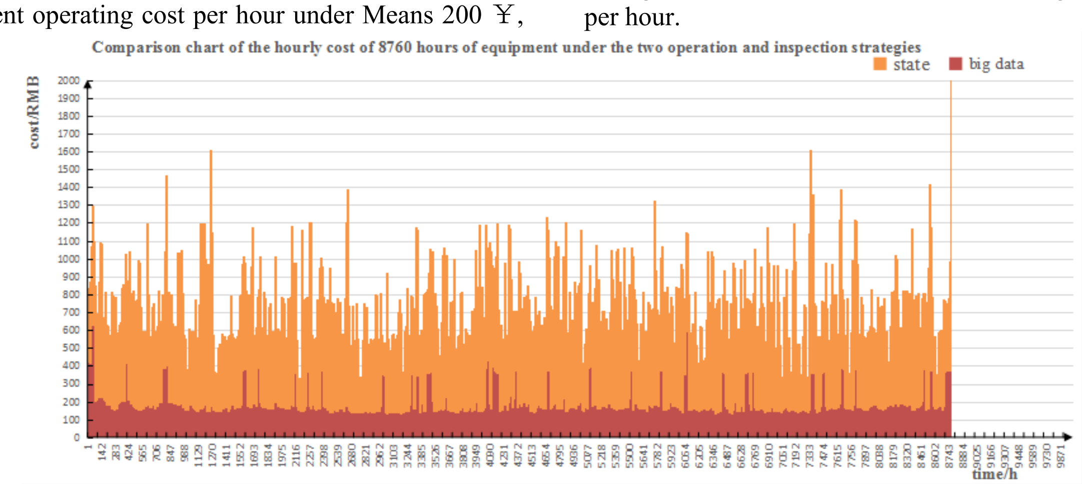


Fig.6 Comparison of the average cost per hour of transformer operation under two maintenance strategies

4 conclusion

Through empirical analysis can be drawn the following conclusions:

Through the simulation and cost estimation of transformer state duration under two kinds of inspection strategies, it can be seen that due to the difference of the inspection strategy, the available and unavailable time of the equipment are different. Compared with the traditional state maintenance strategy, based on big data. On the one hand, the state maintenance strategy greatly prolongs the available time of the equipment, resulting in a slight increase in operating and maintenance costs and operating loss costs; on the other hand, it greatly shortens the unavailability of equipment, resulting in greatly reduced maintenance and troubleshooting costs. . Since the cost of the equipment in the available time is low and the cost is not high in the available time, the big data-based status maintenance strategy can avoid the unavailability time, thereby reducing the cost of running the equipment throughout the year. The latter has a greater advantage for the operation and maintenance of equipment.

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