Research and Analysis of Power Equipment Maintenance Strategy Based on Markov Chain

Haokun Guo

Department of Electronic Information Engineering, Jiangyin Polytechnic College, Jiangyin, 214405 Jiangsu, China

Keywords: Power equipment, Maintenance strategy, Markov chain, Maintenance costs, Operational risk

Abstract: The maintenance strategy of electric power equipment plays an important role in the normal operation and maintenance of the actual power system. This paper uses the Markov chain to simulate the operation and maintenance of electrical equipment. Combined with big data thinking and cloud computing technology, real-time analysis of massive historical data and online data is realized. In the case of an actual wind turbine as a case, the more accurate Markov chain model of the operation and maintenance of the electrical equipment was established. The model's Markov chain transfer matrix is obtained. A reasonable formula for considering maintenance costs and risk costs is given. And the simulation is carried out by using this formula. The simulation results show that the maintenance strategy is reasonable and feasible, which provides a practical maintenance strategy for the operation and maintenance of power equipment.

1. Introduction

The normal operation of electrical equipment can affect the stability of the power system. In order to ensure the development of smart grid, it is necessary to research and analyze the operation and maintenance strategy of electric power equipment [1, 2]. In the process of running the electric power equipment, the aging process, the occurrence of failure and other operating conditions can be seen as a random process, there are many uncertainties [3, 4, 5]. Thus, the use of deterministic models in the past overhaul strategies to analyze these uncertain factors clearly does not achieve the desired results well, and sometimes even leads to erroneous guidance, resulting in unnecessary losses [6, 7, 8].

The Markov process is a class of applications with a wide range of stochastic processes. It can predict the future development process in the given state of the case. At present, the Markov process has been widely used in various fields of power systems [9, 10]. The Markov chain is a discrete Markov process, which by virtue of the "no memory" features in the analysis of the random process is very effective [11, 12]. And the probability model established by Markov chain can quantitatively analyze the research target. Therefore, the Markov chain is very suitable for the establishment of power equipment operation and maintenance model. And the model can be used for quantitative analysis of electrical equipment maintenance policy.

This paper uses the Markov process to simulate the operation and maintenance of electrical equipment. Combined with big data thinking and cloud computing technology, real-time analysis of massive historical data and online data is realized. In the case of an actual wind turbine as a case, the more accurate Markov chain model of the operation and maintenance of the electrical equipment was established. The model's Markov chain transfer matrix is obtained. A reasonable formula for considering maintenance costs and risk costs is given.

2. Markov Maintenance Strategy

Markov chain. In general, the state of the random process at some point is related to the state of the neighboring moment, the farther the time interval, the less the association. After a mathematical

  DOI: 10.25236/soshu.2022.003

abstraction, the state of a certain moment is only related to the state of the adjacent moment, and has nothing to do with the other state, and then this process is the Markov process. Markov chain is a discrete Markov process, which is defined as follows: If the state and time parameters can be seen as a discrete stochastic process X(n), X(k + 1) is only related to X(k) under X(k) known conditions, and has nothing to do with X(k-1), X (k-2), and so on [4]. The above definition means that X (n) satisfies the following formula 1. The probability of transfer of the Markov chain is shown in Equation 2. The transfer matrix of the Markov chain is shown in Equation 3.

$$P\left\{X(n)=j \middle| X(0)=i_0, X(1)=i_1, \cdots, X(n-1)=i\right\}=P\left\{X(n)=j \middle| X(n-1)=i\right\} \tag{1}$$

$$p_{ij}(s,n)=P\{x_n=a_j \mid x_s=a_i\} \tag{2}$$

$$\mathbf{P}(s,n)=\begin{pmatrix} p_{00}(s,n) & \cdots & p_{0N}(s,n) \\ \vdots & \ddots & \vdots \\ p_{N0}(s,n) & \cdots & p_{NN}(s,n) \end{pmatrix} \tag{3}$$

According to the above definition, the Markov chain apparently has the following two properties:

$$p_{ij}(k)\geq 0 \tag{4}$$

$$\sum_{i\in I} p_{ij}(k)=1 \tag{5}$$

Markov maintenance strategy. Electric equipment Markov overhaul strategy is to operate the power equipment and maintenance status as a Markov process. Then the Markov process was dispersed and becomes a Markov chain process. According to the historical data of the operation and maintenance of electrical equipment and the definition of the Markov chain, the state transition matrix of this Markov chain process can be obtained. Among them, the number of state transition matrix can be determined according to the solution adopted. Such as the operation of a state there are three solutions: not repair, minor repair, overhaul, then get the state transfer matrix also has three, respectively, not repair, minor repair, overhaul state transition matrix. Obviously, the more the historical sample is, the closer the transfer matrix is to the true value and the more the machine will run. In the current state of operation of the current power equipment can be judged by the above state transfer matrix, respectively, using different solutions to the gains and losses or benefits, the gains and losses can be based on the actual situation to give a fair and scientific mathematical formula to calculate. The formula must include maintenance costs and operational risks. The cost of maintenance is the cost of different maintenance methods. Operational risk is the use of different maintenance methods in different states and then cause a major failure caused by the loss.

3. Case Analysis and Processing

Historical data. This article will be an actual wind turbine operation and maintenance of historical data as an example of the above maintenance strategy theory for specific analysis and calculation. The literature [5] gives the historical data, after finishing, not repair, minor repair, overhaul three kinds of treatment measures under the three groups of statistical data are obtained, as shown in Table 1 (a), (b), (c) below.

Table 1 Historical Statistical Data

(a) Historical statistical data under no repair

status	1	2	3	4	5
1	108	7	5	2	1
2	0	68	8	5	2
3	0	0	33	18	14
4	0	0	0	23	31
5	0	0	0	0	32

(b) Historical statistical data under minor repairs

status	1	2	3	4	5
1	4	0	0	0	0
2	49	8	4	3	1
3	42	9	5	3	2
4	63	23	12	7	4
5	0	0	0	1	43

(c) Historical statistical data under overhaul

status	1	2	3	4	5
1	2	0	0	0	0
2	64	7	4	2	1
3	56	6	5	1	1
4	59	3	2	1	1
5	44	5	3	2	1

Transfer matrix calculation. Observing the historical data in the table, because the number of samples is limited, it can only be used as proof of “the theoretical reference value” basis, and can not be used as the final basis for actual judgments. If the number of samples is large enough, the more accurate the judgment is. According to the historical data in the table and the definition of the Markov chain, the Markov chain state transfer matrix corresponding to the minor repair and overhaul measures is as follows.

$$\mathbf{P}_1 = \begin{bmatrix} 0.8780 & 0.0569 & 0.0407 & 0.0163 & 0.0008 \\ 0 & 0.8193 & 0.0964 & 0.0602 & 0.0241 \\ 0 & 0 & 0.5077 & 0.2769 & 0.2154 \\ 0 & 0 & 0 & 0.4259 & 0.5741 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\mathbf{P}_2 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0.7538 & 0.1231 & 0.0615 & 0.0462 & 0.0154 \\ 0.6885 & 0.1475 & 0.0820 & 0.0492 & 0.0328 \\ 0.5780 & 0.2110 & 0.1101 & 0.0642 & 0.0367 \\ 0 & 0 & 0 & 0.0227 & 0.9773 \end{bmatrix}$$

$$\mathbf{P}_3 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0.8205 & 0.0897 & 0.0513 & 0.0256 & 0.0129 \\ 0.8116 & 0.0870 & 0.0726 & 0.0144 & 0.0144 \\ 0.8939 & 0.0454 & 0.0303 & 0.0152 & 0.0152 \\ 0.8000 & 0.0909 & 0.0545 & 0.0364 & 0.0182 \end{bmatrix}$$

4. Maintenance Strategy Selection

Maintenance strategy formula. In order to facilitate research, you can calculate the benefits of using a strategy when you encounter different situations. That is, the need to introduce specific maintenance costs and operational risks. This paper gives a reasonable formula for reference, as shown in equation (6).

$$F_{mn} = X_n + \sum_{i=1}^{M} Y_i \mathbf{P}_n(m,i) \tag{6}$$

In equation (1), F_{mn} represents the benefit of using the n^{th} maintenance measure when the current state is m, m indicates the current state of the device, n indicates what maintenance method is used. X_n indicates the cost of using the n^{th} maintenance state. I represents the next possible state of the current state. M is the total number of all states. Y_i represents the risk cost for the next state i. $\mathrm{P}_n(m,i)$ represents the corresponding probability in the transfer matrix using the corresponding maintenance mode. As a result, the greater the calculated F_{mn}, the more unreasonable the use of current maintenance measures.

Calculation and analysis. The historical data in Table 1 is set as a sample. The costs in Table 2 and Table 3 are set to the values of X_n, Y_i in formula (1), respectively. The values in Table 2, Table 3, and the values of the transfer matrices P1, P2, P3, and then F_{mn} is calculated. The results are shown in Table 4.

Table 2 Maintenance Costs X_n

n	1(Not repair)	2(Minor repair)	3(Overhaul)
X_n/ Million yuan	0	2	5

Table 3 I	1	2	3	4	5
Y_i/ Million yuan	0	2	4	6	10

Table 4 F_{mn}/ Million Yuan	1	2	3	4	5
1	0.382	2.626	5.846	8.296	10
2	2	2.923	3.246	3.615	11.909
3	5	5.667	5.508	5.455	5.800

According to the results in Table 4 analysis can be the following conclusions: the 5 states are normal operation, minor failures, moderate failure, serious failure, complete damage. The most reasonable way to deal with of them is not repair, not repair, minor repair, minor repair, and overhaul.

The above result is the result of the current hypothesis. In actual operation, we can calculate according to the real cost. And in the actual operation process, if the maintenance treatment in addition to not repair, minor repair, overhaul three kinds of more ways to deal with, then only need to establish the Markov chain model to expand the state transition matrix rows and columns Enough. At this point, the formula (1) can still be common.

5. Big Data Thinking and Cloud Computing

We all know that the more historical data, the more accurate the corresponding Markov model. As mentioned in the above example, if there are more historical data, and then combined with the corresponding real-time data for analysis, the obtained results will be more accurate. In order to achieve big data analysis of historical data and real-time data, cloud computing-related technologies are introduced, massive data are stored in cloud disks, and a Markov model is established. At the same time, the real-time data is constantly updated, and the established Markov model is constantly revised to ensure the accuracy and accuracy of the model.

6. Conclusions

The maintenance of power equipment plays an important role in the actual power system. The operation and maintenance of the power equipment was simulated based on Markov chain. In the case of an actual wind turbine as a case, the Markov chain model of the operation and maintenance of the electrical equipment was established. The model's Markov chain transfer matrix is obtained. A reasonable formula for considering maintenance costs and risk costs is given. And the simulation is carried out by using this formula. The simulation results show that the maintenance strategy is reasonable and feasible, which provides a practical maintenance strategy for the operation and maintenance of power equipment.

Acknowledgement

Research Subject of Jiangyin Polytechnic College of China (XJ2021LG001); Excellent Teaching Team Project of Jiangsu University Qinglan Project.

References

[1] Chen, C., Lu, N., Jiang, B., & Xing, Y. (2020) “Condition-based Maintenance Optimization for Continuously Monitored Degrading Systems under Imperfect Maintenance Actions”, Journal of Systems Engineering and Electronics, 31(4), pp. 841-851.

[2] Han, M., Yang, J., & Zhao, X. (2021) “Joint Optimization of Inspection, Maintenance, and Spare Ordering Policy Considering Defective Products Loss”, Journal of Systems Engineering and Electronics, 32(5), pp. 1167-1179.

[3] Wang, Q., He, Z., Lin, S., & Liu, Y. (2018) “Availability and Maintenance Modeling for GIS Equipment Served in High-Speed Railway Under Incomplete Maintenance”, IEEE Transactions on Power Delivery, 33(5), pp. 2143-2151.

[4] Yu, P., Fu, W., Wang, L., Zhou, Z., Wang, G., & Zhang, Z. (2021) “Reliability-Centered Maintenance for Modular Multilevel Converter in HVDC Transmission Application”, IEEE Journal of Emerging and Selected Topics in Power Electronics, 9(3), pp. 3166-3176.

[5] Ye, H., Wang, X., & Liu, K. (2021) “Adaptive Preventive Maintenance for Flow Shop Scheduling With Resumable Processing”, IEEE Transactions on Automation Science and Engineering, 18(1), pp. 106-113.

[6] Bertling, L., Allan, R., & Eriksson, R. (2005) “A reliability-centered asset maintenance method for assessing the impact of maintenance in power distribution systems”, IEEE Transactions on Power Systems, 20(1), pp. 75-82.

[7] Liu, B., Lin, J., Zhang, L., & Kumar, U. (2019) “A Dynamic Prescriptive Maintenance Model Considering System Aging and Degradation”, IEEE Access, 7, pp. 2169-3536.

[8] Endrenyi, J. (2001) “The Present Status of Maintenance Strategies and the Impact of Maintenance on Reliability”, IEEE Transaction on Power Systems, 16(4), pp.638-646.

[9] Ephraim, Y., & Roberts, W. (2009) “An EM Algorithm for Markov Modulated Markov Processes”, IEEE Transactions on Signal Processing, 57(2), pp. 463-470.

[10] Cheng, P., He, S., Cheng, J., Luan, X., & Liu, F. (2021) “Asynchronous Output Feedback Control for a Class of Conic-Type Nonlinear Hidden Markov Jump Systems Within a Finite-Time Interval”, IEEE Transactions on Systems, Man, and Cybernetics: Systems, 51(12), pp. 7644-7651.

[11] Carravetta, F., & White, L. (2021) “Embedded Stochastic Syntactic Processes: A Class of Stochastic Grammars Equivalent by Embedding to a Markov Process”, IEEE Transactions on Aerospace and Electronic Systems, 57(4), pp. 1996-2005.

[12] Fritsche, C., & Gustafsson, F. (2016) “The Marginal Bayesian Cramér–Rao Bound for Jump Markov Systems”, IEEE Signal Processing Letters, 23(5), pp. 575-579.