Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Nov-Dec 2021 Page No. 384-392
Article History: Received: 05 October 2021, Revised: 02 November 2021, Accepted: 25 November 2021, Publication: 31 December 2021

Research on Transformer Fault Diagnosis Method Based on Digital Twin Technology

Xiaolong Yang, Chao Ma, Tao Yao, Jing Li, Dongya Zhang, Lin Gao and Jialin Liu
State Grid Hebei Information & Telecommunication Branch, Shijiazhuang, Hebei 050011, China

Abstract:

Real-time fault diagnosis of transformer operation is an important approach to protect the safe and stable operation of the power system. The traditional diagnosis approach has some problems such as low data quality, low fault diagnosis efficiency, and difficult diagnosis model construction, so a transformer fault diagnosis model based on a digital twin is proposed. Firstly, the physical entity of the transformer is combined with the virtual model, and the digital twin model is modified according to the condition monitoring data obtained from the sensor and the simulation data of the twin model, and the characteristic parameters are extracted. Then the BP neural network algorithm is used to diagnose the types of faults and analyze the possible causes of faults, which can help reduce the maintenance cost and cycle of transformers, improve the efficiency of fault diagnosis, and make the transformers operate safely and reliably.

Keywords*: Transformer, fault diagnosis, digital twin, neural network.*

I. INTRODUCTION

The transformer is key equipment in the power transmission and distribution system. The safe and reliable operation of a transformer is the foundation of the safe and reliable operation of the power supply network. Once a fault occurs, power use and safe operation will be affected [1]. Real-time fault diagnosis according to the operation of the transformer can be found and handled in time, to avoid huge economic losses. At present, the transformer fault diagnosis method is mostly through the combination of manual data sampling and online parameter sampling, and the maintenance persons can judge the running state of the transformer according to the sampling data. However, as manual judgment is generally combined with the current sampling data, the fault diagnosis efficiency is low, and the fault source and fault type cannot be found in time [2-3].

Digital twinning provides a new way to solve these problems. The university of the defense acquisition definition digital twin, "twin is made full use of the physical model and digital sensors, operation process, such as data, integrated multidisciplinary, multiple quantities, multi-scale, probability simulation process, completed in the virtual space mapping of the physical world, which reflects the corresponding physical entity full lifecycle process" [4-5]. Digital twinning technology has a wide range of applications. It can also be applied to the field of energy. Chinese Academician Lu Qiang also proposed the concept of digital

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Nov-Dec 2021 Page No. 384-392
Article History: Received: 05 October 2021, Revised: 02 November 2021, Accepted: 25 November 2021, Publication: 31 December 2021

power systems very early and pointed out that digital power systems can be used to improve the security and stability of power systems [6].

Digital twin through digital means to build a digital world in the same entity, to simulate its behavior in the real environment, and the past and present the act or process of dynamically, effectively reflect the system running situation, thus the unpredictable situation more real and comprehensive detection [7]. Using virtual-real interactive feedback, data fusion analysis, and decision iterative optimization, it provides more real-time, efficient, and intelligent operation or operation services for physical entities.

II. RESEARCH STATUS

In the power system, the transformer is used for voltage conversion and transmission, which plays a significant role in the safe operation of the power grid. In industrial applications, it is necessary to monitor the operating state of transformers and find latent faults in time to safeguard the power system security [8]. For the stability of the power system, a lot of researchers have researches the fault diagnosis method of the transformer. Yu Jianli et al. used a neural network to diagnose transformer fault state, and its accuracy is significantly improved [9]. Umasankar L et al. proposed a method of combining wavelet transform and neural network to classify transformer internal fault signals To improve the sensitivity of fault diagnosis [10]. Zou A et al. proposed A multi-input multi-output polynomial neural network method for fault diagnosis, which improved the anti-interference ability of the classification model [11]. Wang YS et al. analyzed the importance of the evaluation uncertainty because of the problems in the life evaluation factors and methods of power equipment and proposed the evaluation method of random fuzzy theory, which provided a basis for the operation and maintenance of transformers and guaranteed the safety of power equipment to a certain extent [12]. Nagpal et al. analyzed the fault of the 110KV transformer by using the diagnosis system of sample fusion and verified the availability and correctness of the system through experiments. The results show that the expert system can simplify the fusion data and improve the fusion accuracy [13]. Canyon L V et al. used a multilayer SYM classifier to classify the processed fault data. The test results show that SVM can predict transformer faults quickly and accurately [14]. Shi Yijin et al. used particle swarm optimization (PSO) to optimize the parameters of kernel function and improve the fault diagnosis accuracy of the transformer [15]. Tu Songjiang et al. used a genetic algorithm to optimize SVM to improve the accuracy of transformer state diagnosis [16]. Tran V T et al. used DBN to extract fault feature signals of compressor valves, and SFAM to identify fault states of compressor valves [17].

Different from the above literature, we use digital twin technology to diagnose transformer faults, maps the condition of the transformer in the physical space in the digital space, conducts interactive feedback between the virtual model and the physical entity, and analyze the fault cause according to the real-time state parameters.

III. DATA COLLECTION AND PROCESSING

3.1 Establishment of three-dimensional transformer model

The structural parameters, material parameters, geometric parameters, and physical relationship of the transformer can be obtained through the specification and actual measurement analysis, and the structure

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Nov-Dec 2021 Page No. 384-392
Article History: Received: 05 October 2021, Revised: 02 November 2021, Accepted: 25 November 2021, Publication: 31 December 2021

and size of the equipment can be accurately expressed, especially the key characteristic parameters. Using CAE modeling software, create a 3d model of the transformer. The three-dimensional model of the transformer is shown in Figure 1:

Fig.1 The 3d model of oil-immersed transformer

3.2 Transformer operating status data collected by the sensor

To carry out real-time monitoring and accurate evaluation of the running state of transformer equipment, it needs to install various sensing devices to realize the comprehensive perception of all aspects of the state quantity. Such as dissolved gas in oil sensing device, moisture sensing device, oil in the electric field sensing device, Uhf sensing device, the SF6 sensing device, grounding current sensing device, etc., as shown in Figure 2.

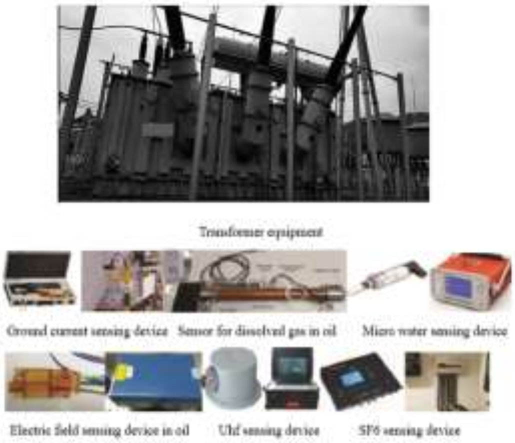

Fig.2 Various sensing devices for transformers

The operating status data obtained from various sensing devices include numerical information of temperature, humidity, and noise of transformer environmental status, numerical information reflecting transformer operating status, and quality information reflecting transformer operating status. Then combined with operating environment data, operation and maintenance data, fault case data, etc., multi-source data fusion technology is used to realize multi-dimensional, whole-process, panoramic, and full-link depth perception of transformer state, providing data guarantee for digital twin technology in transformer diagnosis.

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Nov-Dec 2021 Page No. 384-392
Article History: Received: 05 October 2021, Revised: 02 November 2021, Accepted: 25 November 2021, Publication: 31 December 2021

3.3 Data Processing

Multi-dimensional data of transformer operating state are obtained by various sensing devices, but the data quality is often low, with redundant data, missing data, uncertain data, and inconsistent data. Therefore, the key characteristic parameters of the transformer and the signal collected by the sensor are processed to improve the quality of the data set, to provide quality assurance for the digital twin technology in transformer fault diagnosis.

IV. TRANSFORMER FAULT DIAGNOSIS MODEL BASED ON DIGITAL TWIN

4.1 Create digital twin model of transformer

It is a faithful digital description of a physical entity in virtual space to build a digital twin model with high fidelity. It uses a digital model and reliable perception to transmit data to the information layer in real-time to realize intelligent perception and real-time interaction.

In this paper, the digital twin model of the corresponding transformer is constructed. It integrates and integrates four layers of geometric, physical, behavior, and rule models. The geometric model of the transformer includes the geometric size, shape and position relationship between the components of the transformer and the shell, the winding mode of the first and second windings, the assembly and plug relationship between the lead and the core, and the final box cover and casing assembly structure and other parameters; The physical model is stored in the real environment of the transformer structure parameters, under the impact voltage, electric field force of the transformer winding and insulation stress analysis and test, and under the action of external force of the transformer box and various components of the compressive, damage resistance and other performance test; To realize the function of boost and buck by using the principle of electromagnetic induction and the ratio of winding turns, the transformer fault diagnosis model is constructed to analyze the data of gas in oil and simulate its operation state, so that the digital twin can simulate the actual operation condition in a super realistic way and carry out fault diagnosis analysis. The rule model is the storage transformer field-related industry standards and guidelines, transformer use manual, expert knowledge, and neural network mining rules, etc.

Then after the completion of its geometry, physics, behavior, and rules, and other dimensions of the model, through the connection of the model of each layer fusion and integration, the formation of digital twin virtual model of the transformer, mainly to accomplish the transformer work process simulation, optimization, evaluation, and real-time monitoring. The whole process is shown in Figure 3.

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Nov-Dec 2021 Page No. 384-392
Article History: Received: 05 October 2021, Revised: 02 November 2021, Accepted: 25 November 2021, Publication: 31 December 2021

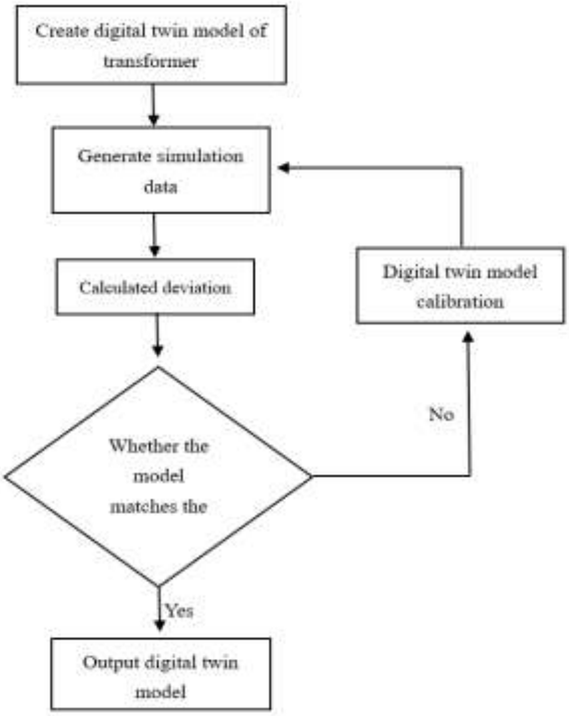

Fig.3 Create the flow chart of transformer digital twin model

4.1.1 Calibration of the digital twin model

To ensure the validity of the digital twin model, it is necessary to verify the constructed model to verify whether the model describes and describes the state or characteristics of physical objects correctly. If the model verification results are not correct, the model needs to be calibrated to make the model closer to the actual running state of the physical object.

Firstly, the operating state data of the transformer is input into the digital twin model, which drives the transformer to work virtually in the computer. Then the data collected in the physical system module is compared with the simulation data, and the deviation value is calculated. Finally, according to the deviation value, whether the digital twin model matches the transformer entity or not is judged. If not, the parameters are adjusted to know the match. If matching, output transformer digital twin model.

4.2 Transformer fault diagnosis model

The transformer fault diagnosis model constructed by digital twinning technology can collect fault data in real-time and simulate the actual operation state. Its model is divided into a physical entity, digital twin, twin database, and connection between parts. The composition of each part is shown in Figure 4:

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Nov-Dec 2021 Page No. 384-392
Article History: Received: 05 October 2021, Revised: 02 November 2021, Accepted: 25 November 2021, Publication: 31 December 2021

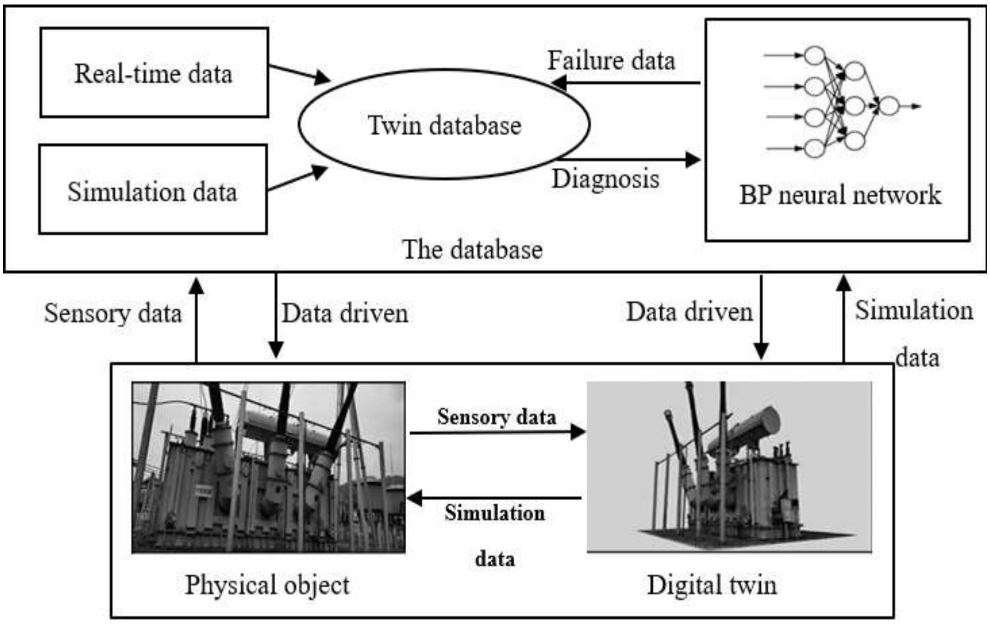

Fig.4 Transformer fault diagnosis model based on digital twin

(1)The physical entity consists of the actual transformer and sensor system. The sensor collects the operation data of the transformer in real-time and transmits it to the twin database for storage.

(2)Digital twin is a digital mapping of physical entities in virtual space, which monitors the operation status of transformer entities in real-time, and the simulation data are uploaded to the database in real-time.

(3)Twin database entities stored in transformer manufacturing, principle, components and structure of virtual transformer geometrical, physical model, behavior rules and all the data information, real-time data, the simulation of virtual transformer data, using the optimized BP transformer fault diagnosis model is derived in the process of fault diagnosis data information.

(4)The connection between each part can realize the dynamic flow of data, real-time update, and iteration of data, optimize the digital twin of simulation, and make it closer to the transformer entity. Through the analysis of transformer fault diagnosis results, the transformer repair and maintenance scheme can be optimized and the probability of fault occurrence can be reduced.

4.2.1 BP neural network for fault diagnosis

For the transformer fault diagnosis model based on digital twinning technology, BP neural network will be used to diagnose the transformer fault. The network is an imitation of human brain thinking and memory patterns, through professional technology to ultimately achieve the integration of information collection processing. Generally, the neural network has super adaptive ability, independent learning ability, and nonlinear mapping ability, which is very convenient and effective in signal processing, management, and fault diagnosis. When the transformer fault is diagnosed by BP neural network, the threshold and weight are adjusted mainly using the difference between the actual output and the initial desired output, so that the difference between the two is gradually reduced and consistency is achieved. In the diagnosis of transformer related faults based on BP neural network, its flow chart is shown in Figure 5:

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Nov-Dec 2021 Page No. 384-392
Article History: Received: 05 October 2021, Revised: 02 November 2021, Accepted: 25 November 2021, Publication: 31 December 2021

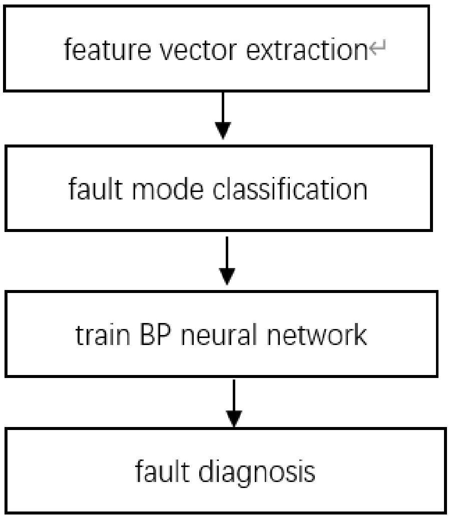

Fig.5 Based on BP neural network for transformer fault diagnosis process

(1) Extract feature vectors

Extract the feature vector group composed of data in the physical system and digital twin module.

(2) Fault mode classification

Transformer fault mode is divided into: normal, low temperature overheating, medium temperature overheating, high temperature overheating, partial discharge, low energy discharge, high energy discharge.

(3) Train BP neural network

First, the proportion of dissolved gases in five kinds of insulating oil, H2, CH4, C2H6, C2H4, and C2H2, is selected as the judgment basis, and the percentage of these five kinds of gases is taken as the input feature vector of BP neural network. Secondly, the seven fault types of normal, low-temperature overheating, medium-temperature overheating, high-temperature overheating, partial discharge, low-energy discharge, and high-energy discharge are coded as the output of the neural network. Third, the neural network of infinite hidden layer nodes can approximate any continuous function in the mapping interval, but the increase of hidden layer nodes will make the neural network structure more complex, increase the calculation workload, and prolong the training time. Therefore, a reasonable number of hidden nodes is required. Fourth, the neural network is calibrated and verified by combining the physical system data of the transformer and the simulation data of the digital twin. If the training requirements are not met, the training parameters are modified and the training continues until the neural network meeting the fitting requirements is trained.

(4) Fault diagnosis

The data collected in the actual operation of the transformer are input into the neural network trained to obtain the fault that is closest to the fitting degree of the fault model. The neural network outputs the current fault type and realizes the fault diagnosis of the transformer.

V. CONCLUDES

The transformer is the most critical and indispensable equipment in the whole power system at present, and it is also the most common equipment in power accidents. Therefore, to ensure the stability of the power system, we use the digital twinning technology to propose a transformer fault diagnosis method based on digital twinning, which monitors the state of the transformer, alarms when the fault occurs and uses BP neural network to analyze the fault and determine the fault reason. The model can reduce the maintenance cost and cycle of the transformer, improve the efficiency of fault diagnosis, and ensure the safe and reliable operation of the transformer.

REFERENCES

[1] Liao R, Y Wang, Liu H, et al. Research Status of Condition Assessment Method for Power Equipment[J]. High Voltage Engineering, 2018, 44(11):3454-3464.
[2] Jiang X, Sheng G. Research and application of big data analysis of power equipment condition[J]. High Voltage Engineering,2018, 44(4): 1041-1050.
[3] Wang H, Jiang H, Wang Z. Transformer fault diagnosis based on multi-classification probabilistic output model [J]. Electrical measurement & instrumentation,2018,55(17):101-106.
[4] Shen C, Jia M, et al. Digital Twin of Energy Internet and its Application [J]. Global energy Internet,2020,3(01):1-13.
[5] ROSEN R, VON WICHERT G, LO G, et al. About the importance of autonomy and digital twins for the future of manufacturing [J]. IFAC-Papers Online, 2015, 48(3): 567-572.
[6] Lu Q, Sun J. Digital Power System (DPS) -- Power Information in the 21st century [A]. China Association for Science and Technology [C]. Proceedings of the 2000 Annual Conference of China Association for Science and Technology. China Association for Science and Technology: China Civil Engineering Society,2000:2.
[7] Bai H, Zhou C, Yuan Z, et al. Outlook and Thinking of digital power grid based on digital twin [J]. Southern Power Grid Technology,2020,14(08):18-24.
[8] Press C. Electric Power Transformer Engineering, Third Edition[J]. CRC Press, 2012.
[9] Yu J, Huang H, Chen H, et al. Research on Application of Neural Network in Transformer Fault Diagnosis [J]. Control Engineering, 2018(10).
[10] Umasankar L, Kalaiarasi N. Multi Wavelet Transform with Radial Basis Function Neural Network for Internal Faults Diagnosis in Power Transformer[J]. Journal of Computational and Theoretical Nanoscience, 2017, 14(11):5525-5538.
[11] Zou A, Rui D, Mei Q, et al. Fault diagnosis of a transformer based on polynomial neural networks[J]. Cluster Computing, 2017(11):1-9.
[12] Wang, Si Y. Residual Life Assessment of Power Transformer Based on Random Fuzzy Theory[J]. Advanced Materials Research, 2014, 1070-1072:1127-1132.
[13] Nagpal T, Brar Y S. Expert System Based Fault Detection of Power Transformer[J]. Journal of Computational and Theoretical Nanoscience, 2015.
[14] Ganyun L V, H Cheng, H Zhai, et al. Fault diagnosis of power transformer based on multi-layer SVM classifier[J]. Electric power systems research, 2005, 74(1): p.1-7.
[15] Tian G, Shi Y, Liu D, et al. Transformer Fault Diagnosis Based on Chaotic Particle Swarm Optimization Support Vector Machine [J]. Journal of Kunming University of Science and Technology: Natural Science Edition, 2019(5):54-61.

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
Nov-Dec 2021 Page No. 384-392
Article History: Received: 05 October 2021, Revised: 02 November 2021, Accepted: 25 November 2021, Publication: 31 December 2021

[16] Tu Song Jian K, Gao W, Zhang Z, et al. Transformer Fault Diagnosis Based on Support Vector Machine and Genetic Algorithm [J]. Journal of Tsinghua University (Natural Science), 2018(7).
[17] Tran V T, Althobiani F, Tinga T, et al. Single and combined fault diagnosis of reciprocating compressor valves using a hybrid deep belief network[J]. ARCHIVE Proceedings of the Institution of Mechanical Engineers Part C Journal of Mechanical Engineering Science 1989-1996 (vols 203-210), 2017:095440621774092.