On-line Fault Diagnosis Method for Electronic Transformer Based on Wavelet Theory

Wei WANG\textsuperscript{1}, Ai-chao YANG\textsuperscript{2}, Xiao-song DENG\textsuperscript{1,\ast}, Chen HU\textsuperscript{2} and Dong-jiang Li\textsuperscript{2}

\textsuperscript{1}The State Key Laboratory of Power Transmission Equipment & System Security and New Technology, Chongqing University, Chongqing 400044, China
\textsuperscript{2}Jiangxi Electric Power Research Institution, Nanchang 330006, China

\ast Corresponding author

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Abstract. Electronic transformer (ET) is wildly used in digital smart substation. However, the actual running time of ETs is generally short, and most of them have higher failure rate than that of traditional transformers. Since the accuracy and stability of ETs data collection affect the safe operation of smart grid, it is necessary to study the fault diagnosis method of ETs. According to the characteristics of ETs, this paper proposes an on-line fault diagnosis method of ET based on wavelet transform theory. After noise reduction the output signal waveform of the transformer, the high frequency decomposition coefficient is obtained by wavelet transform, so as to diagnose and locate the three kinds of faults: drift deviation fault, variable ratio deviation fault, and fixed deviation fault.

Introduction

Smart grid is an innovative power transmission and distribution technology, which contributes to controlling the production and distribution of electrical energy safely and efficiently [1]. The reliable operation of smart substation is an important part of the smart grid, which can realize the functions of voltage level conversion, multi-channel current collection, power distribution optimization and so on [2]. More and more smart devices have been applied in smart substations, gradually realizing digital information interaction in the whole station, standardized information sharing mechanism and networked data transmission platform. ET is the device that can measure the relative parameters of power system and equipment through electronic measurement technology and optical fiber sensing technology, so as to ensure the safe operation of power system.

However, as ET is a kind of emerging device, it has problems such as short running time and unstable reliability, and their measuring accuracy are easily affected by changes of temperature and external magnetic field [3]. As the information source of relay protection and automation equipment, the operation performance of ET directly affects the normal operation and function realization of secondary system inside substation. Once the ET fails, the abnormal output will lead to measurement distortion, protection malfunction, and other problems. In serious cases, it will cause power failure, casualties and other safety accidents. Therefore, it is necessary to study the effective method for the on-line fault diagnosis of ET.

Life Cycle Performance Monitoring and Management of ET

Life cycle performance monitoring and management of ETs refers to the continuous and parallel monitoring, analysis and diagnosis of ET signals by on-line monitoring and diagnosis system during the life cycle operation. The process is shown in Figure 1 [4]. In the management process, the monitoring data are compared with the healthy data pattern, so as to conclude the fault rule of ET. Based on continuous measurement and analysis, the operation state of ET can be judges, the remaining service life of ET can be predicted, and the best maintenance time of ET can be decided.
In the whole life cycle, the typical fault development process of ET can be divided into five stages: (1) Early stage: the fault rate is high and the reason is the problem of ET’s manufacture and installation; (2) Stable operation stage: the fault rate is very low and the reason of fault is mainly sudden operation failure; (3) Deterioration stage: the fault rate starts to rise, which is because ET is aging gradually; (4) Attention stage: the fault rate increases rapidly due to the accelerated aging of ET. (5) Dangerous stage: the ET may fail at any time, which is because that the transformer is not inspected and maintained in time or the real fault source is not found.

During the life cycle operation, the fault of ET usually goes through a gradual process from generation to development, from slight to severe. Therefore, in life cycle monitoring and management of ET, early fault diagnosis is of great significance to reducing the loss caused by fault [5].

**Fault Diagnosis Method Based on Wavelet Transform**

The method based on signal processing can avoid the mathematical model of the diagnosis object, and has other advantages such as strong ability to overcome noise. Therefore, this method is suitable for ET fault diagnosis. Considering the advantage of wavelet analysis theory in mutation point detection [6], this paper proposes a fault detection and location method for ET based on wavelet transform.

**Noising Reduction of ET Signal**

Fault signal detection is the basis of ET fault diagnosis. Because the signal collected by ET is mixed with a large amount of noise, if the signal does not go through noise elimination, the fault diagnosis results of ET will be affected. The idea of signal noise reduction method based on wavelet theory is that after the wavelet decomposition of the signal, the noise signal presents as the wavelet coefficient with small amplitude or the details of higher frequency, thus if the wavelet coefficients are processed with the method of threshold value, the signal can be reconstructed to realize noise reduction.

The principle of signal decomposition processing by wavelet transform is shown in Figure 2. The original signal is decomposed into two parts, $cA_1$ and $cD_1$. It is concluded that $cA_1$ and $cD_1$ are half of the original signal, and $cA_1$ retains the low-frequency information or approximate information of the original signal, while $cD_1$ retains the high-frequency information or detailed information of the signal. For noise filtering, $cA_1$ signal has more active components, while $cD_1$ belongs to noise signal. The signal can be decomposed many times. The wavelet transform method only decomposing the low frequency part, and the noise signal is the high frequency signal, thus the wavelet function can be used to reduce the noise of the signal.

![Figure 1. Management process of life cycle performance monitoring.](image1)

![Figure 2. Structure diagram of wavelet decomposition tree.](image2)
In this paper, the domain value filtering method [7] for wavelet noise reduction is adopted. The noise reduction process is as follows: (1) A wavelet function is selected and the number of decomposition layers N is determined. After wavelet decomposition of N layers on the signal, the high frequency coefficients of each layer are obtained. (2) For high-frequency coefficients of layer 1-N, a certain domain value is selected for domain value quantization. (3) The signal is reconstructed by low-frequency coefficients of the Nth layer and high-frequency coefficients of the 1st -Nth layer.

The comparison of ET output signal before and after the noise reduction is shown in Figure 3. It can be seen that the domain value filtering method can effectively reduce noises in the original signal.

On-line Fault Diagnosis of ET Based on Wavelet Transform

According to the characteristic of faults, this paper divides the actual ET faults into drift deviation fault, fixed deviation fault, variable transformation ratio deviation fault, and complete failures. The signal of complete failure is generally 0 or the maximum value, as shown in Figure 4. Therefore, it can be directly judged by the output signal waveform of ET. However, the other three kinds of faults are difficult to be found, so this paper proposes a diagnosis method based on wavelet theory.

The wavelet decomposition coefficients after wavelet transform will change with the different fault states of ET. Based on this characteristic, the mapping relationship between wavelet coefficient change and fault state is simulated, then the fault is detected and located. The wavelet function ‘db3’ is selected in this paper, whose number of signal decomposition layers is 3, and the fault characteristic vector is the wavelet coefficients of cA₃, cD₃, cD₂ and cD₁, which are obtained by decomposition.

Fixed Deviation Fault Diagnosis

In the case of fixed deviation fault, the measured value of ET differs from the correct value by a constant. The mathematical model of fault is shown in (1):

\[
f(t) = \begin{cases} 
A \sin(\omega t + b), & t < T_f \\
A \sin(\omega t + b) + C, & t \geq T_f
\end{cases}
\]

where \(A\) is the amplitude; \(\omega\) is the angular frequency; \(b\) is the phase; \(C\) is a constant, representing the measurement deviation caused by the fault; \(T_f\) is the time point when the failure occurs.

The signal waveform of fixed deviation fault is shown in Figure 5.
As shown in Figure 6, the fault detection and location results can be obtained by applying wavelet transform to the signal waveform of fixed deviation fault, as shown by cD₁. Therefore, the method proposed in this paper can effectively detect and locate the fixed deviation fault of ET.

**Transformation Ratio Deviation Fault Diagnosis**

In the case of transformation ratio deviation fault, the transformation ratio of the ET suddenly changes, then the output signal waveform of the transformer will be distorted. The mathematical model of the fault is shown in (2):

\[
f(t) = \begin{cases} 
A_1 \sin(\omega t + b), & t < T_f \\
A_2 \sin(\omega t + b), & t \geq T_f 
\end{cases}
\]  

(2)

where, \(A_1\) and \(A_2\) are the different amplitudes of transformer output signals before and after the occurrence of transformation ratio deviation fault, respectively.

The signal waveform of transformation ratio deviation fault is shown in Figure 7.

As shown in Figure 8, the fault detection and location results can be obtained by wavelet transform of signal waveform of transformation ratio deviation fault, as shown by cD₁. Therefore, the method proposed in this paper can effectively detect and locate the transformation ratio deviation fault of ET.
**Drift Deviation Fault Diagnosis**

Drift deviation fault is the most common fault, which means a certain drift shows up in ET’s output signal. The mathematical model of fault is shown in (5):

\[
f(t) = \begin{cases} 
A \sin(\omega t + b), & t < T_f \\
A \sin(\omega t + b) + \alpha t, & t \geq T_f 
\end{cases}
\]

where \( \alpha t \) represents the deviation, thus it can be seen that the measurement deviation caused by drift deviation fault will change with time.

The signal waveform of drift deviation fault is shown in Figure 9.

As shown in Figure 10, the result of fault detection and location can be obtained by wavelet transform of signal waveform of drift deviation fault, as shown by \( cD_1 \). Therefore, the method proposed in this paper can effectively detect and locate the drift deviation fault of ET.

**Conclusion**

Accurate and effective fault diagnosis of ET can improve the reliability of power system operation. In this paper, combining with the wavelet transform which has the advantage in mutation point detection, the detection and location methods of fixed deviation fault, transformation ratio deviation fault and drift deviation fault of ET are proposed. This method consists of two stages: noise reduction and wavelet transform.

The proposed on-line fault diagnosis method based on wavelet transform is able to detect and locate ET’s fixed deviation, drift deviation and transformation ratio deviation faults that often occur but is difficult to find out. The effectiveness of proposed method is verified by simulation cases.

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