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Traction Transformer Core Multipoint Grounded Fault On-line Monitoring System

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***Abstract*—Aiming at detecting the multipoint grounded fault of the traction transformer core in real-time, a comprehensive solution including structure design, hardware scheme and software description is put forward. This scheme is implemented in a industrial PC platform. On-site operation experiences showed the early stage of transformer core multipoint grounded fault can be detected in time by means of the monitoring results with the gas chromatographic analysis.**

***Index Terms*—Traction transformer, core, multipoint grounded fault, on-line monitoring**

I. Introduction

NOWADAYS, high-speed railway prevails in China. Compared to the construction of large-scale railway infrastructure, the development of high-speed railway related electrical monitoring device relatively slow. Traction transformer is one of the foremost devices in the electrified railway. It bears the responsibility on supplying power for trains. It directly affects the level of safety and efficiency of electrified railway systems. If suffering faults, it will have great impacts on the railway transportation. Com-pared to the normal power transformer, the working conditions of the traction transformer are worse. The traction transformer has to bear the impact of overload and short circuit faults that occur much more frequently. Usually, the transient short-circuit faults on the traction transformer are 70 times per year. Therefore, the life cycle of the traction transformer is reduced significantly. Early detection and treatment are urgently needed for a variety of abnormal conditions that may endanger the normal operation of the transformer. Among which, multipoint grounded fault of the traction transformer core is one of the most usual cases.[1]

The core of the traction transformer must have a reliable earthed point during normal operation.[2] Otherwise, the core-to-ground suspended voltage will occur. However, the earthed points will form a closed loop when the core and other metal structural components have two or more earthed points, resulting in circulating current, local overheating, the decomposition of insulating oil and degradation of insulation performance [3, 4]. What's more, the silicon steel core will be burned possibly, leading to the outage due to unplanned maintenance. These scenarios will seriously threaten the safety of the railway power supply system.[5] According to statistics, the percentage of transformer damage resulting from the core (such as earthed faults or insulation faults) accounts for 57% among all trans-former damage cases. Furthermore, among all faults of traction transformers, the occurrence of core multipoint grounded fault ranks the third place. This type of faults was also reported many times in China. For example, the 2# main transformer of Pinghu traction substation of Guangzhou-Shenzhen electrified railway, which was put into operation in 21st July, 1998, experienced oil chromatogram analysis in 15th, December, 1999 and 3rd July, 2000 respectively. It was found that its total hydro-carbon value was much higher than other traction transformers. It was confirmed as an insulation fault at the core earthed point according to chromatographic analysis in 15th December 2000. As seen, the final diagnosis for the core multipoint grounded fault of this traction transformer took a complete year. Presently, the gas chromatographic analysis by means of insulating oil sampling is the primary criterion to find out potential faults, ensure the safe operation and execute the normal maintenance of large-scale transformers and other oil-filled high-voltage electric appliances. However, it cannot uniquely orientate to a multipoint grounded fault of transformer core although the method based on dissolved gas chromatographic analysis of transformer oil can more accurately capture the transformer insulation damage. In addition, the above oil-gas based method has such disadvantages as tedious step, complicated operation, and off-line analysis. Therefore, it has problems with the accuracy and timeliness of detection. As for those methods based on electrical quantities monitoring, the clamp ammeter method is commonly used. The disadvantages of this method rest with that it is susceptible to the interference, and the measurement accuracy is not ideal. The most important is that continuous monitoring cannot be achieved. To resolve these problems, a new on-line monitoring system for detecting multipoint grounded fault of the traction transformer core is studied.

II. Core Multipoint Grounded Fault On-line

This system is to reflect the operating state of the transformer core by monitoring the changes of the current flowing through the earthed wire of the core. For the core fault, especially multi-point grounded fault, the change of the current flowing through the earthed wire is particularly remarkable, which is a "qualitative" change from normal milli-ampere level to ampere level. According to this change, the abnormal conditions of transformer core grounded status can be captured in real-time, and the appropriate alarming

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signal can be issued. It should be noted that the current flowing through the earthed wire is very weak during normal operations, but it becomes very large as long as a two-point or more grounded fault occurs. Therefore, the measurement span is more than 10,000 times[6, 7] . For such a wide range of current measurement, a single current transformer is very difficult to meet the accuracy requirements. To solve this problem, two current transformers in terms of different ranges are simultaneously configured for this monitoring system. The measurement span of the high current transducer ranges from 500mA to 100A, of which the measurement accuracy is 0.5%. The measurement span of the small current transducer ranges from 1mA to 1A, of which the measurement accuracy is 1%.

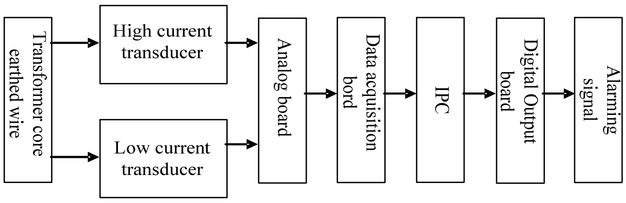

Fig. 1. System structure of traction transformer core multipoint grounded fault on-line monitoring system

The system hardware architecture consists of three parts shown in the Fig. 1, namely, the sampling module, the A/D card and Industrial Personal Computer(IPC). Two-level alarming function is configured in this system when the earth current is greater than 100mA or 300mA respectively. The device adopts industrial A/D Data Acquisition Card-PCI-1710 produced by Advantech Co. Ltd. The main parameters are as follows: 16 bit resolution, 100kHz highest sampling rate, 4k first-in first-out memory cache, and 16 channels. The real sampling rate of this system is 24 samplings per cycle [8, 9] .

The electrification railway traction load belongs to first-level load, which has different characteristics from the general power load. As the train operation process is impacted by acceleration, constant speed driving, braking and road conditions such as ramps, corners, stations, natural climate, the electrification railway traction load has its own unique characteristics as follows.

l) Magnitude of variation of the load. While the weight or speed of a large electric locomotives reach a high level, as well as an increase in train traffic or uphill operation, the traction power system load is high. According to Zhengzhou Railway Bureau records the actual situation , the load current can be up to 1000 A above ; contrarily, the load of the power supply system is very low during the rest time, low to 300A or less , sometimes even with no load (no single track electrified railway traction substation load factor of 40 to 50%) .

2) Load abrupt change. Traction power supply system for electric locomotive power to move, load changes very randomly in a strong magnitude. While the electric locomotives are up- or downhill , power may suddenly loaded or sheded , which makes the load power supply system may suddenly increase and decrease. In a power supply segment, the load may suddenly doubled due to a new electric locomotive drove into. Conversely , the load may be reduced by half due to an electric locomotive drove outside, so the traction power supply system contains a traction load which is stepped of sudden change load.

3) Non-linear . The current electric locomotive has to be driven by AC/DC rectifier, DC traction motor was typically full-wave rectified from the AC system, which is a non-linear process , it is also known as non-linear loads traction load . Traction current waveform during normal operation is generally between square wave and triangular wave, which is easy to observe that they contain a significant harmonic components . Harmonics cause additional heat, accelerated aging of the insulating medium , lower life expectancy and so on problems.

The load of the train has such characteristics as sudden change and non-linear feature, leading to remarkable unbalanced current that is very difficult to be removed completely by the connection of the traction transformer. Part of the unbalanced current is induced to the transformer core and goes through the grounded wire of the core. This current has remarkable higher harmonics, including the non-integer harmonics with high magnitude. It is very difficult to fetch the power-frequency component of it factually based on classic Fourier transform. Therefore, the device often issued wrong alarming signal when the trains passed this traction substation. With respect to one of the mal-alarming scenario, the core current is fetched based on the disturbance recorder, as shown in Fig. 2. The magnitude of the 50Hz component is calculated as 135mA based on Discrete Fourier Transform (DFT), which will trigger the alarming function [10, 11].

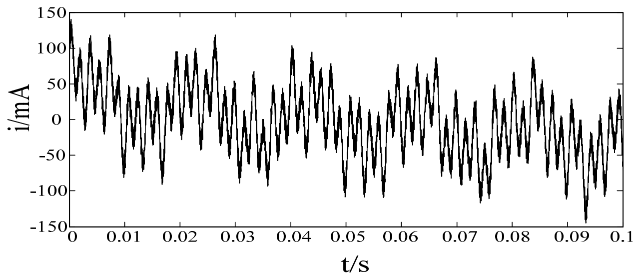

Fig. 2. The core current waveform in a mal-alarming scenario

It is learned that wavelet transform is based on Fourier transform. With reference to the short-time Fourier transform (STFT) used widely in many applications, the main difference between them is the trait of the window function used. Whatever the window function shape, the width and height of the time-frequency window of STFT are fixed for various frequencies in the Hilbert space. However, the window function of wavelet transform (WT) has the good property of ‘self-adaptive zooming’ with the change of the observed frequency. Hence, the BANDPASS filter designed with WT has wider frequency-window to contain more high frequency information when observing a high frequency signal, whereas it extends the time-window and shortens the frequency window to eliminate the high frequency interference when the center frequency is lower. Therefore, wavelet transform naturally has the eminent property to capture the complete information of the signals at any frequencies. Based on the wavelet filters, the transient signals at different frequency bands are then integrated to obtain the corresponding spectral energies. By comparison of spectral energies of the filter bank outputs, either internal or external fault can be diagnosed and if the fault is internal, relay operation will be activated to protect the transformer.

In theory, wavelet can be categorized to be real wavelet and complex wavelet. And the multi-resolution analysis (MRA) together with Mallat algorithm is prevalent in the wavelet application. The real wavelets predominate in the occasion of multi-resolution analysis although this analysis method is also applicable to the complex wavelet. It is a pity that multiresolution analysis is not applicable to extraction of two signals whose central frequencies differ from each other very much. For example, 3kHz and 80kHz. It is because that the MRA adopt frequency-dimidiating technique. In this way, many unnecessary computations will be induced when extracting the lower frequency (e.g. 3kHz) from the raw sampling in high sampling rate (e.g. 200kHz). In this sense, the complex wavelet possessing the ability to focus on any frequency directly like Fourier Transform is more suitable for the application in this paper.

Therefore, more appropriate filter should be adopted for the purpose of the extraction of 50Hz core current.

DFT is actually a short-term Fourier transform (STFT). The length and the shape of the window function are independent of time and frequency. However, in order to extract the characteristic of the signal, short time-window should be adopted to analyze the high-frequency signal while the long time-window should adopted to analyzed the low-frequency signal. STFT cannot meet this requirement of variable time-window. In contrast, the wavelet transform possesses the adaptive time-frequency window, and is promising to solve above problem. Therefore, complex Morlet wavelet is introduced to improve the extraction of 50Hz signal. The pass-band of Morlet wavelet is relatively narrow. Therefore, the effect of frequency aliasing can be reduced. The base function of Morlet is given by

$$\psi_0(t) = \frac{1}{\sqrt{\pi f_b}} e^{j2\pi f_c t} e^{-t^2/f_b} \tag{1}$$

Where, f_c is the central frequency, and f_b is the parameter to control the shape of wavelet. In scale a, the complex wavelet transformation of signal $s(t)$ is given by

$$WTs(a,b) = \frac{1}{\sqrt{\pi a f_b}} \int_{-\infty}^{+\infty} s(t) e^{-j2\pi f_c (t-b)/a} e^{-[(t-b)/a]^2/f_b} dt \tag{2}$$

In addition, selecting an appropriate analysis methods can also reduce the effects of mixing problem. In this paper, the continuous integral wavelet transform scale coefficient a were taken as 1 2 3... So although mixing phenomenon still exists, they still have apparent differences between different wavelet transform coefficients in transform spectrum diagram. Therefore this method can still be used to analyze the harmonic of system.

The result of wavelet transform is equivalent to extract the local energy characteristic of the signal. Sinusoidal waveform feature is each cycle has two energy maximum point. According to this property, we're able to draw the harmonic characteristics from sampling data, at the same time, because the Morlet wavelet in time domain is symmetrical, with linear phase, thus ensuring the wavelet transform is not distortion, therefore, can be analyzed by feature scale reconstruction signal characteristics of the corresponding harmonic.

According to the real part and imaginary part calculated by (2), the magnitude of the signal can be obtained. In the real application, the time window cannot be from $-\infty$ to $+\infty$. Aided by numerous comparative tests, the filtering effect can be highlighted with the following parameters: f_c =50Hz, a=1, $f_b = f_c/3$，time window length: 0.2s.

The magnitude of 50Hz component within the signal in Fig. 2 is calculated as 45mA based on Morlet wavelet transform, which is far below the alarming threshold. Therefore, Morlet wavelet based filter algorithm is adopted in the ultimate design.

III. Engineering Application

This system was put into operation in Qianxi substation, Datong-Qinghuangdao railway in 2009. It was installed on the SFY7-75000/110 scott traction transformer (2# main transformer). On 27th August, 2010, the core current increased from 25mA to 150mA suddenly. The alarming signal was issued accordingly to announce that a core multipoint grounded fault may occur. In this case, oil chromatographic analysis was carried out and the results were as following: 1)total hydrocarbon is much higher than the alarming setting, and its relative gas production rate is 279.3 % per month; 2) IEC three ratio coding of 5 types of various dissolved gas -in –oil is 0, 2, 1; 3) Ethylene accounts for most of the total hydrocarbon, and its gas production rate surged rapidly; 4) Acetylene did not appear. Together with the detection of sudden change of the current flowing through the core earthed wire, the core multipoint fault is confirmed. However, according to the current level, the core multipoint grounded situation is not very serious. Therefore, the outage of this transformer was not forced for maintenance immediately in line with the requirement of continuous power supply. Instead, this multi-point grounded fault was continuously monitored. On September 15th, 2010, the current monitored by the system was increased to 210mA. In this case, the maintenance plan was scheduled and the transformer was out of service for overhaul. During maintenance, the core insulation resistance measured by 2500V tramegger was nearly 0 ohm, and it was 198 ohm measured by multimeter. Therefore, the core multi-points grounded fault was confirmed. After adopting the processing method of capacitor impulsive discharging, this transformer was reconnected to the power system. The current monitored continuously by the device he current decreased to the value less than 50mA and was not increased to 100mA or above again. It suggested that the core multipoint grounded fault was removed successfully and the alarming signal was cleared.

IV. Conclusion

The sudden change of the current through the earthed wire of the core from mA level to ampere level should be the foremost symptom implying that a multipoint grounded fault possibly occurs on the core of the traction transformer. Together with the results of gas chromatographic analysis, this type of fault can be confirmed. Based on above criterion, a traction trans-former core multipoint grounded fault on-line monitoring sys-tem is proposed. The aggregate scheme and corresponding out-lines of hardware and software are provided. The on-site operating experiences demonstrated the advantages of this system at the aspect of multipoint grounded fault monitoring.

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