Analysis of Vibration Characteristic of Single-Phase Three-Limb Transformer under DC Bias

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Abstract. The analysis of vibration characteristic under DC-bias excitation is a key of improving the safety and reliability of transformers. Based on a vibration experiment of a single-phase three-limb transformer under DC bias, this paper investigate the vibration at different measuring points and analyze the spectrum of the experimental results. The results show that DC bias phenomenon will not only aggravate the vibration of the transformer, but also affect its harmonic content. With the DC current increasing to a certain extent, the speed of displacement increment slows down.

1. Introduction

With the rapid development of social economy and industrialization, the demand for electricity in production life is increasing, and the electricity consumption in society is also increasing greatly, which leads to the wide application of high-voltage level and high-capacity transformers. The installation places of transformers are gradually close to the urban areas from the suburbs, which is beneficial to reduce the electric energy loss in the electric power transmission, but the vibration generated from equipment operation can threaten the normal operation, service life and reliability of transformers. In addition, the noise will also have a negative impact on human daily life.

DC-biasd phenomenon is an abnormal working state in the operation of transformers. The geomagnetism, large current of grounding electrode in DC system are the main reasons that lead to DC current flowing into neutral grounded transformer. At present, the vibration of the main transformer in AC system around the ultra-high voltage direct current (UHVDC) system is intnese. Therefore, the research on the vibration of the power transformer under DC-biasd excitation is significant and has wide application, which can help to solve the abnormal problem of large power transformers caused by direct current, improve its safety and reliability and provide technical guarantee for the safe and stable operation of the system and the safety of the main equipment. In this paper, the vibration experiment of the single-phase three-limb transformer under DC bias is carried out and the experimental results are analyzed.

2. Analysis of vibration characteristic under DC bias

2.1. Experimental platform on vibration

The quantity describing the vibration of an object can be divided into two kinds. One is describing the strength of the vibration, including the velocity, the acceleration and the displacement. In general, the
effective value is used to represent the steady-state vibration, and the amplitude or average value are used to represent the transient vibration. Considering the convenience and accuracy of the measurement, the measured value is acceleration. The corresponding displacement can be obtained by calculating the quadratic integral of the acceleration. The other one is describing the rate of change of the vibration, including period and frequency. For different vibration forms, different representations should be selected.

Fig. 2-1 shows the single-phase three-limb transformer which is made of oriented silicon steel sheet. The excitation coils wound around side core in parallel are both 115.

The primary side of the iron core model cascades a DC source to generate DC flux in order to make the iron core operating in DC-bias state. The capacitance in parallel at both ends of the DC source prevents the DC source from being damaged by high voltage. The circuit diagram and experimental setups are shown in Fig.2-2 and Fig.2-3, respectively. The sinusoidal voltage is output by a column type voltage regulator with a range of 0V-380V. The direct current forms a circuit between the primary side of the iron core model and the secondary side of the voltage regulator.
Multipoint acquisition can be realized in the vibration experiment at the same time. Through the measurement of acceleration at different points, the distributing disciplinarian can be find. It is vital to choose suitable points for the measured results. Fig. 2-4 shows the distribution of measured points in experiment. The vibration along the transverse direction and the rolling direction are measured at point 1 and 2, respectively. Point 2 and 3 lies in Y and Z direction to measure the vibration in the rolling direction and the vibration caused by the uneven distributed magnetic flux of the iron core.

In order to describe the value of the DC bias more accurately, this paper introduce the DC-biasd coefficient K\text{dc}, which is the ratio of the peak value of the DC current to the peak value of rated no-load current.

2.2. Analysis of vibration characteristic
The acceleration at measured points is measured under different DC-biasd excitations when voltage is 210V, and the displacement and frequency spectrum can be obtained by quadratic integration and FFT transformation of acceleration time domain signal. Fig. 2-5 shows the displacement waveforms at point 1, 2 and 3 with the change of K\text{dc}. The displacement waveforms under DC bias change obviously compared with that under sinusoidal excitation, the amplitude and high order harmonics of displacement all increase.
Fig. 2-6 shows the frequency spectrum of displacement with different Kdc at point 2. The displacement is dominated by second harmonic (100Hz), the other harmonic components are less. The fundamental harmonics and high harmonics rapidly increase under DC bias, the fundamental harmonic becomes the main frequency of the displacement when Kdc is 1.6.
Fig. 2-7 shows the amplitudes of displacement at point 1 and 2 varies with the increase of DC-bias coefficient Kdc. It can be seen that the vibration is aggravated by DC bias. The amplitude increases rapidly with Kdc When Kdc is less than 1.3, the amplitude at point 2 and point 1 when Kdc is 1.3 is about 1.5 and 1.7 times of that under sinusoidal excitation, respectively. The amplitude increases slowly as Kdc continues to increase.

3. Conclusion
In this paper, the vibration characteristics of single-phase three-limb transformer under DC bias is investigated. The acceleration signal is measured and displacement is obtained by the quadratic integral of acceleration. The corresponding frequency spectrum is obtained by Fourier transform. Through the analysis of the experimental results, it can be seen that the waveform of displacement changes obviously under DC-biased excitation compared with that of unbiased. The displacement is mainly 100Hz under sinusoidal excitation, and the odd harmonic content of the displacement increases under DC bias. The increment speed of displacement amplitude slows down with the increase of DC current.

References
[1] Tanzer, T.; Pregartner, H.; Labinsky, R. Magnetostriction of electrical steel and its relation to the no-load noise of power transformers. IEEE Trans. Ind. Appl. 2018, 54, 4306–4314.
[2] Chang, Y.H.; Hsu, C.H.; Chu, H.L. Magnetomechanical vibrations of three-phase three-leg transformer with different amorphous-cored structures. IEEE Trans. Magn. 2011, 47, 2780–2783.
[3] Mohammed, O.A.; Abed, N.Y.; Liu, S. Investigation of the harmonic behavior of three phase transformer under nonsinusoidal operation using finite element and wavelet packets. IEEE Trans. Magn. 2006, 42, 967–970.
[4] Smajic, J.; Hughes, J.; Steinmetz, T. Numerical computation of ohmic and eddy-current winding losses of converter transformers including higher harmonics of load current. IEEE Trans. Magn. 2012, 48, 827–830.
[5] Maeda, H.; Harada, K.; Ishihara, Y. Performance of the magnetostriction of a silicon steel sheet with a bias field. J. Magn. Magn. Mater. 1996, 160, 149–150.