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The Method to Diagnose Local Abnormalities in Windings of High Temperature Superconducting Transformer During Load Changing

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Abstract

We propose a new monitoring system for high-temperature superconducting transformers. This system consists of pick-up coil pairs arranged outside the cryostat for measuring electric fields and magnetic fields. In a previous paper, it was confirmed that our system can detect the local abnormalities in a test transformer windings when its load doesn't change. In actual operation, however, the transformer load is always changing during practical operation. Therefore, the measured signal also changes with the load change even when abnormalities don't occur in the windings of the transformer. In this paper, we propose a method to cancel the change of the signal with the load change. In this method, our measuring signals are normalized by the power of a current. The purpose of this paper is to confirm that normalized signals don't change with the load change. Local abnormalities in the transformer windings were successfully detected and signal changes due to the changing load of the transformer were canceled.

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Keywords: transformer; monitoring system; quench; ac loss

1. Introduction

Development of high temperature superconducting (HTS) transformers is ongoing [1]. HTS transformers have the advantages of high efficiency, small size and lightweight compared with conventional transformers.

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Electric power devices such as transformers, which are used in power transmission and distribution systems, require high reliability. Therefore, these devices must be constantly monitored to check whether unusual events have occurred. Particularly in the case of HTS transformers, the importance of a monitoring system is higher than in the conventional copper transformers due to the risk of a hotspot which could be caused by both low thermal diffusivity and high current density in HTS transformers. Some quench detection systems for superconducting systems have been developed [2-6]. Although the most reliable system is the balance voltage method using center voltage taps, the system has high risks related to the occurrence of serious troubles such as high voltage sparking. Therefore systems in general use are not suitable for monitoring superconducting transformers systems [7].

In order to develop a new monitoring system with safety, reliability, sensitivity, and utility, we have proposed a new monitoring system by applying the Poynting's vector method [7-10]. We have so far shown that our system can detect local abnormalities occurring in the windings of HTS transformers when the load of the transformer doesn't change [7]. In practice, however, the transformer load always changes. Signals obtained by our system change with the change of the load for reasons mentioned in chapter 2. Therefore, it is difficult to judge which of the factors, the load or the winding conditions, lead to a change of the measured signals.

In this paper, a new method to cancel the change of measured signals with load change is proposed, and then the validity of the method is shown experimentally on a test transformer wound with Bi-2223 multifilamentary tapes.

2. Principle of the monitoring system and proposal of a new method to cancel the influence of load change on measured signal

To measure abnormalities, Poynting's vectors as electromagnetic energy flows are measured around the superconducting transformer. If some abnormalities occur in the windings, some changes in Poynting's vectors into the superconducting transformer should be observed. Therefore, the system can detect abnormalities in windings by means of monitoring temporal changes of Poynting's vectors.

The Poynting's vector, $\boldsymbol{P}$ is given by the cross-product of electric fields $\boldsymbol{E}$ and magnetic fields $\boldsymbol{H}$ ($\boldsymbol{P} = \boldsymbol{E} \times \boldsymbol{H}$) around the transformer. $\boldsymbol{E}$ and $\boldsymbol{H}$ can be obtained by using pick-up coils as shown in Fig. 1. There are two kinds of pick-up coils for measuring local electric fields and local magnetic fields (hereafter we call these pick-up coils, PC-E and PC-H, respectively). Details of the method to measure electric fields have been explained in Refs. [8-10]. The energy flows per cycle W is calculated by one cycle integration of $\boldsymbol{P}$. W is the loss component of energy flow (hereafter called LEF) [7]. Therefore, LEF corresponds to ac losses in the winding. If abnormalities occur in the windings of the transformer, ac losses are affected by the abnormalities. So a change of LEF is observed. Therefore, it is necessary to measure the loss component of the signal voltages from PC-E. In this system, the inductive component of the signal voltage from PC-E is cancelled by using the signal voltage from PC-H.

Ac losses in the windings of the transformer are influenced by both temperature and magnetic fields. Magnetic fields change with change of the load. Therefore, LEFs are affected by temperature and load. Consequently, it is difficult to judge which of the load or the condition of windings lead to a change of the measured signals.

In general, the ac loss properties of HTS transformers can be expressed as the power function of the load currents [11]. Therefore, it is considered that measured signals from our system can also be expressed as the power function of the load currents. It indicates that the measured signals divided by the power of the currents are identical. So, our proposed new method to cancel influences of load change on measured LEFs is to normalize the LEFs by the power of a current.

3. Experiments

3.1. Experimental set up

The experiments were carried out for the small size HTS transformer shown in Table 1. The rated power of this transformer is 800 VA. The rated voltages and currents of primary/secondary windings are 22.5/45 V and 35.6/17.8 A, respectively. Leakage impedance of this transformer is 7.0 %, which in comparison is equal to or smaller than devices currently used. The winding tape is Bi-2223 multifilamentary tape whose critical current is 115 A in self