Physica C: Superconductivity and its applications 527 (2016) 50–54

Contents lists available at ScienceDirect

Physica C: Superconductivity and its applications

journal homepage: www.elsevier.com/locate/physc

Recovery time of high temperature superconducting tapes exposed in liquid nitrogen

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ARTICLE INFO

Article history:
Received 8 January 2016
Revised 2 May 2016
Accepted 23 May 2016
Available online 24 May 2016

PACS:
74.25;-q
85;25-j

Keyword:
Recovery time
Superconducting tapes
Boiling heat transfer
Optimization strategy

ABSTRACT

The recovery time is a crucial parameter to high temperature superconducting tapes, especially in power applications. The cooperation between the reclosing device and the superconducting facilities mostly relies on the recovery time of the superconducting tapes. In this paper, a novel method is presented to measure the recovery time of several different superconducting samples. In this method criterion used to judge whether the sample has recovered is the liquid nitrogen temperature, instead of the critical temperature. An interesting phenomenon is observed during the testing of superconducting samples exposed in the liquid nitrogen. Theoretical explanations of this phenomenon are presented from the aspect of heat transfer. Optimization strategy of recovery characteristics based on this phenomenon is also briefly discussed.

1. Introduction

The recovery characteristic of superconducting materials is a crucial indicator in power application, especially in power systems which contain reclosing facilities. Plenty of previous researches are carried out to quantize the recovery time of different superconducting tapes under no-load or loading conditions. Voltage waveforms over the superconducting tapes under DC current [1], AC current [2-3], or impulse current [4] are used to detect whether the superconducting materials have recovered. However, in these methods, the amplitude of the detecting current is much smaller than the critical current (I_c) of superconducting tape in rated condition (77 K for the liquid nitrogen bath). This means the superconducting tape is considered to recover when the temperature only returns to superconducting state (below the critical temperature T_c) [2]. If the recovery time obtained by these traditional methods is used in design of reclosing system, the superconducting facilities probably do not completely recover to the rated state during reclosing. This may lead to some risks in the operation of superconducting facilities, and also influence the stability and safety of the entire power system. However, if the amplitude of detecting current is set to I_c or a larger value, additional heat will generate during recovery process, and lead to longer recovery time [2]. If this recovery time is used to design the reclosing system, it may bring some difficulties to the setting of reclosing system and also lead to higher fundamental investigation.

A novel method based on a sequence of AC pulses will be introduced in this paper. The amplitude of the AC pulse is set to 1.2 times of I_c, the shape of the voltage waveform over the superconducting tape is used as the criterion to judge whether it has completely recovered to the rated state. This method is performed to several different superconducting samples, so as to discuss the influence of stabilizer and encapsulating technic. An interesting phenomenon is monitored that the recovery time does not increase with the amplitude of the fault current when the superconducting sample is directly exposed to the liquid nitrogen. Discussions on this phenomenon are presented from different aspect of views; optimization strategy of recovery time based on this phenomenon is also performed.

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http://dx.doi.org/10.1016/j.physc.2016.05.021

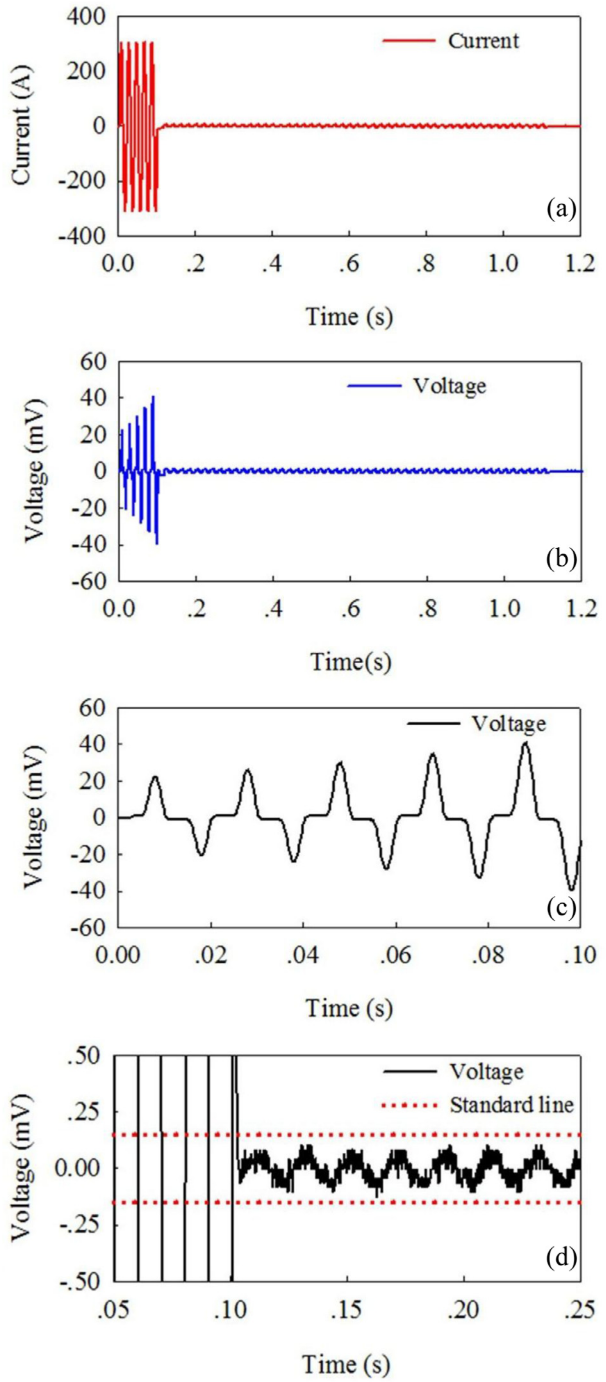

Fig. 1. Typical waveforms of the traditional recovery time testing method: (a) Current curve of the entire process; (b) Voltage curve of the entire process; (c) Voltage curve of the overcurrent process; (d) Voltage curve obtained by acquisition system with high accuracy.

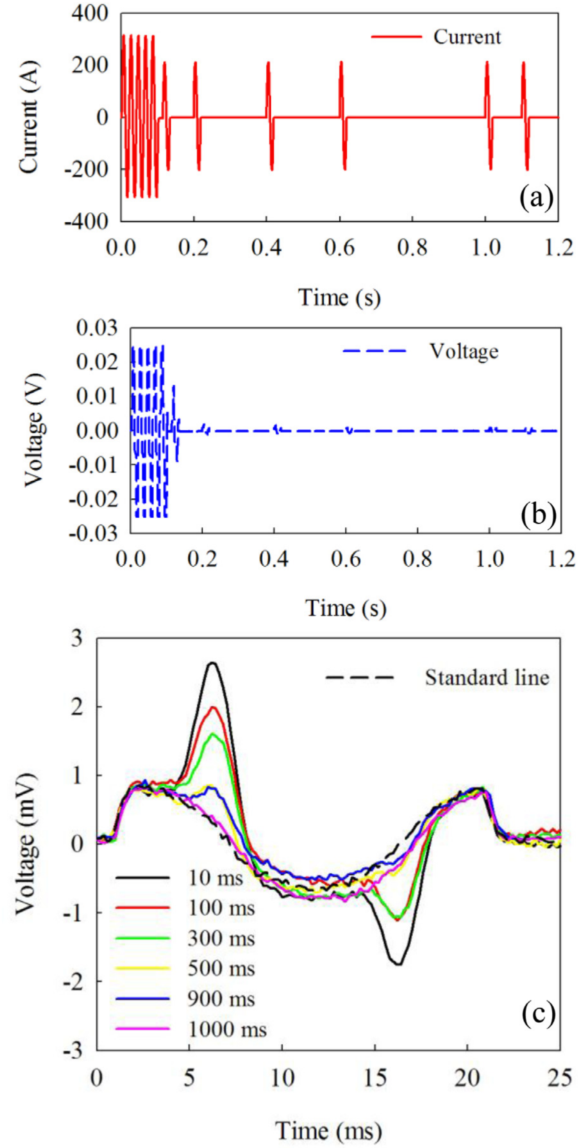

Fig. 2. Typical waveforms of the novel recovery time testing method: (a) Current curve of the entire process; (b) Voltage curve of the entire process; (c) Comparison of voltage curves under different time intervals.

2. Experiment setup

The typical waveforms of the traditional testing method are shown in Fig. 1. The power supply in this testing platform is a high capacity current source controlled by a user-define all function signal generator. The current waveform shown in Fig. 1 (a) consists of two parts: the 5 duties overcurrent part and a long-term small current part. The voltage waveforms over the HTS sample are shown in Fig. 1 (b)-(d), these voltage waveforms are obtained by two acquisition systems with different accuracies. The standard line shown in Fig. 1 (d) is used to judge whether the sample has recovered, and Fig. 1 (d) shows an immediately recovery process of the superconducting tape in traditional methods.

The novel method is performed in the same testing platform; the only difference is that a sequence of large current pulses is used instead of the long-term small current. The amplitude of the current pulse is 1.2 I_c, current and voltage waveforms of this method are shown in Fig. 2 (a) & (b), the voltage waveforms during each pulse are obtained and shown in Fig. 2 (c). The overcurrent characteristic of the sample (1.2 I_c @77 K) is pre-tested and set as the standard line in Fig. 2 (c). It is clearly shown in Fig. 2 (c) that shapes of the voltage waveforms go closer to the standard line when the time interval increases, and after 1000 ms, the voltage waveform becomes the same as the standard line and does not change with the time interval, so the recovery time in Fig. 2 is determined to be 1000 ms.