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Thermal design of external bypass for ITER poloidal field converter

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ABSTRACT

The main objective of our investigation has been to survey thermal condition of equipment working in high power state work. A theoretical thermal model has been developed for the thermal design of external bypass. The junction temperature of thyristor, thermal stability and heat distributions of arms have been numerically studied. The peak junction temperature decreases with the parallel number of thyristor increases, while the parallel number is limited to the current sharing distribution. The calculated results indicate that the external bypass has excellent potential power performance and reliability. It has also been found that the temperature of stainless steel arms is highest and the bypass can work again after its first work in 390 s when all units return initial temperature. The test results show that thermal condition of the prototype is consistent with the analysis data. The research has resulted in a solution of high-power equipment.

1. Introduction

ITER, which is a large-scale scientific experiment intended to prove the viability of fusion as an energy source, is currently under construction in the south of France. In an unprecedented international effort, seven partners—China, the European Union, India, Japan, Korea, Russia and the United States—have pooled their financial and scientific resources to build the biggest fusion reactor in history [1]. The poloidal field (PF) converter module plays an important role in the plasma shape and position control in vertical and horizontal direction [2,3].

In most studies of equipment working in high power state work, thermal stability has been emphasized with attention. In the course of PF converter normal work, there may be ripple current in busbars [4], which poses a severe threat to the operation of PF converter. More seriously, fault current up to 350 kA may exhibit when the misfiring fault occurs in bypass circuit, which is shown in Fig. 1 [3]. Moreover, thyristor may be damaged with the quick increase rate of the fault current and the concomitant induced heat. Experiments of this kind have rarely been performed.

Thermal stability must be considered for the high short-circuit current [3]. In this paper, based on the fault analysis, the external bypass should be designed to provide and test the protection of PF converter under the worst fault condition [4].

In the paper, several different models are built to address these issues and to improve the thermal stability. First, the analysis of thyristors is presented; then the analysis of cooling water system is described based on theoretical calculation, lastly, the experiment results are introduced and the conclusion is given.

2. Analysis method

2.1. Thyristor analysis

From analysis, the maximum fault current of external bypass is up to 350 kA, and there should be no fault propagation and no deformation of the mechanical structure in the test. It is shown in Fig. 2. For bypass arms, thyristors connected in parallel for avoiding misfiring have been considered. The parallel number of thyristor should be analyzed at first [4,5].

As described in precious papers, the transient thermal impedance curve and the classical RC ladder thermal model can be used. It is a novel, highly accurate method of establishing the parameter values for the series connection simple parallel RC mode. The thermal equivalent circuit is illustrated in Fig. 3. The transient thermal impedance, which represents the power dissipation, is the transient response of voltage T_{vj}. When thyristor works, the voltage T_{vj} will be a unit step function of circuit current [6].

$$Z_{thjc}(t) = \sum_{i=1}^{4} R_{thi}(1 - e^{-t/\tau_i}) = R_{th1}(1 - e^{-t/\tau_1}) + R_{th2}(1 - e^{-t/\tau_2}) + R_{th3}(1 - e^{-t/\tau_3}) + R_{th4}(1 - e^{-t/\tau_4}) \quad (1)$$

$$T_{vj} = T_c + R_{thja}P_{tot} + (R_{thjc} + R_{thjch} + R_{thha})P_{th} \quad (2)$$

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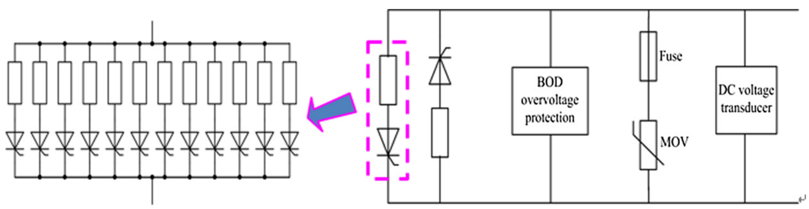

Fig. 1. Circuit of external bypass.

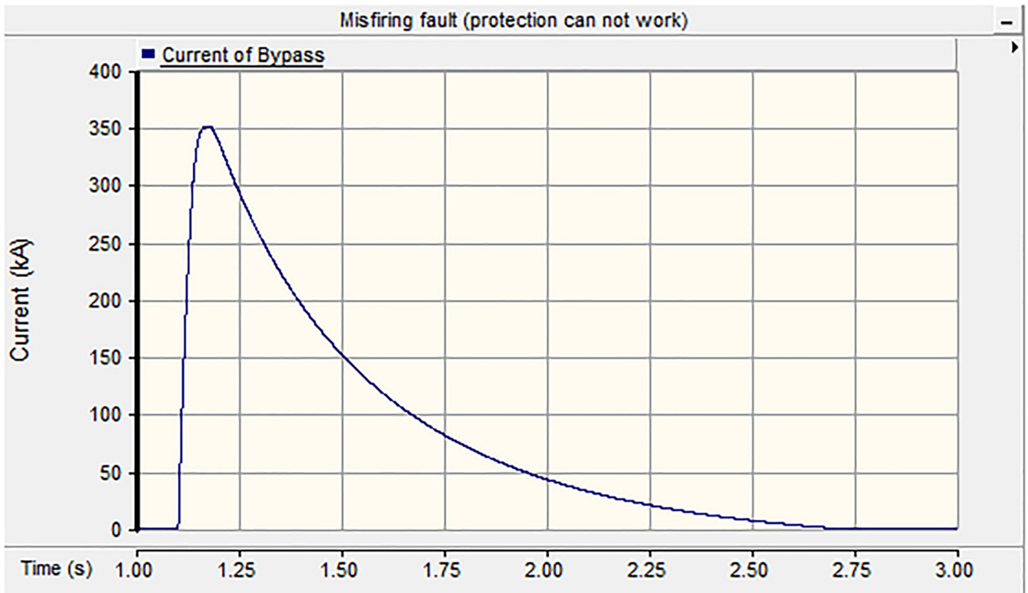

Fig. 2. The current of bypass in misfiring fault.

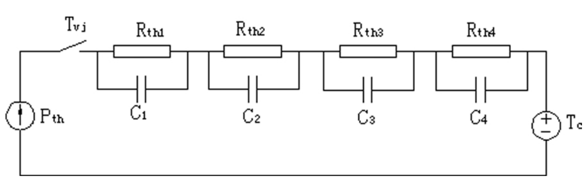

Fig. 3. RC ladder thermal model.

Where

R_{th} Thermal resistance;

Z_{th} Thermal resistance and capacitance;

T_c The shell temperature of thyristor;

P_{th} The dissipation power.

In formula (1) and (2), the various thermal resistance and capacitance are configured as illustrated, and the voltage T_{vj} is equivalent to the virtual junction temperature of the device [7,8].

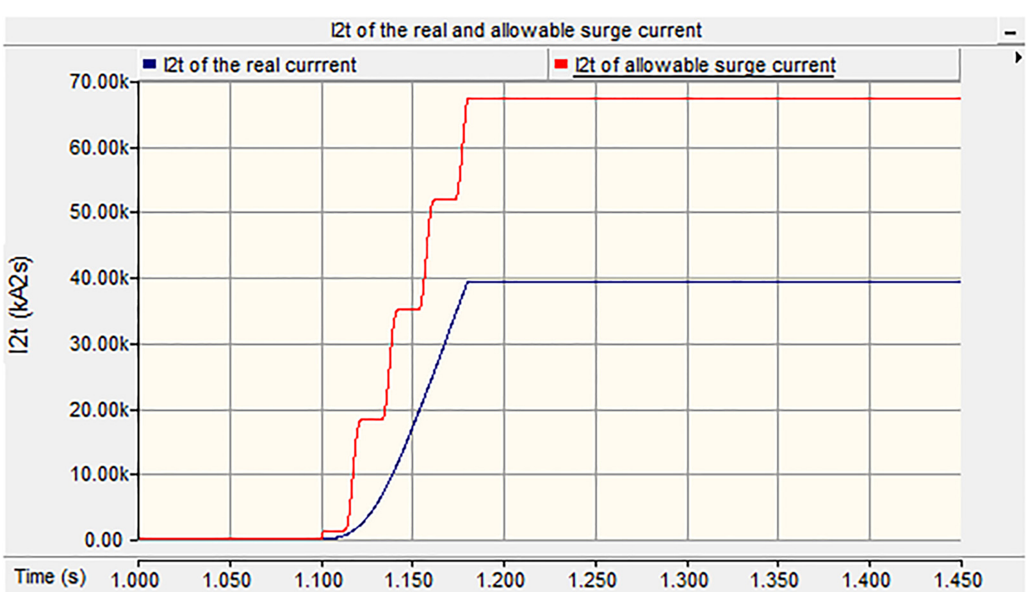

Fig. 4. The I^2t of the thyristor (12 thyristors in parallel).