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Research Article

Research on Equivalent Circuit Model of HVDC Valve and Calculation of Thyristor Junction Temperature

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For the difference of thyristor junction temperature at all levels in the transducer valve assembly in the series water circuit, an equivalent model of thyristor junction temperature calculation for the valve assembly is established, and PLECS simulation software is used to simulate and solve the junction temperature at all levels of the thyristor and check the junction temperature of the thyristor from the highest temperature of the measured radiator surface, and the results of the junction temperature checking show that the equivalent model of thyristor junction temperature calculation for the valve assembly has a high accuracy.

1. Introduction

The converter valve is the core equipment in the high-voltage DC transmission system, and the performance of the converter valve is directly related to the reliability of the entire high-voltage DC transmission system, which in turn affects the safe and stable operation of the power grid. Currently, the converter valve is composed of a certain number of thyristors connected in series. As a power semiconductor device, the thyristor's operational performance and the junction temperature of the thyristor (i.e., the temperature of the internal silicon wafer) are closely related. As the junction temperature increases, the thyristor's voltage blocking ability declines, the reverse recovery of the charge increases, the shutdown voltage overshoot increases, the shutdown time is extended, and the life expectancy is reduced. Therefore, considering the influence of thyristor junction temperature on the operation reliability and service life of a high-voltage direct current (HVDC) converter valve, it is necessary to calculate and verify the junction temperature of thyristor in a high-voltage direct current transmission project.

There are many methods to calculate the junction temperature of a thyristor, and the main methods are the equivalent circuit model method [1] and the finite element analysis method. The temperature response curve of the device is characterised by fast response and long duration. Various temperature measurement techniques and the electrical method have obvious advantages in the acquisition and storage of measurement data, so the equivalent circuit modelling method is usually used for the measurement of the temperature response curve. In the literature [2], the physical structure of the thyristor is known.

In literature [2], under the condition that the physical structure of the thyristor is known, the finite element method is used to solve the thermal impedance of the thyristor case by establishing the physical equations of heat conduction as well as the boundary conditions and the initial conditions model, but the calculation of the junction temperature by using the finite element method takes a long time.

However, the finite element method is time-consuming to calculate the junction temperature, and there is no advantage of the electrical method in the acquisition and storage of measurement data; the literature [3] uses the heat conduction equation to solve the thermal impedance of each material layer of the thyristor to obtain the two-port network parameters in the complex frequency domain and transforms the two-port network parameters into the corresponding Foster network.

The two-port network parameters are transformed into the equivalent circuit of the corresponding Foster network structure and finally converted into a Cauer model, and finally, the Cauer network model of each material layer is cascaded to form the overall thermal impedance Cauer model of the thyristor. In this paper, the Laplace variation of the thermal impedance curve in the time domain is transformed into the frequency domain and then into the time domain after calculation to obtain the Foster network model of each material layer. In this paper, the Foster network model of each layer of material is obtained directly through the derivation and calculation of the differential equation of thermal conductivity without frequency domain analysis. The thermal transient characteristics of the thyristor can reflect many of the internal characteristics of the device, and similarly, the internal characteristics of the thyristor are also reflected by the thermal transient characteristics [4, 5]. There are two main equivalent circuit models for junction temperature calculation of thyristors, Foster model and Cauer model. The Foster model parameters are obtained by fitting the transient temperature response curve of the thyristor to the circuit model. The transient temperature response curve is the rise in transient thermal resistance (or temperature rise) in the active region with power duration after applying a step power to the thyristor. This curve is cumbersome and prone to measurement bias in practical measurements [6]. The Cauer network model is obtained by network equivalent transformation from the Foster network model. In this paper, according to the specific structural dimensions and material properties of the thyristor, the time-domain mathematical model reflecting the transient thermal impedance of the thyristor and the corresponding equivalent circuit model are established through the differential equation of heat conduction of the thyristor.

In this paper, the thermal impedance model of the transducer assembly is established for the transducer assembly of the series water circuit, taking into account the difference of the inlet and outlet temperatures of the radiators on both sides of each thyristor, and the junction temperature of each thyristor is solved, and then, the junction temperature of the thyristor is obtained from the calculation of the temperatures of the radiators and the thyristor contacting surfaces, and the junction temperature of the thyristor is calculated and calibrated.

2. HVDC Converter Valve Assembly Structure

HVDC converter valves are generally composed of several valve assemblies of the same structure connected in series, each valve assembly consists of a valve reactor and several thyristors connected in series, and the cooling water circuit of the valve assembly is shown in Figure 1.

The thyristors are cooled by means of a liquid-cooled heat sink, where the coolant first flows into the valve reactor and cools the valve reactor coil. It flows sequentially into radiators 1, 3, 5, and 7, then into radiator 8, and back from radiator 8, sequentially into radiators 6, 4, and 2 and finally out of the valve assembly from radiator 2. Since the coolant flows through each heat-generating element in the valve assembly in turn, this cooling water circuit is also called a series water circuit, and this series water circuit structure can make the difference in the average value of the inlet water temperature of the radiators on both sides of each thyristor be minimised, that is to say, ultimately realising the purpose of minimising the difference in the junction temperatures of all levels of thyristors in the valve assembly.

3. Thyristor Junction Temperature Calculation

In view of the differences in the junction temperatures of the thyristors at each level of the valve assembly in a series water circuit structure, it is necessary to identify the thyristor at the level with the highest junction temperature, and it is necessary to ensure that the junction temperature of that level of the thyristor does not exceed the upper limit of its permissible junction temperature.

Considering the similarity between the heat flow in the thermal circuit and the current in the circuit in the way of propagation, there is a dyadic relationship between the corresponding physical quantities in the thermal circuit and the circuit [7], as shown in Table 1. Thus, the equivalent circuit method can be adopted to transform the heat propagation equation into the corresponding circuit equation, and the voltage, i.e., the temperature, in the circuit equation can be obtained by solving the system of equations.

The power loss and junction temperature of a thyristor increase immediately during overload operation. The heat generated is transferred to the thyristor case through the silicon wafer, alloying layer, molybdenum wafer and copper base, and then to the external environment through the peripheral heat sink of the thyristor. In the steady state condition, the heat flow (Q), temperature difference (ΔT), thermal resistance (R) and thermal capacitance (C) are equivalent to the electric flow (I), potential difference (U), resistance (R) and capacitance (C) in the circuit theory, respectively, which can be used in the circuit of the basic law to establish the relationship between heat transfer in the thermodynamics. That is, the thermal resistance (K/W) is expressed as the temperature difference between two cross-sections per unit of time per unit of power per unit of cross-sectional area of the heat transfer medium. That is,

$$R_{\mathrm{th}} = \frac{T_j - T_0}{P}, \tag{1}$$

where P is the heat generated in the thyristor (power loss) kW; T_j is the temperature of the thyristor junction, °C; T_0 is the temperature of the external environment, °C; and R_{th} is the total thermal resistance from the thyristor junction to the thyristor housing and from the thyristor housing to the external environment.

If the role of heat dissipation is not taken into account, then R_{th} is the heat bound to the shell resistance and T_0 is the temperature of the thyristor housing.

The thyristor junction temperature at steady state is obtained as

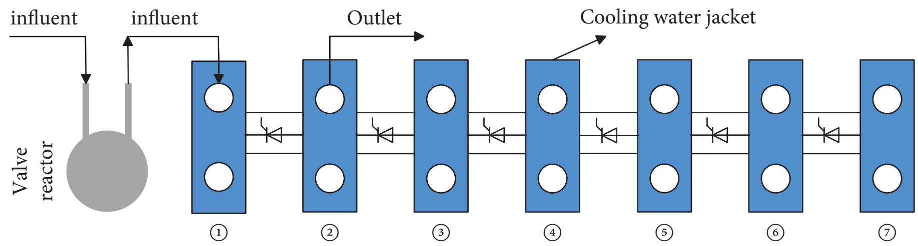

FIGURE 1: Schematic diagram of the water circuit of the diverter valve assembly.

TABLE 1: Correspondence between physical quantities of thermal and electric circuits.

Circuits	Resistive	Capacitors	Amps	Input voltage
Thermal circuit	Thermal resistance	Thermal capacity	Heat flow	Temperature

$$T_j = T_0 + \mathrm{PR}_{\mathrm{th}}. \tag{2}$$

According to the series water circuit structure, the establishment of all levels of thyristor junction temperature calculation equivalent circuit diagram is shown in Figure 2. P_t denotes the thyristor power consumption, for all levels of thyristor junction temperature; $T_{j1}, T_{j2}, \ldots\ldots, T_{\mathrm{jn}}$ denotes all levels of thyristor junction temperature; $P_{\mathrm{i}L(R)}$ denotes all levels of thyristor passed to the left (right) of the power consumption, $= 1 \sim n$, R_j denotes the thyristor single-sided heat dissipation of the case thermal resistance; R_s denotes the heat sink thermal resistance; $T_{\mathrm{in}1}, T_{\mathrm{in}2}, \ldots\ldots, T_{\mathrm{in}7}$ denotes the radiator water temperature, and $m = n + 1$.

Assuming that the power consumption transferred from thyristor no. 2 to cooling water jacket no. 2 is P_{2L} and the power consumption transferred to cooling water jacket no. 3 is P_{2R}, the following equation can be listed:

$$\begin{cases} T_{j2} - T_{s2} = R_j \times P_{2L}, \\ T_{j2} - T_{s3} = R_j \times P_{2R}, \\ P_{2L} + P_{2R} = P_t, \end{cases} \tag{3}$$

where R_{j} is the casing thermal resistance of the thyristor heat dissipation; P_t is the power consumption of the thyristor; T_{s2} is the temperature of the cooling water jacket No. 2, and T_{s3} is the temperature of the cooling water jacket No. 3. Equation (3) can be simplified to obtain the junction temperature of the thyristor 2 calculated as follows:

$$T_{j2} = \frac{(T_{s2} + T_{s3}) + R_j \times P_t}{2}. \tag{4}$$

3.1. Characteristics of Thyristor Heat Transfer. The thyristor adopts double-sided heat dissipation technology, with the silicon chip as its heat source and molybdenum and copper sheets on both sides of the silicon chip, with the thickness of the materials on both sides [8].

The 5 layers are crimped or cold-welded together to form a single layer.

The side is sealed by a ceramic ring, which insulates and protects it from the elements.

The action of the ceramic ring and the internal approximate conductor is filled with a certain pressure between the ceramic ring and the internal approximate conductor.

The insulating properties are guaranteed by the inert gas within the thyristor. Depending on the structure of the thyristor and the heat dissipation mechanism, the heat transfer characteristics of the thyristor can be obtained as shown in Figure 3.

(1) The thyristor wafer is the centre, and both sides are of symmetrical structure, so the consideration of heat conduction is only one side of the heat conduction, and the wafer is divided into two equal pieces, the middle side as an adiabatic layer to consider.

(2) The sides of the silicon, molybdenum, and copper wafers can be regarded as adiabatic cases because of the relatively low thermal conductivity of ceramics and inert gases.

(3) As the thyristor conduction, the silicon wafer is a heat source, according to the characteristics of the electric field distribution inside the thyristor, and the silicon wafer is thin and is regarded as a uniform heat generator.

(4) Since the sides are adiabatic, the heat transfer of the transistor is unidirectional in the direction normal to the centre surface. At the same time, the surface of the copper is treated as a thermostat because it is connected to the copper sheet as a heat sink.

3.2. Foster and Cauer Circuit Network Model Analysis. In the Foster [9] network structure, a resistor and a capacitor are connected in parallel as the basic unit, and several basic units are connected in series to form the Foster network model. R_1 denotes that the Foster network model is based on a resistor and a capacitor connected in parallel, and several basic units are connected in series to form the Foster network model. C_1 and R_2 represent a basic unit, and C_2 also represents a basic unit, as shown in Figure 4(a). The basic unit of the Cauer network structure is a grounded capacitor plus a resistor. In Figure 4(b), R_1 and C_1 represent a basic unit of the Cauer network structure, and R_2 and C_2 also represent a basic unit. The port node voltage in Figure 4 represents the junction temperature, the step current source represents the heat flow generated by the thyristor wafer, and the resistance and

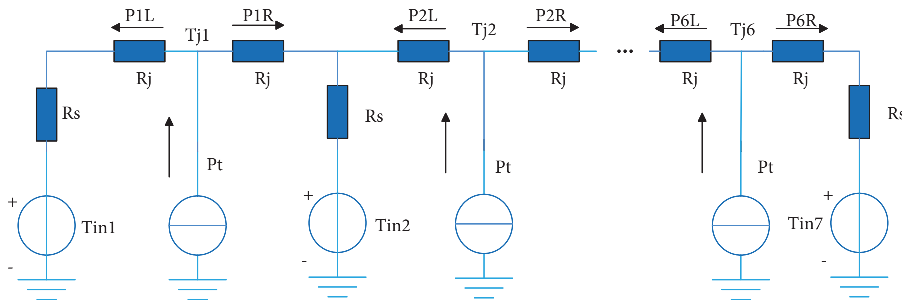

Figure 2: Equivalent circuit diagram for valve assembly transistor junction temperature calculation.

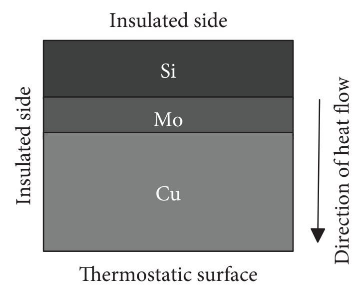

Figure 3: Thyristor heat transfer characteristics.

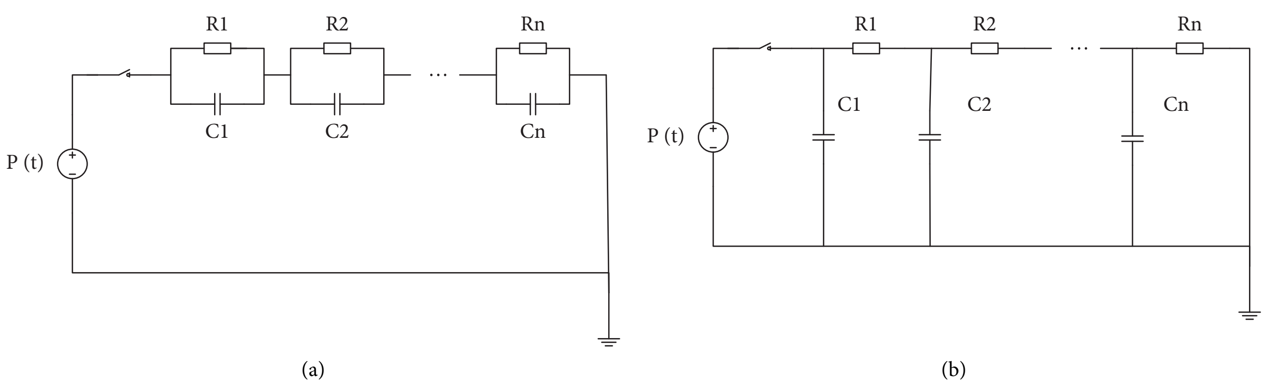

Figure 4: Foster and Cauer network structure. (a) Foster network structure. (b) Cauer network structure.

capacitance represent the resistance and capacitance in the first few basic cells, which functionally correspond to the thermal resistance and heat flow in the thermal circuit.

The Foster network cannot be used as a real thermal resistance network because its capacitance is the corresponding point-to-point specific heat capacity, and there is no actual meaning. The capacitance in a Cauer network is the capacitance of a node to ground, which can be considered as a discrete heat flow structure, and converting the Foster network into a Cauer network is more reflective of the actual thermal resistance.

3.3. Calculation of Parameters in the Model. Remembering the original data series as the heat conduction equation obtained through its corresponding initial and boundary conditions, it is possible to explore the mathematical solution of some typical problems containing partial differential equations. Since the heat conduction equation is linear and chi-square case, it can be solved by applying the separated variable method. For cylindrical copper plates with a length of L, the conditions for steady heat flow density and heat transfer involve one side with steady temperature and the other side with steady heat flow (assuming zero degrees for ease of calculation). It is assumed that each transverse circular surface is a thermostatic surface, and that there is a side $x = 0$ that stabilizes the heat flow and a side $x = L$ that stabilizes the temperature. The temperature of the copper material, $u = u(x, t)$, is a function of distance and time. It is possible to obtain the following differential equation (10):

$$\begin{cases} \dfrac{\partial u}{\partial t} = K\dfrac{\partial^2 u}{\partial x^2}, & 0 < x < L, t > 0, \\ \dfrac{\partial u}{\partial x} = -\dfrac{Q}{k}, & x = 0;\ u = 0, x = L, \\ u(x, 0) = 0, & 0 < x < L, \end{cases} \tag{5}$$

where u denotes the point material temperature; t is the time; x is the distance; introduced thermal diffusivity $K = k/(\rho c)$; k is the thermal conductivity; ρ is the density; c is the specific heat capacity; and Q is the heat transfer per unit area per unit time. Equation (5) is a system of partial differential equations that are not chi-square and should be solved as a system of chi-square equations. Let

$$u(x,t) = u_s(x) + v(x,t). \tag{6}$$

Among them,

$$u(x,t) = -\frac{Q}{K}x + \frac{LQ}{k}. \tag{7}$$

A new system of chi-square partial differential equations is obtained:

$$\begin{cases} \dfrac{\partial v}{\partial t} = K\dfrac{\partial^2 v}{\partial x^2}, & 0 < x < L, t > 0, \\ \dfrac{\partial v}{\partial x} = 0, & x = 0;\ u = 0, x = L, \\ v(x,0) = -u_s(x), & 0 < x < L. \end{cases} \tag{8}$$

Eventually, it is possible to find

$$\begin{aligned} u(x,t) &= u_s(x) + v(x,t) \\ &= -\frac{Q}{K}x + \frac{LQ}{k} + \sum_{n=0}^{\infty}\frac{2Q}{Lk} \\ &\quad \cdot \left\{\frac{1}{(n+(1/2))\pi/L}\left[L - \frac{(-1)^n}{(n+(1/2))\pi/L}\right] - \frac{L^2}{(n+(1/2))\pi}\right\} \\ &\quad \times \sin\frac{(n+(1/2))\pi(L-x)}{L}e^{-K[(n+(1/2))\pi/L]^2 t} \\ u(0,t) &= \sum_{n=1}^{\infty} r_n\left(1 - e^{-(t/r_n c_n)}\right). \end{aligned} \tag{9}$$

Among them,

$$\begin{cases} r_n = \dfrac{8L}{k\pi^3(2n-1)^2}, \\ c_n = \dfrac{\rho c \pi L}{2}. \end{cases} \tag{10}$$

3.4. Calculation of Crust Thermal Resistance. After the Cauer model has been established, the thermal resistance and heat capacity of each order can be determined according to the thyristor manual (in general, the first- or second-order parameters can be modelled better), and the equivalent crustal thermal resistance at any point in time can be determined by using the following equation:

$$Z_t(t) = \sum_{i=1}^{n} z_i\left(1 - e^{(t/\tau_i)}\right), \tag{11}$$

where z_i is the sum of equivalent thermal resistance and heat capacity of each order; τ_i is the thermal time constant of each order; and n is the order of the model.

3.5. Calculation Method of Converter Valve Loss. The commutator valve consumes electrical power and generates a lot of heat during normal operation.

The junction temperature of the thyristor is determined by the total power loss and the amount of heat dissipated [10]. Excessive junction temperature may result in false conduction or thermal breakdown damage to the thyristor valve, so the junction temperature of the thyristor should not exceed its maximum allowable junction temperature [11].

Thyristor losses include both pass-state losses and dynamic losses.

$$P_{TH} = P_{TH0} + P_t, \tag{12}$$

where P_{TH0} is the thyristor on-state loss, kW, and P_t is the thyristor dynamic loss, kW.

The through-state loss is determined by the parameters of the thyristor and the operating parameters. Its standard calculation formula is as follows [9]:

$$P_{TH0} = \left[U_0 + R_0 \times I_d \times \left(\frac{2\pi - \mu}{2\pi}\right)\right] \times \frac{I_d}{3}, \tag{13}$$

where I_d is the DC current, kA; U_0 is the current-independent part of the average on-state voltage drop of the thyristor (referred to as the threshold voltage), V; R_0 is the slope resistance in the average on-state volt-ampere characteristic of the thyristor (referred to as the slope resistance), mΩ; and μ is the phase-change angle, rad. In the actual calculations, due to the complexity of the calculation of the phase-change angle of the 12-vehicle phase-controlled commutator valve, the change of the triggering angle has little impact on the loss; in order to simplify the calculations, equation (13) is usually simplified by ignoring the sub-formula containing μ. In order to simplify the calculation, we usually ignore the equation containing μ, and we simplify equation (13) as follows:

$$P_{TH0} = [U_0 + R_0 \times I_d] \times \frac{I_d}{3}. \tag{14}$$

The dynamic loss is related to the thyristor turn-on and turn-off time, turn-on and turn-off frequency, and the operating state of the work, usually according to the specific operating conditions of the converter valve and the control mode to take the empirical value [12].

For the circuit diagram shown in Figure 2, the corresponding circuit model can be established, in which the power consumption of the thyristor can be equated with a current source, and the inlet water temperature of the radiator is equated with a voltage source. The inlet water temperature of the radiator is directly related to the power consumption of the thyristor, and the inlet water temperature of the radiator can be calculated according to equation (15) for a valve assembly with 7 levels of thyristors connected in series, for example,

$$\begin{cases} T_{\text{in1}} = \dfrac{T_{\text{in}} + P_{\text{reactor}}}{(C \times \rho \times L)}, \\ T_{\text{in3}} = \dfrac{T_{\text{in1}} + P_{1L}}{(C \times \rho \times L)}, \\ T_{\text{in5}} = \dfrac{T_{\text{in3}} + (P_{3L} + P_{2R})}{(C \times \rho \times L)}, \\ T_{\text{in7}} = \dfrac{T_{\text{in5}} + (P_{5L} + P_{4R})}{(C \times \rho \times L)}, \\ T_{\text{in8}} = \dfrac{T_{\text{in7}} + (P_{7L} + P_{6R})}{(C \times \rho \times L)}, \\ T_{\text{in6}} = \dfrac{T_{\text{in8}} + P_{7R}}{(C \times \rho \times L)}, \\ T_{\text{in4}} = \dfrac{T_{\text{in6}} + (P_{6L} + P_{5R})}{(C \times \rho \times L)}, \\ T_{\text{in2}} = \dfrac{T_{\text{in4}} + (P_{4L} + P_{3R})}{(C \times \rho \times L)}, \end{cases} \tag{15}$$

where P_{reactor} is the power consumption of the valve reactor; C is the coolant specific heat capacity; ρ is the coolant density; L is the coolant flow rate; and T_{in} is the temperature of the inlet water for the valve assembly. To take a converter valve as an example, the valve assembly has a thyristor series level of 7, a thyristor loss of 4.39 kW, a valve reactor loss of 3.33 kW, and the coolant used is pure water. The water temperature entering the valve is 46°C, with a flow rate of 60 L/min. All levels of thyristor junction temperature calculations are shown in Table 2.

According to the calculation results in Table 2, it can be seen that the valve assembly is located in the heat sink.

The highest junction temperature was found in thyristor #4 between devices 4 and 5, and the lowest junction temperature was found in the thyristor at the edge of the valve assembly. The difference in junction temperature between the different levels of the thyristors was 4.6°C.

4. Thyristor Junction Temperature Calibration

4.1. Calculation of Junction Temperature. The calculations above show that the highest junction temperature is found in thyristor 4, which is located in the middle of the valve assembly. Therefore, a slot was cut in the radiator surface on both sides of thyristor 4, and a temperature measurement fibre was embedded to measure the temperature of the surface of radiators 4 and 5 by fibre-optic measurement.

The maximum continuous operation test of the converter valve assembly was carried out on the synthetic test circuit: test current 5 300 A, test voltage 22.4 kV, inlet valve water temperature adjusted to 46°C, and flow rate 60 L/min, and the results of the bench-top temperature test of radiators 4 and 5 are shown in Table 3.

The measured maximum temperature $T1$ of the radiator table is used to calibrate the junction temperature of thyristor no. 4. Assuming that the power consumption of thyristor no. 4 transferred to radiator no. 4 is P_{4L} and that the power consumption transferred to radiator no. 5 is P_{4R}, the following equation can be listed according to the equivalent model as shown in Figure 2:

$$\begin{cases} T_{j4} - T_{s4} = R_j \times P_{4L}, \\ T_{j4} - T_{s5} = R_j \times P_{4R}, \\ P_{4L} + P_{4R} = P_t, \end{cases} \tag{16}$$

where T_{s4} is the maximum table temperature of the radiator 4 and T_{s5} is the maximum table temperature of radiator 5, which can be tested by fibre-optic temperature measurement.

Solving equation (16) in quadrature yields

$$\begin{aligned} T_{j4} &= \frac{(T_{s4} + T_{s5}) + R_j \times P_t}{2} \\ &= \frac{(65.5 + 66.4) + 6.8 \times 4.39}{2} \\ &= 80.9^{\circ}\text{C}. \end{aligned} \tag{17}$$

The calculated value for the thyristor junction temperature is 81.6°C, which is lower than the allowable deviation range of 0.7°C in engineering. Additionally, the reason for the low junction temperature calibration results is mainly due to the fact that the heat dissipation of the air was not taken into account in the calculation of the junction temperature.

4.2. Simulation Verification. The simulation software used for temperature simulation verification in this paper is PLECS. PLECS simulation software is a system-level simulation platform for the field of power electronics and drives train systems, which can model and simulate complex systems such as electrical circuits, control loops, and thermal losses. Especially for the simulation of power-switching device losses and heat dissipation systems, the software can quickly simulate the losses and temperatures of power-switching devices with a certain degree of accuracy by means of simple and reliable calculation models.

The thermal simulation model built based on PLECS simulation software is shown in Figure 5.

The heat sink setup is shown in Figure 6

The simulation results obtained are shown in Figure 7

Table 2: Calculation results of junction temperature of thyristor at each level.

Number of thyristor series stages	1	2	3	4	5	6	7
Junction temperature (°C)	77.0	80.8	81.1	81.6	81.3	81.1	77.9

Table 3: Countertop temperature test results for heat sinks 4 and 5.

Car radiator	T1 (°C)	T2 (°C)	T3 (°C)
4	65.5	64.1	62.2
5	66.4	64.8	62.6

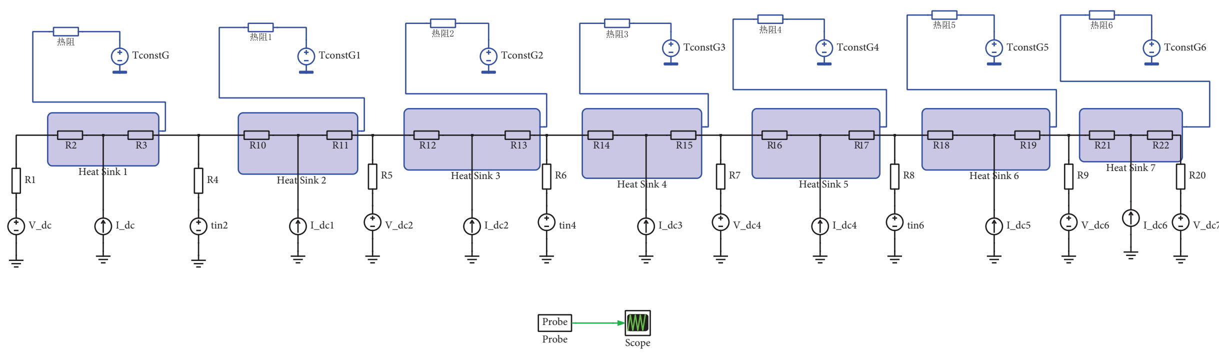

Figure 5: Thermal simulation model.

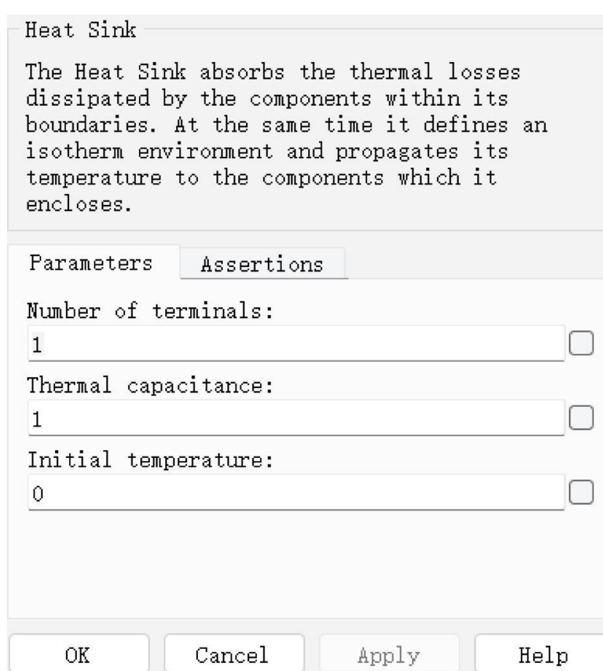

Figure 6: Heat sink setup.

From the simulation results, it can be seen that radiator 1 warms up to 71.02° at the 2 s moment and reaches stability at the 10 s moment with a result of 77.01°, radiator 2 warms up to 73.03° at the 2 s moment and reaches stability at the 10 s moment with a result of 80.70°, radiator 3 warms up to 73.36° at the 2 s moment and reaches stability at the 10 s moment with a result of 81.28°, radiator 4 warmed up to 73.66° at the 2 s moment and reached stability at the 10 s moment with a result of 81.81°, radiator 5 warmed up to 73.40° at the 2 s moment and reached stability at the 10 s moment with a result of 81.35°, radiator 6 warmed up to 73.29° at the 2 s moment and reached stability at the 10 s moment with a result of 81.17°, radiator 7 warmed up to 71.28° at the 10 s moment to reach stability, the result is 77.45°, after comparison, and the calculation results are basically consistent.

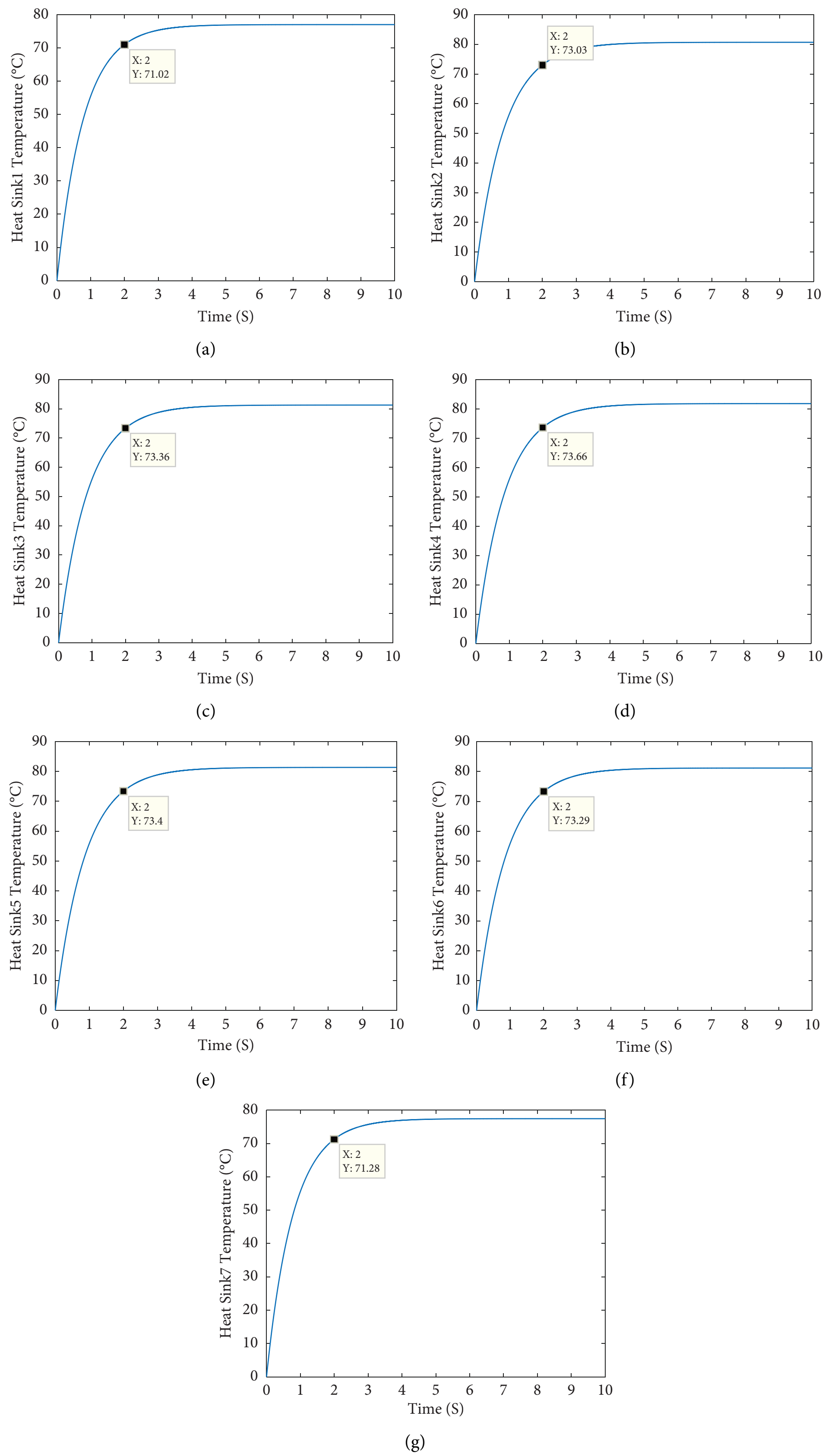

Figure 7: Simulation results. (a) Change in temperature rise of radiator 1. (b) Change in temperature rise of radiator 2. (c) Change in temperature rise of radiator 3. (d) Change in temperature rise of radiator 4. (e) Change in temperature rise of radiator 5. (f) Change in temperature rise of radiator 6. (g) Change in temperature rise of radiator 7.

5. Conclusion

In this paper, under the premise of analysing the current calculation methods of thyristor junction temperature at home and abroad, a calculation method is proposed to transform the thyristor junction temperature into a functional equation about "cooling water jacket temperature, thyristor power consumption, and thyristor heat dissipation casing thermal resistance" by establishing an equivalent circuit model for the water circuit of the converter valve, and simulation is carried out by combining with examples. At the same time, according to the calculation results, a rectification method for the converter valve water temperature protection is proposed. The main work is as follows [13, 14]:

(1) The calculation methods of the junction temperature of converter valve thyristor at home and abroad are reviewed, the advantages and disadvantages of various methods are analysed, and a new calculation method is explored and verified by simulation

(2) The water circuit of the converter valve cooling system is analysed, the equivalent circuit model of the converter valve junction temperature calculation is established by using the dyadic relationship between the thermal circuit and the electric circuit, and the complex junction temperature calculation is transformed into the functional equation of "cooling water jacket temperature, thyristor power consumption, and thermal resistance of thyristor heat dissipation casing"

(3) Starting from the heat transfer characteristics of the thyristor, the advantages and disadvantages of the Foster model and Cauer model in the equivalent thyristor heat transfer model are analysed, and the Cauer model is chosen as the equivalent thyristor heat transfer network model, and the formula for the transient thermal impedance is derived, which is verified by simulation using PLECS software

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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