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Implications of Direct and Indirect Heating of Bi-metallic Strip in MCCBs – Challenges and Solutions

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Abstract

This describes about the main differences between direct and indirect heating of bi-metals for overload protection for MCCBs. It also explains about analysis of thermal behavior of bimetal strip during both steady-state and transient conditions. To validate the thermal model, experimental tests both in steady-state and transient conditions have been done. The time current characteristics curves for both types of MCCB are plotted for meeting relevant product standards and same is validated with actual tripping time. There is a good correlation between experimental and theoretical results. Direct heating of bi-metal element can help in reduction of electrical stresses and also increases the life span of the power cables. It also outlines the challenges overcome during development and solutions for implementation of direct and indirect heating of bi-metal strips for developing the MCCBs for fulfillment of IEC 60947-2 as well as REC specifications.

Keywords: Bi-metallic Strip, Characteristics, Circuit Breaker, Deflection, Deformation, Direct Heating, IEC Standards, Indirect Heating, Loads, Magnetic, Overload, Performance, Power Cables, Rated Current, Curves, REC Specifications, Resistance, Short circuit, Temperature, Thermal, Tripping, MCCB

Abbreviations

IEC: International Electrotechnical Commission.
MCCB: Molded Case Circuit Breaker
REC: Rural Electrification Corporation

1. Introduction

MCCBs find their application for protection of electrical equipment against overloads and short circuit faults. Thermal-magnetic circuit breakers employ bimetallic strip and electro magnet for sensing and protection against overload conditions. The circuit breakers need to perform at rated current and must be able to make and break at rated currents and over load conditions. Depending upon the values of over current values in case of thermal magnetic type MCCBs the tripping can be done by deflection of bimetal or by the actuation of electro magnet. The inverse time characteristics of MCCB are met by deflection co-efficient of bimetals and behavior of electromagnets with values of over load current. Bimetal deflection will trip the MCCBs for over load currents higher than 1.20 to 6~8 times the rated current. The electro magnet will trip once the over load current is higher than 8~10 times rated current[1,2].

When over current flows through the circuit breaker's current path, heat builds up due to increase of resistance and causes the bimetallic strip to deflect, after attaining predetermined deflection distance; the bimetallic strip makes contact with the tripping bar which activates the tripping mechanism. Time required for reaching predetermined deflection varies with amount of over load current which depends on inverse time characteristics. When the over load current reaches higher than 6~8 times rated current the actuation of electro magnet will trip the MCCB instantaneously. The coordination of bimetallic release, electromagnetic release, repulsive

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nature of contact system and mechanism coordination is required for proper functioning of MCCBs[1,2].

A bimetallic strip is made of two dissimilar metals with different coefficients of expansion are bonded together. The two metals have different thermal expansion characteristics, so the bimetallic strip deflects towards high expansion side when heated. As current rises, heat also rises. The hotter the bimetallic becomes, the rate of deflection is directly proportional to amount of overload current. After the source of heat is removed, when the circuit breaker contacts open, the bimetallic strip cools and returns to its original condition. Normalization of bimetal will allow circuit breaker to be normally reset once the overload condition has been corrected[1,2].

2. Types of Bi-metal Heating Methods

The heating of the bimetallic strip can be done multiple methods as explained and are shown in Figure 1.

2.1 Direct Electric Heating

This method uses Joule heat effect, when the electric current flows through the bimetallic strip it causes a direct heating in the whole cross-section of the bimetallic strip. The deflection values will vary from the anchored location to the actuation point[3]. In general, this method is applicable where the rated currents “In” < = 160A. Different grades of bimetals are chosen depending on the rated current. The preferred currents offered are 16A, 20A, 25A, 32A, 40A, 50A, 63A, 80A, 100A, 125A and 160A.

2.2 Indirect Electric Heating

Resistors are connected in parallel with bimetals for this type. The bimetallic strip is connected in parallel with varying resistances depending on rated current. In general, indirect method of heating is used for wider range of currents starting from 16A~1200A. In case of indirect heating single bimetal with varied resistors for heating can meet multiple currents offered for given frame size[3].

2.3 Mixed Electric Heating

This method is a combination between thermal effect with direct electric current which flows through the bimetallic strip and a winding with high resistivity wires or ribbons[3].

2.4 CT Method

CT method is kind of the indirect heating method. The Joule heat in the secondary coil is generated by the secondary current induced according to the current of the primary conductor passing the core is applied indirectly to the bimetal. This method can be used only with AC for the reasons of principle. It is used for devices with large thermal currents the values are higher than 2000 A or in particular for air circuit breakers[3].

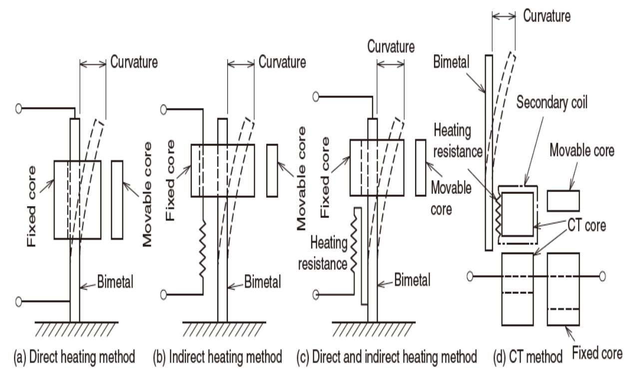

Figure 1. Different types of Bi-Metallic Heating Methods[3].

3. Operating Tripping Mechanism

The molded case circuit breaker thermal trip element is a Root Means Square (RMS) sensing device. The bimetal thermal element is constructed from metals of dissimilar rates of expansion bonded together. The thermal portion responds to overloads by reacting to the heat generated both by the current flowing through the circuit breaker and by the heat contribution from the ambient conditions. The bending force of the bimetal causes the circuit breaker to trip. The deflection of the bimetal is predictable as a function of current and time. This is the inverse time tripping characteristics of the thermal element (i.e., the tripping time decreases as the magnitude of the current increases). When the bimetal reaches a certain operating temperature, the tripping operation will be performed according to the displacement of the bimetal. As the current value increases, the time to reach the operating temperature becomes shorter. When this relationship is plotted on the current-operating time scale, inverse time tripping characteristics can be obtained as shown in Figure 2 [3,4].

When over current reaches higher than 8~10 times rated current it is necessary to break the circuit immediately

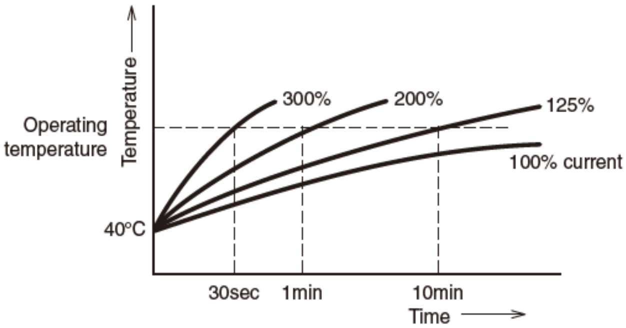

Figure 2. Deflection of bi-metallic strip as a function of Time and current[3].

without any time delay. In this case, the electromagnetic trip device will instantaneously trip the circuit before the bimetal deflects. The instantaneous tripping current value is generally designed to operate at higher currents and actuation will vary 8 to 10 times or more current to avoid undesirable opening of MCCB due to starting current of motors, capacitors and transformers[3,4] for which the MCCB is used for protection. Depending on connected load the starting currents will vary, and it is maximum for motor starting which is around 6 to 10 times rated current depending on type of motor.

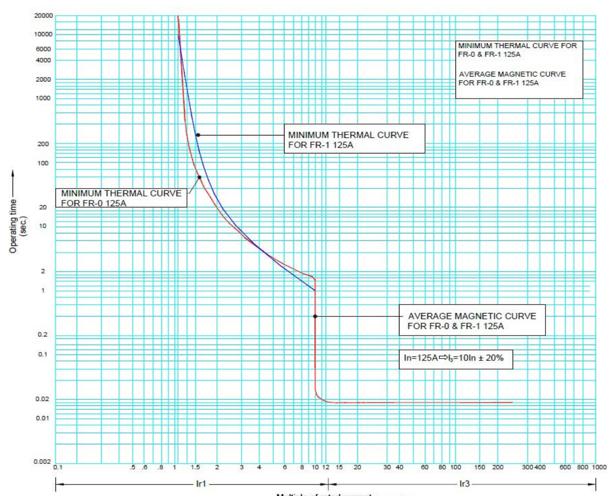

Figure 3. Thermal Magnetic TCC Curve for In = 125A (Frame-S &1).

4. Selection of Bi-metals

The selection of bi metals depends on rated current, type of heating method, the deflection co efficient and geometry of current path. Figure 4 explains the deflection co efficient of different grades of bi metals. Table 1 provides details of bi metal grades used for 125A MCCB rating for direct heating and indirect heating method. Figures 5 and 6 explains the cross sectional view of direct heating and indirect heating MCCBs.

Table 1. Selection of bi-metal strips

S.No	Method of Heating	Frame Size	Rated Current	Type of Bimetal Selected
01	Direct Heating	Frame-S	In = 125A	721Cu5
02	Indirect Heating	Frame-1	In = 125A	Bi metal 721-112 Heaters – Copper & Brass

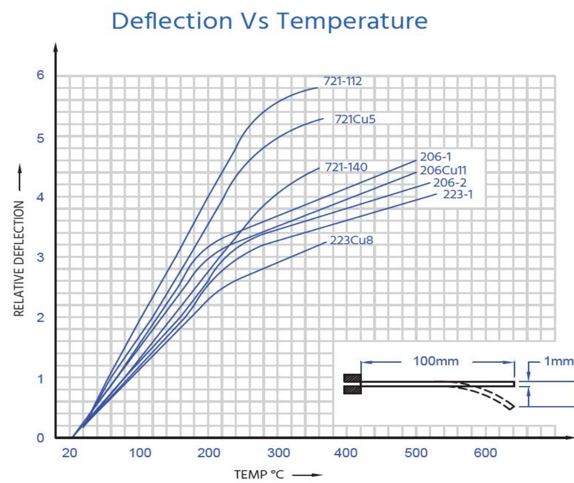

Figure 4. Relative deflection of bimetallic strip with respect to temperature.

5. Method to Control Reverse Bending of Bi-metal during Short Circuit Condition

MCCB when experiences short circuit current high value of current passes through the circuit breaker. During this condition high magnetic repulsive forces which are caused due to currents flowing in opposite directions of bimetal will be repelled away from current carrying through terminal and gets deflected in opposite to normal thermal deflection or reverse deflection. Due to this reverse deflection of the bimetal develops permanent deformation, which renders the circuit breaker inoperative because the bimetal can no longer deflect the distance required to release the latch. This can be overcome by providing support walls to avoid deflection in opposite direction and may be by bimetal geometry to avoid deflection in wrong direction during short circuit condition[6]. Measures adopted to avoid reverse bending are explained in Figure 5.

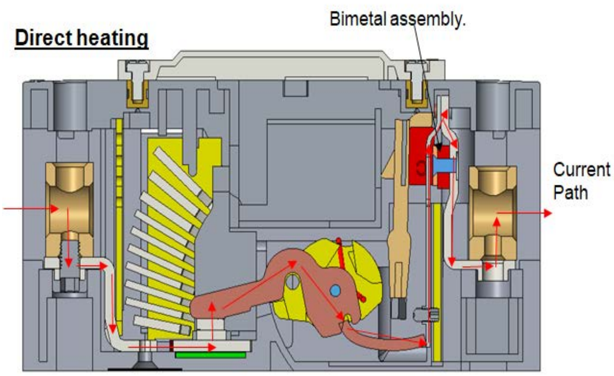

Figure 5. Cross sectional view for Direct Heating Method.

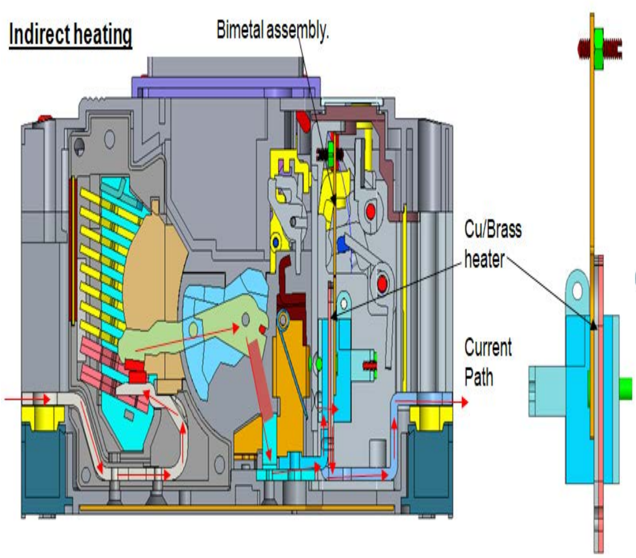

Figure 6. Cross sectional view for indirect heating.

6. Life of the Cables/Loads can be Increase by Direct Heating Method

The joule's first law shows the relationship between heats produced due to current flowing through a conductor[5].

$\Delta T = (I2 \times R \times t) / (m \times c)$

ΔT = Change in temperature.

I = Current in Amperes

R = Resistance in Ohms

t = tripping time in seconds.

m = mass of bimetal strip

c = specific heat capacity.

Table 2. Tripping Time for direct and indirect heating methods

S.No	Parameters	Direct Heating Method	Indirect heating of Method
01	ΔT	60 ° C	60 ° C
02	m	6.75 g	2.49 g
03	c	0.45 Ws/g ° C	0.45 Ws/g ° C
04	I^2 at 2.5In (In = 125A)	97656.25 A	97656.25 A
05	R in Ohms	0.00805	0.00013
06	$t = \Delta T \times (m \times c) / (I^2 \times R)$	0.23 sec	5.29 sec

From the Table 2, we can conclude that tripping time for direct heating method will be lesser than the indirect heating method by considering change in temperature and current at constant. Direct heating method can be advantage to power cables for increase in their life by reducing the electrical stresses within in a shortest time as compared with the indirect heating method. Indirect heating method uses parallel resistors for heating and there is a chance of energy wasted with decreased in energy efficiency.

Thermal memory is inbuilt feature of direct and indirect type of heating methods MCCBs which ensures breaker switching depending on bimetal temperatures. Breaker needs cooling time for reset and switching on to electrical loads.

7. Knee Point for Both Direct and Indirect Methods of Heating

The changeover from over current to instantaneous zone calls for steep change in slope of time current characteristics curve. The bimetals used in direct and indirect heating of MCCBs must overcome the thermal stresses during this change over zone. In case of over load performance test as per IEC 60947 the bimetal experiences maximum stress. The design of bimetals must ensure the geometry is rigid enough to take thermal stresses during overload performance. As per IEC 60947 -2 MCCB has to withstand 9 over load operations by manual opening by ensuring over load current for 2 sec and 3 operations by automatic for rated currents up to 630A.

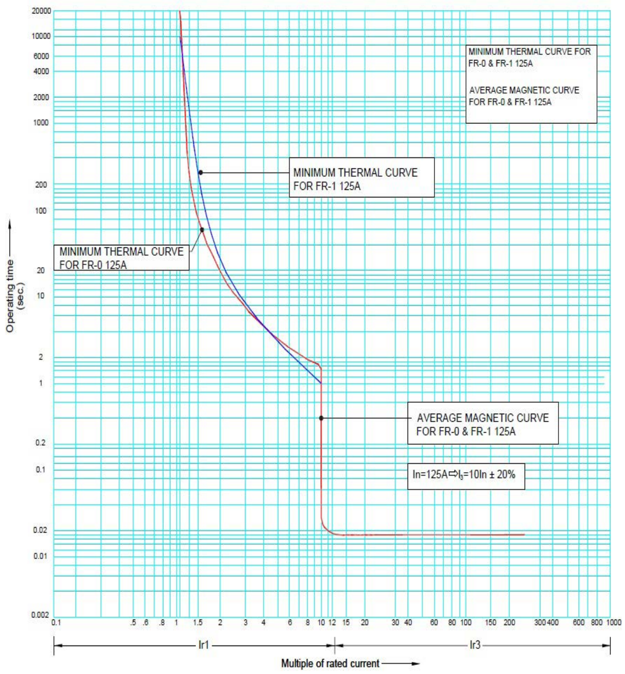

Figure 7. Knee point for both direct and indirect heating methods.

Table 3. Tripping Time Specifications as per IEC 60947-2 & REC specification[7,8]

S. No	Current Multiple for Tripping Threshold	As per IEC 60947-2 Overload Tripping Time	As per REC requirements for overload tripping time
1	1.05 In	t > 2 hrs (No Trip)	t ≥ 2.5 hrs (No Trip)
2	1.20 In	Trip as per OEM specified in TCC Curve	10 Min ≤ t ≥ 2hrs (Trip)
3	1.30 In when (In <= 63A)	t < 1 hrs (Trip)	t ≤ 30 Min
4	1.30 In when (In > 63A)	within 2hrs (Trip)	t ≤ 30 Min
5	1.40 In		t ≤ 10 Min
6	2.50 In	Trip as per OEM specified in TCC Curve	t ≤ 1 Min
7	4.00 In	Trip as per OEM specified in TCC Curve	t ≥ 05 Sec
8	6.00 In	Trip as per OEM specified in TCC Curve	t ≤ 05 Sec
9	8.00 In	t ≥ 200 msec (For instantaneous setting 10 In)	
11	12.00 In	t ≤ 200 msec (For instantaneous setting 10 In)	t ≤ 40 msec

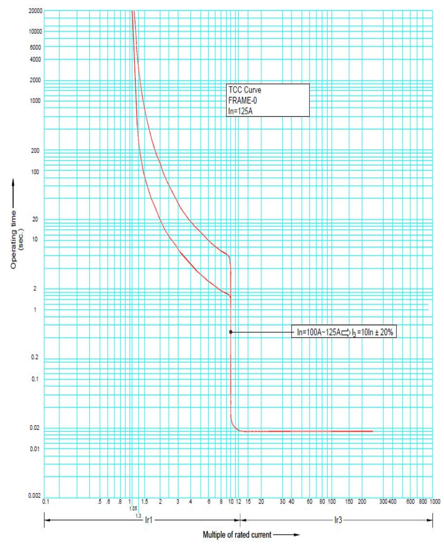

Figure 8. Time current characteristics for In = 125A (Frame-S).

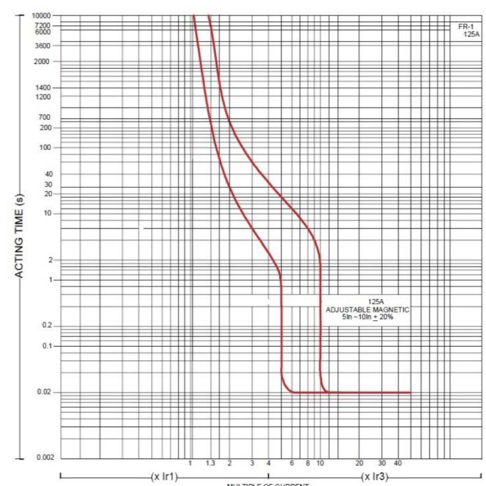

Figure 9. Time current characteristics for In = 125A (Frame-1).

8. Conclusion

In general, MCCBs are designed for conformance with IEC 60947. The requirements from REC specifications need additional requirements of meeting tripping times for 2.5, 4 and 6 In. As per Table 3; direct heating MCCBs of S type is designed for currents from 16A to 125A can satisfy both IEC 60947-2 as well as REC tripping specification method because of faster acting bimetals as shown in Figures 7 and 8. Time current characteristics as shown in Figure 9 meets IEC 60947 part 2 and does not comply to REC specifications.

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