Application of Fishbone Diagram & Pareto Analysis for Improving Quality and Reliability of MCCB – A Case Study

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***Abstract* - The Moulded Case Circuit Breaker (MCCB) is employed in electrical systems to safeguard the circuit from excessive current. During the overload conditions of an MCCB, tripping characteristics should be performed as per the applicable standard. Also, the operational efficiency of the MCCB with the accessories is crucial. Here, the concerned MCCB was experiencing thermal inconsistency under overload conditions and operational inefficiency with the UVR. The objective of this research is to improve its overall quality and enhance its reliability. Hence, to investigate the problem, cause and effect analysis and Pareto analysis are carried out, and subsequently, various tests have been carried out on a batch of MCCB. Further, the main reason for the issue has been identified. To resolve the issue, a modification bracket has been done in the operating mechanism of the breaker. After modification in the latch bracket, constant trip travel is achieved. So, the modification resulted in achieving operational efficiency with UVR and improving the thermal characteristics of the breaker.**

***Index Terms* – MCCB, mechanism, overload, trip plate, UVR**

I. INTRODUCTION

The MCCB, also known as a moulded case circuit breaker, is used to shield an electrical current from the excessive current that could result in an overload or short circuit. MCCBs have configurable trip settings and can be utilised for a wide range of voltages and frequencies, with a current rating of up to 2500 A. Its trustworthiness is essential for ensuring the smooth operation of electrical networks. To fulfil these requirements, the MCCB combines a temperature-sensitive device (the thermal element) with a current-sensitive electromagnetic device (the magnetic element). The core function of a MCCB is to prevent overload and short circuits [1][2][3].

The MCCB should be reliable in that it can provide protection under overload conditions and short circuit conditions. This reliability of the MCCB is tested with different types of tests performed on it. The MCCB should perform these tests as per the industry standards.

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Additionally, MCCB can support various types of accessories, namely, auxiliary switches, shunt trips, phase insulation barriers, under-voltage releases, rotating handles, and change-over systems. Through different tests and experiments, it was found that a particular MCCB is experiencing operational inefficiency with the UVR. Also, during 2In tests, it was observed that the tripping characteristics of the MCCB were inconsistent under overload conditions.

Under voltage releases cause the circuit breaker to open when the power supply falls below a predetermined voltage threshold. The MCCB trips due to UVR when the operational voltage drops to a level that is between 35% to 70% of its rated voltage, or when it is not applied.

To find the solution to these challenges and to improve the quality and reliability of the MCCB a comprehensive literature review was carried out which is discussed in the next section.

II. LITERATURE REVIEW

In this section, a comprehensive literature review is presented on various studies and experiments carried out on MCCBs to show their behaviour under different conditions. Below, each research or study shows various phenomena and limitations while working with the MCCB.

Rane et al., 2019 discussed that in the lack of failure data, this case study offers a thorough method for evaluating a complicated system's reliability. It is investigated here that the mechanism failure was the primary cause of most circuit breakers failing. This work uses Boolean algebra and the Accelerated Life Test (ALT) to show how the MCCB mechanism's dependability can be evaluated and improved. Furthermore, after comparing it to various distributions, the Weibull distribution is chosen for dependability prediction. The suggested approach identifies the underlying reason for failure, and flaws are fixed while the product is still being designed and developed. The mechanism's reliability is evaluated both before and after the improvement conditions. In reliability testing, ALT is employed, and the result shows the frequency of latch link failure is maximum owing to denting and distortion of the link. The mechanism dependability increases from 72.44% to 95.06% in this instance.[10]

Ji et al.,2011 explain the phenomena of linkage transfer, which occurs during the MCCB's operational mechanism's opening phase, is described. An analysis is conducted to determine how the linkage transfer position affects the mechanism's behaviour. The analysis results show that the software ADAMS, a virtual prototype, improves the linkage transfer location of a real operational mechanism. The mechanism's opening time is reduced by roughly 1 ms following modification, according to simulation and experiment results. Short-circuit testing shows that the improved linkage transfer position of the operating mechanism helps to improve the MCCB's interruption performance while rupturing low-current faults.[12]

Shaikh et al.,2020 the concept of a different model for the MCCB mechanism is the subject of this work. Since the mechanism's forces are directly correlated with the friction between its parts, we may be able to lower the mechanism's reset force if we can lower the friction coefficient between the parts without impairing the mechanism's functionality. Compared to the current mechanism, the new model of the sub-assembly in the MCCB mechanism features a roller contact between the surfaces rather than a sliding contact. Using roller friction to calculate the forces between each component; it is possible to determine that a 3-4 kg reduction in reset force is anticipated.[13]

R. S. Raman et al.,2019 implemented the fishbone diagram and Pareto chart to analyse all the defects of a capacitor. From, the outcome of the charts, they found the particular reason for maximum problems. To minimise the defects, a fishbone diagram was prepared to find the root causes and to analyse them through a Pareto chart. Then some actions were suggested for the improvement of capacitors. Similarly, F. P. Dharma et al.,2019 used the same methods to improve the quality of unevenness of yarn in a ring spinning machine. Data analysis was done through testing and daily check data in the form of a Pareto diagram. Form that the cause with the highest frequency was found and was prioritised for completion to improve quality. [20,21]

In conclusion, the reviewed literature showcases different studies, results, and experiments of MCCBs. It also reveals various probable issues and limitations while working with the circuit breakers. Overall, these studies provide a strong foundation and relevant studies for this project.

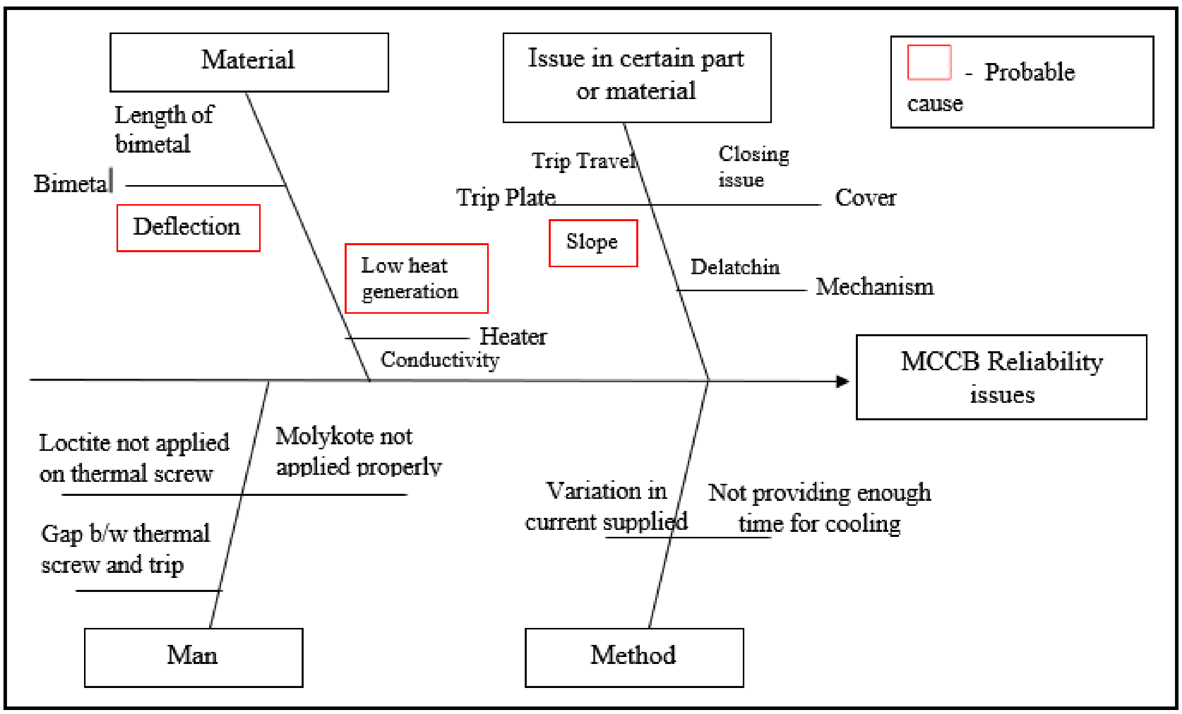

Fig.1 Cause -Effect Diagram

III. Methodology & Analysis of Causes

To analyse how the MCCB experience's reliability issues, the identification of the cause is necessary. For that, a cause-and-effect diagram was prepared as shown in Fig. 1.

The above diagram shows all the probable causes. To verify these causes, various tests were carried out, and then different variables were analysed and verified. For validation, defect analysis was done total of 25 breakers, which were taken from the manufacturing line and inspected. All these causes and their validation are discussed in Table 3.1. The mechanism and assembly of the MCCB were also as per the standard operating procedures. Similarly, the bimetal deflection was validated by the theoretical calculation. In addition to that, the heat generation was verified by the temperature rise test. Trip plate measurements were also checked with the drawing with the help of the QC in about 25 breakers. Similarly, a Pareto analysis (Fig. 2) was carried out to define the frequencies of the various defects.

From the graph, it can be interpreted that the first two defects contribute to the majority of the reliability issue of the MCCB. From the cause-effect diagram and Pareto analysis, it can be concluded that the main cause is related to the trip plate. So, different variables have been identified related to the trip plate – trip travel, trip force, and the gap between the thermal screw and the trip plate. Thus, the work is focused on those defects to eliminate them to improve the quality and reliability of the MCCB.

TABLE 1 TF, TT & 2IN DATA

Breaker no.	**2In testing**			**Trip Travel**			**Trip Force**
	R	**Y**	**B**	**R**	**Y**	**B**	
1	NT	99	NT	2.57	1.97	2.7	350
2	138	88	128	2.13	1.82	2.11	320
3	NT	136	89	2.08	1.87	2.08	270
4	101	91	104	2.15	1.89	2.15	290
5	254	101	NT	2.35	2.02	2.48	320

From the data of Table 1, it had been observed that the breaker showed inconsistent tripping behaviour under overload conditions. In addition to that the trip force of the breakers were within the permissible range of 220 to 320. Then a batch of breakers is tested with the UVR. Their results are shown in Table 2.

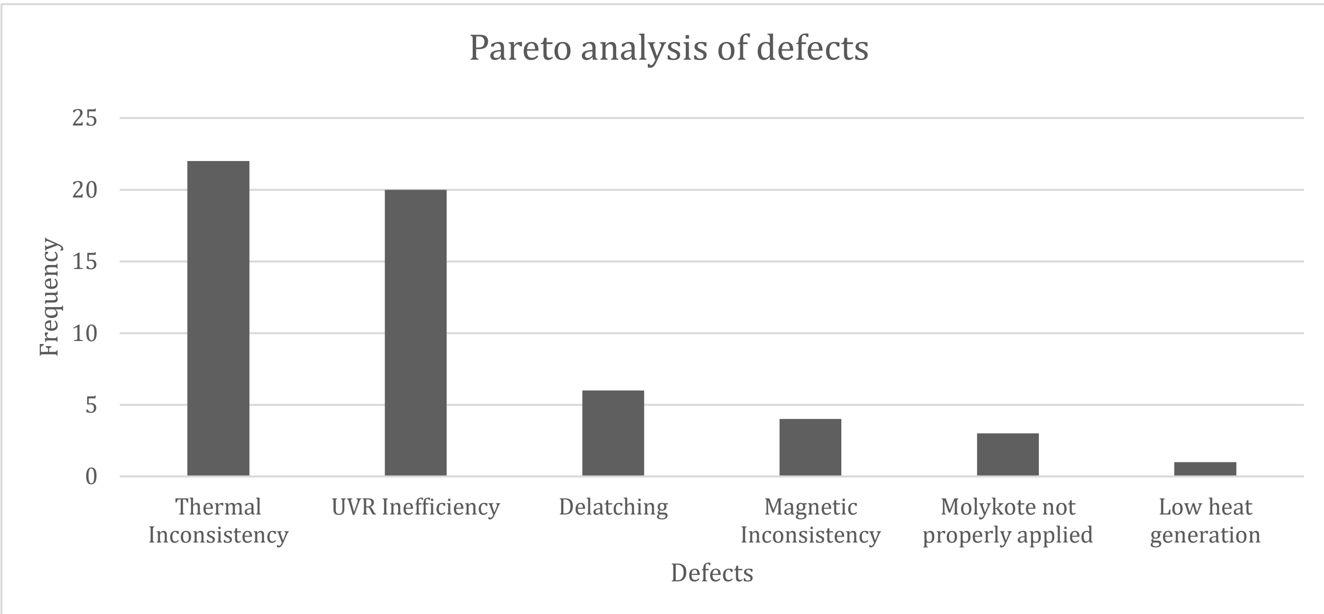

Fig.2 Pareto Analysis of new latch bracket

IV. Collection of Data

The data was collected related to the main cause, which was a trip plate. So, the different variables related to trip plate have been identified.

These variables are Trip force, Trip Travel, 2In testing: Trip force is the force required to trip the breaker. It was measured with a force gauge in the form of N. Trip travel is the distance traveled by the trip plate to trip the breaker. It was measured by a height gauge in mm. 2In testing replicates the overload condition. Here, 2 times the rated current is supplied to the breaker and the breaker should trip in the given time band.

The trip plate can be adjusted in the MCCB in such a way that it can put the MCCB in two positions: minimum and maximum. At minimum the MCCB works with 70% of its rated capacity and at maximum it works with 100% of its rated capacity.

So, for around 25 breakers all data of trip travel and trip force were measured and collected and finally, analyzed.

TABLE 2 UVR OBSERVATION

Breakers	**UVR 1**		**UVR 2**	
	Min	**Max**	**Min**	**Max**
1	Not ok	Ok	Not ok	Ok
2	Ok	Ok	Ok	Ok
3	Not ok	Ok	Not ok	Ok
4	Not ok	Not ok	Not ok	Ok
5	Not ok	Ok	Not ok	Ok

The data of trip travel is also measured for the 25 breakers. These data are shown in the Table 3.

TABLE 3 MIN & MAX TT, TF DATA

Breaker	**Trip Travel**		**Trip Force**	
	Min	**Max**	**Min**	**Max**
1	1.51	1.04	290	276
2	1.37	1.58	263	276
3	1.46	1.64	280	283
4	1.50	1.27	343	346
5	1.33	1.47	280	270

From the data of Table 3, it can be observed that the trip force in both the trip positions is relatively the same. So, that variable is ruled out. Another variable is trip travel, which is fairly inconsistent.

V. Analysis of data & Solution

From the collected data, it was very clear that the trip force of the MCCB is well within its permissible range of 220 to 320. So, that variable is ruled out from the analysis. Then, the experiment with the two different UVRs confirmed the operational inefficiency.

From the Table, it was found that the trip travel is fairly inconsistent when measured in both minimum and maximum positions. Hence, this variable – trip travel had to be removed or decreased. For that, a modification has been made to the latch bracket of the mechanism of the breaker. The modification was to remove the slot in the latch bracket so that the trip travel remains the same in both the minimum and maximum position of the trip plate. Because the slot shown in Fig. 3 was responsible for variation in trip travel. At the top part of the slot, the latch was rested when the breaker was in ON condition. By removing the slot, the breaker's trip time was made consistent. The trip travel was also measured before the final assembly.

Then, the mechanism with the new latch bracket was assembled in 30 new breakers – 15 three-pole and 15 four-pole. All the breakers were passed through the testing stations on the line. These testing stations are contact pressure & trip force testing station, thermal test bench, magnetic test bench, visual inspection, mv drop test, accessories test setup, hv test setup, and final inspection.

After this modification, the trip travel in both positions is measured. Due to the modification, the trip travel remains constant which helps the breaker to trip in the given time band.

TABLE 4 TT DATA WITH NEW MECHANISM

Breaker	Trip Travel	Breaker	Trip Travel
1	1.33	6	1.35
2	1.07	7	1.29
3	1.28	8	1.47
4	1.44	9	1.34
5	1.33	10	1.38

Table 4 shows the data of trip travel from the breakers with the new latch bracket assembled. The average trip travel from the above data was 1.3 mm. The average trip travel measured from the old latch bracket and mechanism was around 1.5 mm, and

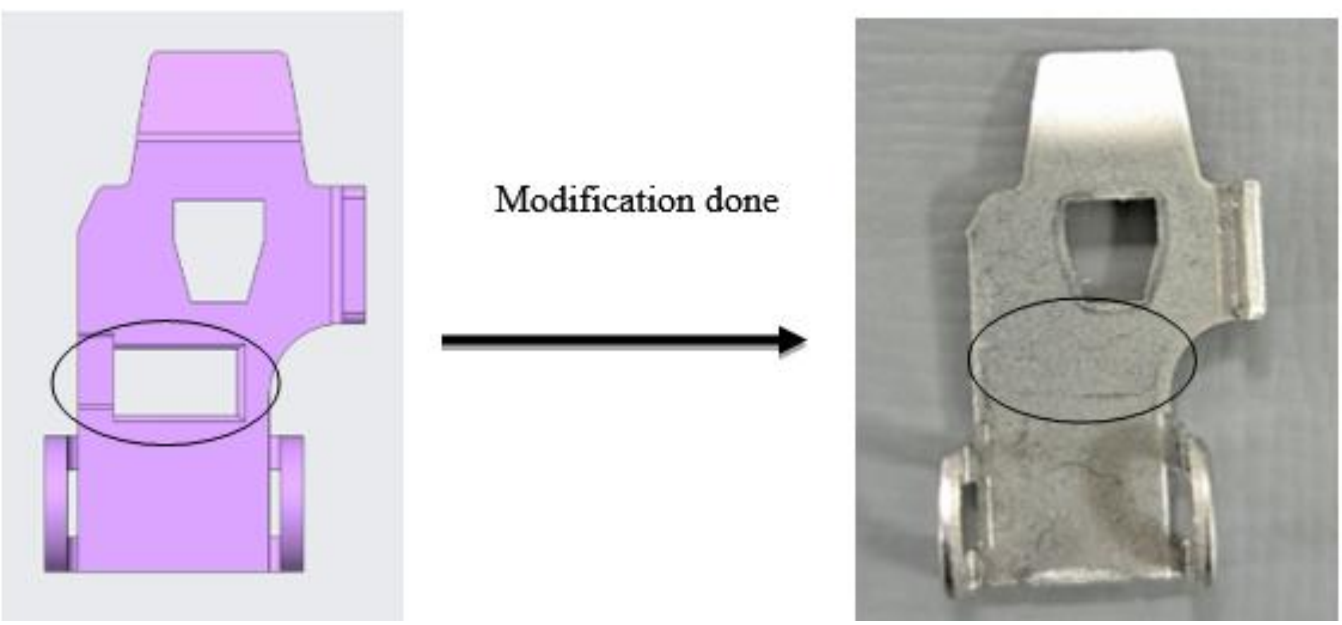

Fig.3 Modification Done

most importantly, there was wide variation in trip travel at min & max trip plate position. So, that variation was removed, and trip travel was decreased at both positions after the changes done in the latch bracket, which ultimately helped the breaker to trip earlier than before to achieve its thermal characteristics. After implementing the new mechanism with the improved design of the latch bracket, some regulatory tests were also performed on the MCCB. And the MCCB performed well in these tests. These tests were the IS testing and 2In testing.

issue of contacts engaging with the UVR inserted was also mitigated, which increased the operational efficiency with the UVR.

Further, the circuit breaker was tested with regulatory tests like IS testing and 2In testing. In both tests, the circuit breaker performed as per the standards followed by the industry. In conclusion, a change made to the mechanism of the MCCB resulted in the improved reliability of the MCCB in thermal characteristics and with the accessory–under–voltage relay.

Rating (A)	Phase	Release setting	Corrected rating (A)	Current multiple	Test current (A)	Trip time (sec)	Trip band (sec)
100	R	1	106	2	212	89	<300
	Y					36	<300
	B					67	<300
100	R	1	106	2	212	69	<300
	Y					52	<300
	B					81	<300

TABLE 5 IS Testing

Rating (A)	Release setting	Corrected rating (A)	Current multiple	Test current (A)	Trip time (sec)	Trip band (sec)
100	1	106	1.05	111.3	NT	>7200
			1.5	159	59	<7200
100	0.8	106	1.05	89.04	NT	>7200
			1.5	127.2	932	<7200

TABLE 6 2IN Testing

VI. Conclusion & Future work

Here, the concerned MCCB was exhibiting some concerns with its operational efficiency with UVR. Also, the inconsistent tripping behavior under overload conditions was a major issue. To investigate the problems the cause and effect analysis and Pareto analysis are carried out.

Based on the analysis carried out, the cause was identified as the trip plate not rotating sufficiently to trip the breaker because the trip travel was more than required and was also inconsistent in different trip plate positions. So, to overcome these challenges, a modification was made to the latch bracket by removing the slot in it which was in the mechanism of the MCCB.

By implementing this modification, the trip travel was reduced, and the variation was removed. Thus, the breaker can be tripped within the permissible time band. By applying this change, the

For the further research and work, the remaining defects can be targeted. Various modifications and changes can be made to the mechanism of the breaker. Also, there is some scope for modification for the outer body of the circuit breaker. So, this type of research and work can be done to increase the reliability of the circuit breaker.

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