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Research Article

Comparative study of ARC elongation of flat and inclined splitter plates in arc chamber of moulded case circuit breaker

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ABSTRACT

The components that make up a power system are generation, transmission, distribution, and substation. When a failure occurs in the electrical grid, the whole system must be protected by a reliable protection mechanism. Due to its affordability and reliability, the low-voltage circuit breaker (LVCB) has become a widely adopted safety device in various low-voltage distribution systems. In recent years, there has been significant attention directed towards the low-voltage circuit breaker. To prevent electrical overload or short circuits, moulded case circuit breakers (MCCBs) are employed in low-voltage electrical systems. This device prevents electrical system damage by instantly turning off the power in the case of a malfunction or overcurrent scenario.Industry identified a problem of heating in the MCCB arc chamber due to a large arc quenching time in operation. An electric arc always carries out the interruption process of the current in the MCCB. To overcome this issue, the effect of inclination and blow out coil voltage on arc extinction phenomenon of splitter plates in arc chamber is analysed using ANSYS software in this research work.MCCB model has current rating 200 A, rated voltage is 500V and breaking capacity of 65 kA is considered for modelling and simulation. A splitter plate with a taper angle along the direction of the arc shows the better results in the 2-D analysis of MCCB model.

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INTRODUCTION

Low-voltage circuit breakers (LVCBs) find frequent applications within the distribution network. Electrical life is dependent on safe and reliable electric energy production. The conventional arc erosion model neglects the effect of working circumstances, for example, supply voltage and power factor on electrical life. It solely focussed on the impact of current on contact wear. The arc voltage alters the circuit architecture, which causes the current to zero out

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prematurely. The breaking current waveform experiences distortion when subjected to AC supply voltages within the range of 220-660 V, leading to a reduced amount of contact erosion (CEA) compared to the ideal conditions.

Liu and Wang [1] conducted research to investigate the impact of arc voltage on breaking current, developed a model encompassing arc voltage in the context of arc erosion and contrasted the CEA curves across various supply voltages and power factor scenarios. Monte Carlo analysis was used to simulate the LVCB›s electrical life under different conditions of use and to get an estimate of the distribution of electrical life. The discoveries show that the electrical lifetime of the LVCB diminishes with expanding supply voltage at a constant power factor and that this fall is followed by an increase when the power factor rises at a constant supply voltage. Depending on the values of two factors, the LVCB›s electrical life difference may be as high as 21.4% (220 V, 0.95 and 660 V, 0.65). This technology makes LVCB life evaluation under varying operating circumstances more accurate. Almurr et al.[2] looked into what would happen to the electric arc produced by opening the contacts of a low-voltage switch in the presence of a high external magnetic field. A DC generator charging at RL voltage, similar to those used in PV systems, powers the low-voltage switch. During the opening of contact, the primary factors governing arc motion are Laplace and hydrodynamic forces. The magnetic forces are amplified and the arc extinction is hastened by the addition of an external magnetic field. It is possible to study significant variations in response to varying strengths of an external magnetic field. COMSOL Multiphysics-created numerical simulations are compared to actual measurements taken on purpose-built testing apparatus in order to get insight into the underlying physical processes. Tan et al. [3] presented, along with an examination of the technology›s defining features and a suggestion of four use cases. The pilot project demonstrated that the circuit breaker provided strong support for information perception, digital operation and maintenance, and distributed solar systems inside the distribution network. Mironov et al. [4] conducted research on computational and experimental research on the formation process of electric arc discharges in a three-phase Zvezda-type alternating current arc heater. A flow modeling in the arc heater, as well as an experiment on providing a visual control for the location and the shape of arc discharges, were conducted. A device of a visual control system is presented. The analysis of the results obtained from experimental research is carried out.

Circuit breakers used in direct current microgrids (DCMGs) for protection against electrical disturbances, this article explores their history and looks forward to their development and potential problems. There has been an increase in proposed improvements to circuit breakers in recent years. In light of this, it is crucial to examine the background of DCMG circuit breakers. Perea-Mena et al. [5] gave a historical overview of DCMG circuit breakers, including fuses, MCBs, SSCBs, and HCBs, with an emphasis on the progression from mechanical to solid state. The history of these tools is detailed, with commentary on the benefits and drawbacks of each new iteration. In the realm of distributed control and monitoring systems (DCMGs), while modern circuit breakers are gradually becoming available for commercial use, a number of them are still in the developmental phase. Consequently, conventional fuses and miniature circuit breakers (MCBs) continue to find application in DCMGs, albeit with certain restrictions. Circuit breakers in DCMGs are discussed, along with the future problems that must be overcome to ensure their effective and suitable adoption. Utilizing the Discrete Ordinate method, Huo and Cao [6] carefully examined radiative heat transfer in a banded fashion to precisely calculate the plasma temperature. This investigation revealed that radiation exerts a substantial impact on the thermal condition of the plasma. Furthermore, in addition to the ingestion coefficient, the presence of metal fume was seen to hoist the porousness of the plasma mass, subsequently heightening the nearby attractive field. The author modelled the plasma using the magnetohydrodynamics approach, including vaporisation of metals, movement of species, and radiative heat transfer. According to the modelling findings, metal vapour not only serves to reduce the temperature field as a whole, but it also speeds up the arc interruption. Improved arc behaviour knowledge and more realistic low-voltage circuit breaker designs may be achieved by a more precise calculation of metal vapour accelerated radiative heat transfer. Kolimas et al. [7] used finite element analysis (FEA) software like SolidWorks, COMSOL, and ANSYS to facilitate the designing and modelling of electrical devices; specifically, the arc chambers of modular circuit breakers. Simulations of heating, electric potential distribution, electric charge velocity, and pathfinding have been performed using arc chamber models that have been purchased. The experimental findings were found to be consistent with the theoretical framework. The mutual areas of the modelled element precisely reflected the circumstances under which it was tested, expressing the same physical attributes and robustness faults. It was also possible to predict the requisite physical events for electrical engineering even before the model was built. This method was really helpful in terms of saving resources during developing and engineering. Lee and Ko [8] presented study on re-ignition after current zero associated with the dielectric recovery properties of a moulded case circuit breaker (MCCB). In the event of re-ignition despite trip unit functioning, this feature reduces the MCCB›s interruption dependability. Therefore, it is necessary to enhance the dielectric recovery characteristic in order to stop electric leakage during re-ignition. Dielectric recovery properties after current-zero were studied to determine their impact on the splitter plate and a design to enhance the splitter plate was offered. Low-voltage circuit breakers assume an essential part in guaranteeing the security of business and private power frameworks by utilizing the voltage drop at the terminal plasma connection point to accomplish current interference. This wellbeing instrument is achieved through the usage of attractive power and the use of imbalanced powers. At the point when the contacts of the electrical switch open, these powers follow up on the electrical circular segment, pushing it towards a heap of steel plates. As a consequence, the arc is fragmented into sub arcs, leading to an increase in voltage drop across the stack. However, this process entails the dissipation of a significant amount of energy, primarily due to the presence of substantial fault currents. This energy dissipation gives rise to interactions between the arc and solid components, resulting in phenomena such as wall removal and metal evaporation. Studies zeroing in on removal are directed to clarify its significant effect on both the curve voltage and the related tension field. Striking headways have been made in the domain of reenacting circular segment elements by connecting fluid dynamics with electromagnetics. Nonetheless, a critical aspect of the arc interruption process, namely, the influence of Stefan flow brought about by the formation of species, has hitherto been overlooked in these models.

Huo et al. [9] developed a numerical method for include the influence of Stefan flow in particular. With this method, we can predict how the stream field and the attributes of the plasma combination will change as a result of the addition of species from the evaporation surfaces, which are introduced by diffusion. When mimicking an arc interruption, this process is just as crucial as the voltage drop. Stefan flow computation allows for a deeper knowledge of arc behaviours and a more realistic approach to designing low-voltage circuit breakers. Arcing within low-voltage circuit breakers involves a lot of complicated physical behaviour, and one of the most important parameters we can measure is the distribution of current density in the arcs. Dong et al. [10] considered the inversion of magnetic fields as a means of reversing the backwards issue of deciding the ongoing thickness dispersion in circular segments. In order to compute the regularisation procedure, set regularisation parameters, and estimate systematic error, a simple 2D arc chamber is explored. Exploring Tikhonov regularization as a remedy for the badly presented nature of the opposite issue includes deciding the regularization boundary through Morozov›s error rule, the L-bend, summed up cross-approval, and the semi optimality measures. Much more options for how to choose regularisation parameters are supplied than in prior studies. The signal-to-noise ratio, measurement distance, and measuring space size are only few of the factors that have been studied in relation to the performance of these criteria. Simulation results demonstrate that robustness and accuracy are improved by using the generalised cross-validation and quasi-optimality criteria. Furthermore, when utilising a planner sensor array to take magnetic measurements, the ideal measurement distance is to be predicted. Bizzarri et al. [11] provided a tangible framework for a discovery model of minimized circuit breakers, we participate in demonstrating air plasma compound elements and its transaction with the physical surroundings of the breaker, encompassing considerations such as chamber geometry, splitter plates, and arc traversal. This modelling endeavour is executed through the utilization of two distinct sets of differential-algebraic equations, aligning meticulously with fundamental principles, engineering expertise, and simulations involving magneto-hydrodynamic arcs. We propose optimizing the numerical efficiency and precision of the electrical model at the terminals of the breaker. Short circuit tests and computer simulations are compared to demonstrate its behaviour. System-level applications encompass a variety of scenarios, for example, tending to multiphase exchanging homeless people, guaranteeing selectivity and coordination with wires, other circuit breakers, and flood insurance gadgets, and the modelling of networks involving numerous circuit breakers. Goh et al. [12] explored various types of circuit interrupters, encompassing oil circuit interrupters, air circuit interrupters, sulphur hexafluoride (SF6) circuit interrupters, vacuum circuit interrupters, as well as two variations of direct current (DC) breakers. hybrid DC breakers and solid-state DC breakers. Faults often cause disruptions or damage to the underlying system or circuit. In order to establish a protection system in a system or circuit, it is necessary to have a firm grasp of the various failure types and their root causes. The substation regulates the high-voltage current that is transferred from the producing plant in order to provide the consumer with an appropriate voltage. There must also be a protection system in a substation. The most pressing issue is how to stop the arc›s development and the extinction from happening. references to LVCB arcs in published research. Yang et al. [13] concentrated on modelling and measuring the three stages of the arcing process that may be broken down into sub-processes according to the underlying working principle: commutation, motion, and splitting. Radiation, metal erosion, wall ablation, and air arc turbulence are also explored as examples of important physical phenomena and how other studies have dealt with them. In order to better understand air arcs, we provide some suggestions on how to model and quantify them. Freton and Gonzalez [14] highlighted this particular point for emphasis. How they function, what kind of restrictions they have, and what sorts of occurrences manifest themselves when breaking have all been detailed. Then, the challenges of interpreting arc behavior are highlighted and examined in two major sections: the research of arc movement during the breaking process, and the analysis of physical arc properties. We offer a literature study on the topics at hand, in which we will confront and debate both experimental and theoretical findings from the literature, as well as identify technological challenges.To empirically investigate the motion and rekindling of arcs in an AC contactor, four different quenching chamber configurations are utilized. This is achieved through the application of a two-dimensional optical fiber measurement system. Chen et al. [15] demonstrated that the configuration of the splitter plates has a notable impact on the circular segment movement inside the curve extinguishing chamber. Moreover, getting the curve sprinter in both the underlying and finishing up splitter plates has displayed to improve the circular segment movement while at the same time hoisting the dielectric recuperation strength. High-performance quenching chamber design in AC contactors may benefit greatly from these findings. Wang et al. [16] used simulation methods based on the magnetohydrodynamic (MHD) model of the arc to obtain the macroscopic motion of the arc within the interrupter and the interaction of the arc with the contacts, walls, and splitter plates. Nag [17] presented the surface degradation analysis of contact tips of commercial (20A, 110 V) molded case circuit breaker due to multiple electrical interruptions during experimental electrical test. In the experimental electric test, and according to the post arc current observation, the arc voltage and current were categorized. Multiple high-current interruption has been identified, and the phenomena that regulate the interruption failure have been established. Also, post-arc current sprinted for a short period of time (10–200 μs) during multiple electrical interruptions. These interruptions cause the failure of the contact tips of MCCB.

Industrial automation company work in the Switchgear operation of low-voltage circuit breaker (LVCB) identified a problem of heating in the AC MCCB arc chamber due to a large arc quenching time in operation. An electric arc always carries out the interruption process of the current in the MCCB as discussed in various literatures. To avoid this issue, solution of an the effect of blow out coil voltage and electric potential distribution with respect to inclination of splitter plates and direction of flow is considered for optimisation through simulation using ANSYS software.

ELEMENT ATTRIBUTES

There are 3 predominant detail attributes which might be given underneath:

- Element type
- Real constants
- Material properties

It is important to offer material characteristics of the geometry that turned into both constructed or imported, for instance permittivity, permeability, resistivity, density, particular heat, thermal conductivity, emissivity, friction coefficient, and so on.

PROPERTIES OF MCCB COMPONENTS

The electrical capacity analysis is executed on the 2-D version of the arc chamber. MCCB rankings are taken into consideration as :

- Operating voltage 500 V
- Number of poles 3
- Rated current 100 – 800 A
- Breaking current 65 kA
- Breakers operating time 1ms
- Rated frequency 50 Hz

Properties of Arc Chamber Components

The MCCB taken into consideration for analysis has breaking potential of sixty five kA at 500 V. Each of the pinnacle and bottom of the arc chamber have two blowout coils and 4 arc splitter plates. Connectors, splitter plates,

Table 1. Material properties of MCCB components

Sr. No	Part of MCCB	Material Used	Permeability	Permittivity
1	Arc splitter plates	Ferro magnetic Materials	8.1×10^{-4}	10
2	Fixed and Moving Contacts	Silver alloy	1.2566×10^{-6}	1
3	Blow out coil	Copper	1.27×10^{-6}	1
4	Air	-	1	8.85×10^{-12}

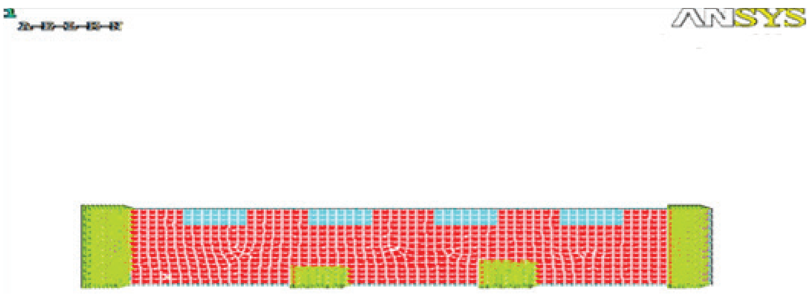

Figure 1. 2-D mesh model with load voltage.

and coils all have natural air between them. The electrolytic copper or silver alloy is used for the constant and movable contacts. Material properties of MCCB components with its permeability and permittivity is shown in Table 1.

An electric arc is formed when current flows from a stationary contact to a moving one during the fault. Potential of 500 V developed at cathode (fixed) contact and ground (zero) potential developed at anode. 2-D meshed arc chamber MCCB model with load voltage is shown in Figure 1.

RESULT AND DISCUSSION

The results obtained after simulation has been discussed in this section.

Blow Out Coil Voltage Effect On Arc Elongation

The distribution of electrical capability under a defect is seen in Figure 2.

The shifting contact receives no capability while the stationary touch gets 500 V. The voltage at the blowout coil is maintained at a constant zero volts.

The electrical capability distribution all through a fault state is visible in Figure 3. Initially 20 V is carried out to blowout coils.

The electric capability distribution at some stage in a fault is visible in Figure 3. It shows a miles more rapid drop in electric capability from the desk bound touch to the moving contact than Figure 2. After increasing the blowout coil voltage the electric capability at center node is going on increasing, this suggests rapid extinction of electrical arc.

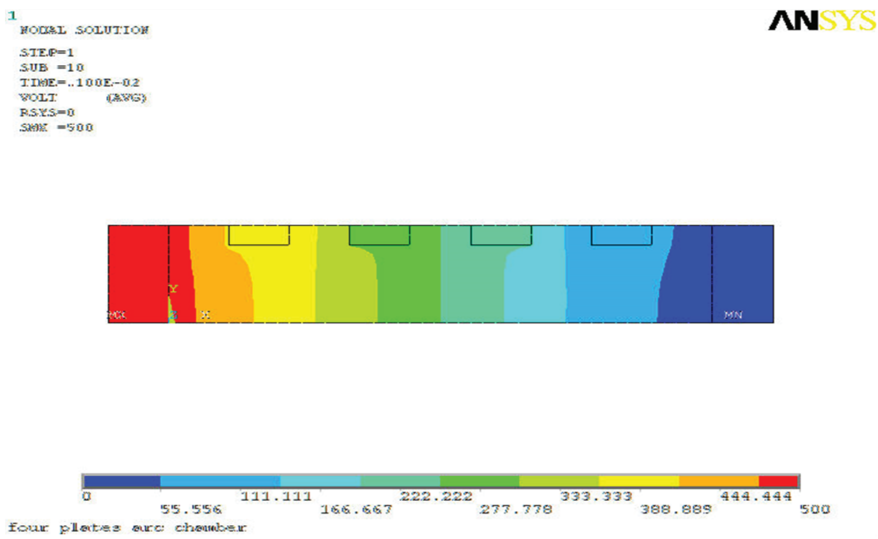

Figure 2. Electric potential distribution without blowout coil effect.

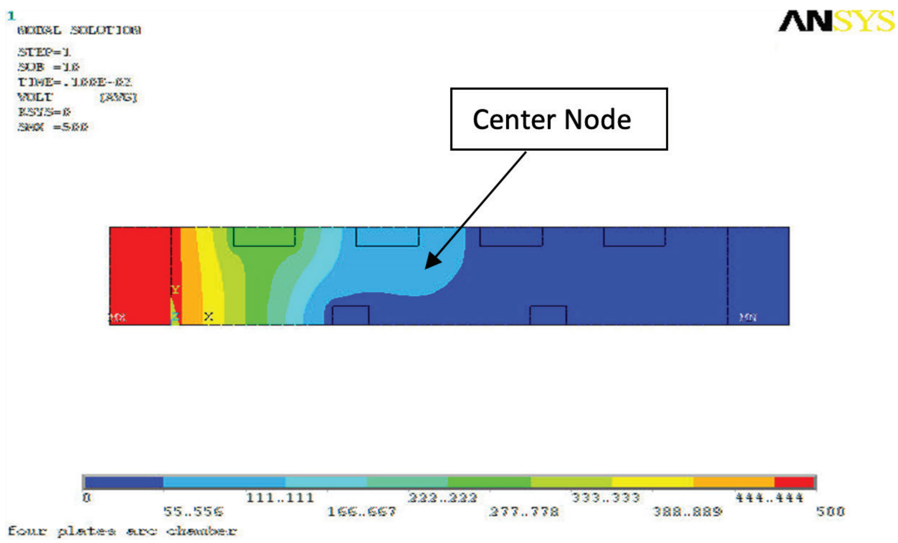

Figure 3. Electric potential distribution with blowout coil effect.

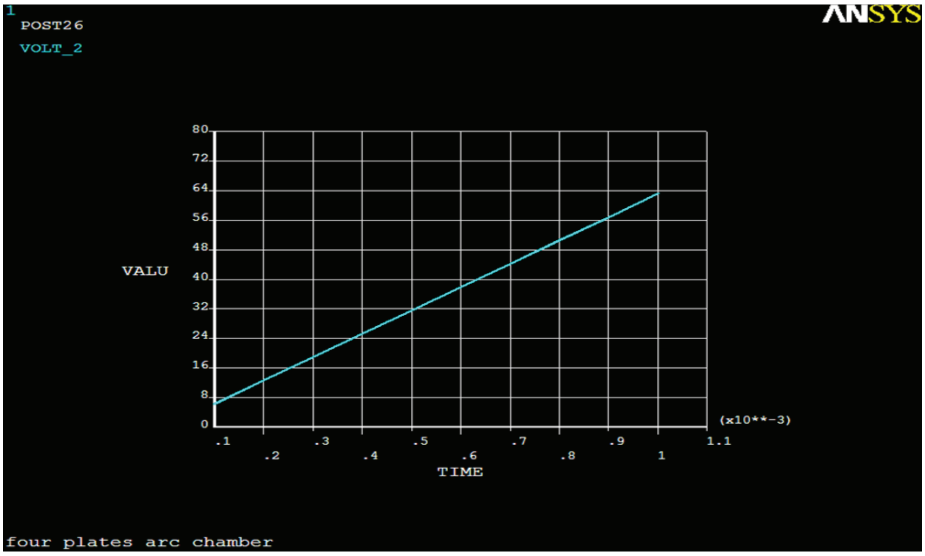

Figure 4. Time verses voltage graph at center node.

The circuit breaker fault clearing time taken into consideration for analysis is 1ms. Figure 4 shows that as the time will increase the voltage at the specified node is also increases linearly.

Voltage to blow out coils is numerous and its effect on arc potential on the third splitter plate is located. Special blowout coils voltage verses potential at third splitter plate is shown in Figure 5. as the blow out coil voltage is increased the potential on the third splitter plate varies linearly.

Effect of Splitter Plate Taper Angle On Arc Elongation

The simulations are carried by varying the tapering angle of the splitter plates. Two conditions has been performed. First is with 40 degree tapering angle in the direction of arc and second is 40 degree tapering angle in opposite direction of arc. Fig. 4.5 shows the electric potential distribution in a circuit breaker with splitter plate tapering angle 40^0 in the direction of arc.

By considering the operating time of MCCB as 1ms graph is ploted between time and voltage at center node of Figure 6. From Figure 7. it is clear that maximum voltage 60 V corresponds to the end of time period is, 1msec.

Figure 8 shows potential distribution in a circuit breaker with splitter plates tapering angle opposite to the direction of arc flow.

The graph is plotted between voltage and time at center node of fig. 8. The maximum voltage is 38 V corresponding to maximum operating time of MCCB, which is much smaller than the earlier case is as shown in Figure 9.

Graph is plotted for different values of voltage with time for the tapering angle of splitter plate in direction of arc and in reverse direction of arc Figure 10. The graph shows that at any perticular time within the specified range the voltage increases much faster for the splitter plate tapering angle in direction of arc than the tapering angle in reverse direction

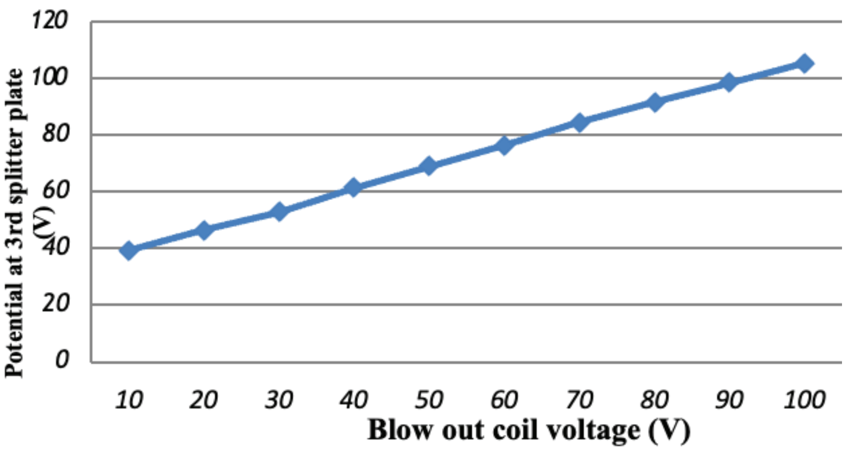

Figure 5. Graph of blow out coil verses potential at third splitter plate.

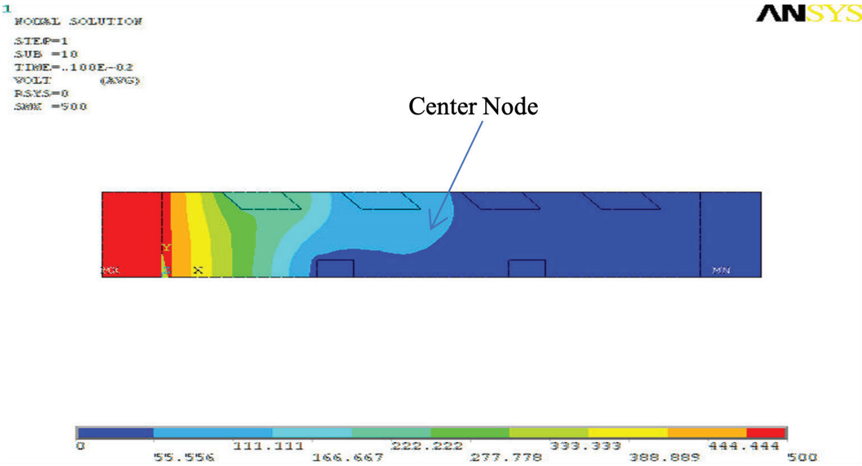

Figure 6. Potential distribution with 40 degree taper angle in arc flow direction.

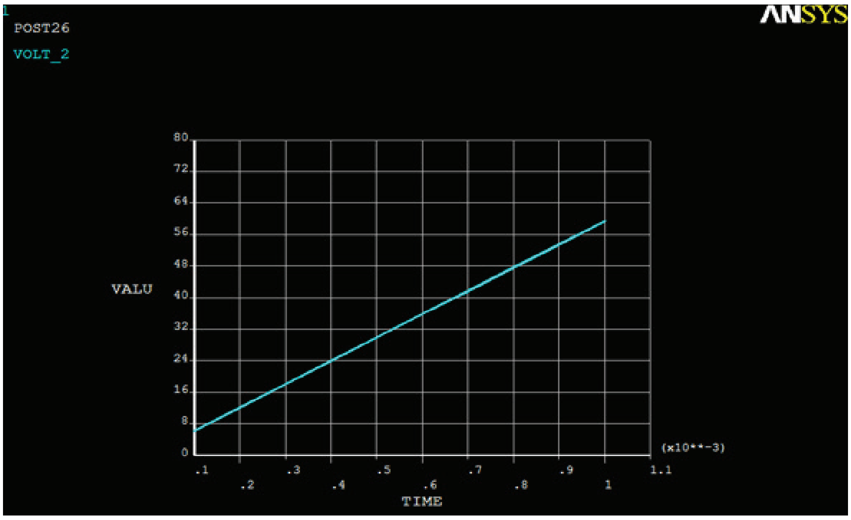

Figure 7. Time verses voltage graph at center node.

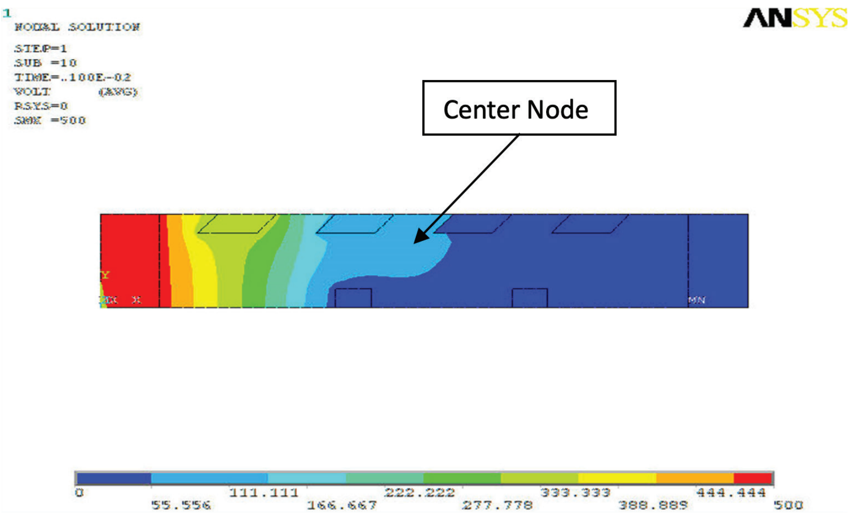

Figure 8. Potential distribution of 40 degree tapering plate angle in opposite direction of arc flow.

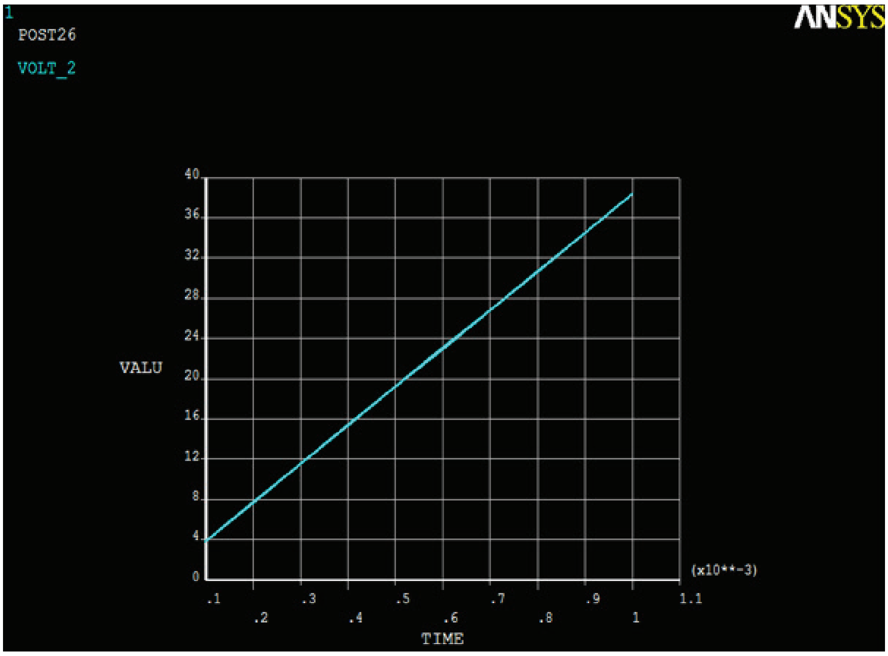

Figure 9. Time verses voltage graph at center node no for reverse 40 degree tapering angle.

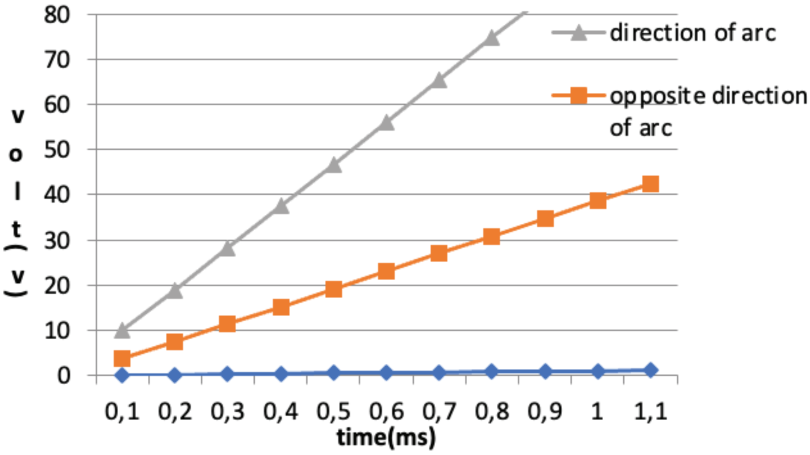

Figure 10. Time verses voltage graph at center node of 40 degree taper plates in and opposite direction of arc.

of arc. So it is clear that arc get elongated quickly in case of 40 degree tapering angle in the direction of arc flow.

CONCLUSION

For numerous years, the low-voltage circuit breaker has served as a reliable safeguard for both networks and individuals. Prior research papers concerning these devices predominantly concentrate on electrical facets or offer macro-level insights into arc-related details. However, only a limited number of these papers delve into the intricate intricacies of the arc's behaviour, encompassing its ignition at the opening contact and the subsequent current limitation stage triggered by its existence within the splitter plates.

MCCBs are an essential part of any commercial, industrial, or residential electrical system. These are flexible and can accommodate varying currents. It may be utilised in motors and welding equipment for their trip settings, and these can handle big electrical feeds to their increased capacity.

A crucial and potent numerical tool, FEM (finite element method) may precisely optimise the design process of electrical devices. In order for an MCCB to function, the electric arc must first be established. With the help of the modeling software ANSYS it is easy to calculate electric potential distribution during arc motion in arc chamber. Simple 2-D models are made and simulated. Arc formation in this models within the arc chamber has been observed. From the results obtained it concludes as:

1. An increase in blowout coil voltage reduces the arc extinction time.
2. It also shows better quenching in inclined plate as compared to flat splitter plate.
3. Splitter plate tapering angle of 40 degree along the direction of arc shows the best results compared with reverse direction flow in considered MCCB model.

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AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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