Steady State Thermal Analysis and Design of Air Circuit Breaker

Syed Ibrahim Dilawer[1], Md. Abdul Raheem Junaidi[2], Mohd Abdul Samad[3] Dr. Mohd. Mohinoddin[4]

[1]Department of Mechanical Engineering, Muffakham jah college of engineering and Technology, Hyderabad, 500034,

[2]Department of Mechanical Engineering, Muffakham jah college of engineering and Technology, Hyderabad, 500034,

[3]Department of Mechanical Engineering, Muffakham jah college of engineering and Technology, Hyderabad, 500034,

[4]Department of Mechanical Engineering, Muffakham jah college of engineering and Technology, Hyderabad, 500034,

Abstract*: A circuit breaker is an apparatus in electrical systems that have the capability to switch from being an ideal conductor to an ideal insulator and vice versa, in the shortest possible time. It is used in an electrical panel that monitors and controls the amount of amperes being sent through the electrical wiring. Essentially, a circuit breaker is a safety device, which protects against overload, short circuit and ground fault. They must, therefore, be reliable in the static situations, but be effective instantaneously when they are called to perform any switching operation. An Air circuit breaker (ACB) is a kind of circuit breaker, which generally operates in a low voltage range and current range of 400A – 6300A. These can be used both as circuit breakers for general protection (of plants, of user complexes, of electric lines) and as protection circuit breakers of electrical machines (generators, motors, transformers, capacitors). They are used in all types of plants (mechanical, civil, industrial, and in the service sector) as well as in the equipment on-board ships, in mines, in prefabricated substations, and for primary and secondary distribution in general. Circuit breakers encounter high temperatures due to internal heat generation and due to arcing at the interface of contact making and contact breaking. This temperature distributes throughout the current path. The temperature rise test being experimented and analysed is to test and certify that the temperature rise in the breaker remains well within the threshold limit for safety of equipment's in and connected to the breaker under normal operating condition.*

Keywords: *Circuit Breaker***,** *Electro thermal analysis***,** *Optimization, stress, Thermal conductivity, Aluminium bus bar.*

1. Introduction

A Circuit breaker is basically an electro-magnetic safety device which protects against overload, short circuit and ground fault. Thus, it is expected to be reliable and effective in its operation. When the circuit breaker operates it encounters high temperatures due to internal heat generation by its conductors when current flows through it. As the current rises, the temperature of the conductor increases. Heat is also generated due to arcing at the interface of contact making and contact breaking. This heat gets absorbed into the conductors causing increase in their temperatures. Excess heat causes damage to the insulation of conductors. High levels of heat can cause the insulation to breakdown and flake off, exposing conductors. Thus the heat generated is to be dissipated to the ambient so that the temperature of the breaker and the components is within specified limits. In the current project temperature rise tests were conducted on a breaker which determines the rise in temperature in various components along the current path of the breaker from source to load. The temperature rise limits are specified by IEEE and American National Standard Institute in IEEE C37.13 and IEC 60947-2. The temperature rise test involves application of rated current for long time till thermal equilibrium is achieved, making it expensive. Thermal design aspect of breaker involves designing a breaker for low temperature rise. To avoid frequent tests, Electro-thermal analysis is carried out with analysis tools in order to predict the effect of any change on temperature rise along breaker current path. In this Research paper, ANSYS 12 has been used for the electro thermal analysis on an air circuit breaker [7][25].

2. Circuit Breaker Design

There are various classifications of circuit breakers. Based on operation they are classified into Miniature Circuit Breaker, Molded Case Circuit Breaker, Air Circuit Breaker, Vacuum Circuit Breaker, SF6 Circuit Breaker. Based on voltage there are three circuit breakers i.e., low, medium and high voltage circuit breaker. Based on poles, there are Single, Two Pole Circuit Breaker, Three Pole Circuit Breaker and Four Pole Circuit Breaker.

Based on construction there are Fixed Breaker, Draw-out Breakers.

Air Circuit Breaker: The research paper being done is carried out on an Air circuit breaker. An Air circuit breaker (ACB) is a kind of circuit breaker, which generally operates in the low voltage range and within a current range of 400A – 6300A. These can be used both as circuit breakers for general protection (of plants, of user complexes, of electric lines) and as protection circuit breakers of electrical machines (generators, motors, transformers, capacitors). They are used in all types of plants (mechanical, civil, industrial, and in the service sector) as well as in the equipment on-board ships, in mines, in prefabricated substations, and for primary and secondary distribution in general. An air circuit breaker can be frame1, frame 2 or frame 3 based on the size of its terminal. When supplying a branch circuit with more than one live conductor, each live conductor must be protected by a breaker pole [17][21]. An ACB can have two poles, three poles or four poles. Each pole has number of parallel current carrying paths called "fingers". Fingers are moving parts of the breaker and its tip is the point of contact making and contact breaking. Each pole may have two to twelve fingers depending upon the requirement. The research paper is carried out on frame 1 and frame 2, having three poles but with two and six fingers respectively. To test the reliability of an air circuit breaker, various tests are conducted including but not limited to Withstand Test, Interruption test, over load test, Short circuit test, mechanical and electrical endurance test and temperature rise test. Thermal design of a circuit breaker includes designing a circuit breaker for proper dissipation of generated heat so that its temperature remains within limits. A temperature rise test tests the ability of the circuit breaker to effectively dissipate the heat generated within its current carrying components to the external ambient. The objective of a good design would therefore be to reduce the temperature at thermal equilibrium [25][26][27].

Need for Temperature-Rise Test: A circuit breaker may be connected to a portion of an electrical installation such as industrial machinery, or the whole of it. The rise in temperature in the breaker above a certain critical threshold adversely affects the service life of equipment that is connected to it through conductors. Excess heat caused damage to the conductors and their insulation. High levels of heat can cause the insulation to breakdown and flake off, exposing conductors. Whenever a breaker is in closed condition, carrying current in regular operation, a heat is generated due to "ohmic losses" which needs to be dissipated effectively. If this heat is not dissipated appropriately, it will cause a rise in temperature that is beyond the safe operating temperature of the components of breaker, particularly electrical insulation, resulting in consequences ranging from improper functioning of the components to outright and sometimes, violent failures. The ability of an enclosed assembly to sufficiently dissipate heat at a rate and to a level that components and materials fitted to the assembly can operate in accordance with the original equipment manufacturers (OEM) prescriptions will decide the success of the temperature rise test [10][21][24].

Temperature Rise Test (**Experimental setup)**: Temperature rise test also referred to as continuous current test is performed in order to verify current carrying capability of the circuit breaker. During this test, based on the design of contact system and conductors, the temperature of current flow path will increase.

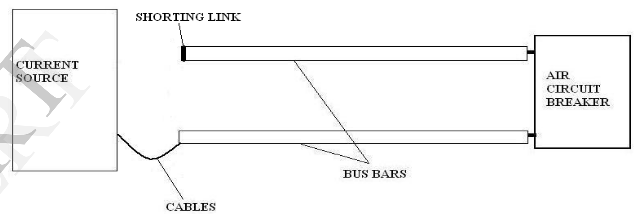


Figure.1 Temperature rise setup

The current source provides continuous flow of rated current which, through the cables and the busbars, reaches the breaker. From the breaker the current, which normally goes to the load, is shorted using shorting links for the test purpose.

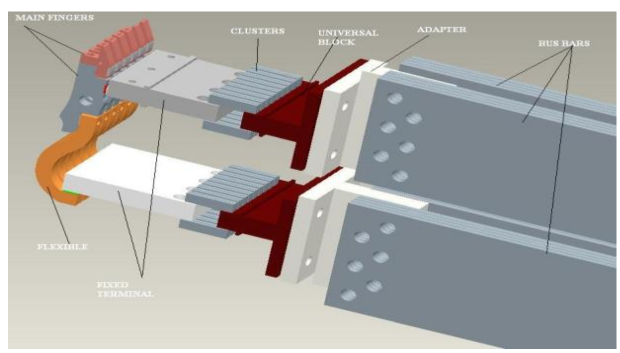


Figure.2 Solid model of the current path

As the current flows through the conductor current flow path, the parts generate heat because of flow of current through them. This heat causes the temperature of the components to rise. This heat needs to be dissipated into the atmosphere as it may cause damage to conductors and their insulation. In order to measure the temperature, thermocouples are connected at various places along the current path. These thermocouples sense the temperature throughout the duration of the test, which are recorded in a computer. A thermometer is kept at a distance from the tested device which shows the ambient temperature at any instant. Temperature rise is measured with respect to the ambient temperature. The difference of temperatures from thermocouple and thermometer gives the temperature rise at a particular point in the current path with respect to ambient. The test is carried out over a period of time sufficient for the temperature rise to reach a stable value. The final temperature rise is reported as the difference between temperatures of thermocouple and thermometer at the end of the test after the temperature readings stabilize.


Figure.3.Practical Temperature rise setup

Standards: *IEEE C37.13*, a standard that is approved by IEEE standard board and American National Standard Institute (ANSI), is a standard developed for low voltage AC power circuit breakers, which gives the limits of temperature rise. According the standard the temperature limits on which the rating of circuit breaker is based are determined by the characteristics of the insulating materials used and metals that are used in current carrying parts and other components.

Limits of temperature rise: The temperature rise of the various parts of the circuit breaker above the temperature of the air surrounding the circuit breaker test enclosure when subjected to temperature tests in accordance with this standard shall not exceed the values given in Table.1 on IEEE C37.13. This table applies only to a circuit breaker having all contacts silver surfaced , silver alloy or equivalent, and in addition , having all conducting joints , moving or fixed , including terminal connection , either (1) silver surfaced and held mechanically; or (2) brazed, welded or silver soldered; or (3) fixed rigid mechanical joints surfaced with suitable material other than silver.

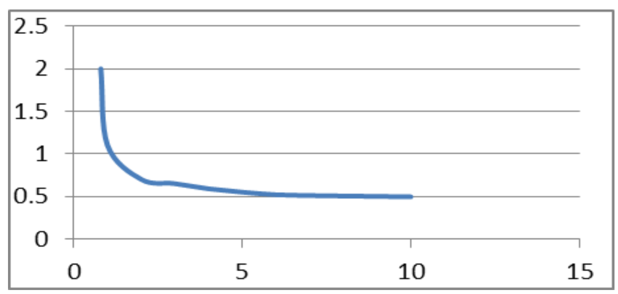
Table.1 Limits of Temperature Rise IEEE C37.13

	Limit of Temperature Rise Over Air Surrounding Enclosure (°C)	Limit of Total Temper (°C)
Class 90 insulation	50	90
Class 105 insulation	65	105
Class 130 insulation	90	130
Class 155 insulation	115	155
Class 180 insulation	140	180
Class 220 insulation	180	220
Circuit-breaker contacts, conducting joints, and other parts, except the following:	85	125
Fuse terminals	(1)	(1)
Series coils with over Class 220 insulation or bare	(1)	(1)
Terminal connections (2)	55	95

3. HEAT GENERATION

Joint Resistance: The resistance of a joint is affected mainly by two factors: a) Streamline effect or spreading resistance Rs, the diversion of the current flow through a joint, b) The contact resistance or interface resistance of the joint Ri. The total joint resistance Rj = Rs + Ri.

Streamline effect: The relation between the resistance due to streamline effect of an overlapping joint between two flat copper conductors and the ratio of the length of the overlap to the thickness is shown in Figure.

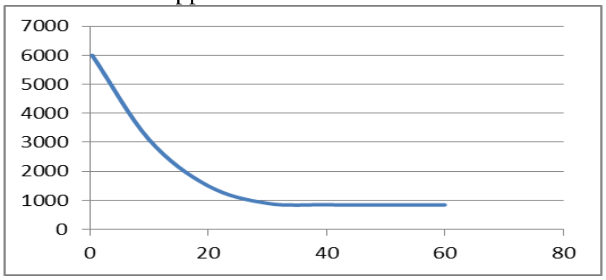


Graph.1 Streamline effect graph showing Resistance ratio vs overlap/thickness

It has also been found that the distortion effect in a T-joint is about the same as a straight joint. The resistance ratio e is the ratio of the resistance of a joint due to streamline effect R_s, to the resistance of an equal length of single conductor R_b, i.e. $\mathbf{e = R_s / R_b = ab/\rho l * R_s}$ Where a = breadth of bar, mm, b = thickness of bar, mm, **ρ =** Thermal Constant**,** l = length of overlap, mm, r = resistivity of the conductor, mW mm. From the graph it can be seen then that the effect falls very rapidly for ratios up to two and then very much more slowly for values up to seven. This means that in most cases the streamline effect has very little effect as the overlap is of necessity much greater than seven[16][5][25].

Preparation of surfaces: Contact surfaces should be flattened by machining if necessary and thoroughly cleaned. A ground or sand-roughened surface is preferable to a smooth one. It is important to prevent the re-oxidation of the joint in service and it is therefore recommended that the contact faces should be covered with a thin layer of petroleum jelly immediately after cleaning the contact surfaces. The joint surfaces should then be bolted together, the excess petroleum jelly being pressed out as the contact pressure is applied. The remaining jelly will help to protect the joint from deterioration. It should be noted that in cases where joints have to perform reliably in higher than normal ambient temperature conditions, it may be advisable to use a high melting point jelly to prevent it from flowing out of the joint, leaving it liable to attack by oxidation and the environment. The process of tinning and silver or nickel plating describes the use of coating on conductor contact surfaces. It should be noted that recent tests carried out to investigate the performance of bolted joints under cyclic heating with wide temperature variations indicate that joints without coatings give the most reliable long-term performance (Jackson 1982). The reason for this is that most coatings are of soft materials which when subjected to continuous pressures and raised temperatures tend to flow. This has the effect of reducing the number of high pressure contact points formed when the joint is newly bolted together [7][1][20].

Effect of pressure on contact resistance: The pressure on the contact surface has the advantage that the high pressure helps to prevent deterioration of the joint. Figure shows the effect of pressure on joint resistance. Following graph shows the effect of pressure on the contact resistance of a joint between two copper conductors mm.



Graph.2 Effect of pressure on contact resistance graph showing Resistance μΩ/mm-2 V/s Pressure N/mm-2

Joint resistance falls rapidly with increasing pressure, but above a pressure of about 15 N/mm2 there is little further improvement. Certain precautions must be observed to ensure that the contact pressure is not unduly high, since it is important that the proof stress of the conductor material or its bolts and clamps is not exceeded. As a bar heats up under load the contact pressure in a joint made with steel bolts tends to increase because of the difference in expansion coefficients between copper and the steel [21][22].

Bolting Arrangements: In deciding the number, size and distribution of bolts required to produce the necessary contact pressure to give high joint efficiency, both electrical and mechanical aspects have to be considered. The methods used to determine these requirements have been given in previous sections. A joint normally decreases in resistance with an increase in the size and number of bolts used. Bolt sizes usually vary from M6 to M20 with between four and six being used in each joint with a preference for four bolts in narrow conductors and six in large conductors. The torque chosen for each bolt size is dependent on the bolt material and the maximum operating temperature expected. Because of the strength of copper, deformation of the conductor under the pressure of the joint is not normally a consideration.

Current Path: The solid model is prepared on 3D modelling tool Pro Engineer. The components are modelled individually and assembled as the current path. The dimensioning of the models is done in millimetres. In Figure.10, the finger assembly contains Flexible, Moving contact, Ag-Ni Tip and Arc Runner. The Flexible is a copper foil welded at the ends. It is responsible for easy open-close movement of the finger assembly. Moving contact is the copper part which is pivoted in the middle through a pin. The Silver-Nickel tip is brazed on the moving contact in the slot provided. It is the point of making and breaking of the current. The arc runner is an extruded copper part which guides the arc away from the finger assembly during opening operation.

Terminals: Top and bottom terminals are copper blocks. The finger assembly is always in contact with bottom terminal as it is bolted to the bottom terminal where as it makes and breaks contact with top terminal during operation. The current from source through the current path enters bottom terminal goes to fingers and then to top terminal. During opening operation, finger assembly moves away from top terminal interrupting the current flow.

Clusters: The clusters connect the withdrawable part of the breaker with the stationary part and facilitate withdrawal of the breaker for inspection, maintenance or component change. They are limited to withdrawable breakers. Clusters are spring loaded which provides continuous pressure on the terminals and universal pad, assuring their electrical and mechanical contact.

Universal pad and Busbar Terminal: The universal pad is a copper part which fits in the back mould of the breaker. Universal pad, Clusters, terminals and finger assembly remain inside the breaker casing. The universal pad is fixed to the cluster on one end and bolted to busbar terminal, a silver plated copper part, on the other end.

Aluminium Busbar and components assembly: Busbars are of copper or aluminum which connect the current source to the breaker and breaker to the load. Busbars are available in standard sizes which are bolted to the busbar terminal. In the electrical sense, the term bus is used to describe a junction of circuits, usually in the form of a small number of inputs and many outputs. 'Busbar' describes the form the bus system usually takes, a bar or bars of conducting material. In any electrical circuit some electrical energy is lost as heat which, if not kept within safe limits, may impair the performance of the system. This energy loss, which also represents a financial loss over a period of time, is proportional to the effective resistance of the conductor and the square of the current flowing through it. A low resistance therefore means a low loss; a factor of increasing importance as the magnitude of the current increases. The heat dissipated per unit area by convection depends on the shape and size of the conductor and its temperature rise. This value is usually calculated for still air conditions but can be increased greatly if forced air cooling is permissible. Where outdoor busbar systems are concerned calculations should always be treated as in still air unless specific information is given to the contrary.

4. Electro Thermal Analysis

Ansys analysis procedure: The solid model created in Pro-Engineer is imported into Ansys 11 Classic Multiphysics by converting it into IGES format. Before applying the loads, material properties and meshing is to be done. The contact volumes which are the critical points are given refined mesh.

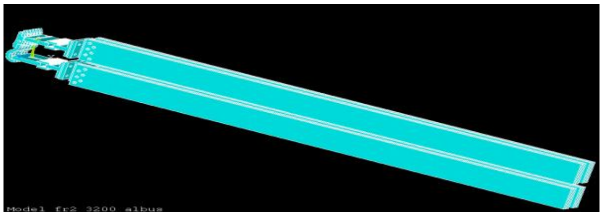
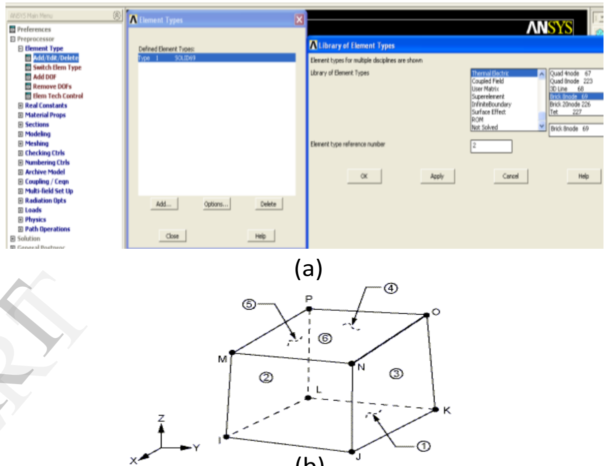


Figure.4 Current path assembly after being imported in Ansys 11 Classic Multiphysics.

Before defining the loads on the model, material properties and the element are to be specified. The material properties that are to be specified are thermal conductivity and resistivity for all the materials that are included in the current path. The first step is to choose the element to be considered by the tool for the thermal electric analysis. The choice of element is the one of the most important steps in the analysis procedure as it directly affects the result. The element is chosen on the basis of inputs a given and output required. Every element in the Ansys directory has its own degrees of freedom. The user has to choose the element depending upon his requirements [10][25].



(a)

(b)

Figure.5 (a) Element selection in ANSYS 11 Classic Multiphysics; (b) Element SOLID69

For the thermal electric analysis being carried out , 8 Noded thermal electric SOLID69 element is chosen. **SOLID69** has a 3-D thermal and electrical conduction capability. Joule heat generated by the current flow is also included in the heat balance. The element has eight nodes with two degrees of freedom, temperature and voltage, at each node. The thermal-electric solid element is applicable to a 3-D, steady-state or transient thermal analysis, although no transient electrical capacitance or inductance effects are included in the element. The element requires an iterative solution to include the Joule heating effect in the thermal solution.

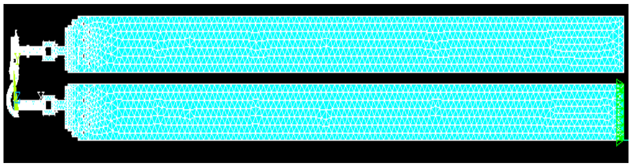


Figure.6 Meshed model in ANSYS11 Classic Multiphysics

A meshed model is ready to be assigned with the required loads. The loads being applied include

Current, Voltage and Convection. The required current is applied by selecting the node and coupling it to the entire surface which is assumed to be connected to the current source so that the current is assumed to enter from the entire surface.

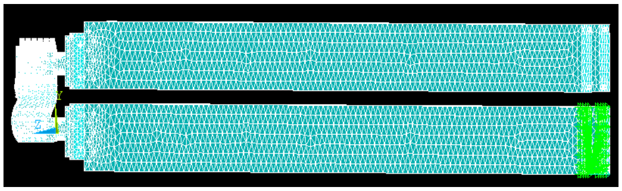


Figure.7 Applied current in ANSYS11 Classic multiphysics

Zero Voltage is applied to the selected areas which assumed to be connected to the load.

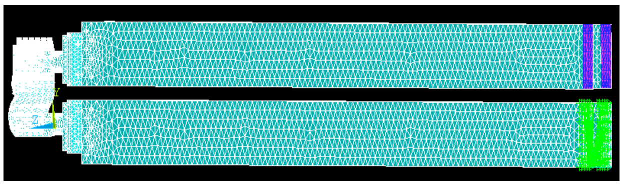


Figure.8 Applied voltage in ANSYS11 Classic multiphysics

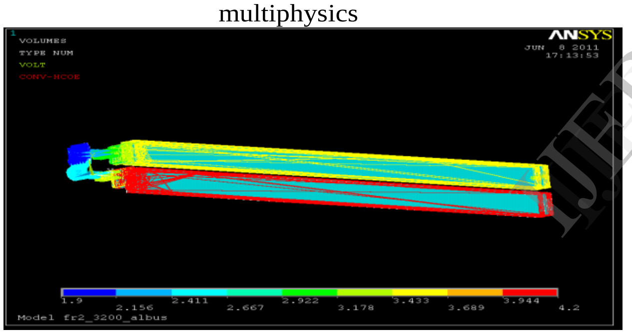


Figure.9 Applied convection in ANSYS11 Classic multiphysics

Convection is specified as a surface load on conducting solid elements or shell elements. Convection film coefficient and the bulk fluid temperature is specified at the surface, ANSYS then calculates the appropriate heat transfer across that surface. The areas which have more exposure to atmosphere have a higher convection coefficient as the convection would be more in such areas. Bus bars have the highest atmospheric exposure and so their convection coefficient is higher than other components of the current path which remain inside the breaker. After the loads have been applied the analysis is to be started by selecting the 'SOLVE' command in the solution tree. Ansys solves the model by solving each element and integrating all the elements. Ansys runs iterations till it gets a converged solution. As the convergence is achieved it prompts that the solution is done. If the convergence is not achieved, the analysis terminates prompting that the solution is not convergent. In case of unconvergent solution the user needs to recheck the model and gluing procedure to avoid electrical discontinuity. After the solution is achieved, the results are viewed in postprocessor of Ansys. Solution may be in the form of values, graph or a contour plot. In this case, a contour plot showing the temperature contour along the current path is achieved. A contour plot showing electrical potential across the current path is also achieved to check the resistivity distribution along the path. It is to be noted that the solution achieved through Ansys is an approximate solution which has its share of inaccuracies.

Analysis information: For modelling the current path we have used Pro Engineer modelling software and for analysis we have used ANSYS 11 Classic multiphasic.

Range of Air Circuit Breakers: A range of breakers are being analysed for temperature rise by conducting electro thermal steady state analysis on different current path models of different breakers on Ansys 11 Classic multiphasic. The range of breakers that are being analysed include 4000A, 3200A, 2500A, 1600A and 1000A breakers of frame1 and frame 2 sizes. A 6 finger pole construction is used for frame 2 size whereas 4 finger and 2 finger pole construction is being used for frame 1 construction. The current path of all the breakers will differ in sizes, shapes and number of components used. All the current paths are modelled in Pro Engineer so as to be imported to Ansys for analysis. The analysis is conducted in the above mentioned procedure. The result of the analysis will be a contour plot showing the distribution of temperature along the current paths of these breakers. Any design idea which requires change in the current path can be modelled accordingly and analysed in Ansys and the result due to the change can be observed in the resulting contour plot.

Contact Volumes: As mentioned earlier, one of the causes for heat generation in the breaker is the joule effect. The current flowing through its path encounters resistance which caused heat generation. This heat generated due to resistance is more at the joints like bolting surfaces. In order to give higher resistance values in such surfaces during analysis, contact volumes are provided in the current path model at the joining surfaces. A resistivity value measured experimentally across the joint is given as input during analysis. Rest of the materials like copper and aluminum are given standard resistivity and thermal conductivity values. The addition of contact volumes for joint resistivity consideration gives a better solution. The contact volumes are the most critical points in the current path. Any error in their resistivity values can cause large variations in results.

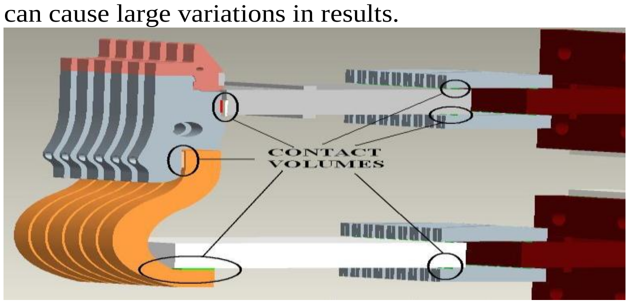


Figure.10 Contact Volumes

4. ANALYSYS, RESULTS AND DISCUSSION

Frame 2, (3200A and 4000A) , 6 Finger with 8 Aluminum busbars: Current Path in Ansys

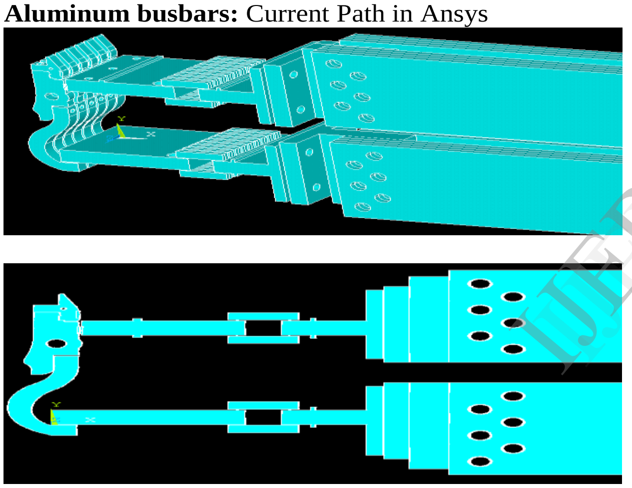


Figure 11 Current path in ANSYS

Material Properties

Aluminium: Thermal Conductivity = 220 W/m/k,
Resistivity = 2.82e-8 Ohm.m

Copper: Thermal Conductivity = 390.08 W/m/k,
Resistivity = 1.72e-8 Ohm.m

Ag-C: Thermal Conductivity = 310 W/m/k,
Resistivity = 2.44e-8 Ohm.m

Ag-Ni: Thermal Conductivity = 240 W/m/k,
Resistivity = 2.33e-8 Ohm.m

Temperature Contour Plot:

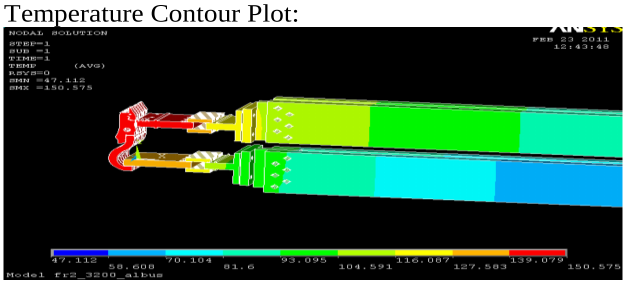


Figure.12 Temperature contour plot for Frame 2, 3200A 6 Finger with 8 Aluminum busbars

Table.2 – Experimental and analysis data for Frame 2, 3200A 6 Finger with 8 Aluminum busbars

3200A	EXPERIMENTAL DATA		ANALYSIS DATA	
POSITION	Absolute temperature (EXP)	Temperature rise (EXP)	Absolute Temperature(ANSYS)	Temperature Rise(ANSYS)
Fixed Terminal Top	145.39	111.58	144.628	109.608
Fixed Terminal Bottom	135.08	101.27	134.124	99.124
Busbar terminal Top	119.17	85.36	118.174	83.174
Busbar terminal bottom	109.95	76.14	100.659	65.659
Busbar start top	108.53	74.72	113.246	78.246
Busbar start bottom	100.97	67.16	94.1018	59.1018
Busbar middle top	66.74	32.93	78.835	43.835
Busbar middle bottom	71.16	37.35	65.067	30.067

The plot shows variation of temperature along the current path in Frame 2, 3200A breaker with 6 Fingers and 8 Aluminum busbars. We can observe that the temperature is the highest at the interphase of contact making and breaking because the resistance is highest at that point. The temperature shown by the plot is the absolute temperature at the surface of the component. The rise is calculated by subtracting ambient temperature from absolute temperature. The above table shows a comparison between experimental data and analysis results. According to standards, the rise is measured at busbar terminal. Temperature rise at top busbar terminal for the above case according to experiment is 85.36^{o} and that according to Ansys is 83.174^{o}.

Table.3 Experimental and analysis data for Frame 2, 4000A 6 Finger with 8 Aluminum

4000A	EXPERIMENTAL DATA		ANALYSIS DATA	
POSITION	Absolute temperature (EXP)	Temperature rise (EXP)	Absolute Temperature(ANSYS)	Temperature Rise(ANSYS)
Fixed Terminal Top	184.5	151.9	186.885	151.885
Fixed Terminal Bottom	168.73	136.13	168.876	133.876
Busbar terminal Top	144.9	112.3	144.249	109.249
Busbar terminal bottom	131.6	99	117.19	82.19
Busbar start top	131.62	99.02	138.983	103.913
Busbar start bottom	119.63	87.03	106.735	71.135
Busbar middle top	78.43	45.83	100.77	65.77
Busbar middle bottom	88.38	55.78	70.22	35.22

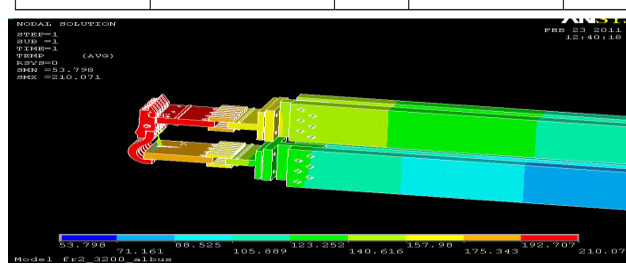


Figure.13 Temperature contour plot for Frame 2, 4000A 6 Finger with 8 Aluminum busbars

The contour plot in Fig.13 shows variation of temperature along the current path in Frame 2, 3200A breaker with 6 Fingers and 8 Al busbars. Temperature rise at top busbar terminal for the above case according to experiment is 112.3^{o} and that according to Ansys is 109.25^{o}.

Frame2, 3200A and 4000A, 6 finger and 6 Aluminum busbars

Material Properties

Aluminium thermal Conductivity = 220 W/m/k, Resistivity = 2.82e-8 Ohm.m

Copper thermal Conductivity = 390.08 W/m/k, Resistivity = 1.72e-8 Ohm.m

Ag-C thermal Conductivity = 310 W/m/k, Resistivity = 2.44e-8 Ohm.m

Ag-Ni thermal Conductivity = 240 W/m/k, Resistivity = 2.33e-8 Ohm.m

Temperature Contour plot

3200A

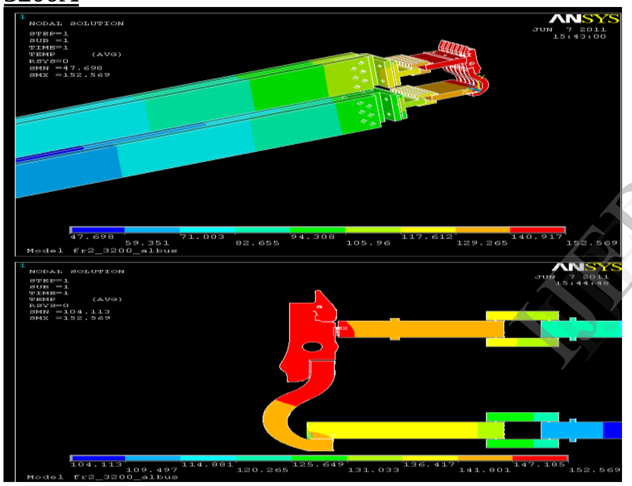
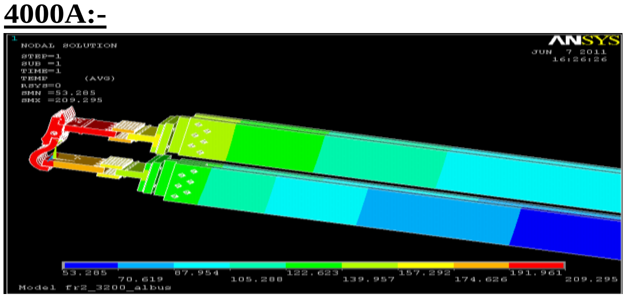


Figure.14 Temperature contour plot for Frame 2, 3200A 6 Finger with 6 Aluminium busbars

The temperature contour plot in Fig.14 shows variation of temperature along the current path in Frame 2, 3200A breaker with 6 Fingers and 6 Aluminium busbars. The absolute temperature at the top busbar terminal is 120.265. The temperature rise is calculated as the difference between absolute temperature and ambient temperature which comes to 85.265.

4000A:-



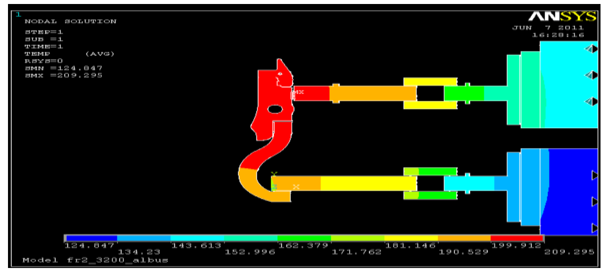


Figure.15 Temperature contour plot for Frame 2, 4000A 6 Finger with 6 Aluminium busbars

The temperature contour plot in Fig.15 shows variation of temperature along the current path in Frame 2, 4000A breaker with 6 Fingers and 6 Aluminium busbars. The absolute temperature at the top busbar terminal is 152.996. The temperature rise is calculated as the difference between absolute temperature and ambient temperature which comes to 112.996.

Fr2-3200A, 6 Fingers, 8 Aluminium Busbars (Terminal hole removal)

Electro-Thermal analysis conducted to predict the effect of removal change in temperature rise with and without holes at the cluster end of the top and bottom terminals.

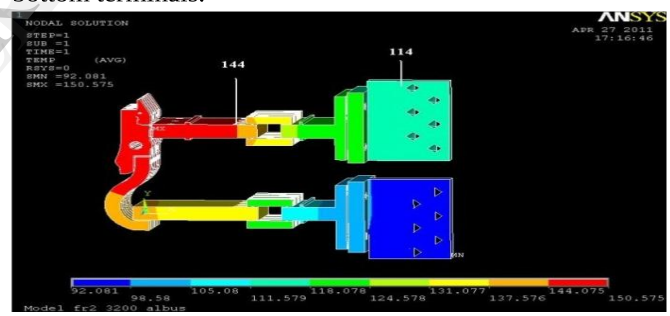


Figure.16 (a) Temperature contour plot for Frame 2, 3200A 6 Finger with 8 Aluminium bus bars with terminal holes

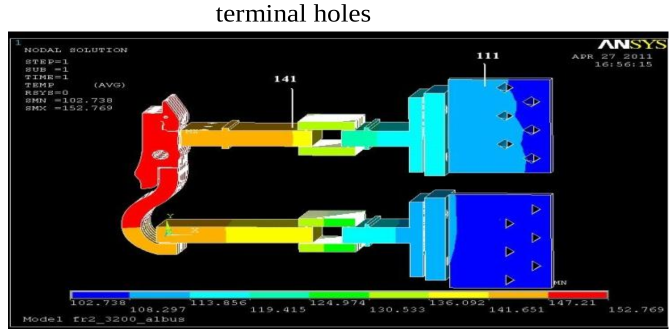


Figure.16 (b) Temperature contour plot for Frame 2, 4000A 6 Finger with 8 Aluminium busbars without terminal holes

We observe from the temperature contour plots that the removal of holes from the cluster end of the terminals has caused drop in temperature by 2-5 ^{0}.

The possible reason for the reduction in temperature is the addition of area and decrease in resistance. The removal of holes caused an increase in surface area that is exposed to the atmosphere for convection. The same caused the decrease in resistance because when holes are present, the surface area for current flow reduces causing increase in resistance. But when the holes were removed, the surface area increased causing decrease in resistance. Thus thermal analysis was instrumental in predicting the temperature rise without actual testing.

Frame 1- 2500A, 4 finger,4 Aluminium Busbars

Solid Model

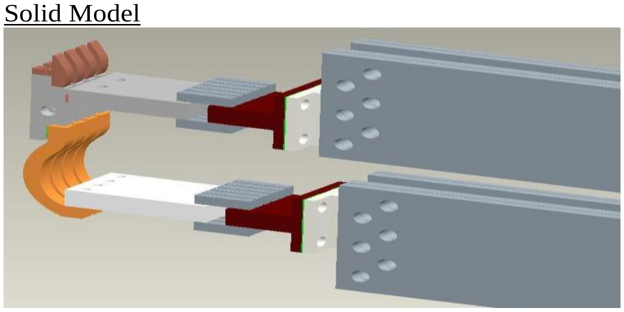


Figure.17 Temperature contour plot for Frame 2, 4000A 6 Finger with 8 Aluminium busbars with terminal holes

Temperature Contour Plot

The temperature contour plot in Fig.18 shows variation of temperature along the current path in Frame 1, 2500A breaker with 4 Fingers and 4 Aluminium busbars. The absolute temperature at the top busbar terminal is 111.631. The temperature rise is calculated as the difference between absolute temperature and ambient temperature which comes to 76.631

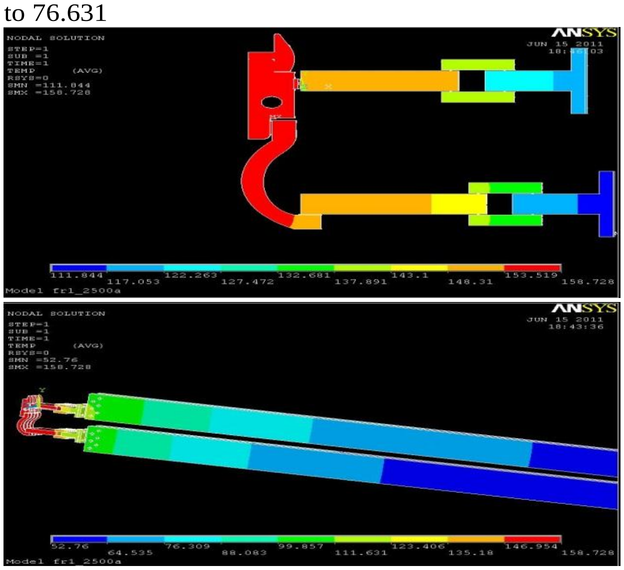


Figure.18 Temperature contour plot for Frame 1, 2500A 4 Finger with 4 Aluminium busbars

New design proposed for Frame 1, 1600A, 2 Finger: A new design for current path is proposed which is being tested. The design, which is expected to achieve more than 25% cost reduction, should be tested for thermal reliability. Electro-thermal analyses have been conducted on the present design and proposed design and have been compared. According to company policies it is not allowed to mention any dimensions, name and solid models of the new design.

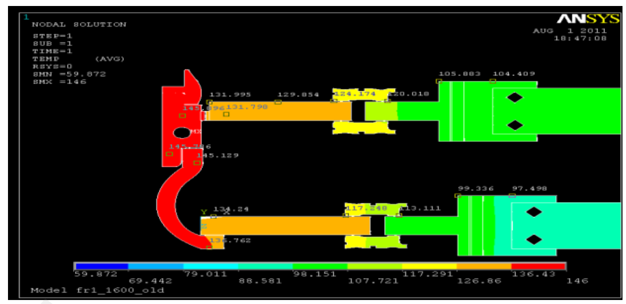


Figure.19 Temperature rise plot for present design

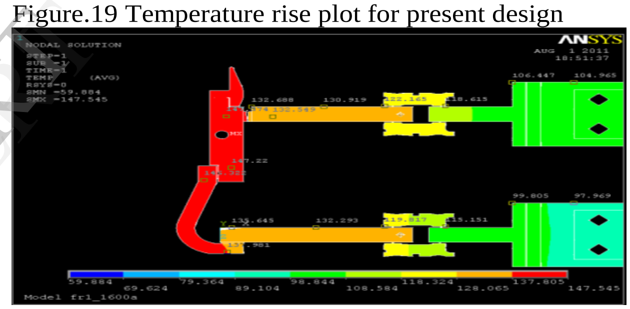


Figure.20 Temperature rise plot for new design

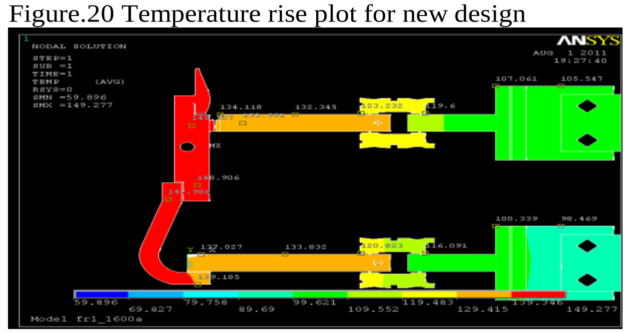


Figure.21 Temperature rise plot for new design with old contact tips

The comparison of temperature rise values achieved through the analysis predicts that the new design is within the thermal limits. The new contact tips can be used instead of old contact tips as their use did not affect the design thermally. The new design proposed is yet to undergo short circuit testing which would determine its strength to withstand high electrical loading under short circuit conditions.

Table 4 Comparison of present design, new design and new design with old contact tips

Parts	Present Design	New Design	New Design with old contact tips
Adapter (top)	1.5	1.5	1.6
Adapter (bottom)	1.8	1.8	1.8
Universal pad (top)	14.1	12.1	12.5
Universal pad (bottom)	13.7	15.3	15.7
Cluster (top)	4.1	3.5	3.6
Cluster (bottom)	4.1	4.6	4.7
Breaker Terminal(Top)	7.8	10.5	10.8
Breaker Terminal(bottom)	17	15.5	16.2
Contact tips	14.1	14.8	15.1
Bottom terminal and Flexible	2.5	2.3	2.1

Significance of Electro Thermal Analysis: The temperature rise test requires a current source to supply high currents for hours together making it costly and time consuming process. The current path of the breaker undergoes numerous minor changes in design. Testing the change in temperature rise for minor changes in design will not be logical. Thus, electro thermal analysis is carried out which would predict the change in the temperature rise due to these minor changes. The assumed parameters are given by trial and error method, trying to match the result with an experimental result. In the analysis being carried out, the convective heat transfer coefficient is to be assumed. A number of analyses are carried out by, varying the convective heat transfer coefficient, to match the experimental result. Once the experimental results are matched, the parameters are recorded and the analysis is saved as base line analysis. Any change in design will call for creation of new geometric model with new design and analysis is carried out on it keeping the assumed parameters same as the base line analysis. The results of the new analysis are compared with the base line analysis which gives the change in results due to the new design change. The thermal analysis saves time and resources which would get spent due to repetitive testing.

V. CONCLUSIONS

The heat generated in the current path can be reduced mainly by exposing more area into the atmosphere for convection and by reducing resistances at the joints. Former can be achieved by a design which would space the parts providing area exposure and latter can be achieved by using proper joining method which would provide good contact pressure so as to reduce contact resistance. In the analysis being conducted, the effect of increase in temperature on the resistance is neglected. Practically when the temperature increases, the resistance of body increases. This change is considered in transient electro thermal analysis where the values of different resistances at different temperatures are given as input in the Ansys. The heat generated is higher in 4000A analysis than in 3200A and 2500A. This is because of the fact that the heat generated is proportional to square of the current. Use of 6 busbars shown in analysis aimed to provide more convection surface exposure between busbars of two consecutive poles. The disadvantage of this was the increase in resistance per bar as more current flows per bar. Additional current per bar causes more heat generation causing more temperature rise. From analysis it is observed that removal of holes is advantageous thermally as well as cost wise. In the analysis on Frame2 3200 with and without holes in terminals it is observed that the temperature rise is more in the case of terminals with hole. This is because the presence of hole causes a bottle neck in the current flow path causing increase in resistance whereas without holes there will be more area exposed to atmosphere for convection. In the new design proposed, the diameter of hole in the finger is reduced increasing the area for current flow, decreasing the resistance and in turn reducing the heat generated. The use of new contact tips which are critical parts of the current path is predicted to be within thermal limits in addition to achieving significant cost reduction. It is recommended that the busbars may be provided with spacers (aluminium or wooden blocks), which would space the busbars away from each other, causing significant area to be exposed to atmosphere for convection. It is also recommended that mounting adapters of busbars called busbar terminals for the corner terminals may be provided offset to allow space between busbars of two consecutive poles allowing convection.

VI. FUTURE SCOPE

The thermal analysis conducted is a steady state thermal analysis, in which it is assumed that resistance remains constant throughout the duration of test which is not true in practical applications. Practically, as the temperature increases the resistance increases. Thus there is a need for a transient analysis to be conducted which takes into account the change in resistance with temperature. The value of resistance corresponding to different temperatures is to be fed into ANSYS which intern would consider the value of resistance corresponding to the temperature reached at that particular time while solving. The analysis has been carried out for only D.C current inputs, but an A.C input analysis also needs to be conducted which would be called harmonic analysis.

REFERENCES

[1] Z. Xiang, G. Ernst, L. Zhaolin, C. Haibo, Y. Linghui, Reliability estimation of High Voltage Circuit Breaker by statistical analysis on the basis of the field data, *Electric Power System Research*, 103(1), 2013, PP.105-113.

[2] R.P. Carlos, E.E. Guillermo, C.C. Francisco, R.B. Carlos, Nuisance tripping of residual current circuit breaker: Apractical case, *Electrical Power System Research*, 106(1), 2014, pp.180-187.

[3] M.A.H. Sadi, M.H. Ali, Combined operation of SVC and optimal reclosing of circuit breakers for power system transient stability enhancement, *Electrical Power Systems Research*, 106(1), 2014, pp.241-248.

[4] Ziani, H. Moulai, Hybrid model of electric arc in high voltage circuit breakers, *Electric Power System Research*, 92(1), 2012, pp.37-42.

[5] X. Niu, X. Zhao, The study of fault diagnosis the high-Voltage Circuit Breaker Based on Neural Network and Expert System, *Procedia Engineering*, 29(1), 2012, pp.3286-3291.

[6] Yanbin, C. Bo, The Condition based Maintenance Evaluation Model on On-post Vacuum Circuit Breaker, *Systems Engineering Procedia*, 4(1), 2012, 182-188.

[7] S. Natti, M. Kezunovic, Assessing Circuit breaker performance using condition-based data and Bayesian approach, *Electric Power System Research*, 81(9), 2011, pp.1796-1804.

[8] Roodenburg, B. Evenblij, Design of a fast linear drive for hybrid circuit breakers-Development and validation of a multi domain simulation environment, *Mechatronics*, 18(3), 2008, pp.159-171.

[9] J.Y. Trepanier, R. Camarero, V. Gindre, E. Serres, Circuit-Breaker Design Using an integrated CAD/CAE Tool, *Manufacturing Research and Technology*, 16(1), 1993, pp.177-186.

[10] L.H. Saw, K. Somasundaram, Y. Ye, A.A.O. Tay, Electro-thermal analysis of Lithium Iron Phosphate battery for vehicles, *Journal of Power Source*, 4(3), 2013, pp.175-191.

[11] S.J. Huang, C.H. Hsieh, Relation analysis for ferro-resonance of bus potential transfer and circuit breaker grading capacitance, *International Journal of Electrical Power & Energy System*, 51(1), 2013, pp61-70.

[12] T.G. Zhou, Z.Y. Jiang, J.L.Wen, A.K. Tieu, A method to produce aluminium Bus bars by continuous casting expansion extrusion, *Journal of Materials Processing Technology*, 177(3), 2006, pp163-166.

[13] J.D. Yan, MM.T.C. Fang, W. Hall, The development of pc based CAD tools for auto-expansion circuit breaker design, *IEEE Power & Energy Society*, 14(1), 2002, pp.176-181.

[14] P.U. Frei, H.O. Weichert, Advanced thermal simulation of a circuit breaker, *Electrical Contacts*, 5(1), 2004, pp.104-110.

[15] M. Popov, V.D. Sluis, G.C. Paap, Investigation of the circuit breaker reignition overvoltage caused by no-load transformer switching surges, *Euro Trans Electric Power*, 11(1), 2001, pp.413-422.

[16] George. G, G.T. Heydt, E.S. Gel, F. Hubele, The Utilization of Micromechanical Devices in a Power Circuit Breaker, *Electric Power Components and Systems*, 33(10), 2005, pp.1159-1174.

[17] X.D. Zhang, J.Y. Trepanier, R. Camarero, Modelling and Computation of Arc-Flow Interaction in Circuit Breakers, *International Journal of Computational Fluid Dynamics*, 2(1), 1994, pp.41-64.

[18] Zhang, W.Li, X. Xiong, R. Liao, Evaluating Condition Index and its Probability Distribution Using Monitored Data of Circuit Breaker, *Electric Power Components and Systems*, 39(10), 2011, pp.965-978.

[19] R.E. Voshall, Circuit Breaker, *Electrical and Electronics Engineering*.

[20] C.H. Fluscheim, Power Circuit Breaker Theory and Design, *IET*, USA, 1982.

[21] R.D. Garzon, High Voltage Circuit Breakers: Design and Application, *CRC Press*, 2002.

[22] D.R. Carpenter, Fundamentals of Electrical Design: Preliminary and detailed design analysis: Module 2, *Integrity Institute of Technology*, 2008.

[23] The Cutter Electrical and Manufacturing, Handbook of the I-T-E Circuit Breaker, *BibloBazaar*, 2011.

[24] A.B. Shimp, R.P. Putkovich, Circuit Breaker Development and application, *Westinghouse Electric Corporation, Research Laboratories*, 2009.

[25] Y. Hase, Switching Surge Phenomenon by Circuit Breakers and line switches, Handbook of Power System Engineering, *John Wiley & Sons, Ltd, Chichester*, U.K, 2001.

[26] L.V. Sluis, Circuit Breakers, Transients in Power System, *John Wiley & Sons Ltd, Chichester*, U.K, 2002.

[27] L.V. Sluis, Testing of Circuit Breakers, Transients in Power System, *John Wiley & Sons Ltd, Chichester*, U.K, 2000.

[28] M.E. Brumbach, Industrial Electricity, *Cengage Learning*, USA, 2009.

[29] M.A. Laughton, D.F. Warne, Electrical Engineers Reference Book, *Newnes*, USA, 2002.

[30] H.M. Ryan, High Voltage Engineering and Testing, *IET*, U.K, 2001.