# Development of busbar termination scheme to offer lower cross-section for same current rating of Air Circuit Breaker

**Major Project Report**

*Submitted in Partial Fulfillment of the Requirements for the Degree of*

**MASTER OF TECHNOLOGY**

**IN**

**ELECTRICAL ENGINEERING**

**(Electrical Power Systems)**

By

**Kamesh S. Shah**
**(14MEEE24)**

DEPARTMENT OF ELECTRICAL ENGINEERING
INSTITUTE OF TECHNOLOGY
NIRMA UNIVERSITY
AHMEDABAD-382481

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# CERTIFICATE

This is to certify that the Major Project Report entitled "Development of busbar termination scheme to offer lower cross-section for same current rating of Air Circuit Breaker" submitted by **Mr. Kamesh S. Shah (Roll No: 14MEEE24)** towards the partial fulfillment of the requirements for the award of degree in Master of Technology (Electrical Engineering) in the field of Electrical Power Systems of Nirma University is the record of work carried out by him under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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# Undertaking for Originality of the Work

I, Kamesh Shah, Roll. No.14MEEE24, give undertaking that the Major Project entitled "Development of busbar termination scheme to offer lower cross-section for same current rating of Air Circuit Breaker" submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in Electrical Engineering (Electrical Power Systems) of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

**Signature of Student**

Date:

Place: Nirma University, Ahmedabad.

Endorsed By:

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# Abstract

Air Circuit Breaker (ACB) is an upstream protection device for LV distribution system. ACB is designed to protect the system in case its downstream protective device fails to clear the fault. Busbar termination schemes generally used for ACB termination where proper termination of ACB plays very important role in healthy working of ACB. There exist standardize practices & guidelines for ACB termination. Any deviation in above standardize practice may cause overheating of breaker inside distribution panel. IEC standard has recommended busbar cross-section for defined current rating but deviation to use recommended cross-section was observed at customer end to reduce cost impact. To overcome that new busbar termination scheme has to be developed to offer lower cross-section for same current rating without any compromise in thermal performance. Which will serve cost-effective termination for customer.

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# Abbreviation

| | |
|---|---|
| ACB | Air Circuit Breaker |
| LV | Low Voltage |
| FC | Fix Contact |
| MC | Moving Contact |
| AC | Alternating Current |
| DC | Direct Current |
| FEM | Finite Element Method |
| TR | Temperature Rise Testing |
| mv | millivolt drop Testing |

# Contents

# Chapter 1

# Introduction

## 1.1 General

Air Circuit Breaker (ACB) is a mechanical switching device, capable of making, carrying and breaking currents under normal circuit conditions using air as arc quenching medium. It is also capable of making and carrying currents for a specified short duration of time and breaking currents under specified abnormal circuit conditions such as over load and short circuit.

ACB is an upstream protection device for LV distribution system which is designed to protect the system in case its down-stream protective device fails to clear the fault. Breaker consists of two contacts: Fixed Contact (FC) and Moving Contact (MC). Moving Contact is used to make and break the circuit using stored energies in the form of spring or compressed air. Spring, pneumatic or oil damping is used to arrest the speed of MC while closing. Operating Mechanism is of stored energy type, which operates using pre-charged springs. The springs are charged manually with the help of charging handle or with the help of charging motor, if provided. The same operating mechanism is used for the entire range. Mechanism has been developed using less number of parts resulting in more reliability, longer mechanical life and requiring very less maintenance. It can be operated using manual input or remote signal which gives signal to release assembly.

## 1.2 Problem Identification

Busbar termination schemes generally used for ACB termination where proper Termination of ACB plays very important role in healthy working of ACB. There exist standardize practices & guidelines for ACB termination. Any deviation in above standardize practice may cause overheating of breaker inside distribution panel. IEC standard has recommended busbar cross-section for defined current rating but deviation to use recommended cross-section was observed at customer end to reduce cost impact.

To overcome this a new busbar termination scheme has to be developed to offer lower cross-section for same current rating without any compromise in thermal performance. Which will serve cost-effective termination for customer.

## 1.3 Objective

The main objective of this project is to develop a new and improved busbar termination scheme for ACB such that it significantly reduce the termination cost for end users. Key objectives are listed below:

- Develop cost effective termination scheme.
- Reduce the cross-section area of termination scheme.
- Improve thermal performance.

## 1.4 Methodology

- Study of existing termination scheme & standard practices.
  Understand all ACB's present termination scheme and also study the IEC standard 60947 part-1 & part-2 in order to understand the recommended standard practices of ACB termination.

- Study of affecting factors for electrical & thermal performance of scheme.

  Find out all the possible factors which can directly or indirectly affect performance of ACB by doing literature survey.

- Concept development.

  Analyse all the factors as well as the study of existing schemes & standard practice and develop a new concepts by doing the brain storming.

- Theoretical calculation and software simulation of concept.

  Make the concept more stronger with theoretical calculations and the software simulations.

- Prototyping.

  Once the concept finalized and all theoretical calculations as well as software simulations are in favour, prototype of the concept.

- Testing & validation.

  Validate satisfactory behaviour of the new developed concept by the testing.

# Chapter 2

# Literature Survey

For the better understanding of project literature survey plays a very important role. Literature survey consists of papers and IEC standards referred which gives fundamental knowledge about different electrical and thermal aspects related to flat conductors.

- **Y. J. Bao, K. W. E. Cheng, K. Ding, D. H. Wang**[1], "The Study on the Busbar System and its Fault Analysis", Power Electronics Systems and Application (PESA), 2013
  In this paper basic study of busbar system is given along with the analysis of busbar failure. In this paper authors have given the basic information about the busbar system and listed different factors which are affecting the practical busbar system, They have also analysed some practical failures of busbar system.

- **Milenko Braunovic**[2], "Effect of Connection Design on the Contact Resistance of High Power Overlapping Bolted Joints", IEEE Transactions on Components and Packaging Technologies, Vol. 25, No. 4, December 2002
  This paper introduced the overview of different factors which are affecting the contact resistance of bolted joints and discussed the experimental results obtained by slotting and slanting the busbar. This experimental results shows that slotting and slanting in the bolted joints effectively affect and reduce the contact resistance.

- **Sung Won Park, Hyunsu Cho**[3], "A Practical Study on Electrical Contact Resistance and Temperature Rise at at the Connections of the Copper Busbars in Switchgears", 978-1-4799-6068-2-14/2014 IEEE
  In this paper authors have shown the importance of electrical contact resistance and how it is affecting the temperature rise. Along with this in this paper authors have done thermal simulation of bolted busbar connection and analysed the results which shows that wide and plated connection reduces the contact resistance.

- **Torbjorn Imrell ABB Corporate Research, Vasteras Sweden**[4], "The Importance of The Thickness of Silver Coating in The Corrosion Behaviour of Copper Contacts", 0-7803-0231-1/91 1991 IEEE
  This paper introduces the importance of plating thickness. In this paper author has shown the experimental results of contact resistance with different silver plating thickness this result shows that as plating thickness increases it make contact resistance constant throughout its life and make conductor chemically more stable.

- **Robert T. Coneybeer,W. Z. Black, R. A. Bush**[5], "Steady-State and Transient Ampacity of Busbar", IEEE Transactions on Power Delivery, Vol. 9, No. 4, October 1994
  In this paper authors have presented the thermal model that can be used to calculate steady-state and transient current carrying capacity (ampacity)of busbar. This thermal model is made based on the maximum temperature rise allowed in a busbar during normal as well as in abnormal conditions.

- **Jugal Lotiya**[6], "Thermal Analysis and Optimization of Temperature Rise in Busbar Joints Configuration by FEM", 978-1-4799-6042-2/14/ 2014 IEEE
  This paper deals with the thermal simulations of different busbar jointing configuration and shows how the slotting at true jointing area can reduce the temperature of the joint. The thermal simulation is done in ANSYS multi physics which is matching with the practical results.

- **Roland Barrett**[7], "Operating Temperature of Current Carrying Copper Busbar Conductors", University of Southern Queensland,October, 2013
  In this report author had shown the theoretical calculation to find the busbar temperature when it is enclosed in a bus duct. Detail description of all the way of heat dissipation e.g. conduction, convection, radiation is done and their mathematical modeling is also provided along with the extensive MATlab programming.

- **C. Kilindjian**[8], "Thermal study of LV electric switchboards", Cahiers Techniques, Group Schneider,December 1997
  In this document author shown different thermal problem related to LV switchboards and their equipments and stated cause of it and remedies to prevent it. Also the nodal method for finding the temperature for enclosed system is explained and modeling of the same is shown according to IEC standard 890.

- "Copper For Busbar"[9], Copper Development Association, UK, 2014
  This document is produced by Copper Development Association (CDA), CDA is a non-profit making trade association incorporated in 1933, supporting and promoting copper usage in the UK in such areas as building and construction, industrial alloys, public health and communications. CDA's remit is to promote and support the correct and efficient use of copper and copper alloys for all major applications through the provision of information, literature, software and training to material specifiers, designers, engineers, architects, consultants and contractors.
  This document covers different chapters related to copper busbar. and discusses various factors which directly or indirectly affect the performance of busbar. In chapter-6 of this document brief introduction about busbar jointing method has been given along with this different factors affecting bolted busbar joints has been discussed

# Chapter 3

# Existing busbar scheme

## 3.1 Introduction

From the electrical aspect, the term “bus” usually means a junction of circuits with many inputs and outputs. The busbar, as a bar or bars using conducting material, insulated by layers of insulation, with number of phases packed together for distribution purpose.

The flat bar conductors isolated by insulating material and wrapped together for making a single phase multi layer busbar system. The clearance between each conductor is well defined. Using busbar system for high current density connection significantly reduce the number of cable connections. Advantages of busbar system are as below:

- Low inductance
- High reliability
- Space saving
- Quick & simple assembling

From old days the busbar is being widely used in different areas such as power system, military, communication base station etc. In any industry low voltage power distribution system is very important as all the electrical equipment is being energised through this distribution system. ACB is generally used as a main protective device in LV distribution system and busbar system is generally preferred for internal electrical connections of panel. Multi-layer busbar scheme is being used for ACB connection in panel.

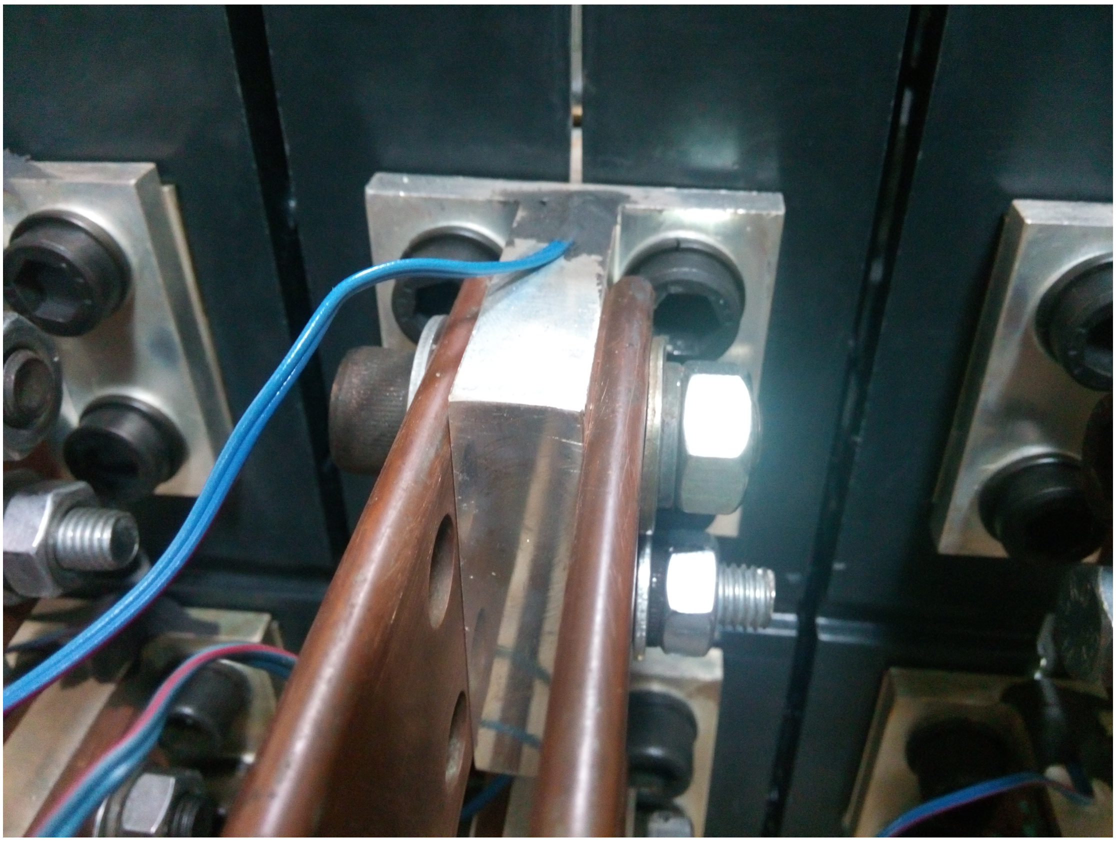

Figure 3.1: ACB connection with multi-layer busbar

## 3.2 Existing schemes

In industrial market many busbar manufacturers and many panel builders are available and this panel builders are supplying panels to many industries. To make panels non-proprietary busbar manufacturers are manufacturing busbar of standardised cross-sections, and panel builders are using this different busbars according to current rating.

It is observed that panel builders are connecting ACB using busbar of lower cross-section than that specified with ACB to reduce cost of their panel. Which lead to abnormal temperature rise inside the panel as well as in the ACB during normal operating condition. This practice may lead ACB to mal-operate. Due to high current density it is mandatory to use multi-layer busbar (more than one busbar per phase) for each phase and it is observed at panel builders end that they are using all busbar of same cross-section in multi-layer busbar.

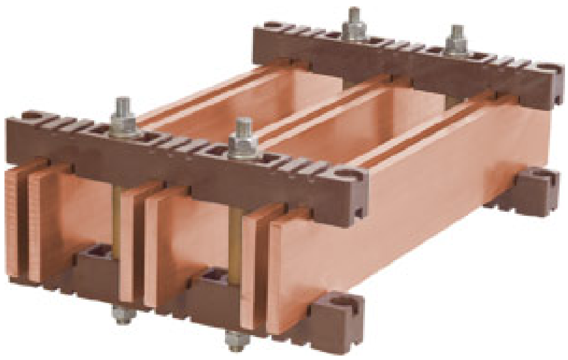

Figure 3.2: Multi-layer busbar scheme

# Chapter 4

# Factors Affecting Electrical Performance

## 4.1 Introduction

ACB is generally used as an upstream device to feed electrical supply to the ultimate load connected to it. General practice is to mount ACB inside the panel where it is connected to other equipments with the help of busbars. Rated amount of load current always flows through the circuit breaker during the normal operation, during the abnormal conditions ACB needs to withstand the short circuit currents up to 3 seconds. Current flowing through the current path of ACB get distorted due to electromagnetic forces acting on it. This electromagnetic forces are produced due to an alternating current flowing through the current path itself as well as the alternating current flowing through adjacent current paths. So, it is mandatory to study and understand all the factors which are affecting the electrical performance of ACB. Factors affecting the electrical performance of the ACB are as listed below

- Skin effect
- Proximity effect
- Eddy current effect
- Jointing method

- Plating material and its thickness

- Some other factors

## 4.2 Skin effect

When an alternating current flow through the conductor it will produce an alternating magnetic field which will circulate around the conductor axis. This magnetic field will link with the conductor itself and will induce an electrical field which will drive current in a conductor in such a way that current density in the centre of the conductor will get reduce and increase on the outer periphery. The current induced due to its own magnetic field inside the conductor is known as an eddy current and the overall phenomenon is known as a skin effect.
The depth at which the current density falls to the $e^{-1}$ of the surface current density is known as the skin depth and this depth of the conductor is generally being used for the theoretical calculations. This fall of current will reduce the effective cross section of the conductor, and will increases the effective resistance of the conductor.
The effective AC resistance of the conductor can be found by using the skin effect ratio which is defined as the ratio of the AC resistance to the DC resistance.

$$S = \frac{R_{ac}}{R_{dc}}$$

where...
$S$ = skin effect ratio(which can be found from the graph which is plotted from the practical results)
$R_{ac}$ =AC resistance of the conductor
$R_{dc}$ =DC resistance of the conductor

## 4.3 Proximity effect

When conductor carrying an alternating current placed parallel the current in a conductor will further redistribute due to magnetic field of other conductor this is known as proximity effect. Generally the proximity effect can be divided in to three configurations.

a. Direct proximity effect

   Current redistribution due to neighbouring conductor carrying current in the same direction.

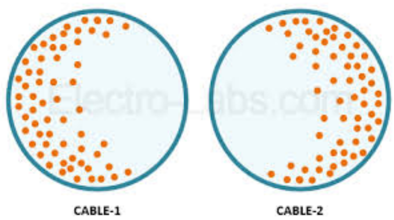


Figure 4.1: Direct proximity effect

b. Inverse proximity effect

   Current redistribution due to neighbouring conductor carrying current in the opposite direction.

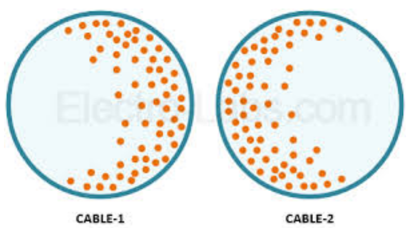


Figure 4.2: Inverse proximity effect

c. The induced proximity effect

   Current induced in the metallic parts due to neighbouring conductors carrying current.

Due to redistribution of the current the AC resistance further increases, and the increases in the resistance is mainly affected by the geometry of the conductors. The precise calculation of the skin effect and proximity effect for busbars requires finite difference or other numerical computational procedures, this procedures require extensive programming or access to one of the commercially available software.
When several busbars used for one phase the overall resistivity increases due to skin effect and proximity effect which reduces the ampacity of the conductor. Below table is provided in the IEC standard 943 which gives typical values of co-efficient by which to multiply the permitted current flowing in a single busbar in order to obtain the permitted current in a multiple bar made up of several elementary bars on edge for same temperature rise in both the cases.

| Number of Elementary bars | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| K | Cu | 1 | 1.72 | 2.25 | 2.52 | - |
| | Al | 1 | 1.80 | 2.50 | 3.10 | 3.70 |

## 4.4 Busbar Jointing Methods

### 4.4.1 Introduction

Busbar joints can be divided in to two main parts i.e. linear joints and T-joints. Linear joints are used to connect two or more manageable linear busbars, and T-joints are used for tapping. This joints should be mechanically strong, should have low resistance and should be resistive to environmental effects. An efficient busbar joint should maintain all above properties throughout the life of joint.

### 4.4.2 Busbar jointing methods

busbars can be jointed using either of the following methods

- Bolting
- Clamping

- Riveting
- Soldering
- Welding

Bolting and clamping are extensively used in industry, to joint busbar with ACB bolted joints are generally used.

### 4.4.3 Joint resistance

The resistance of a joint is mainly dependent on following two factors:

a. The streamline effect or spreading resistance $R_s$, due to the distortion of the current flow through the joint

b. The interface resistance or contact resistance of the joint $R_i$.

The total joint resistance $R_j$, is given by:

$$R_j = R_s + R_i$$

This formula is valid specifically for direct current (DC) applications. Where for alternating currents (AC) the changes in resistance due to skin effect and proximity effect must be taken into account for the joint zone.

**Streamline effect**

When current flows through the joint formed by the conductors overlapping the lines of the current flow are distorted and the effective resistance of the joint is increased due to flow of current through a portion of the conductor. This is known as the streamline effect. Current density in the perpendicular direction of the busbar e.g. as current transfers from one bar to another bar is highly non uniform and is concentrated to the edges. Here in the fig the resistance ratio $e$ is the ratio of resistance of a joint due to streamline to the resistance of the equal length single bar.

$$e = \frac{R_s}{R_b} = \frac{ab}{\rho l} R_s$$

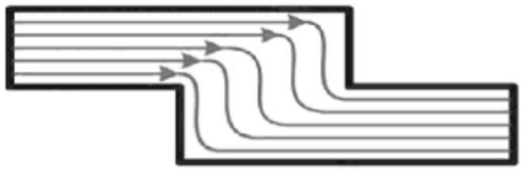

Figure 4.3: Streamlines in a busbar joint

where...

$a$ =width of the bar($mm$)

$b$ =thickness of the bar($mm$)

$l$ =length of the overlap($mm$)

$\rho$ =resistivity of the conductor($\mu\Omega$)

$R_s$ =the resistance of overlap section($\mu\Omega$)

In the case of bolted joints, the holes for bolting further reduce efficiency due to the streamline effect. The resistance ratio of a bolted overlap section can be determined by

$$e = \frac{R_{sb}}{R_b} = \frac{(a - nd)b}{\rho l} R_{sb}$$

where...

$a$ =width of the bar($mm$)

$b$ =thickness of the bar($mm$)

$l$ =length of the overlap($mm$)

$n$ =number of holes across the width of bar

$d$ =diameter of the hole

$\rho$ =resistivity of the conductor($\mu\Omega$)

$R_{sb}$ =the resistance of overlap section for bolted joint($\mu\Omega$)

hence:

$$e = \frac{R_{sb}}{R_b} = \frac{(a - nd)b}{\rho l} R_{sb}$$

$$R_{sb} = \frac{e\rho l}{(a - nd)b}$$

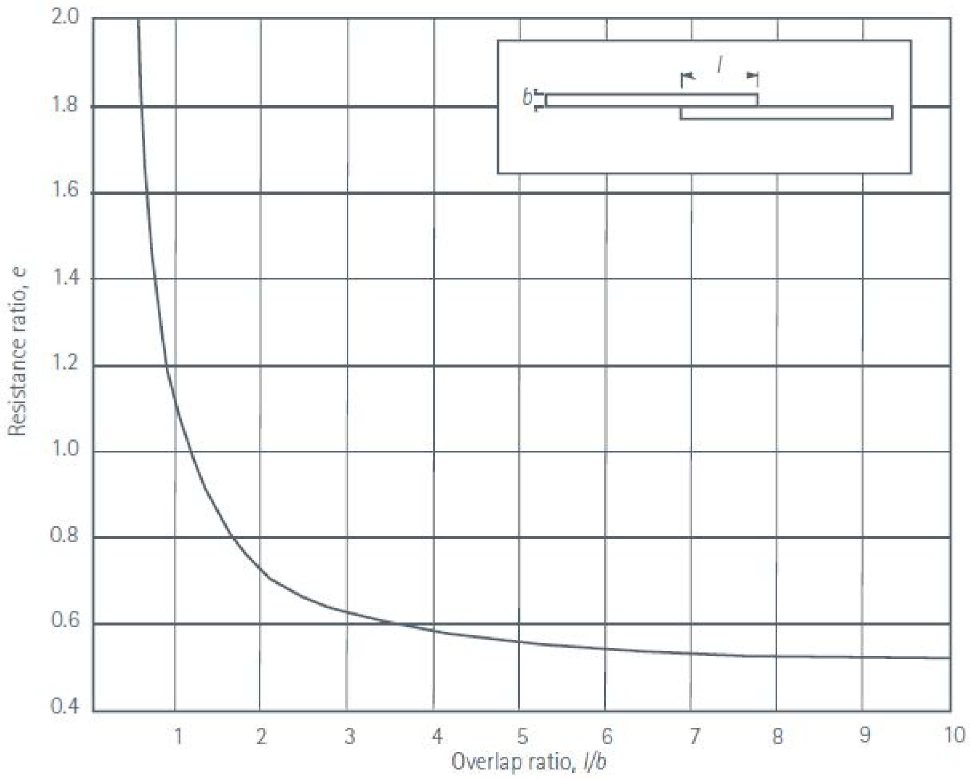


Figure 4.4: Streamline effect in overlapped joints

### Contact resistance

Contact resistance is mainly dependent on two factors

- Surface condition
- Contact pressure

### Surface condition

In real practice an electrical contact between two surfaces are formed at some discrete areas which are known as a-spot which are the only current conducting path. The a-spot occupy only 1% of the overlap area, obviously the larger number of a-spot the more uniform will be the current distribution throughout the joint area. This can be maintain by having the flat and roughened surfaces of the conductor. Many times in real practice contact gel is being used before assembling.

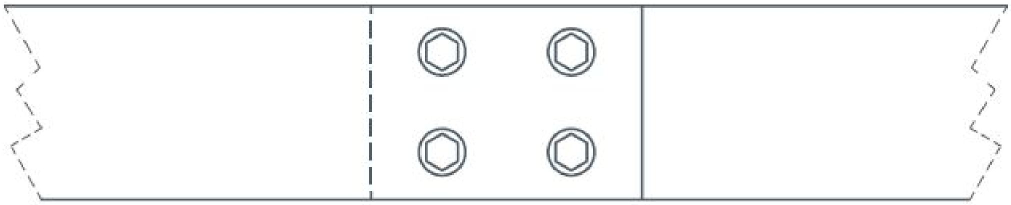

Figure 4.5: A typical bolted joint

### Contact pressure

Generally the joint resistance decreases with increase in the pressure, size and the number of the bolts. As this increases the number of a-spot. Contact resistance falls down rapidly with increase in the contact pressure which is as shown in the figure, but above $30N/mm^2$ there is little decreases in the contact resistance so it is generally preferred to have pressure up to $30N/mm^2$. The value of the contact resistance can

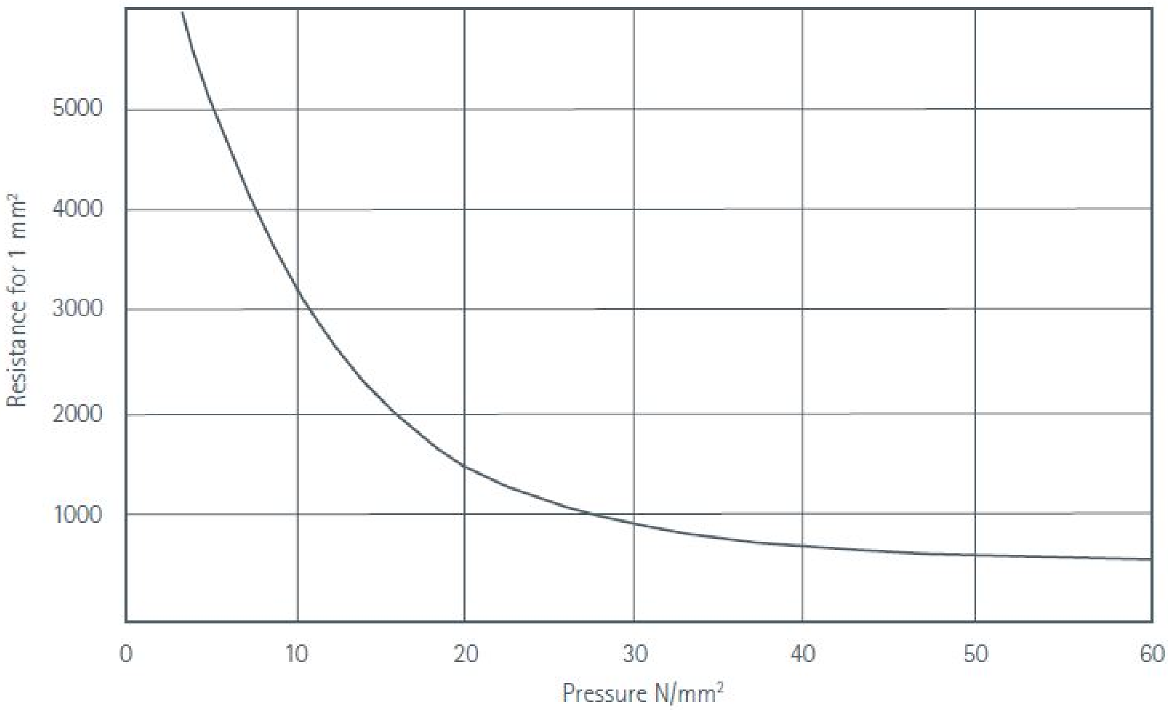


Figure 4.6: The effect of pressure on the contact resistance of a joint

be calculated from the following formula

$$R_i = \frac{Y}{al}$$

where...

$R_i$ =contact resistance

$Y$ =contact resistance of unit area OR resistance for $1mm^2$

$a$ =width of the bar

$l$ =length of the overlap

### 4.4.4 Mathematical modeling of joint resistance

The mathematical modeling to find the joint resistance is as below:

$$R_j = R_{sb} + R_i$$

where...

$R_j$ =joint resistance

$R_{sb}$ =streamline effect resistance for bolted joint

$R_i$ =contact resistance

Now stream line effect resistance can be found as below:

$$R_{sb} = \frac{e\rho l}{(a - nd)l}$$

where...

$a$ =width of the bar($mm$)

$b$ =thickness of the bar($mm$)

$l$ =length of the overlap($mm$)

$n$ =number of holes across the width of bar

$d$ =diameter of the hole

$\rho$ =resistivity of the conductor($\mu\Omega$)

$R_{sb}$ =the resistance of overlap section for bolted joint($\mu\Omega$)

Here value of e can be found from fig. no 4.9

The contact resistance can be found from the following formula:

$$R_i = \frac{Y}{al}$$

where...

$R_i$ =contact resistance

$Y$ =contact resistance of unit area OR resistance for $1mm^2$

$a$ =width of the bar

$l$ =length of the overlap

Here value of $Y$ can be found from fig. no 4.11 and this requires the value of pressure($N/mm^2$) which can be found as below

$$P = \frac{F}{A}$$

Where...

$P$ =pressure ($N/mm^2$)

$A$ =area of joint($mm^2$)

$F$ =Force($N$)

$$F = \frac{nT}{KD}$$

where...

$F$ =Force($KN$)

$n$ =number of holes across the width of bar

$T$ =tightning torque($Nm$)

$K$ =constant, generally Referred as 'nut factor'($\approx$0.2)

$D$ =nominal bolt diameter($mm$)

## 4.5 Plating material and its thickness

Generally the plating of the busbars are not done but to prevent the base material (e.g. copper) from the corrosion it is plated with a chemically stable material. Different materials are used and available in the market for plating e.g. nickel, silver etc. generally the plating thickness is getting varied from 0.5micron to 30microns.
Different methods are available for calculating the overall resistance for plating and one of the method which is adopted is series and parallel combination of all the resistances. Practical result shows that.

## 4.6 Some other factors electrically affecting

- Material and its conductivity
- Short circuit current stresses and protection
- Material deterioration
- Cross section of the conductor

# Chapter 5

# Factors Affecting Thermal Performance

## 5.1 Introduction

When any ACB is in service it carries certain amount of current according to its load rating which is generally being in terms of hundreds so, the $I^2R$ losses occurring during the normal operation as well as during the abnormal operation are crucial and affect the performance of the ACB and its life. Generally the ACBs are mounted in a panel which is a closed premises or a vessel. High amount of $I^2R$ losses in ACB produces an excessive amount of heat which will affect the ACBs performance as well as the surrounding equipments performance when it is mounted in a panel. If any how the heat generation in ACB can be controlled or reduced then the conductors cross section area can be reduced or a terminations cross section area which is the ultimate goal of this project can be reduced. So, study of thermally affecting factor of ACB is crucial and needs an attention.
Following are the factors affecting thermal performance.

- External temperature
- Short circuit or overloading
- Loose connection

- Small conductor cross section
- Materials heat conductivity
- Ventilation
- Conduction, Convection, Radiation

## 5.2 External temperature

When ACB is mounted in a switchboard or in a panel it is surrounded by the air which is working as a main fluid for heat dissipation. If external temperature is being too high it can trip the thermal release, will make the enclosures wall temperature too high. Heat will always flow from high temperature to low temperature and the amount of heat flow will depends on the difference of the temperature. So, it is recommended to have normal or lower external temperature which can be maintained by proper ventilation.

## 5.3 Short circuit or overloading

Generally the ACBs are used as an upstream protection devices and needs to withstand the short circuit currents up to 3 seconds to give the selectivity to its downstream devices. So, while carrying high short circuit current high amount of heat will be generated for short time due to $I^2R$ losses, it is recommended to use the proper cross section of the conductor so that it will generate amount of heat in a certain limit during the short circuit due to $I^2R$ losses as well as can withstand the electromagnetic forces and stresses during the short circuit.

## 5.4 Loose connection

As discussed earlier the contact pressure plays an important role in a connections or in a termination. Loose connection will form at the joint if the pressure of the joint is not maintained and this will reduce the number of a-spot in joint which will increase the joint resistance and force the more amount of current to flow from a one a-spot. This will make the joint portion a heat source and will flow the heat in both the direction of the joint or will extract less amount of heat from the ACB in case of ACBs termination due to less temperature difference. So, it is recommended to have proper connection and maintain the pressure of the joint.

## 5.5 Materials heat conductivity

The heat dissipation capability of a material is dependent on the materials property and its heat conductivity. Different materials have different amount of free atoms which will carry the heat and decide the heat conductivity of the material. Generally the copper is used as a current carrying path of ACB which is having high heat conductivity but many times the silver plated copper is also used. As silver have the high heat conductivity then the copper it will improve the thermal performance of the ACB. The plating material and thickness of the plating affects the thermal performance of the ACB.

## 5.6 Ventilation

Generally the ACBs are mounted in the panel and surrounded by many other equipment and the thermal performance of all this equipment are critical, their performance will affect the downstream load. So, it is mandatory to maintain the temperature inside the panel and the temperature of the equipment. This will need the careful attention to the ventilation of the panel. Air is working as a fluid in the low voltage switchgear panel and the flow of air is dependent on the ventilation scheme as well as the supply connection inside the panel e.g. top feed or bottom feed. A good ventilation can improve the thermal performance of the ACB.

## 5.7 Conduction, Convection, Radiation

Any electrical switchboard or a panel system is made up of a fluid (air) and the electrical equipment. When current flows through this equipment they generate heat as an energy loss and to achieve the thermal equilibrium they dissipate the heat to the surrounding by following three phenomena.

- Conduction
- Convection
- Radiation

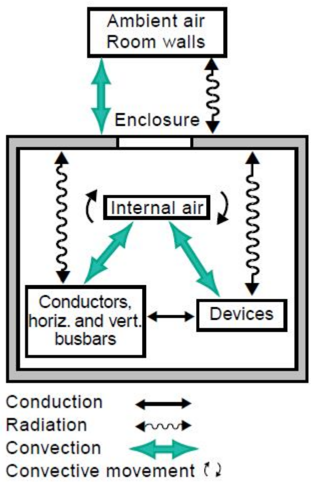


Figure 5.1: thermal behaviour inside an enclosure

### Conduction

Conduction is taking place in gases, liquid and solids, solids offer the least amount of resistance to heat transfer by conduction. The physical contact between the materials is required for conduction of heat through it. Molecule available at higher temperature side moves at high velocity and transfer the kinetic energy to the adjacent molecules which are at the lower temperature this is known as the conduction process. Heat transferred through a wall by the conduction can be found by following formula.

$$Q_{co} = \frac{KA}{X}(T1 - T2)$$

hence:

$$Q_{co} = hA(T1 - T2)$$

Where...

$Q_{co}$ =heat transferred through the conduction($W$)

$h = \frac{K}{X}$ =over all heat transfer coefficient($Wm^{-2}K^{-1}$)

$A$ =area($mm^2$)

$X$ =enclouser wall thickness($m$)

$T1$ =inside (hot) temperature ($K$)

$T2$ =outside (cooler) temperature ($K$)

So, from the above formula the factors which affect the conduction are:

- Thermal conductivity of material
- thickness of the material
- surface area

**Convection**

Any hot body or surface surrounded by the fluid e.g. gas or liquid transfers the heat to fluid by conduction. This will reduce the density of the fluid and rises it to be replaced by the colder fluid having higher density. This process continues results in the convective flow of fluid and enhance the transfer of the heat through the fluid. Calculation of heat transferred through the convection is very complicated. The calculation formulas varies for different surface conditions. For busbar case where surface of convection are vertical it can be calculated by following formulas.

$$Q_{conv} = h_q A_v$$

$$h_q = \frac{NUK}{H}$$

$$NU = 0.68 + \frac{0.670R_a^{1/4}}{\left[1 + (\frac{0.492}{p_r})^{9/16}\right]^{4/9}}$$

$$R_a = \frac{g\beta(T1 - T2)H^3}{v\alpha}$$

Where...

$Q_{conv}$ =heat dissipated from vertical surface through convection($W$)

$h_q$ =heat transfer coefficient for vertical convection($Wm^{-2}K^{-1}$)

$A_v$ =vertical surface area($m^2$)

$NU$ =average nusselt number

$K$ =thermal conductivity($W/mK$)

$H$ =hight of encloser($m$)

$R_a$ =rayleigh number

$P_r$ =prandtl number

$g$ =gravity constant,(9.8$m/s^2$)

$\beta$ =volumetric thermal expansion coefficient($K^{-1}$)

$T1$ =average temperature of surface($K$)

$T2$ =average temperature of surrounding($K$)

$v$ =kinematic viscosity($m^2/s$)

$\alpha$ =thermal diffusivity($m^2/s$)

So, from above formula the factors which are affecting the heat transferred by convection are:

- Thermal conductivity
- Vertical surface area

- Hight of encloser
- Temperature difference

**Radiation**

Heat energy transferred by the radiation of the heat wave from the hot body to the colder body is known as the radiation of the heat. This is same as the energy transfer as light, radio, x-ray or sound. The rate of heat waves emission from hot body is dependent on the temperature difference, distance between the surfaces, and the emissivity of the surface. Reflective and bright surfaces have lowest (e.g. 0) emissivity where the dark and dull surfaces have the highest emissivity (e.g. 1.0). The amount of heat transferred by the radiation can be found from the following formula.

$$Q_r = \alpha A(e_1 T_1^4 - e_2 T_2^4)$$

Writing the above formula in terms of heat transfer coefficient.

$$Q_r = h_r A(T_1 - T_2)$$

where...
$h_r = \alpha e_1 (T_1 + T_2)(T_1^2 + T_2^2)$
$h_r$ =heat transfer coefficient for radiation($Wm^{-2}K^{-1}$)
$Q_r$ =heat transferred through radiation($W$)
$\alpha$ =stephens boltzmann constant($5.673 * 10^{-8} Wm^{-2}K^{-4}$)
$A$ =surface area($mm^2$)
$T_1$ =temperatur of radiating body($K$)
$T_2$ =temperatur of surrounding($K$)
$e_1$ =emissivity of radiating surface
$e_2$ =emissivity of surrounding
So, heat transferred by radiation is affected by following factors:

- Emissivity of material

- Surface area

- Temperature difference

# Chapter 6

# Developed Concepts

## 6.1 Introduction

The main goal of this project is to reduce the cross section of the termination without affecting the thermal performance of the ACB. The thermal performance of the ACB is depending on the $I^2R$ losses. The value of current is depends on the load so, it is uncontrolled parameter. If any how the value of resistance can be reduced or the heat dissipation can be improved then it is possible to achieve the goal of this project. Following are the concepts developed during this project to reduce the overall resistance and improve the thermal performance.

## 6.2 Different cross section busbar schemes

During the existing busbar termination scheme study it was observed at the panel builders end that for ACBs termination they use multilayer busbar schemes (more than one busbar per phase) and all busbar stacked per phase have same cross section which lead the total cross section to higher or the lower side of the cross section provided in the IEC standard. This will either lead to malfunction of the ACB due to lower cross section or to the high cost for the termination for higher cross section. Also it is provided in the IEC standard 943 that as the more number of parallel busbar stacked together the amount of current that can flow through it reduces to have the temperature rise in the permitted limit. So, it is recommended to use the less number of parallel busbar per phase.

The new concept developed which recommends to use busbars having different cross section per phase such that the total cross section lead to the recommended cross section in IEC standard by having least numbers of parallel paths.

## 6.3 Slotting and slanting of joint area

During the study of the busbar joints it was observed that the pressure is not being uniform throughout the joint of the overlapping area which reduces the number of a-spot generated in the jointing area. It was found that by using the slot at the jointing portion the joint resistance can be improved as this will provide the more uniform pressure throughout the joint which will increase the number of a-spot. And by slanting the joint portion from the end the overlapping length of the joint can be increased and this will further reduce the resistance of the joint. The new concept of the slotting and slanting the termination is developed and the resistance of this can be found by using the same formulas used for busbar joint resistance calculation.

## 6.4 Aluminium arc chute covers

During the thermal study of ACB it was observed that existing arc chutes have the plastic covers which are made up from the unsaturated polyester sheet moulding compound which is having less heat conductivity. The arc chutes are placed exactly above the main current path where the heat generation is maximum and the arc chute covers are directly in contact with surrounding air. If arc chute covers are replaced with the aluminium arc chute covers the heat dissipation from the arc chute cover can be improved. As the heat dissipation improves the heat which is needed to be extracted from the ACB through the external termination is reduced and hence some cross section at the termination can be reduced.

# Chapter 7

# Analysis, Testing and Results

## 7.1 Introduction

The termination of the ACB includes the consideration of different parameters which are affecting the performance of the ACB electrically, thermally as well as mechanically. Also some of this parameters have mathematical modelling to calculate their effect individually but it is needed to consider all this factor at a same time to have their combined effect as an output. This kind of calculations are extremely complicated and needs any mathematical programming or a commercially available software support. For the above project different software which can be used for simulation purpose are MAGNET, JMAG and ANSYS which can be used to find magnetic fields, electromagnetic forces, current density, temperature rise due to heat dissipation etc.

## 7.2 Concept-1: Different cross section busbar schemes

For 2500A rated ACB 2000$mm^2$ cross section is needed which is existingly achieved by using 100*5*4 busbars per phase. As a new developed concept (160*5*2+80*5*1) busbars should be used per phase. Geometry for both this concepts are as shown in fig. no 7.1 & 7.2. This way the total cross section will be same for both the cases but according to IEC standard 943 the second configuration should conduct more amount of heat than the first one. Analysis of current density, magnetic field density and electromagnetic force for this concept is simulated in MAGNET and

JMAG software. And practically tested by Temperature rise (TR) testing. Results of this are as shown below.

### 7.2.1 Current density

Theoretical result shows that in existing scheme the current density should be same in all four conductors and in new developed scheme the current density should be more on one side then the other side due to more conductor cross section available on one side. The same is affiliated by the simulation done in MAGNET. simulation results are as shown in fig. no 7.3, 7.4.
Fig. no 7.3 shows the current density distribution for same cross section busbar scheme. The result shows that current density in both half of the geometry is more or less same also higher current density at the surface shows the skin effect. Fig. no 7.4 shows the current density distribution for different cross section busbar scheme. The result shows that current density is not uniform throughout the geometry due to different cross section, and value of current density is more at higher cross section side of the geometry.

### 7.2.2 Magnetic field density

Magnetic field generates due to flow of current and density of magnetic field is directly proportional to the value of current and hence the density of magnetic field should be more uniform in existing scheme where it should be nonuniform in developed concept which is also supported by the following simulation result shown in fig. no 7.5, 7.6.
Fig. no 7.5 shows the result of Magnetic field density analysis for same cross section busbar scheme. The result shows that the magnetic field is uniformly distributed on both the side of the adaptor and the maximum magnetic field density point is available at center of the geometry. Fig. no 7.6 shows the result of Magnetic field density analysis for different cross section busbar scheme. The result shows that the magnetic field is nonuniformly distributed throughout the geometry and the maximum current density point is shifted towards the more cross section in geometry. This shows that

the new developed concept needs to deal with the nonuniform electromagnetic forces.

### 7.2.3 Electromagnetic Forces

Effect of electromagnetic forces should be considered for existing as well as for new concept as both are having a parallel current carrying conductors. As existing busbar scheme is having uniform current density throughout the geometry it should have less electromagnetic forces as compared to the new proposed busbar scheme where current density is non-uniform. Same thing is supported by the software simulation. Graph of electromagnetic force is shown in fig no. 7.7 and 7.8

Fig no. 7.7 shows the graph of electromagnetic force acting on existing busbar scheme where the maximum value of force is 0.24N. Fig no. 7.8 shows the graph of electromagnetic force acting on new proposed busbar scheme where the maximum value of force is 0.325N.

### 7.2.4 Temperature rise testing

The use of different cross-section busbar scheme suchthat, recommended cross-section can be achieved with use of minimum number of parallel conductors offers following advantages, more phase to phase clearance, more heat dissipating vertical surface, low skin & proximity effect and all of this contribute in improvement of thermal performance of ACB's termination.

To verify this practically temperature rise testing is done on ACB with different termination schemes. For temperature rise testing, rated amount of current (2500A) flowed through TR setup till it achieve thermal stability (e.g. <1 degree Celsius rise in temperature per hour). Rise in temperature of different components are recorded at the time of thermal stability. Total four TR tests are done, two for existing same cross-section scheme (100*5*4) and two for different cross-section scheme (160*5*2+80*5*1). Result of TR tests are as shown in table.

Result of TR testing shows that use of different cross-section termination scheme effectively reduces temperature rise at termination point by 4.35° Celsius and at main

| Component | Existing termination scheme (100*5*4) | | | Different cross-section scheme (160*5*2+80*5*1) | | | Difference of Maximum |
|---|---|---|---|---|---|---|---|
| | in Celsius | | | | | | |
| | TR1 | TR2 | Max | TR3 | TR4 | Max | |
| Cradle adaptor top | 51.5 | 55.75 | 55.75 | 51.4 | 50.8 | 51.4 | 4.35 |
| Cradle terminal top | 62 | 69.05 | 69.05 | 64.3 | 54.25 | 64.3 | 4.75 |
| Contact jaw top | 71.4 | 77.96 | 77.96 | 72.7 | 71.35 | 72.7 | 5.26 |
| Breaker terminal top | 72.4 | 76.65 | 76.65 | 71 | 70.95 | 71 | 5.65 |
| Fix contact | 85.4 | 91.15 | 91.15 | 84.1 | 84.95 | 84.95 | 6.2 |
| Moving contact | 99.7 | 100.65 | 100.65 | 90.7 | 93.15 | 93.15 | 7.5 |
| Breaker terminal bottom | 62.9 | 69.55 | 69.55 | 63.2 | 60.85 | 63.2 | 6.35 |
| Contact jaw bottom | 65.5 | 70.05 | 70.05 | 64.1 | 64.65 | 64.65 | 5.4 |
| Cradle terminal bottom | 60 | 61.75 | 61.75 | 56.5 | 53.54 | 56.5 | 5.25 |
| Cradle adaptor bottom | 54.2 | 52.75 | 54.2 | 48.5 | 49.88 | 49.88 | 4.32 |

Table I: Temperature rise test result for Diff cross-section

contact point by 7.5° Celsius.

## 7.3 Concept-2: slotting and slanting

Slotting the jointing area will make the contact pressure more uniform where slanting the end points of the joint will increase the overlapping length. Both this action target to the reduction of the joint resistance but joint resistance is affected by many other parameters. So, it is needed to analyse this concept by theoretical calculation, carbon paper testing and mv drop testing. Results are as shown below.

### 7.3.1 Theoretical Calculation of joint resistance

Value of joint resistance depends on many parameter and all this parameter contribute differently in the value of joint resistance. Effectiveness of slotting and slanting de-

| Parameter | Contribution(in%) |
|---|---|
| Width of bar | 6.00 |
| Thickness of bar | 2.41 |
| Length of overlap | 2.39 |
| Diameter of hole | -2.80 |
| Diameter of screw | -5.64 |
| Number of hole | 2.50 |
| Resistivity of material | 3.82 |
| Bolt's tightening torque | 4.70 |

Table II: Contribution of all parameters

| Slot Dimension | % Change in Joint Resistance | % Change in Total Resistance |
|---|---|---|
| | WRT without slot case | |
| 1*1*10 | 12.26 | 1.16 |
| 1*1*15 | 13.45 | 1.70 |
| 1*1*20 | 14.98 | 1.55 |
| 1*1*30 | 15.97 | 2.31 |

Table III: Slot dimension's effect on joint resistance

pends on how much they contribute in the value of joint resistance. All parameters along with their contribution is shown in below table no. II Along with that % change in joint resistance and overall resistance for different dimension of slot with respect to without slot joint resistance and overall resistance is shown in table no. III

Table no. II shows that width of bar is contributing 6.00% in joint resistance which will be affected by slotting and overlap length is contributing 2.39% in joint resistance which will be affected by slanting. Table no. III shows that slot of 1*1*30 mm dimension will effectively reduce the joint resistance by 15.97% and over all resistance by 2.31%.

### 7.3.2 Carbon Paper and mv Drop Testing

Practically the value of joint resistance depends on the total number of a-spot (true joint spot) available in the joint area which can be found by carbon paper testing. And the true value of joint resistance can be found by mv drop testing. Fig no. 7.9,

| Surface condition | Slot | mv deop | | Resistance in ohm | |
|---|---|---|---|---|---|
| | | at joint | over all | at joint | over all |
| Uncleaned | N | 0.2 | 0.45 | $0.2 * e^{-}5$ | $0.45 * e^{-}5$ |
| cleaned | N | 0.093 | 0.32 | $0.093 * e^{-}5$ | $0.32 * e^{-}5$ |
| cleaned | Y | 0.083 | 0.23 | $0.083 * e^{-}5$ | $0.23 * e^{-}5$ |

Table IV: mv drop test result

7.10, 7.11 shows result of carbon paper test and Table no. IV shows result of mv drop test.

Result of carbon paper testing shows that slotting improves the joint, increases the number of a-spots and make contact pressure more uniform. Result of mv drop testing shows that slotting and slanting improves the joint resistance by 10.75% and over all resistance by 28.12%.

## 7.4 Concept-3: aluminium arc chute

As arc chute are placed exactly above the main heat generation point e.g. main contact of fix contact and moving contact. The top cover of the arc chute is in direct contact of the surrounding air. Existing arc chute top cover is made up of unsaturated polyester which is less heat conductive material this is replaced by the aluminium which is more heat conductive material. This concept target to improvement in the thermal performance of the ACB. For this concept prototypes of the aluminium arc chute cover is prepared and tested by TR (Temperature Rise) testing. Result of TR testing is shown in table no. V

### 7.4.1 Temperature rise testing

Result of TR testing shows that this will reduce the temperature by 2.25° Celsius for moving contact and 3.15° Celsius for fix contact. This reduction in temperature is becoming less for component which are away from main contact e.g. for cradle adaptor top and bottom it is 0.85° and 0.55° Celsius.

| **Component** | **Existing arc chute** | **Aluminium arc chute** | **Difference** |
|---|---|---|---|
| | **in Celsius** | | |
| Cradle adaptor top | 53.25 | 52.4 | 0.85 |
| Cradle terminal top | 55.85 | 55.6 | 0.25 |
| Contact jaw top | 71.75 | 70 | 1.75 |
| Breaker terminal top | 81.05 | 79.6 | 1.45 |
| Fix contact | 94.85 | 91.7 | 3.15 |
| Moving contact | 90.95 | 88.7 | 2.25 |
| Breaker terminal bottom | 73.55 | 71.6 | 1.95 |
| Contact jaw bottom | 64.65 | 63 | 1.65 |
| Cradle terminal bottom | 49.25 | 48.9 | 0.35 |
| Cradle adaptor bottom | 46.75 | 46.2 | 0.55 |

Table V: Temperature rise test result for AL arc chute

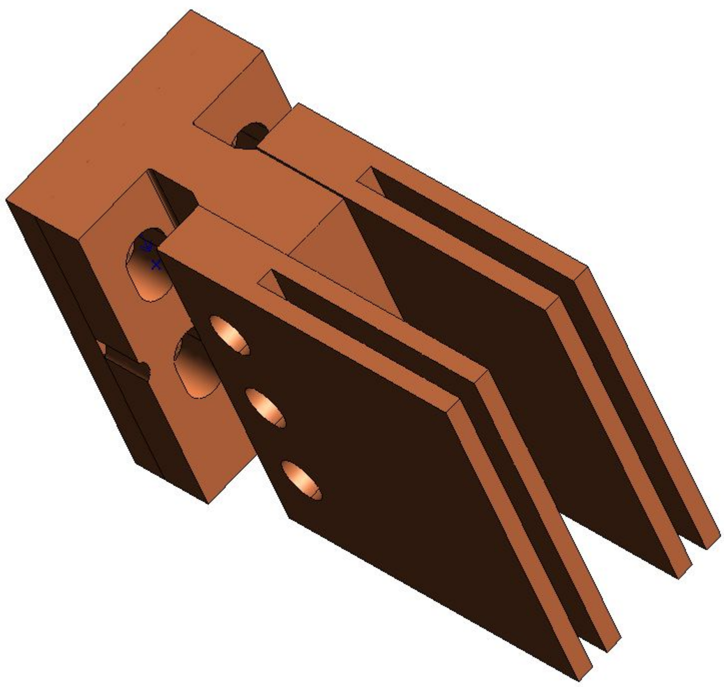

Figure 7.1: Existing scheme(100*5*4)

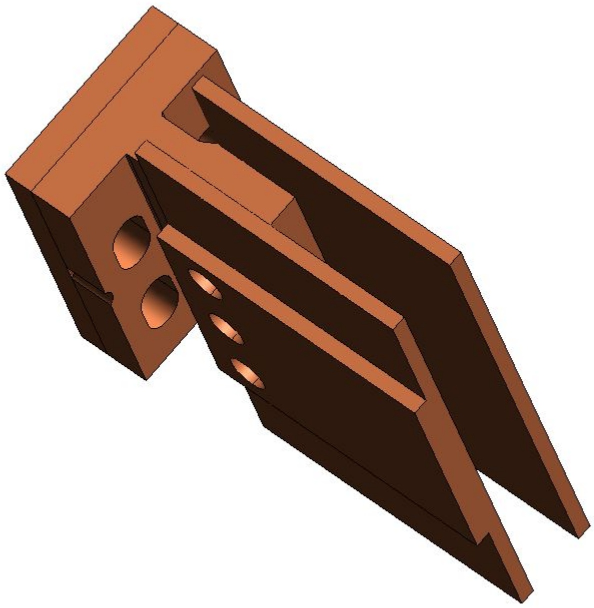

Figure 7.2: Developed scheme(160*5*2+80*5*1)

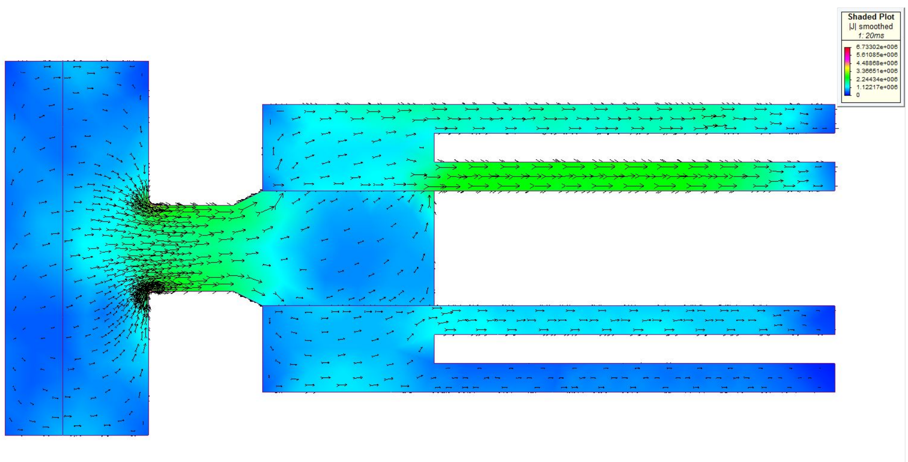


Figure 7.3: Current density in Existing scheme(100*5*4)

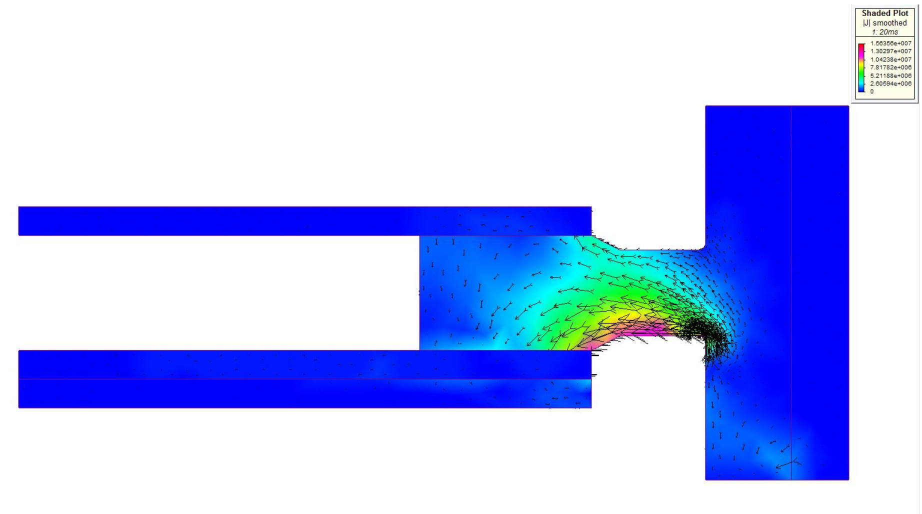


Figure 7.4: Current density in Developed scheme(160*5*2+80*5*1)

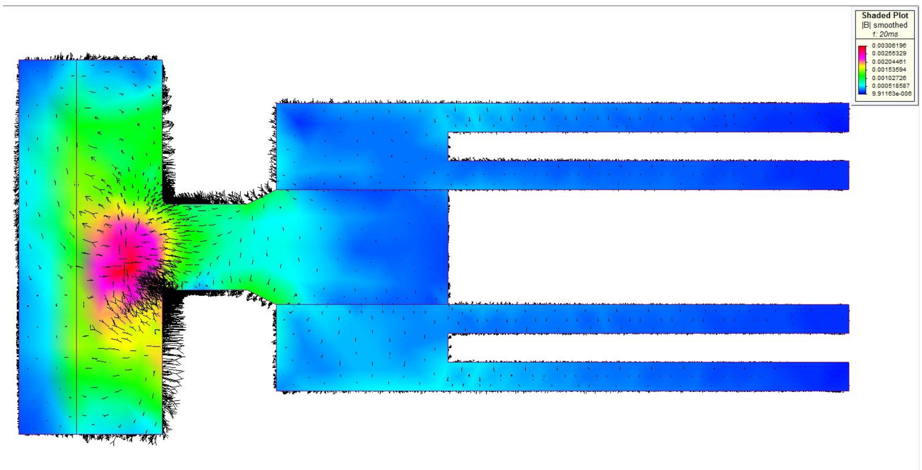


Figure 7.5: Magnetic field density in Existing scheme(100*5*4)

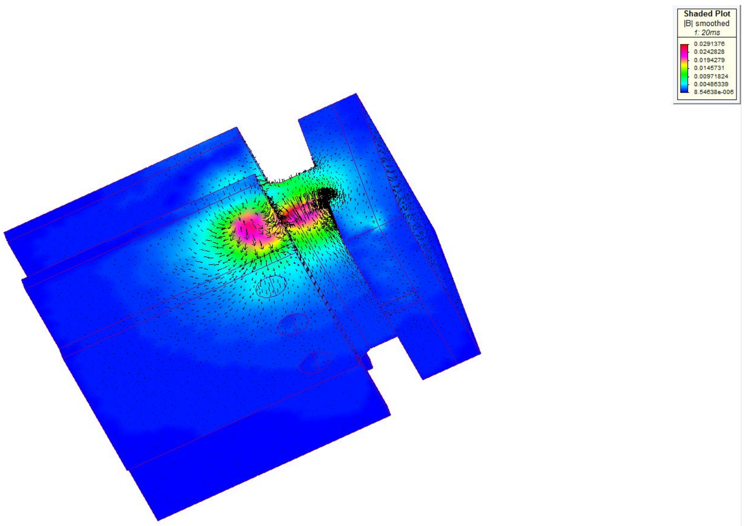


Figure 7.6: Magnetic field density in Developed scheme(160*5*2+80*5*1)

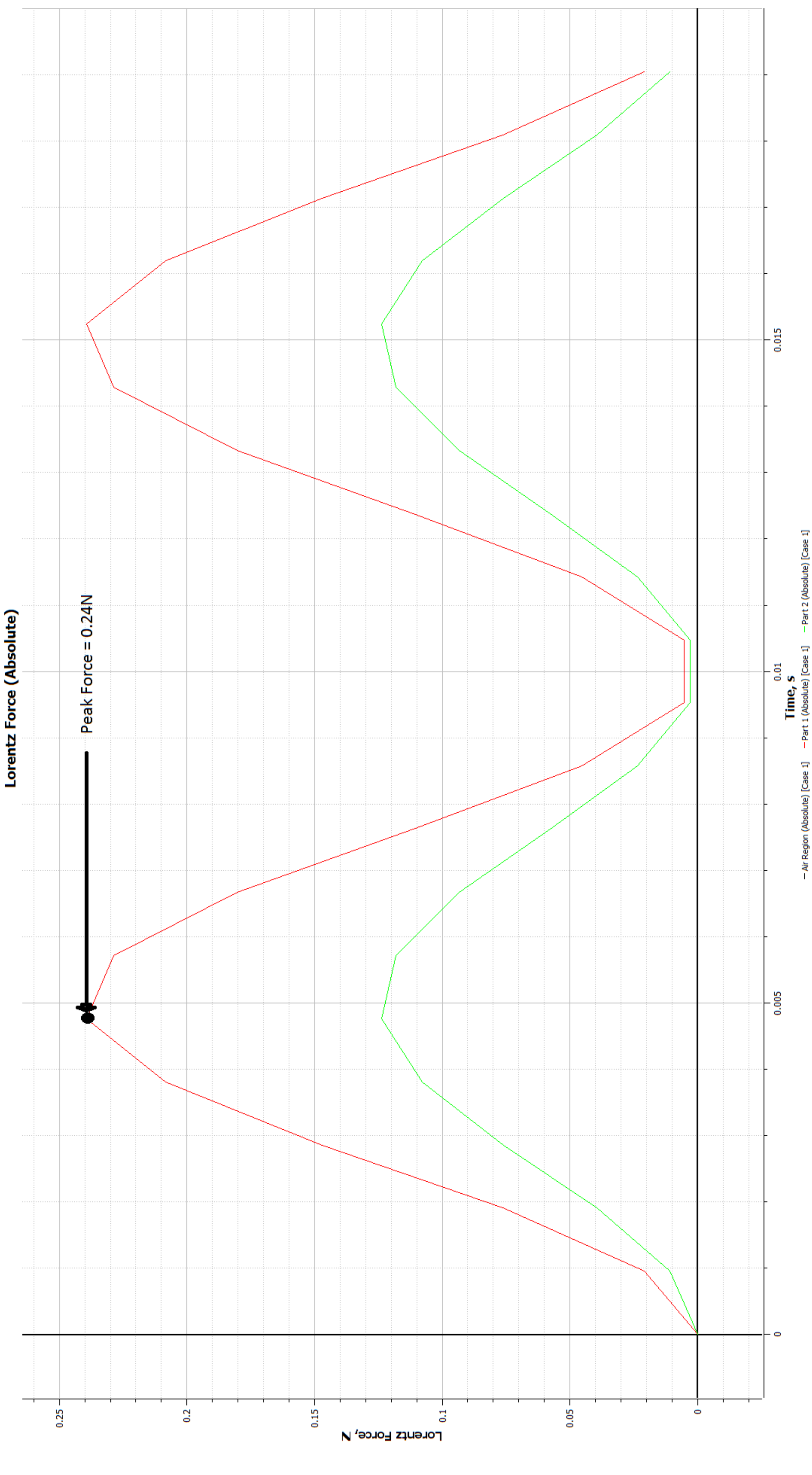


Figure 7.7: Electromagnetic Forces in Existing Scheme(100*5*4)

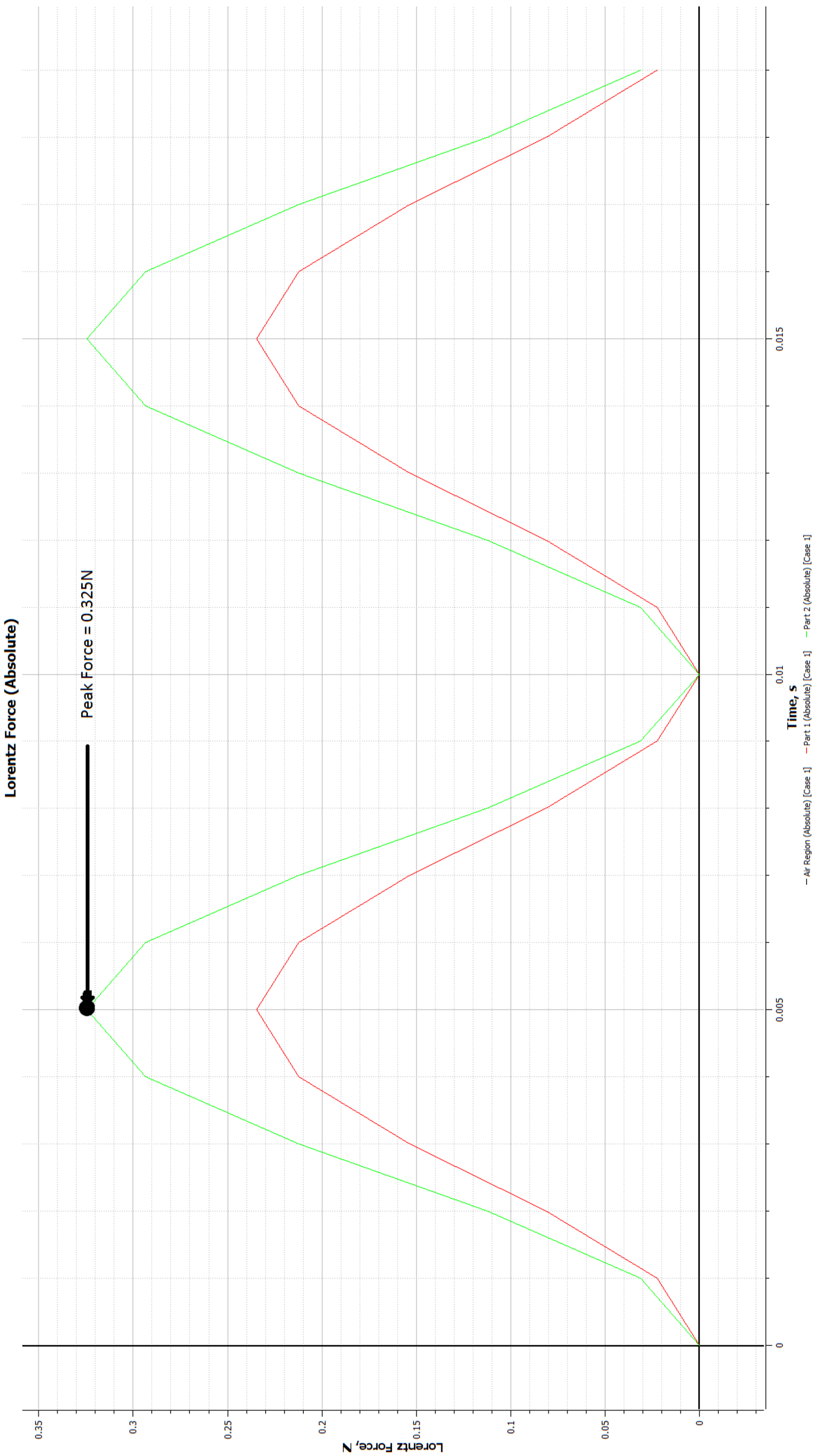


Figure 7.8: Forces in Developed scheme(160*5*2+80*5*1)

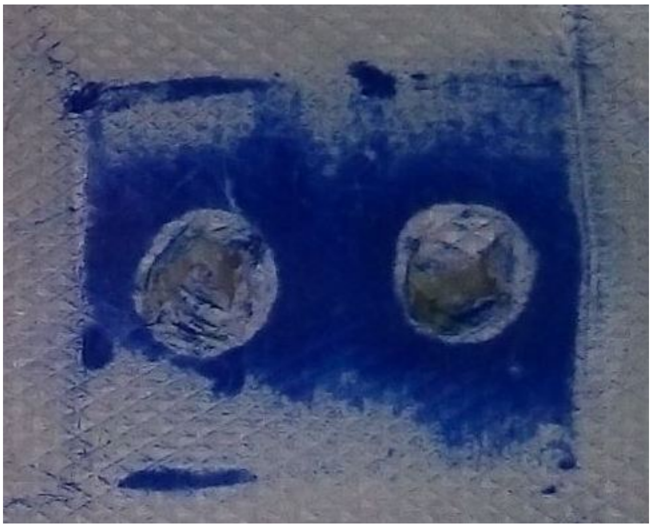

Figure 7.9: Carbon paper testing for uncleaned joint without slot

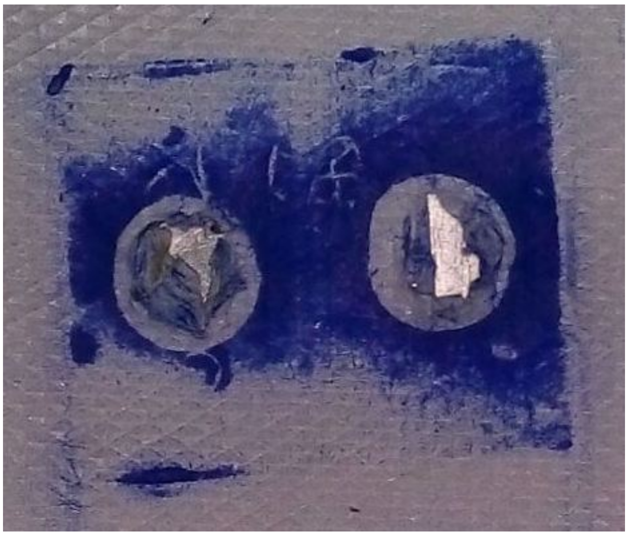

Figure 7.10: Carbon paper testing for cleaned joint without slot

Figure 7.11: Carbon paper testing for cleaned joint with slot

# Chapter 8

# Conclusion and Future scope

## 8.1 Conclusion

From different studies three new concepts e.g. different cross section busbar scheme, slotting and slanting of joint area and aluminium arc chute cover has been developed. Simulation of different cross section busbar scheme concept is done in MAGNET and JMAG software, result shows that the different cross-section busbar scheme needs to deal with nonuniform electromagnetic forces which increases surface forces by 0.085 N compared to existing busbar scheme which is not sufficient to make system mechanically unstable. Temperature rise testing result shows that with use of different cross-section busbar scheme 4.35° and 7.5° Celsius reduction in temperature can be achieved at termination point and at main contact respectively.

Theoretical calculations supports the slotting and slanting of joint area concept and shows that slotting and slanting will reduce the joint resistance by 15.97% and over all resistance by 2.31%. Further carbon paper and mv drop testing is done which shows that slotting improves the contact pressure by making it uniform and reduces the joint resistance by 10.75% and over all resistance by 28.12%.

For aluminium arc chute cover concept temperature rise testing is done which shows that reduction in temperature is done effectively at main contact area (e.g. 2.25°) but not done effectively at termination point (e.g. 0.8°) which is away from main contact.

All above developed concepts and their analysis shows that different cross-section busbar termination can dominantly improve the thermal performance of ACB and offer lower cross-section for same current rating of ACB.

## 8.2 Future scope of work

The above mentioned research work can be carried out further by performing following activities.

- TR testing for all range of ACB with different termination schemes can be done in order to further validate different cross-section concept.
- Thermal performance study can be further extended to black body study and how it can be applied for ACB in order to improve thermal performance.

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