Design and Prototype Development of H.T Sandwich Bus Duct for 7.2 kV System

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By

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Undertaking For Originality of the Work

I, **Mr.Vishal H. Ramnani**, (**Roll No:12MEEE25**), give undertaking that the Major Project entitled **"Design and Prototype Development of H.T Sandwich Bus Duct for 7.2kV system"** submitted by me, towards the partial fulfillment of the requirement for the degree of Master of Technology in **Electrical Power Systems**, **Electrical Engineering**,under Institute of Technology, 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.

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Abstract

Sandwich bus ducts are normally used for power distribution in large building. In electrical power distribution, bus-bar is a strip of copper or aluminum that transfer power from one point to another point.Now a days the use of bus bar system is widely used for distribution of power in place of cable due to its compact size and less voltage drop. Sandwich bus duct is recently available in the market with the rated voltage ranging from 415V-1000 V A.C and 1500V D.C.

Usually Isolated phase bus duct and Segregated bus duct are used for high voltage power distribution. The cost of insulated phase bus duct and Segregated bus duct is very high and the size is also very large.

Objective of project is to model and design of H T sandwich bus duct system using FEM analysis and to develop the prototype module of the same. Moreover, the project will also portray the benefits of the sandwich type construction over the conventional bus duct system.

The project work consist of finding suitable insulating material for the HT sandwich bus duct and making of sandwich duct model using SOLID-EDGE software and then analysis for various insulation material using electrodynamics analysis, electromagnetic and electrostatic analysis with help of ANSYS and ANSOFT MAXWELL software during the project work.Further temperature rise and dielectric tests have been performed on the designed prototype model as well.

On the base of analysis and testing carried out, the corrective ness of proposed design of sandwich bus duct system is justified. With this study superiority and limitation of sandwich configuration over conventional system has been evaluated. The study also provides a base for exploring design of H T sandwich bus duct having larger current carrying capacity and better insulation wrapping techniques.

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Nomenclatures

δ .... Penetration Depth
$\overrightarrow{B}$ .... Flux Density (T)
ρ_v .... Volume charge density
$\overrightarrow{E}$ .... Electric Field
$\overrightarrow{D}$ .... Electric Flux Density
$\overrightarrow{H}$ .... Magnetic field strength
$\overrightarrow{J}$ .... Current Density
Z .... Impedance
X_L .... Inductive reactance

Abbreviations

AIPBD .... Air Insulated Phase Bus Duct

SPBD .... Segregated Phase Bus Duct

S. C. current .... Short Circuit current

EM Loss .... Electromagnetic Loss

T. R .... Temperature Rise

Contents

Chapter 1

Introduction

1.1 Bus duct technology

Bus ducts is used for the effective and efficient supply of electricity in mostly industrial locations. Copper or aluminum is used as a conductor of bus duct that can be insulated and enclosed completely for protection against mechanical damage and dust accumulation. A bus-duct system is an-effective method of distributing power to switchgear and various loads. The main advantage of bus duct is its fast and easy installation and maintenance. They may be available in variety of configuration like elbow and offset shape to make the directional changes and these make the bus duct flexible. Several manufacturers offer a wide range of options of bus bar system from few amperes to thousand amperes to meet various electrical needs. Bus bar system also includes a 200 percent neutral for applications affected by harmonics, or an isolated ground for such loads as sensitive computer equipment. For special applications, some offer bus ways with a 200 percent neutral a housing ground and an isolated ground all in one system. Some manufacturer makes a paired phasing bus bar configuration, in which it groups the bus bars in pairs. This allows the AC current in each pair to be nearly equal in magnitude and opposite in direction, producing a balanced phase-to-phase voltage. This configuration uses two bus bars per phase,with Phase C paired with Phase A, Phase A with Phase B, and Phase B with Phase C.

In electrical system there is some waste of energy in the form of heat when the current is flowing in the conductor. If loss of energy is not maintained within the safe limit it affects the performance of the system. The energy loss in the form of heat increase the temperature

Figure 1.1: Segregated Phase Bus Duct

of bus bar and it may affect the performance of the insulation material. It is essential that material that is selected should have good elecrical and mechanical properties . Different type testing are being carried out as per IEC 61439 for L T bus duct and in case of H.T as per IEC 62271-200 and IS-8084.

1.2 Bus Duct System and Types

As per NEC-368.2, bus duct is defined as a a grounded metal enclosure containing factory-mounted bare or insulated conductors useful for effective distribution of power. The conductor may be copper or aluminium. There are four types of bus duct system.

1. Segregated phase bus duct: In Segregated phase bus duct all phase conductors are placed in a common metal enclosure but are segregated by ground metal barriers between each phase conductor. Segregated are generally available for voltage application ranging from 3.3kVto 13 kV and current up to 5000A. Segregated phase Bus duct find its application in Power generation station and Industrial or distribution plants for lower capacity generator connection and also for inter-connection between switchgear and transformer.

2. Non- segregated phase bus :- In non segregated phase bus duct where all phase conductors are in a common metal enclosure without barriers between phases. Non segregated bus duct is available for low voltage application ranging from 415 to 1.1 KV and current up to 5000A. Non segregated phase bus duct is used in industrial utilities, power plants for inter connection between switch gear and transformer and also for lower capacity of generator(viz D.G sets).

Figure 1.2: Non Segregated Phase Bus Duct

Figure 1.3: Isolated Phase Bus Duct

3. Isolated phase bus duct system:- Conductor in each phase has individual enclosures, providing total safety to the personnel. Both the conductor and the enclosures are circular in cross section offering optimum and most economic design for given parameters.

   The conductor in phase insulated is supported by spring loaded insulators is free to align itself along the line of zero force during short circuits, so the insulator is stressed to the lower level.

Figure 1.4: Isolated Phase Bus Duct

The enclosures is not perfectly circular in shape due to the manufacuring limitation and due to this the central line of enclosure is not the magnetic center line. The insulators in this cases is over stressed during short circuits. In the spring loaded design, the insulators align themselves along the magnetic center line and stresses to much lower levels.

The conductor held by the machined Aluminum shoes on the insulators is freely supported. This arrangements allows the free axial movement of bus bars without stressing the insulators. The material of shoes is made of aluminum, same as conductor to prevent wear during axial movement of conductor. The IPB is air tight in construction and prevents entry of dust/moisture.

There are two types of Insulated phase bus duct: 1) Discontinuous Isolated phase bus duct:Discontinuous IPB(Isolated phase bus duct) system in which the various section of bus duct are so interconnected and earthed that no path is provided for the induced circulating current to flow from one phase enclosure to other phase enclosure.2)Continuous Isolated Phase bus duct: Continuous IPB(Isolated phase bus duct) system in which the various section of bus duct are so interconnected that low resistance path for the induced circulating current is provided from one phase enclosure to another phase enclosure. The continuous bus duct with ends of enclosures shorted significantly lowers the magnetic fields outside the enclosure and prevents heating effect in the surrounding support structure.No separate earth bus is required as the enclosure itself forms an earth bus.

The supporting insulator can be taken out or put back in position without disturbing the other insulators or the conductor. This is a very significant factor in the maintenance of the bus duct.

Insulated phase bus duct is available in the range from 11kV to 36kV with current up to 28000A with maximum short circuit with stand capacity up to 285 kA r.m.s for 1 sec and 900kA peak.

4. Sandwich Bus Duct System:Sandwich Bus-duct System is light weight, low impedance, non-ventilated, naturally cooled and totally enclosed for protection against mechanical damages and dust accumulation in compact and sandwich type.

   Design does not require fire stop or internal barriers in each bus duct length/unit due to its compact & sandwich type construction. Moreover, galvanized steel housing or

Figure 1.5: Sandwich Bus Duct System

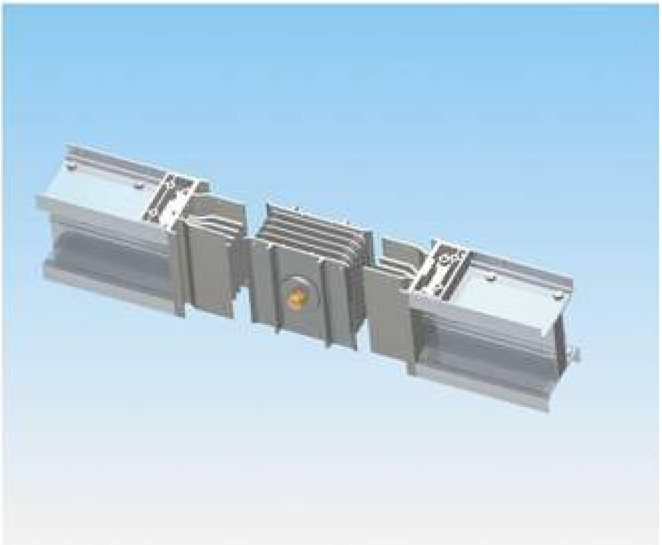

Figure 1.6: Bus Duct Joint

extruded aluminum housing with epoxy compound powder coated by an automated electrostatic process enables to achieve fire resistance, and housing would give integral ground as standard requirement.

Busbar :- 99.9 percent copper bus bar are tin coated with epoxy compound insulation. This is to prevent from water and moisture that cancause reduction in dielectric resistance, and its flame retardant ensures the safety. Likewise, aluminum busbar is silver coated at the joint parts for better conductivity.

Joints: To check for tightness without de-energizing the bus ductsystem, the joints shall be of maintenance-free system with one-bolt type. The high strength bolt is insulated by a high quality insulation material for heat and impact forces.For uniformed distribution of the clamping force over the joints all bolted connections are equipped with Belleville washers. The joint design shall permit safe practical testing of joints for tightness without de-energizing the bus duct and it is possible to remove any one section in a run without disturbing the two adjacent bus duct sections .It shall have an adjustability of ±14mm for a precise alignment and to facilitate an easy field installation. The maintenance-free nut is provided where the outer head will be twisted off once it reaches 1500kg•cm which will act as lock nut.

Advantage of Sandwich Bus Duct :-

The on-site installation times of bus duct is less compared to hard-wired systems thus leading to cost and time savings. It provides increased flexibility in design and versatility with regard to future modifications. Greater safety and peace of mind for specifies, contractors and end-users.Due to the simplicity of bus bar, it is easy to estimate costs from the design/estimating stage through the installation on site. This is because the technical characteristics and price of each component are always known. It is short sighted to compare the cost of bus bar against that of a length of cable and not the real cost of a cable installation to include multiple runs of cable, tray and fixing let alone the protracted time and effort of pulling cables.

Distribution bus bar distributes power along its length through tap-off points along the bus bar at typically at 0.5 or 1 m centers. Tap-off units are plugged in along the length of the bus bar to supply a load, this could be a sub distribution board or in a factory or to individual machines. Tap-offs can normally be added or removed with bus bar live, eliminating production down time. If installed vertically the same systems can be used for rising-mains applications, with tap-offs feeding individual floors. Protection devices such as fuses, switch fuses or circuit breakers are located along the bus bar run thus reducing the need for large distribution boards and the large quantities of distribution cables running to and from installed equipment. Very compact so provides space savings.

Bus bar trunking has several key advantages over conventional forms of power distribution including: -

(a) Reduced onsite installation times when compared to hard-wired systems thus leading to cost saving.

(b) Increased flexibility in design and versatility with regard to future modifications.

There is also uneven distribution of current takes place if multiple cables are run in parallel. Bus bar trunking has tap-off points is provided at regular intervals along each length to allow power to be taken off and distributed to where it is needed.

For higher ratings of power distribution we need to have multiple runs of cable. In such conditions unbalanced distribution of current takes place and causing overheating of some cable. This is completely avoided in the BTS systems.

When multiple runs of cables are used it often leads to improper end connections thereby causing overheating of contacts, burning of cables ends, and is a major cause of fire. This is completely avoided in BTS systems. Specification of Sandwich Bus Duct:-

Normally Available in market from 415V to 1000V A.C and 1500 V D.C and current up to 6000A for copper and 5000A for aluminum.

1.3 Comparision of Sandwich bus duct over Air insulated Bus Duct and Cable

1.3.1 Advantage of Sandwich construction over Air insulated bus duct

1. Sandwich bus duct has low impedance, light in weight, naturally cooled and totally enclosed compared to normal bus duct.

2. It is simple and modular in design and requires less space than cables and normal bus duct.

3. Because of compactness of sandwich bus duct system than normal air insulated bus duct thus it makes more preferred choice in plants and building application.

4. Sandwich contruction doesnt have air gap due to which natural progression of fire is inhibited.

Sr no	Issue	Cable	Bus bar
1	Number of circuits	One circuit per floor. Hence for a 20-floor building, you need 20 circuits.	Just one circuit can cover all floors.
2	Main Switchboard	Need 1 outgoing for each circuit. Hence 20 nos. MCCB outgoings. Higher cost and larger space requirement in electrical room	Need only 1 outgoing for each riser. **Lower cost and size of main panel.**
3	Shaft Size	Using 4 core cables, and considering 1 cable per feeder, you need 20 cables on the lowest floor. Large space required for cables/ cable tray.	Typical size of 1600A riser is 185mm x 180mm. Leads to big savings on riser shaft size, and hence **more usable floor area on every floor**.
4	Fire & safety	The high concentration of insulating materials used in cables and conductors involves a very high level of combustive energy	The volume of insulating materials used in trunking is reduced to a minimum so combustive energy is considerably lower than cables. The insulating materials used do not release corrosive or toxic gases in the event of a fire.
5	Combustive Energy	1600A – approx 60 kWh/sq.m	1600A – approx 5 kWh/sq.m. Combustive energy is typically 80% -90% less than cables.
6	Future expansion	If load on any floor exceeds initial plan, owner has to run an additional cable from a spare feeder on main board to that floor. .	By providing extra tap off slots on each floor at the design stage, owner only has to procure a tap off box and plug it in wherever additional load is required.
7	Fault withstand levels	Limited by conductor size of each circuit.	Much higher – typically a 1600 A riser has a fault withstand capability of 60 to 70 kA. Safer in an electrical fault.
8	Installation time	Much longer	Each riser on a 20-floor building can be installed in approximately 2 to 3 days
9	Voltage drop	High impedance if choose cable size based on each floor currentrating	Much lower impedance. Hence substantially lower voltage drop.

Figure 1.7: Advantage of sandwich bus duct over cable

1.3.2 Advantages of Sandwich Bus Duct over Cable

Sandwich Bus Duct is normally used for low voltage power distribution. Power loss and voltage drop is less in sandwich bus duct then cable because of low impedance.

1.4 Problem Identified

Usually Insulated phase bus duct and Segregated phase bus duct are used for power distribution in industrial load at High Voltage. The size of this bus duct is very large. Space of air insulated bus duct is more. Power loss and voltage drop is also more due to high impedance.

Sandwich bus duct is efficient, safe and economical distribution of power in large building and industrial. Sandwich Bus duct has lower impedance due to this power loss and voltage drop is less. Space occupied by Sandwich Bus Duct is also small.

Sandwich bus duct is available in market up to 1000V A.C and 1500V D.C voltage and current up to 6000 A.Sandwich bus duct designed more than 1kV is a challenging factor.

1.5 Objective of Project

Design and Development of H.T Sandwich Bus Duct System.

1.6 Scope of Work

1. Find out the best and economical insulating material followed by experimental and numerical result that can with stand rated voltage up to 7.2KV.
2. Different analysis
   (a) Electrostatic analysis
   (b) Magneto static analysis
   (c) Eddy current solver and Thermal analysis
   (d) Transient analysis.
3. BDV Test, Dielectric Test, Temperature rise test etc.
4. Finally comparison of experimental and numerical result.

1.7 Methodology To be Adopted

For Medium voltage sandwich bus duct of 7.2KV there are basically three challenging factors:-

1. Insulation Design
2. Thermal Design
3. Short Circuit Force and Deformation problem

1. Insulation Design:-

   For High voltage Sandwich Bus Duct the insulation material between the conductors is stressed more as compared to low voltage sandwich bus duct. In that insulation failure is possible. In Electro-Static analysis electric field stress between the two conductors is find out and basis on this result the finding out best and economical insulating material having dielectric strength that easily withstand the stress.

2. Thermal Design:-There are two types of losses occur in Bus bar system when current flow through it.

   a) Ohmic loss b) Magnetic Loss

   When current flow through the conductor there is ohmic losses occur across the conductor. In D.C Conduction analysis the ohmic loss across the surface of the conductor is calculated. In Sandwich construction the conductor are placed near to each other so there will be consideration of skin effect and proximity effect. When the current flow through the each conductor there be non uniform distribution of flux because of interaction of two fluxes and as result these electrical energy will be wasted and this energy will be the source of heat. The heat generated increase the temperature of the surrounding. These losses are the magnetic losses and can be calculated with the eddy current solver. Energy input and energy output is taken consideration in Eddy Current solver and basis on these it provides the temperature across the bus bar and helps to find out the inductance matrix. Inductance matrix is generated is used to find out the power loss occur in the system.Because of these losses temperature will be rise and it is necessary to maintain the temperature rise within safe limit. Thermal analysis is used to find temperature rise.

3. Short Circuit Force and Deformation Problem:-

   Short circuit force calculation and deformation of bus bar can be estimated on the basis of transient analysis. Finally comparison of the experimental result and result obtained from numerical analysis.

1.8 Thesis Organization

Chapter 1 introduces the bus duct technology and different types of bus duct, problem identification , Objective of project, Scope of work and Methodology to be adopted.
Chapter 2 gives the literature survey which inducles the summary of different IEEE paper realted to the bus bar technology.

Chapter 3 deals with the fundamental background of Electromagnetics analysis.

Chapter 4 gives the introduction on ANSYS software,importance of meshing,Different analysis and comparision study of H.T sandwich bus duct and H.T air insulated bus duct .

Chapter 5 includes the Experimental testing and Comparision of the result.

Chapter 6 includes conclusion and future scope of project work.

Chapter 2

Literature Survey

[1]Bus bar technology is widely used for power distribution due to its compact features. In this paper mathematical model is proposed for the transient condition of the bus bar heating. The bus bar length wise heating with two different electrical contacts at its end terminals is calculated with the thermal equation. When current flow the conductor the conductor are heated . The equation are derived that help to calculate the thermal behaviour of the conductor or bus bar with constant cross section during transient condition. Equation also provide the lengthwise heating distribution and help to find out maximum heating. There is good correlation between experimental and computed heating values.

[2]In this paper temperature distribution in the system is accurately predicted which not only include losses but also include eddy current losses in the steel plates. With the help of FEM it is used to calculate losses generated in bar and steel plates. Combined magneto and thermal analysis is studied for calculating the thermal field on the bus duct system. Convection of heat os approximately present. The result of this combined analysis should lead to a better understanding of the bus duct thermal performance in an application .

[3]In this paper the new numerical method of calculating rectangular bus bar impedance is developed. This method is based on integral equation method and partial inductance theory. The impedances of shielded and unshielded three-phase systems with rectangular phase and neutral bus bars conductive enclosure and use of the method are found. Results for resistances and reactance for these systems of multiple rectangular conductors have been derived and skin and proximity effect is also taken in consideration. The impact of the enclosure on impedances is also predicted. Finally, two applications to three-phase shielded

and unshielded systems bus bars are described. The result is validated by FEM based model. In this new method the equation for finding the self and the mutual inductance of rectangular conductor of any dimensions, including any length is derived. It not only do we not use the geometric mean distance here, we do not use the formula for mutual inductance between two lament wires either. A complete approach to the solution of impedances of high-current bus ducts of rectangular cross-section is presented in this paper. The proposed approach combines Partial Element Equivalent Circuit(PEEC) method with the exact closed formulae for AC self and mutual inductances of rectangular conductors of any dimensions which allows the precise accounting of skin and proximity effect. Complete electromagnetic coupling between phase bus bars and the neutral bus bar is also taken into account.

[4]In this paper presents an analytical method of calculating the voltage distribution across such a resistive termination when subjected to AC voltage stress. The proposed method is used to determine the effect of different design parameters on voltage and stress distribution on such cable ends. The method is simple and can be used to understand the importance of stress control at a cable termination which constitutes a critical part of such cables. High Voltage cables are used for transmission and distribution of electrical power. Such cables are subjected to extensive high voltage testing for performance evaluation and quality control purposes. During such testing the cable ends have to be prepared carefully to make a proper end termination. Using a circuit model for high voltage cable end immersed in a resistive medium, expressions for voltage and stress distributions are derived. The method is simple and can be used to study the importance of electric stress control in cable terminations. The effect of different design parameters on the performance of such a termination is briefly described.

[5]In these paper three-phase bus bar arrangement with straight rigid conductors carrying short-circuit currents is investigated. Calculations are made assuming steady-state ac current with a peak value equal to the peak value of the short-circuit current. The electromagnetic forces are calculated by solving the electromagnetic field diffusion equation numerically, using finite elements method. A large number of arrangements have been examined, covering a wide variety of cases as used in a.c indoor installations of medium and low voltage. For this purpose, the finite element procedure has been fully automated to a degree of minimal human intervention. The FEM analysis is used for short circuit force calculation. For force calculation automatic mesh generator was used and result are compared with corresponding

standard.

[6]In this paper, a three-dimensional eddy-current field model for calculating the eddy-current losses in a compact bus duct system is described. The temperature rises in the compact bus duct system, including both the long linear section and connecting unit, are evaluated using finite-element method when solving the governing thermal equations. The contact resistance between copper conductors and the corresponding temperature rises are measured in the test also. The computations are validated by test results and the results confirm the proposed algorithm is accurate and practical.

[7]In this paper model of bus bar system is taken in consideration skin and proximity effect and any other possible connection of sub conductors. The proposed approach is based on the finite element method for computing electromagnetic field to deduce the impedance matrix and on a successive network analysis to predict the device behavior. This technique can be used for stimulating bus bar system under periodic operating condition even if the supply quantities are affected by harmonics. This method is based on the assumption of lineratiy of the system which is usually verified except under short circuit condition in presence of ferromagnetic enclosures.

[8]In this paper calculation of bus bar temperature of naturally and liquid cooled D C bus is presented. Estimation of time constant allow the calculation of the time varying bus temperature while determination of span constant is helpful in calculating heat gradients along bus bar.

[9]In this paper numerical and analytical approaches for the study of bus bar system are analyzed and compared. In the first part of this paper ,the multi conductor model is presented for studying a general bus bar system and the equation are formalized for current and voltage driven problem. Afterwards the MC method has been applied for solving a current driven problem related to an industrial bus bar . The evaluation of current distribution and electrodynamics forces of the system are compared with the one obtained by using a classical FEM method. In second part analytical approach for evaluating the electro dynamic forces is presented.

Chapter 3

Electromagnetic Analysis

3.1 Introduction

For designing the bus duct model its electromagnetic design help us for effcient designing of the model. The theory of electromagnetic field was started with the deduction of the inverse square law of electric force verified by Coulomb. The magnetic effect of charges was first observed by Orested when he saw the deflection of a compass needle when placed near the current carrying conductor. The magnetic effect of charge was presented in quantitative form by Biot and Savart. The experimental work require for the combined study of electricity and magnetism was completed by Faraday when he observed the generation of electric field by changing current.Field theory was derived mathematically and applied to electricity and magnetism by Laplace, Poisson, Green and Gauss. Maxwell combined this ideas with his idea of a displacement field in a set of equation to correctly represent all changing electromagnetic effects. The displacement current was a key to describe the nature of relationship between electricity and magnetism. In this chapter we have introduced the basis of electromagnetism in the frame of Maxwell's equation, steady state electric and magnetostatic field system.

3.2 Maxwell's Equation

In electromagnetics, the electromagnetic field helps to completely determine the location and motion of the source charges. In many problem of electromagnetic field there arise the situation in which the location and motion of the charges are not completely known. In

Table 3.1: Maxwell's equation in differential form

Sr. No	Name	Differential form
1.	Gauss's law for electricity	$div\overrightarrow{D} = \rho_v$
2.	Gauss's law for magnetism	$div\overrightarrow{B} = 0$
3.	Faraday's law of induction	$curl\overrightarrow{E} = -\frac{\partial\overrightarrow{B}}{\partial t}$
4.	Ampere's law	$curl\overrightarrow{H} = \overrightarrow{J} + \frac{\partial\overrightarrow{B}}{\partial t}$

1831-1879 James Clerk Maxwell elegantly integrated the electric, magnetic and the electromagnetic induction theories prior to his area and formed a set of four equations that describe the behavior of both electric and magnetic field. Maxwell's sets of four equation describes how the electric charges produce the electric field, how the currents and changing elecrtric field produced the magnetic field and how changing electric field produce electric field.

$\overrightarrow{D}$ $[\frac{C}{m2}]$ denotes electric displacement called electric flux density,

$\overrightarrow{E}$ $[\frac{v}{m}]$ is the electric field,

$\overrightarrow{B}$ $[\frac{W}{m2}]$ is the magnetic flux density,

$\overrightarrow{J}[\frac{A}{m2}]$ is the current density,

$\overrightarrow{H}[\frac{A}{m}]$ is the current density,

ρ_v is the free electric charge density.

Material equation are as follows:-

$$\overrightarrow{D} = \epsilon\overrightarrow{E} \tag{3.1}$$

$$\overrightarrow{B} = \mu\overrightarrow{H} \tag{3.2}$$

$$\overrightarrow{J} = \sigma\overrightarrow{E} \tag{3.3}$$

Maxwell's equation describes the behaviour of the electromagnetic fields. ϵ,μ and σ determines the material properties. Gauss law for electricity is shown in table 3.1 for the integral and differential form. The intergral form of Gauss law states that the electric flux passing through any closed surface is equal to the charge enclosed by that surface. In differential form of Gauss Law states that the electric flux per unit volume leaving a vanishingly small volume unit is equal to the volume charge density there.

Gauss law for magnetism is shown in table 3.1 for the integral and differential form. The intergral form of gauss law states that the total magnetic flux passing through any closed surface is always equal to zero. The differential form of Gauss law states that divergence of any vector field is proportional to the source density.

Faraday's law of induction states that the induced electric field in any closed circuit is equal to the negative of the time rate of change of the magnetic flux through the circuit. This law also forms the basis for indutors and transformers.

Finally, Ampere's law state that the line intergral of the magnetic field about any closed path is exactly equal to the direct current enclosed by that path.

3.3 Electrostatic Field

Electric field is generated by the electrically charged particle and time varying magnetic field. Electric field describes the forced experienced by the motionless positively electrically charged test particle at any point in space relative to the source(s) of the field.

$$E = \frac{F}{q} \tag{3.4}$$

Electrostatic field means the electric field which does not change with time and this happen when charges are stationary.Gauss law and Faradays law allow the the E-field to be calculated in terms of a continuous distribution of the charge density and the equation are as follow as The electric field at a point E(r) is equal to the negative gradient of the electric potential and is a scalar field at the same point.

$$E = - \bigtriangledown V \tag{3.5}$$

or

$$V = \int E.dl \tag{3.6}$$

The Poissions equation is:

$$\epsilon \bigtriangledown^2 V = -\rho \tag{3.7}$$

when ρ_v=0, this equation becomes laplace equation:

$$\bigtriangledown^2 V = 0 \tag{3.8}$$

Similarities between electrostatic and gravitational forces:

1. Both act in a vacuum.
2. Both are central and conservative.
3. Both obey an inverse-square law (both are inversely proportional to square of r).

Differences between electrostatic and gravitational forces:

1. Electrostatic forces are much greater than gravitational forces for natural values of charge and mass. For instance, the ratio of the electrostatic force to the gravitational force between two electrons is about 10^{42}.

2. There are not negative gravitational charges (no negative mass) while there are both positive and negative electric charges. This difference, combined with the previous two, implies that gravitational forces are always attractive, while electrostatic forces may be either attractive or repulsive.

3. Gravitational forces are attractive for like charges whereas electrostatic forces are repulsive for like charges.

3.4 Electric Potential

In electrodyanmics the electric field is denoted by V and it is also called electric field potential or electro static potential at a point is the amount of electric potential energy that a unitary point charge would have been located at that point. V is a scalar quantity. The electric potential at a point is equal to the electric potential energy (measured in joules)of any charged particle at that location divided by the charge (measured in coulombs) of the particle. Since the charge of the test particle has been divided out and the electric potential is a "property" related only to the electric field itself and not the test particle. The electric potential can be calculated at a point in either a static (time-invariant) electric field or in a dynamic (varying with time) electric field at a specific time and has the units of joules per coulomb or volts(V).There is also a generalized electric scalar potential that is used in electrodynamics when time-varying electromagnetic fields are present. This generalized electric potential cannot be simply interpreted as the ratio of potential energy to charge. The electric potential created by a point charge Q, at a distance r from the charge (relative to the potential at infinity), can be shown to be

$$V = \frac{Q}{4\pi\epsilon r} \tag{3.9}$$

3.4.1 Current Density and Continuity Equation

Electric current density is the electric current flowing per unit area. It is denoted by J. When a current is flowing through conductor of uniform cross section the current density is also uniform.

$$J = \frac{\Delta I}{\Delta S} \tag{3.10}$$

Since charge is conserved, current density must satisfy a continuity equation. The net flow out of some volume V (which can have an arbitrary shape but fixed for the calculation) must equal to negative of the net change in charge held inside the volume. It can also be states as net cuurent flow out from the volume is the negative of time rate of charge per unit volume. The continuity equation explain the law of conservation of charge as well as continuity of current.

$$divJ = \frac{-d\rho}{dt} \tag{3.11}$$

According to the law of conservation energy nither be created nor destroyed. Same charge keep flowing.

3.5 Magnetostatic Field

Magnetostatics is the study of magnetic fields in systems where the currents are steady (not changing with time). It is the magnetic analogue of electrostatics, where the charges are stationary. It is a branch of electromagnetic studies which involves magnetic fields produced by steady non-time varying currents. Evidently currents are produced by moving charges undergoing trans lational motion. An effective current (called magnetization current) is also produced if magnetic dipoles are nonuniformly distributed. Magnetostatics is even a good approximation when the currents are not static as long as the currents do not alternate rapidly. Magnetostatics is widely used in applications of micromagnetics such as models of magnetic recording devices. The magnetic field is most define in terms of the Lorentz force that exerts on the moving eletric charge. Lorentz gives the relation between B and E in terms of force equation.

Lorentz force equation is as follows:

$$F = q(E + vxB) \tag{3.12}$$

There are two seprate magnetic field but are closely related to each other. One is magnetic field B and second is magnetic field H. The equation that show the relation between B and H is:

$$B = \mu H \tag{3.13}$$

The basic law for magenetostatic field are Ampers law and the law of the conservation of magnetic field. The equation in terms of magnetic potential A is given as:

$$B = \bigtriangledown XA \tag{3.14}$$

Poissons equation for magnetostatic field is

$$\bigtriangledown^2 A = -\mu J \tag{3.15}$$

when J=0, this equation become Laplaces equation:

$$\bigtriangledown^2 A = 0 \tag{3.16}$$

3.5.1 Magnetic Flux Density

A vector quantity measuring the strength and direction of the magnetic field around a magnet or an electric current. Magnetic flux density is equal to magnetic field strength times the magnetic permeability in the region in which the field exists. Electric charges moving through a magnetic field are subject to a force described by the equation$F$=$qvXB$), where q is the amount of electric charge, v is the velocity of the charge, B is the magnetic flux density at the position of the charge, and × is the vector product. Magnetic flux density also can be understood as the density of magnetic lines of force, or magnetic flux lines, passing through a specific area.

$$B = \frac{-d\phi}{ds} \tag{3.17}$$

on intergrating the above equation we get

$$\phi = \int B.dS \tag{3.18}$$

3.5.2 Magnetic Field Intensity

Magnetic field strength (H) is the amount of magnetizing force. It is proportional to the length of a conductor and the amount of electrical current passing through the conductor. Magnetic field strength is a vector quantity whose magnitude is the strength of a magnetic field at a point in the direction of the magnetic field at that point. Flux density (B), the amount of magnetism induced in a body, is a function of the magnetizing force (H). The magnetic filed strength is calculated from Ampere's law and Biot-Savart Law.

$$H = \int \frac{\overrightarrow{IdL}.\overrightarrow{r}}{4\pi \mathrm{r}} \tag{3.19}$$

Chapter 4

Modelling and Simulation Results

4.1 Introduction of ANSYS

ANSYS is a finite element analysis (FEA) code widely used in the computer-aided engineering (CAE) field. ANSYS software allows engineers to construct computer models of structures machine components or systems and apply the operating loads and other design criteria to study the physical responses of a structure such as stress levels temperature distributions pressure etc. It allows an evaluation of a design without having to build and destroy multiple prototypes in testing. The ANSYS program has a variety of design analysis applications ranging from such everyday items as dishwashers, cookware, automobiles, running shoes and beverage cans to such complicated systems as aircraft, nuclear reactor containment buildings, bridges, farm machinery, X-ray equipment and orbiting satellites.
ANSYS was developed by ANSYSInc. USA is a dedicated Computer Aided Finite Element Modeling and Finite Element Analysis tool. The Graphical Uses Interface (GUI)of ANSYS enables the user to to work with (3-D) models and also helps to generate results from them.The following are the list of analyses that we can perform on ANSYS.

1. Structural Analysis

2. Thermal Analysis

3. Fluid flow analysis

4. Electromagentic field analysis

5. Coupled filed analysis
6. Acostic analysis

4.2 FEA through ANSYS

In ANSYS the general process of finite element analysis is divided into three main phases:-

- Preprocessor
- Solution
- Post processor

4.2.1 Preprocessor

The preprocessor is a program that processes the input data to produce the output that is used as input to the subsequent phase(solution). Following are the input data that needs to be given to the preprocessor:

1. Type of analysis(structural or thermal, static or dynamic and linear or nonlinear).
2. Element type.
3. Real constants.
4. Material properties.
5. Geometric model.
6. Meshed model.
7. Loading and boundary condition.

The input data will be preprocessed for which the output data and preprocessor will generate the data files automatically help to users. These data files will be used by the subsequent phase(solution).

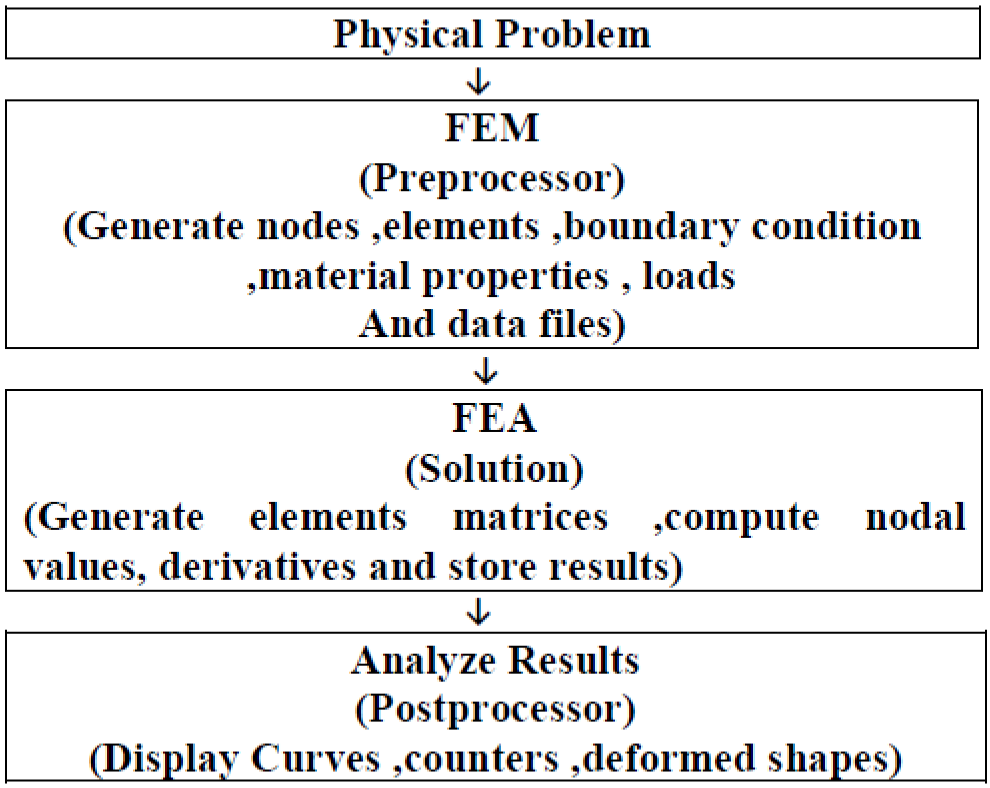

Figure 4.1: FEA through ANSYS

4.2.2 Solution

Solution phase is completely automatic. The FEA software generates the element matrices that computes nodal values and derivaties and stores the result data in files. These files are further used by the subsequent phase to review and analyze the result through the graphic display and tabular listing.

4.2.3 Postprocessor

The output from the solution phase is in the numerical form and consist of nodal values of the field variable and its derivatives. For example in structural analysis the output is nodal displacement and stress in the element. The postprocessor processes the result data and display them in grapical form to check or analyze the result. The graphical output gives the detailed information about the required result data. The post processor phase is automatic and generates the graphical output in the form specified by the user.

4.3 Meshing

Meshing is the important part in the FEM analysis of the model. The model is divided into the number of nodes and elements. The mesh can be generated manaully or automatically. In manual meshing we can create the mesh of different sizes in different location in the model. This process of varying the mesh size is called mesh refinement. Manual meshing is a tedious and time taking process for complicated model where as automatic meshing is avery easy and popular method with which meshing is created automatically in the preprocessor using just asingle command in GUI. We just have to specify mesh denstiy. For complicated models the automatic mesh is considered a better option. Automatic meshing has limitation over the mesh quality and accuarcy in the result. The meshed model of the sandwich bus duct system is shown in figure 4.2 and 4.3:

Some important point to be considered while performing the meshing process are:

1. The mesh should not contain holes,self intersection and faces joined at two or more edges.

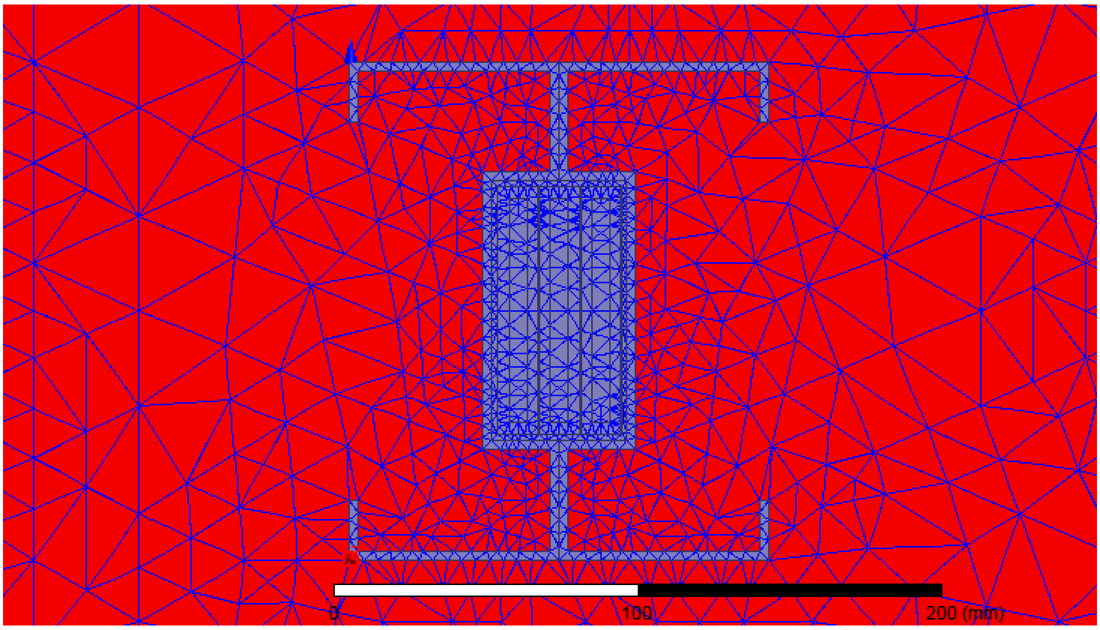

Figure 4.2: Meshed Model

2. The density of the mesh should be controlled to set a better balance between the accuarcy and the time.

3. The area with holes and sharp corners should be meshed densely to get better result because stress will be more in that areas.

4. The aspect ratio of the element is the ratio of the length of thr longest side to the shortest side.The value of the aspect ratio should be greater than or equal to 1.

5. The linear element require finer mesh than the mesh required in quadratic elements.

6. The element unit of the mesh should be as equiangular as possible.Highly distorted element such as long and thin triangles deformed tetrahedron and so lead to numerical instabiltiy caused by rounding off errors.

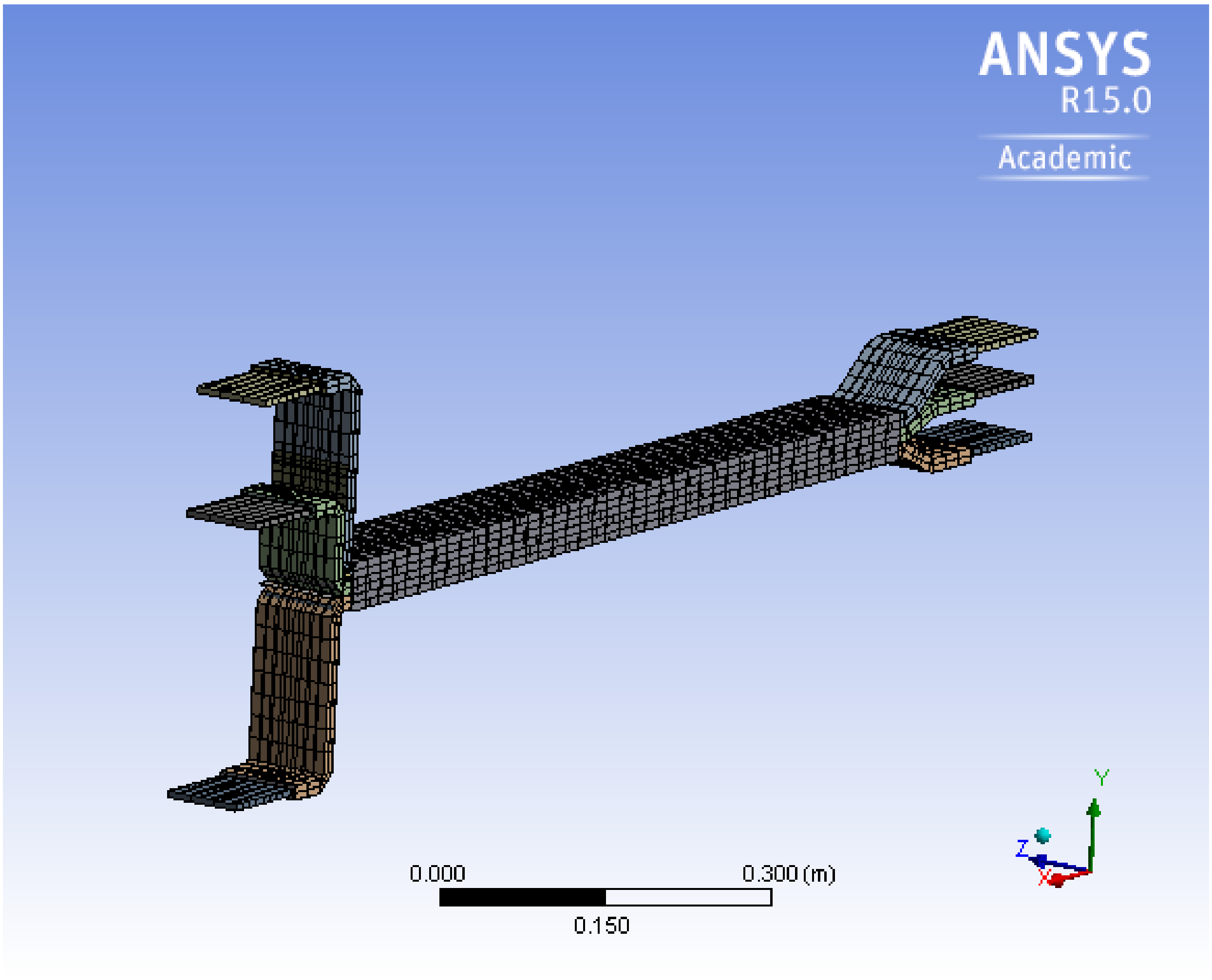

Figure 4.3: Meshed Model

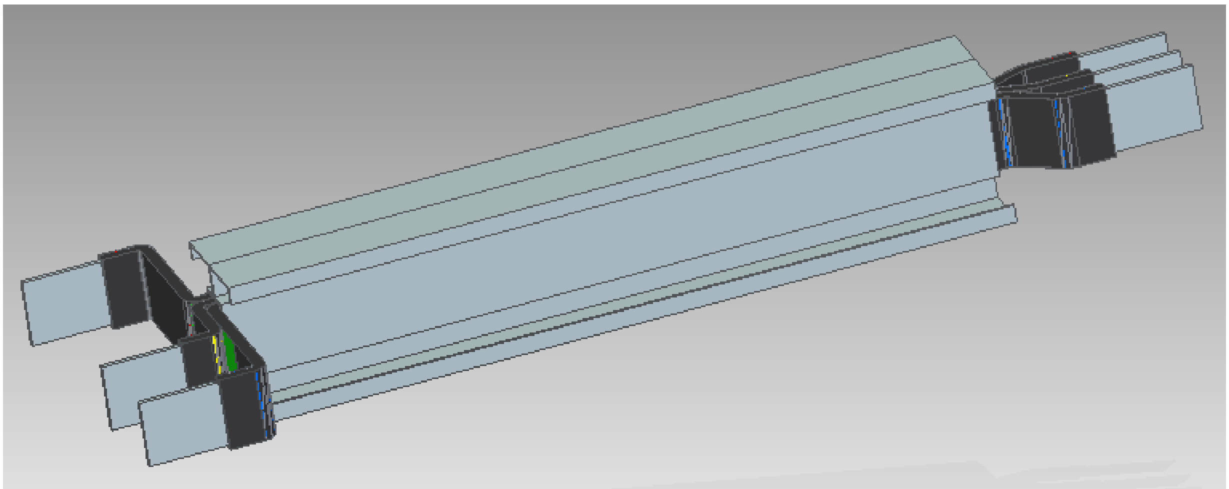

Figure 4.4: Sandwich Bus Duct Model

4.4 Geometry

The geometry of the sandwich bus duct model is drawn in the CAD software. The sandwich bus duct model is design for the 7.2kV, 800A system. The cross-section of the conductor 75x6.The length of conductor is 1258mm. The thickness of insulation for one layer is 0.15mm. The sandwich bus duct with end position considered with end flange connection shown in figure 4.4.

4.5 Simulation Result

4.5.1 Simulation for 7.2kV 800A High Voltage Sandwich Bus Duct System

Simualtion is carried out on ANSYS and MAXWELL Software. The Electrostatic analysis approach is used to find the the maximum electric field strength between phase to phase and phase to ground during Power frequency excitation. For 7.2kV(R.M.S) system, the bus duct has to passed the one minute power frequency test at 20kV. During this excitation the maximum electric field strength on dielectric material can be find with the help of Electrostatic analysis. With the help of the result obtained from this analysis is used to find out the best dielectric material. Figure 4.5 show the voltage distribution through the bus duct. The voltage distribution through out the conductor can be found out from the Possion's equation.

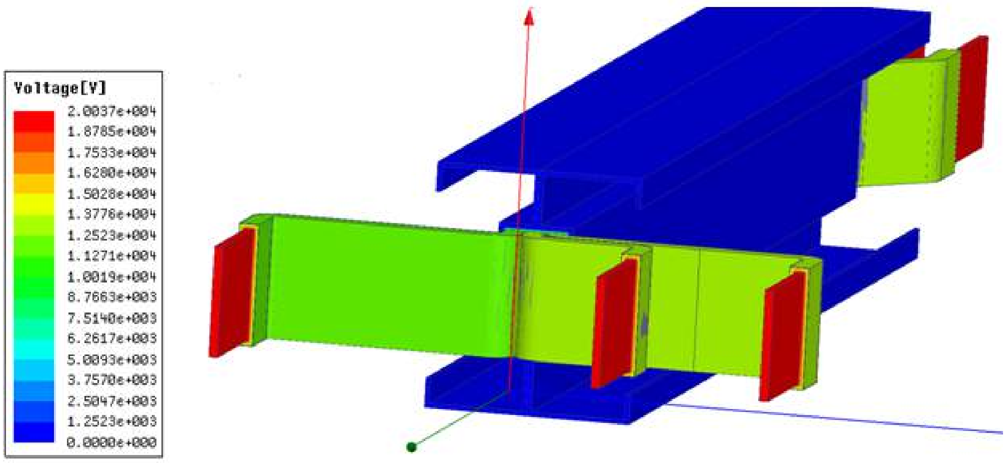

Figure 4.5: Voltage Countour through the Bus Duct

$$\epsilon^2 V = -\rho_v \tag{4.1}$$

Case I: All the phases are excited with 20kV and enclosure is grounded. With the help of this analysis the maximum stress between phase to ground can be found. The maximum phase to ground electric field strength is 7.5kV/mm as shown in figure 4.6. The dielectric matterial with higher permitivitty is stress less compared to material with lower value of permitvitty.

$$E = \frac{Q}{4\pi\epsilon R^2} \tag{4.2}$$

Case II : When only one phase is excited with remaining two phases and enclsoured is grounded. With the help of this the maximum phase to phase stress is founded and it is 3kV/mm as shown in figure 4.7.

For magnetostaic analysis, the analysis is carried out on 2-D model which is created from the 3-D model of the bus duct. In this first the constant excitatiuon(800A) is applied to each phase conductor from which inductance matrix is calculated which will be useful for power loss computation. The magnetic field vector and magnetic flux density is produced on the bus bar,enclosure and the surrounding region(induced current is avoided) is shown in

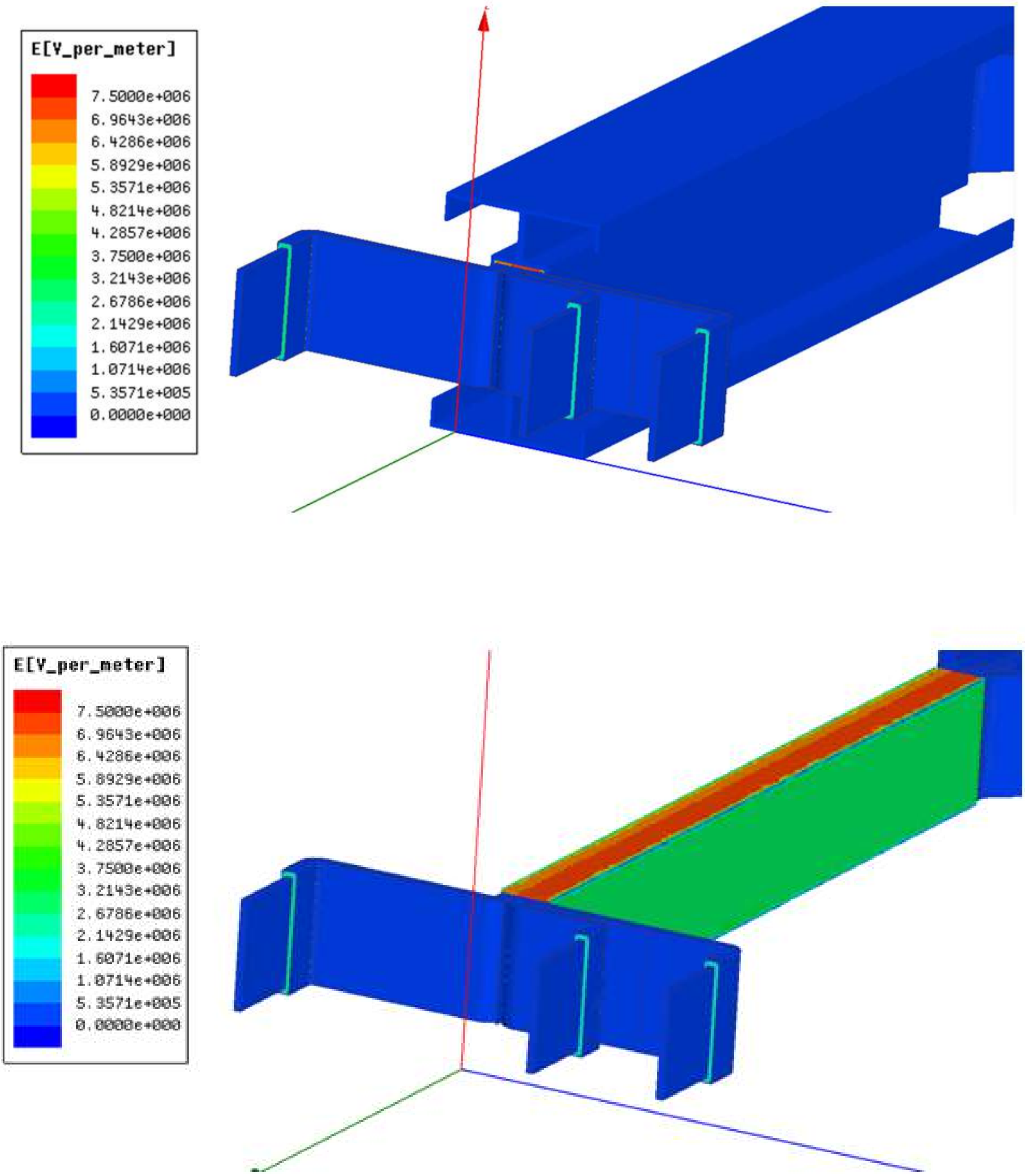

Figure 4.6: Electric field stress for phase to ground

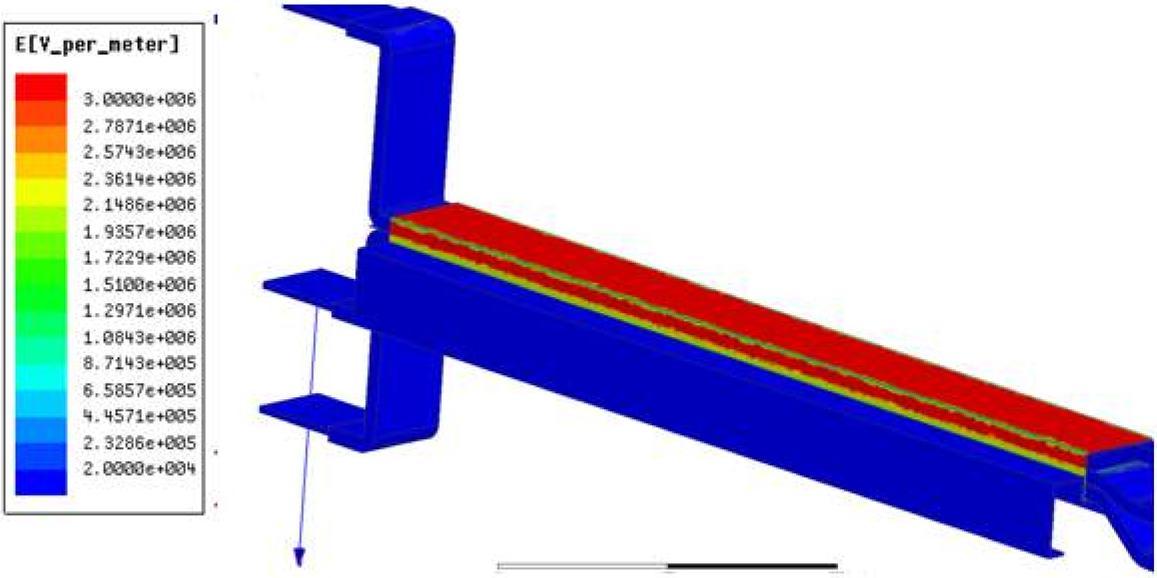

Figure 4.7: Electric field stress for phase to phase

the figure 4.8 and 4.9. The red portion indicates that flux density is more concentrated on the top and bottom surface of the individual phase bus bar and the maximum flux density is 0.002T.

When the same configuration is used for time varying current including the eddy effect the flux density throughout the bus duct model is shown in figure 4.10. Flux density is concentrated more in between the Rphase and Yphase middle portion. The maximum flux density during time varying excitation is 0.01T. Due to time varying current, eddy current will induced in the conductor. These induced eddy current will cause the power loss due to skin effect and proximity effect. Skin effects is mainly depend on the penetration depth.

Penetration Depth:

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} \tag{4.3}$$

With increased in frequency the peneration depth is decreased which cause more losses due to skin effect. The inductance of the system decrease with increase in frequency. This is because skin effect is the tendency of an alternating current to become distributed within a conductor such that current density is largest near the surface of the conductor and decrease

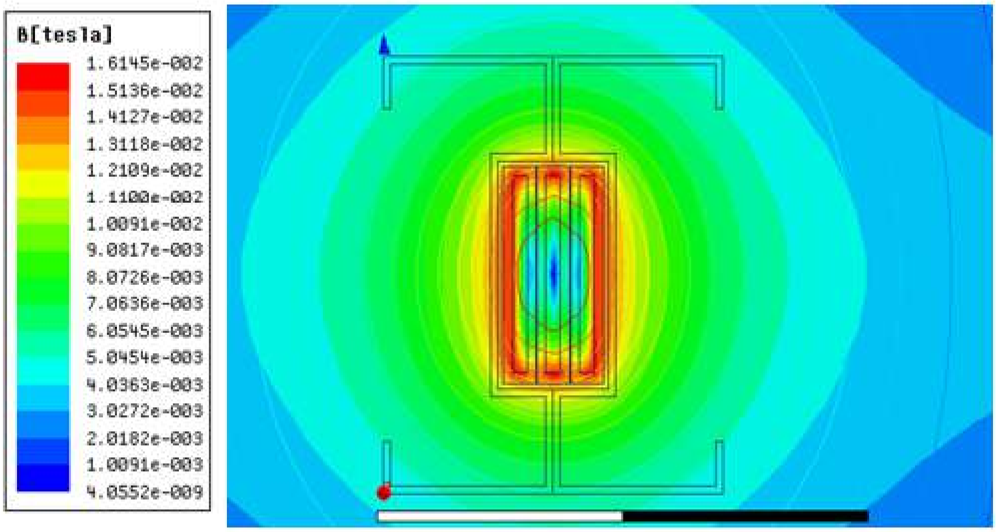

Figure 4.8: Flux Density through the Bus Duct

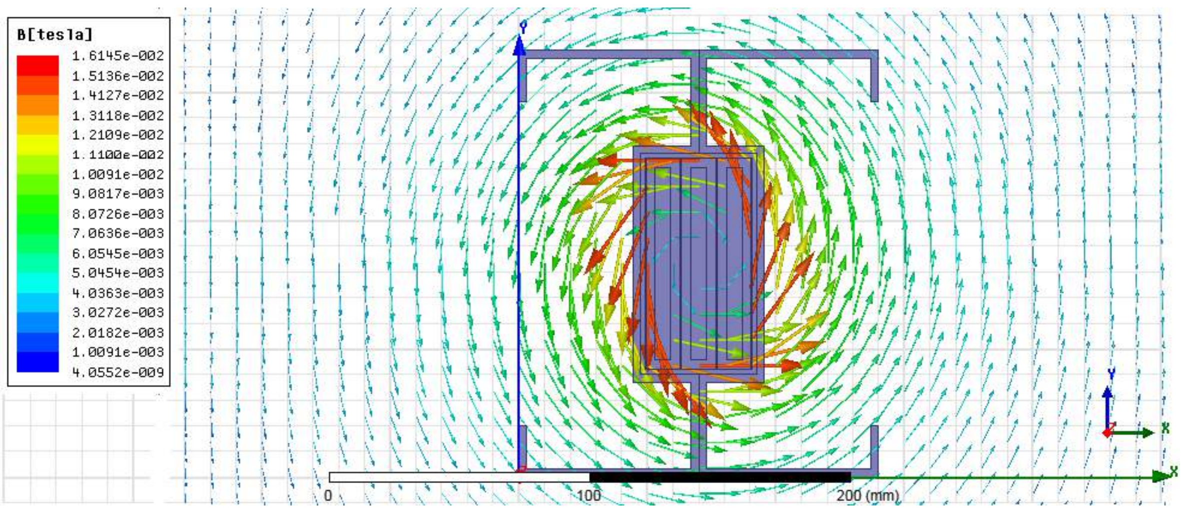

Figure 4.9: Flux vector through out the bus duct

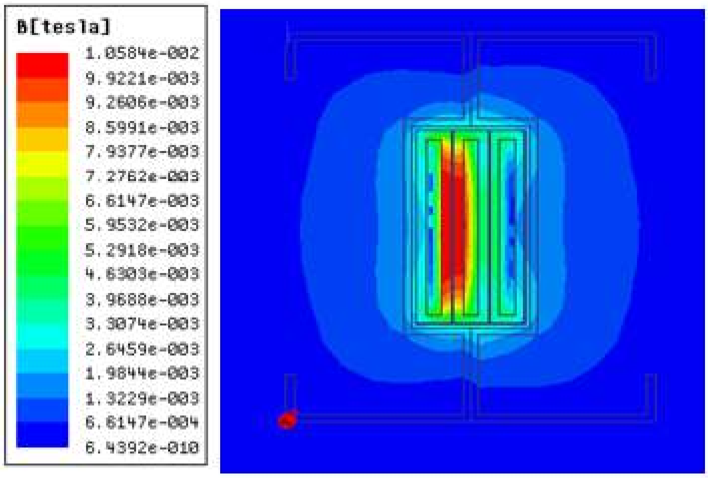

Figure 4.10: Flux density during time varying excitation

with greater depth in the conductor. The electric current flow at the skin of the conductor between the outer surface and level called skin depth(penetration depth). The skin effect causes the effective resistance of the conductor to increase at higher frequencies where the skin depth is smaller and thus reducing the effective area of the conductor. The skin effect is due to opposing eddy current induced by the changing magnetic field resulting from alternating current.

$$X_l=2\pi f L \tag{4.4}$$

$$Z = \sqrt{R^2 + X_l^2} \tag{4.5}$$

The losses due to this induced eddy current called EM losses which includes(skin effect and proximity effect) is shown in the figure 4.11.

Some amount of losses are induced in the enclsoure due to this induced eddy current. Total Losses are 170W/m (Ohmic and Em Loss). EM Loss will be increased with the increased in the frequency because of decreased in the peneration depth with increase in frequency.

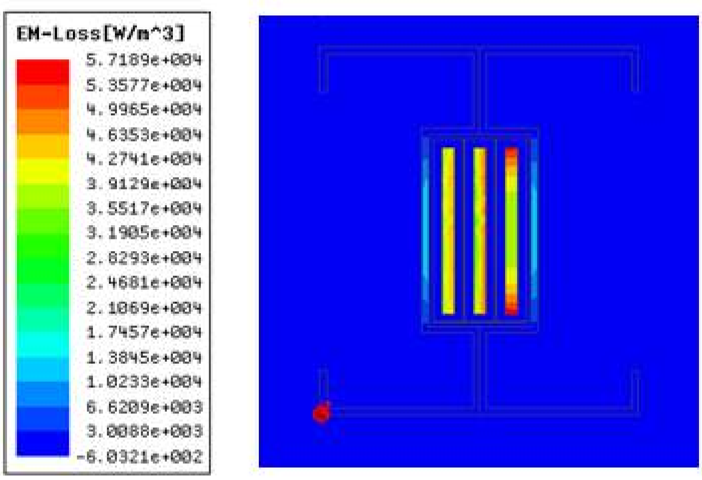

Figure 4.11: Em Loss

When the current flow through each conductor its cause some portion of electrical energy wasted due to its own resistance and this wasted energy will be the source of heat. The heat generated due to this is called joule heating or ohmic heating and is shown in figure 4.13. Heat generated due to this will increase the temperature of the surrounding. Ambient temperature is 40^0C. The maximum temperature rise is 71.94^0C as shown in figure 4.14.

During the S.C test for 800 A rated current the sandwich bus duct system has to be supplied with 50KA for 1sec and temperature rise should be within the limits. While doing this we can find out the the maximum force on each bus bar during the short circuit. The waveform for the S.C for each phases is shown in figure 4.15,4.16, and 4.17.

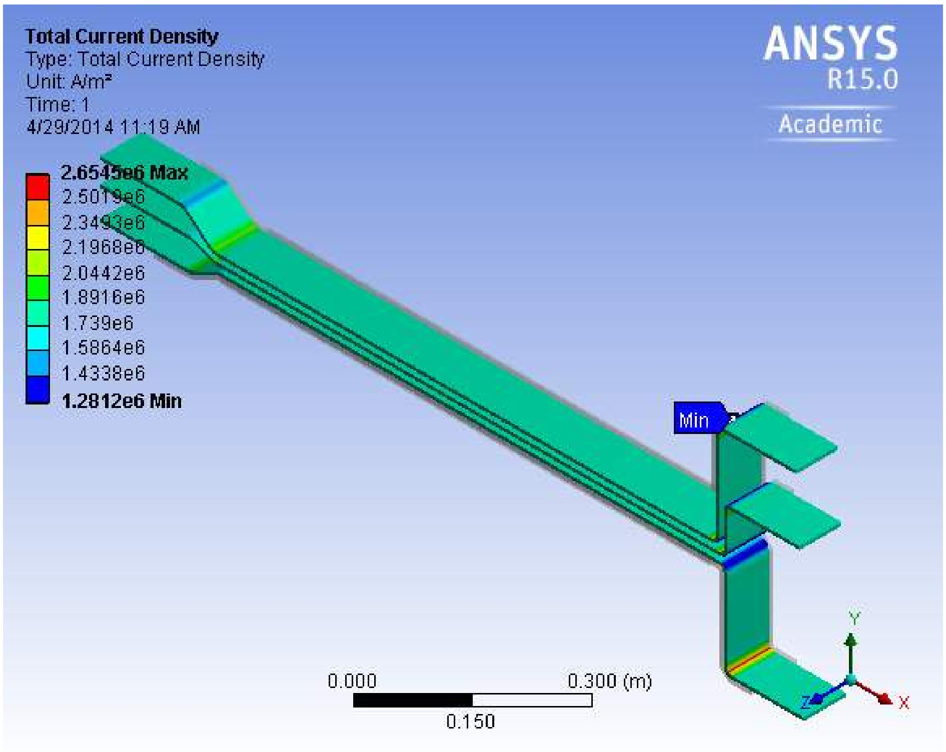

Figure 4.12: Current Density distribution over the bus bar

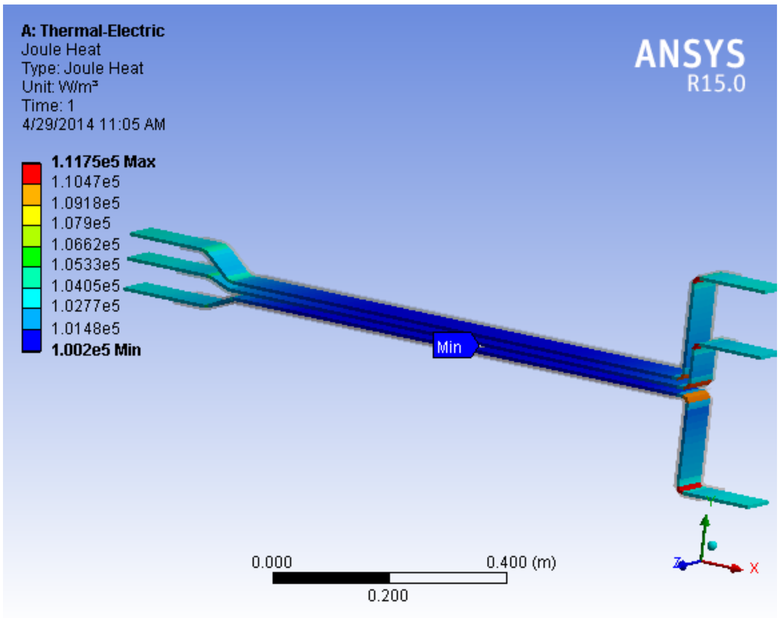

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Figure 4.13: Joule Heat distribution

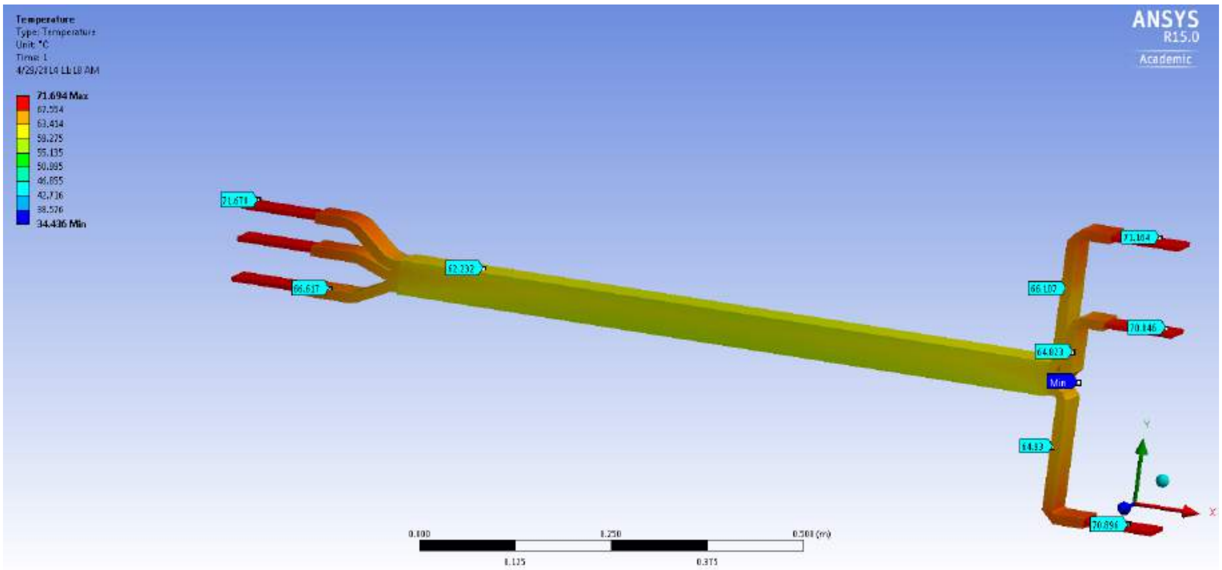


Figure 4.14: Temperature distribution

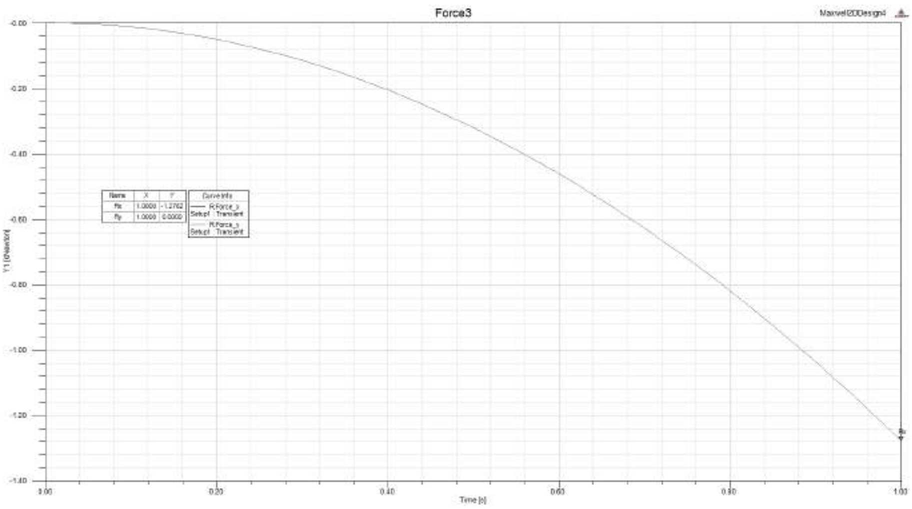


Figure 4.15: R-phase forces

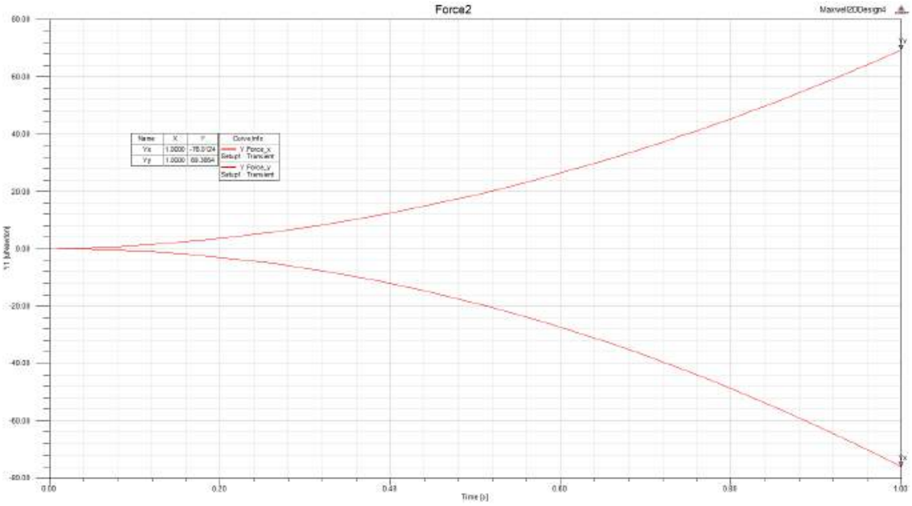


Figure 4.16: Y-phase forces

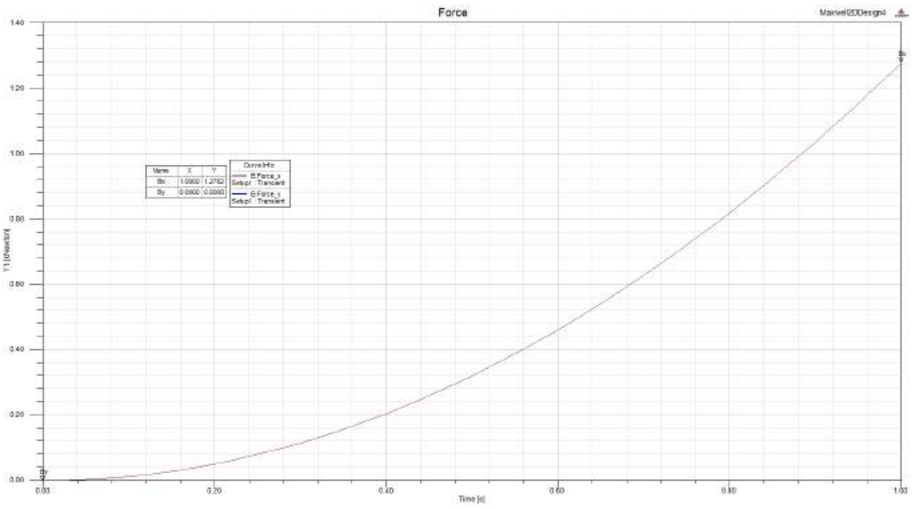


Figure 4.17: B-phase forces

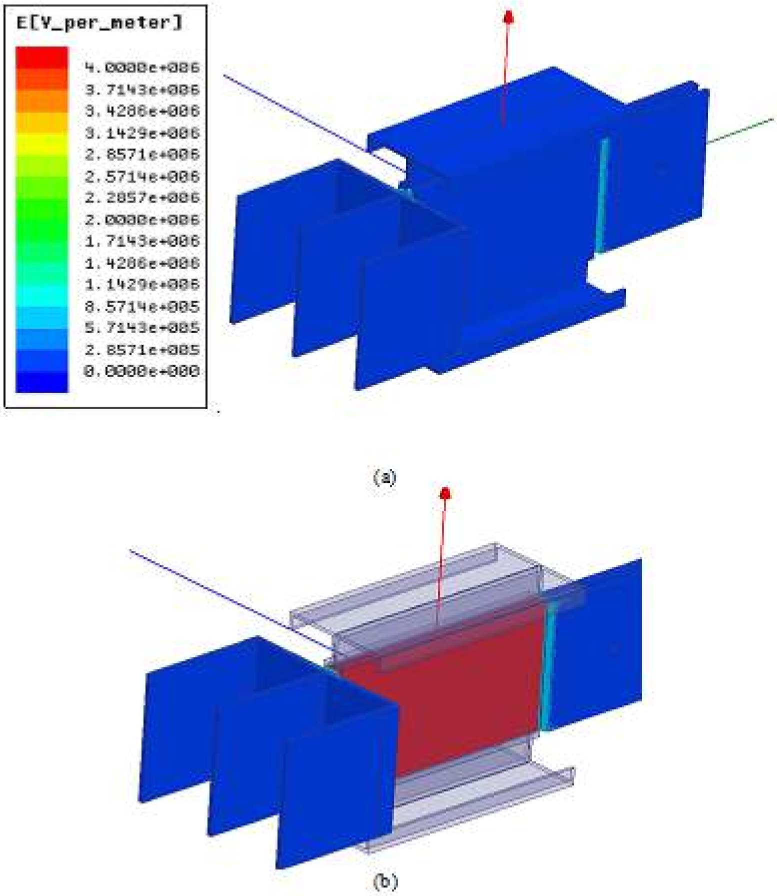


Figure 4.18: Electric field strength in Sandwich bus duct

4.5.2 Comparision Study of 7.2kV 1600A High Volatge Sandwich Bus Duct and High Voltage Air Insulated Bus Duct

Comparision of High voltage sandwich bus duct and High volatge air Insulated bus duct is done in terms of electric stress, losses and voltage drop with the help of the simulation result obtained.

For 7.2kV (Phase to Phase) 1600A system, both sandwich bus duct and air insulated bus duct has to withstand power frequency test of 20kV for 1min. So each phase is excited with 20kV and enclosure is grounded so the stress in both cases can be found.The figure 4.18(a) & (b) show the maximum field strength in sandwich bus duct. The maximum phase to ground stress is 4kV/mm.

In case of Air insulated bus duct electric filed strength in almost negligible due to more clearance between phase and enclosure and also between two phases. The maximum stress is 0.5kV/mm as shown in figure 4.19.

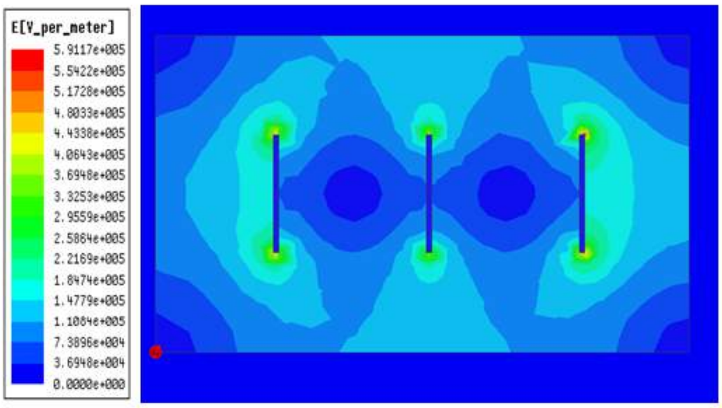


Figure 4.19: Electric Field strength in Air insulated bus duct

Now 1600A cuurent is supplied to each phase of sandwich bus duct and air insulated bus duct to find out ohmic losses and EM losses. Figure 4.20 show the maximum flux density in sandwich bus duct and air insulated bus duct during constant excitation and time varying excitation.

The ohmic losses almost same in both but EM losses varies according to the clearance between two phases. Total EM losses in Sandwich bus duct system are 73.59W/m (3-ϕ) and in Air insulated bus duct are 88.134W/m(3-ϕ). Figure 4.21 show Em Loss in Sandwich bus duct and Air insulated bus duct.

In Sandwich Bus Duct the total loss are 220.71W/m and 235.25 W/m losses in Air insulated bus duct. So from the comparison so that almost 15w/m losses are less in sandwich bus duct system. For finding voltage drop, the equvivalent circuit of both Sandwich bus duct system and Air insulated bus duct with the help of inductance and capacitane matrix obtained in both during analysis.

4.5.2.1 Equivalent Circuit of Bus Duct

Equivalent circuit of the Sandwich Bus Duct is shown in figure 4.22 and the parameter of resistance, self inductance and mutual inductance is taken from the matrix generated during the analysis.

The given input voltage is 7.2kV(line to line) system and output voltage is about 7.11kV voltage drop is of 89.66Volts(line to line). The waveform for Vin and Vout is shown in figure

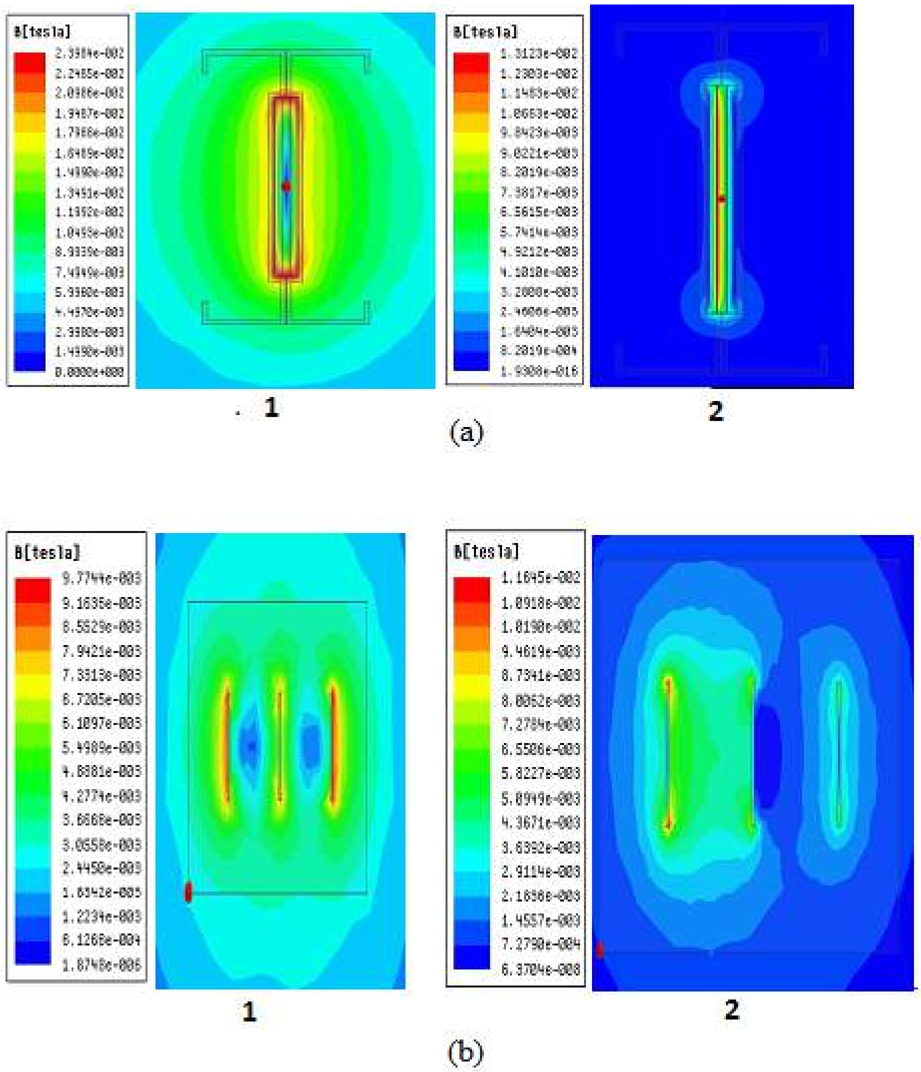


Figure 4.20: (a)Flux density in Sandwich bus duct (b)Flux density in Air insulated bus duct

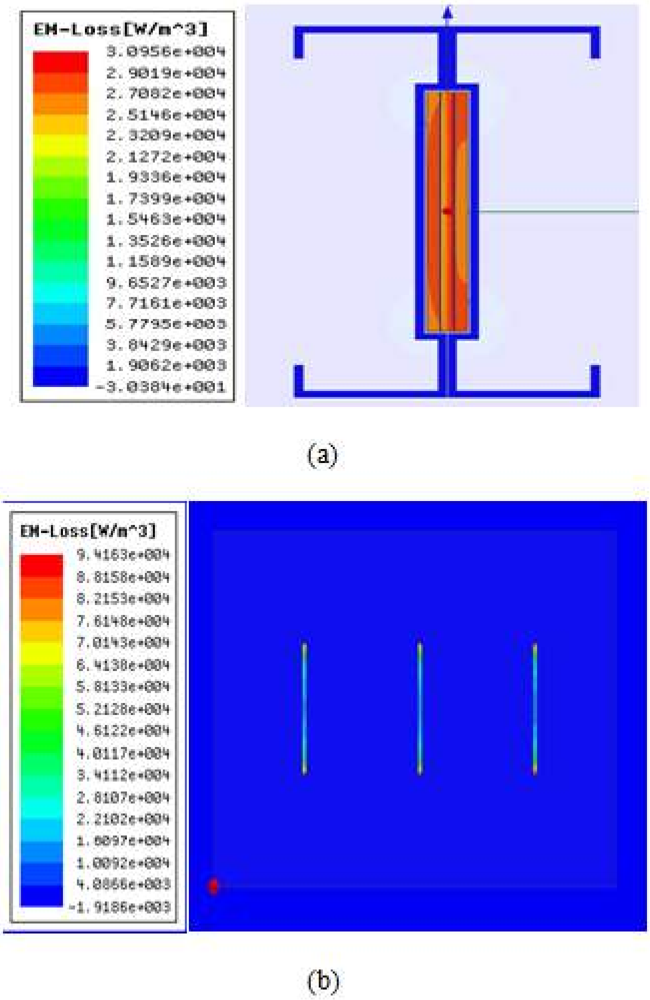


Figure 4.21: EM losses (a)Sandwich bus duct (b) Air insulated bus duct

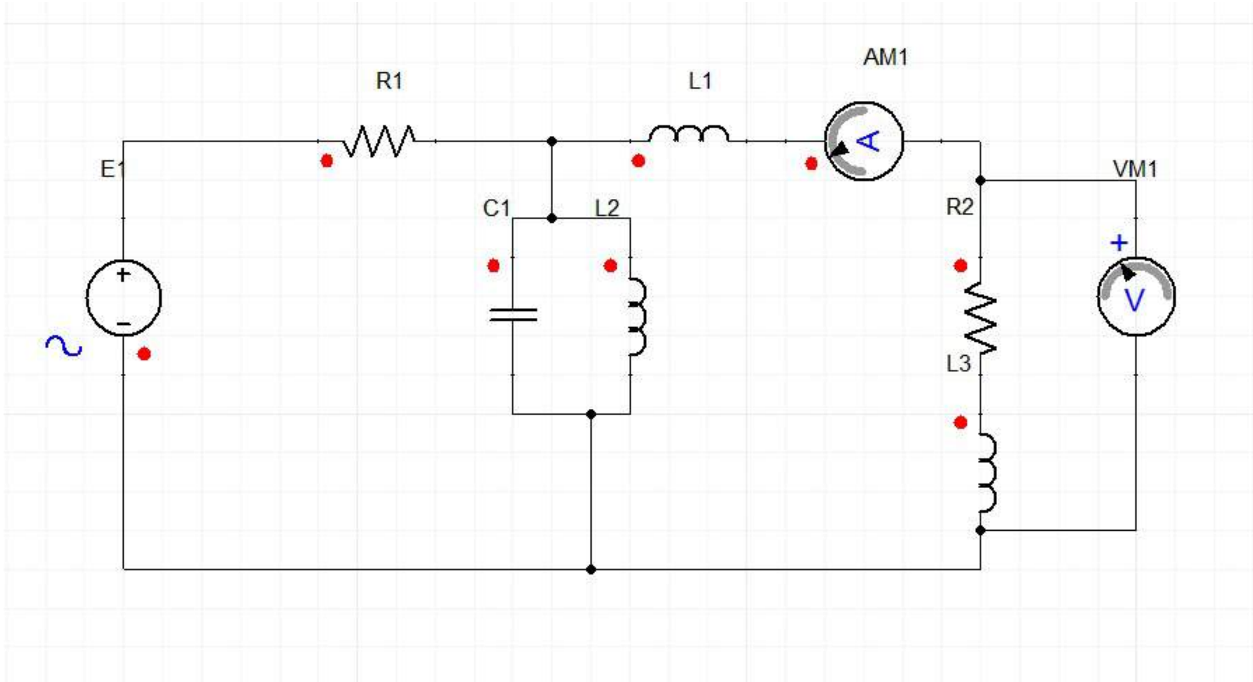


Figure 4.22: Equivalent circuit of Sandwich bus duct system

4.23 which clearly show the voltage drop in output. The load is maintain in a such a way that current drawn from the sorce is almost 1600A and power factor is maintain 0.9 lagging as shown in figure 4.24.

The mutual inductace play a important role in voltage drop and power loss. More the value of mutual inductance lower will be the voltage drop. Mutual inductace is directly proporional to the air gap flux density between two phases. Air gap flux density is more in sandwich bus duct compared to the air insulated bus duct because in sandwich contruction all the phase conductor are seperated by insulation only have thickeness of about 1 to 2mm only. So the air gap flux density is more in sandwich construction and volytage drop and power loss is less in sandwich construction. The figure 4.25 show how the voltage drop varies by varying mutual inductance value.

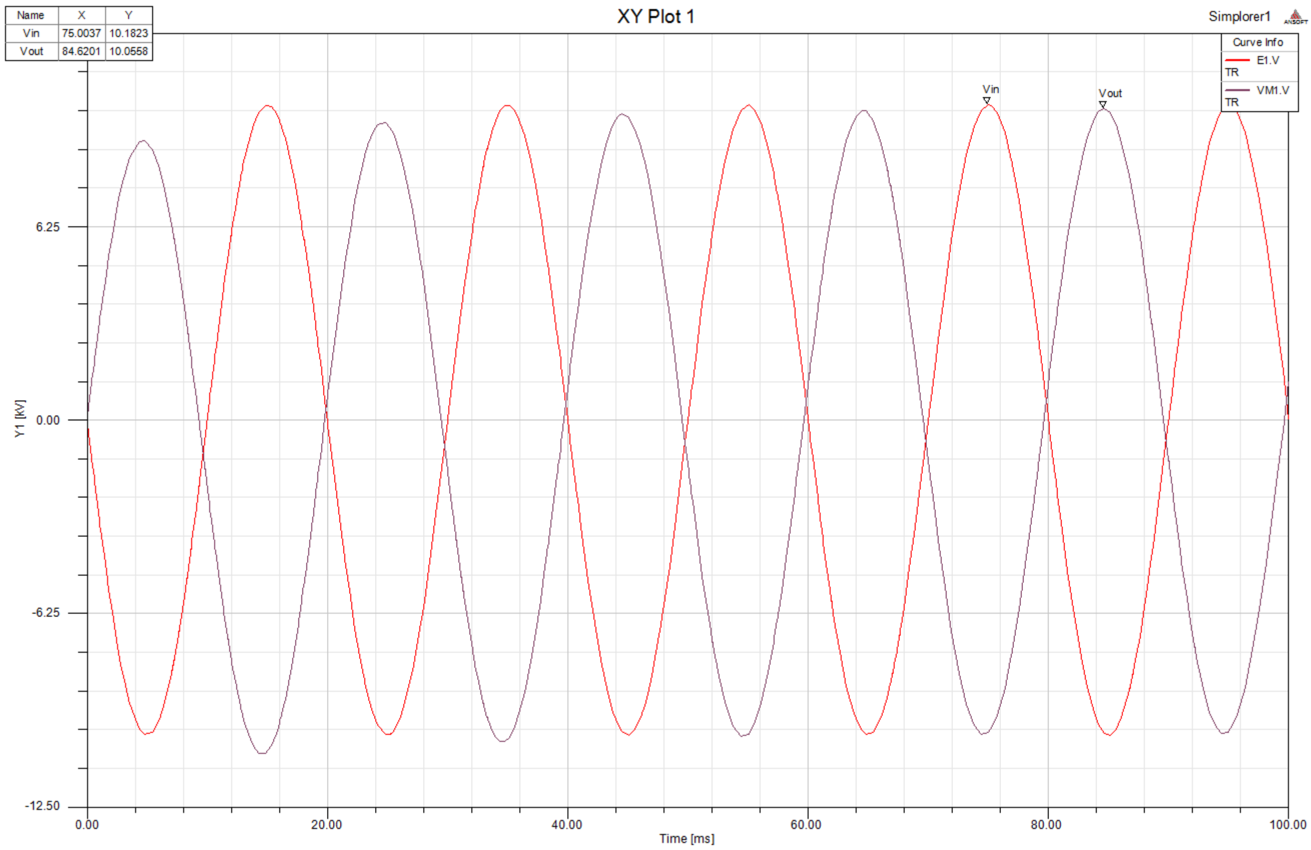


Figure 4.23: Waveforms for V_{in}&V_{out}

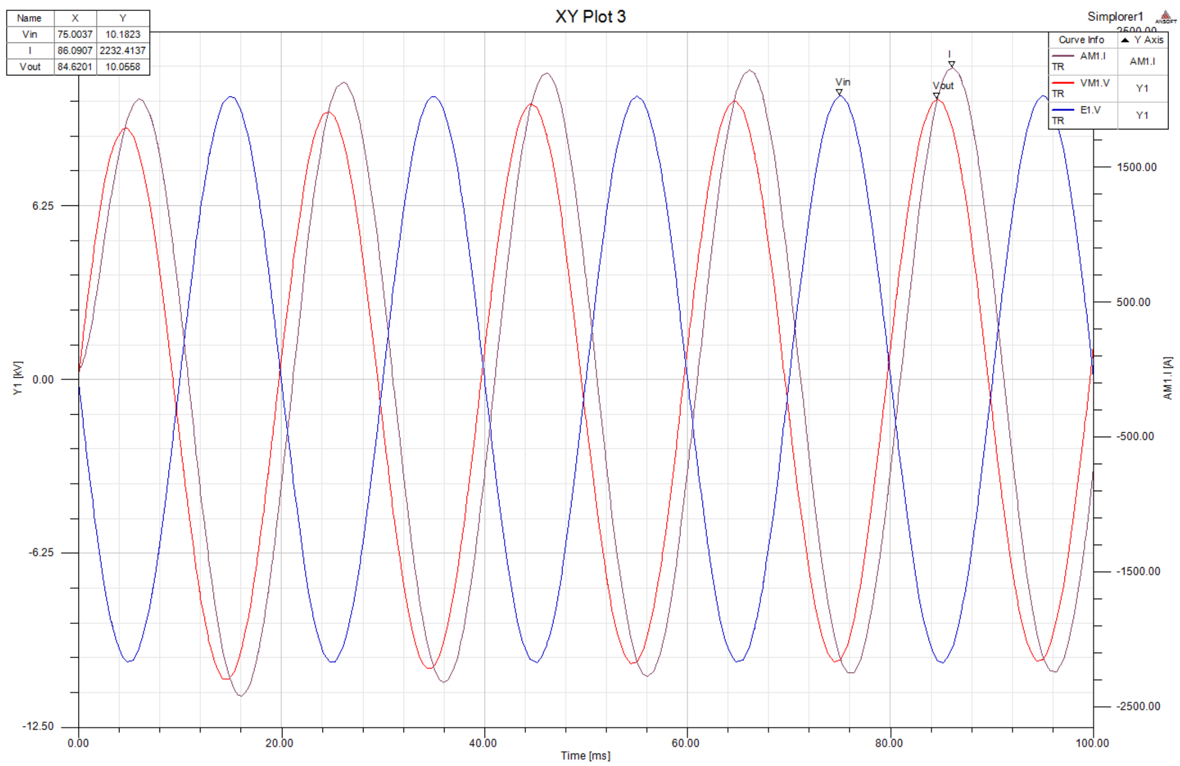


Figure 4.24: Waveforms for V_{in},V_{out}& I

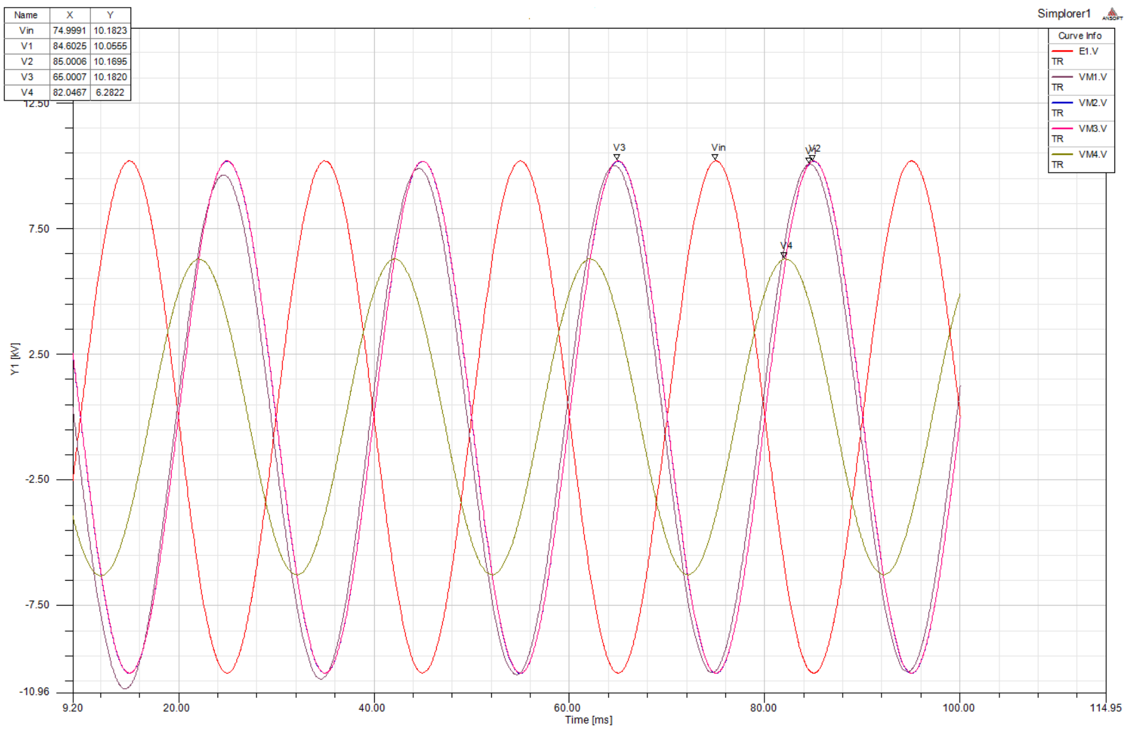


Figure 4.25: Variation of voltage drop by varying mutual inductance

Equvivalent circuit of Air insulated bus system is shown in figure 4.26 and the parameter are taken from the matrix generated during the analysis.

The given input voltage is 7.2kV(Line to Line) and output voltage is 7.08kV and drop is about 120V(Line to Line) shown in figure 4.27. The voltage drop is more in air insulated phase bus duct system due to lower value of mutual inductance. Air gap flux desity is less due to more clearance between two phases due to this the value of mutual inductance is low.

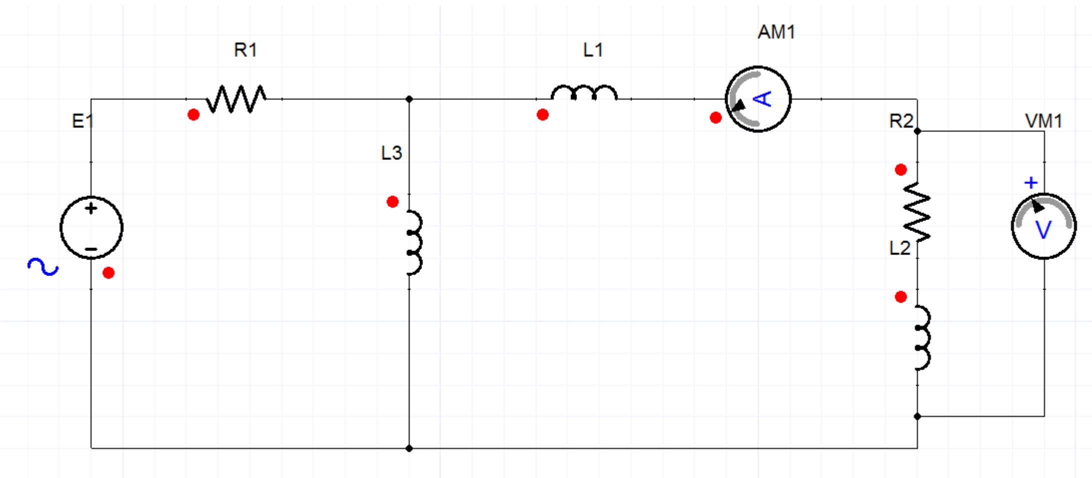


Figure 4.26: Equivalent circuit of Air insulated bus duct

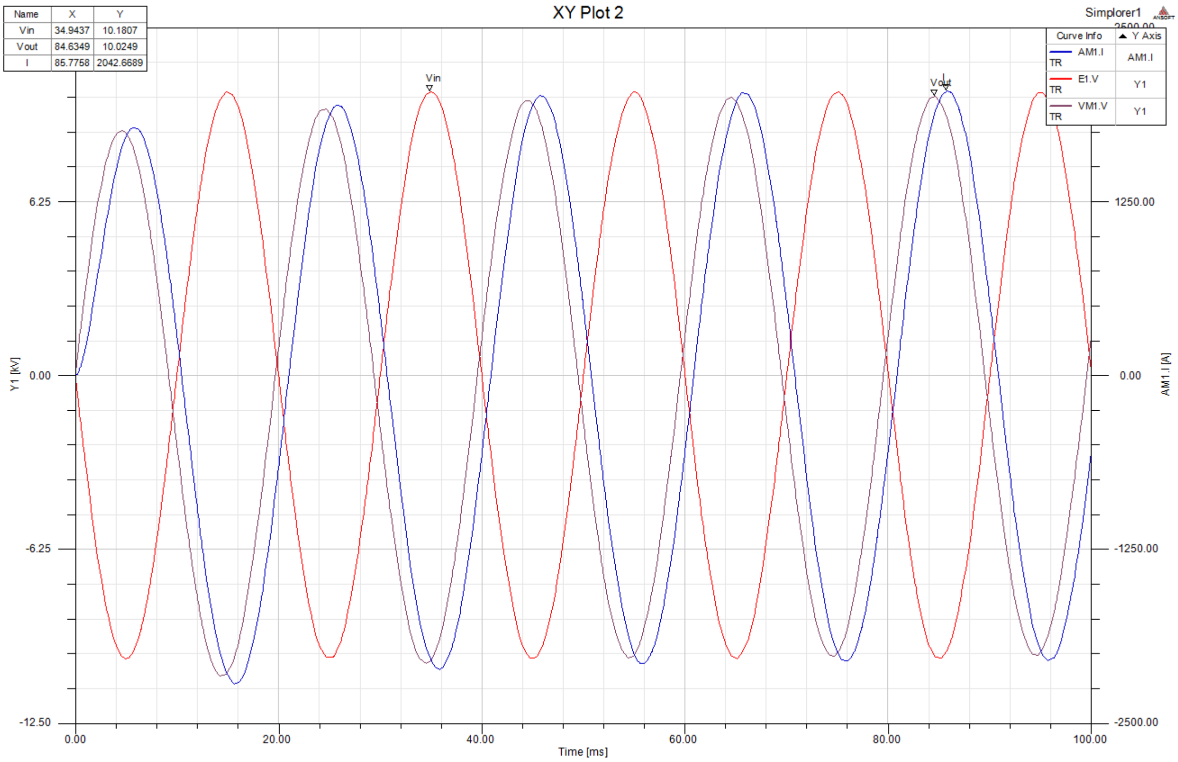


Figure 4.27: Waveforms for V_{in},V_{out}& I

Table 4.1: Comparision of Sandwich bus duct over Air insulated bus duct

Sr. No	Parameter	Sandwich Bus Duct	AIPBD
1	Flux Density	0.02T	0.009T
2	Mutual Inductance	6.243e-7H	4.8165e-7
3	Total Loss	220.71W/m	235.25W/m
4	Percentage Voltage drop	1.24%	1.535
5	Space required	1/3of AIPB	more
6	S.C withstand capacity	Large	Limited by coductor size
7	Initial cost	More	Less

Chapter 5

Experimental Testing and Result Comparision

Testing with different insulation material has been carried out to find the suitable breakdown voltage(Dielectric strength). The testing is done at some atmosphereic condition.The experimental setup is shown in figure 5.1. It is a 100kV source with 1A leakage current and 60percent relative humidity and at the temperature 28^0C.

Following materials are used during the testing:

1. Glass mica tape
2. Glass mica epoxy tape
3. Glass resin tape
4. Self amalagam tape

Materials like glass mica tape and glass mica epoxy tape has been cured for some hour at particular temperature and pressure. The cured material then gives the suitable performance. The material is been cured in the oven shown in the figure 5.2. The temperature range of ths oven is from -180^0C to $+180^0C$.

The first material is glass mica epoxy tape. The material is first wrapped on the aluminium conductor with 50 over lapping and then placed between two wooden plates then pressed is applied on wooden plates by wrapping the pink tapes so that pressure is maintain during

Figure 5.1: Experimental test setup

Figure 5.2: Oven used for curing material

Figure 5.3: Glass mica epoxy tape model

the curing the material when placed in oven. The material is cured for 5hours at 160 ^0C temperatue and after curing the material becomes hard and gives the best performance. It's thermal class F insulation(155^0C). The material is wrapped on the aluminium conductor with 50 percent overlapping as shown in figure 5.3.After material is cured, it is tested for voltage withstand test.It's dielectric strength is 55kV/mm for thickness 0.18mm. The leakage current is 0.1mA.

The second material is glass mica tape. The material is first wrapped on the aluminium conductor with 50 over lapping and then placed between two wooden plates then pressed is applied on wooden plates by wrapping the pink tapes so that pressure is maintain during the curing the material when placed in oven. This material is also to be cured for5 hours at 150^0C

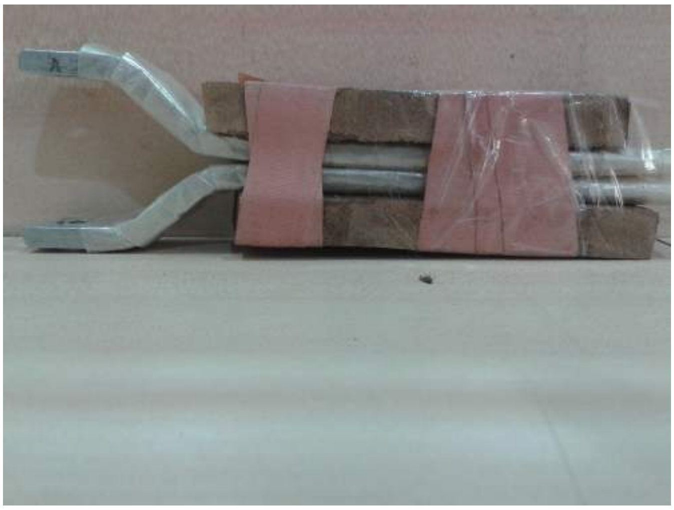


Figure 5.4: Glass mica tape model

Figure 5.5: Self amalgam tape

temperature and after curing the material becomes hard and gives the best performance. It's thermal class F insulation(150^0C). The material is wrapped on the aluminium conductor with 50 percent overlapping as shown in figure 5.4. After material is cured, it is tested for voltage withstand test. It's dielectrci strength of is 53kV/mm for thickness 0.16mm.

The third material is self amalgam tape as shown in figure 5.5. Its dilectric strength is 34kV/mm for thickness 0.80mm. While wrapping this material, the material stretch and wrapped with 50percent overlapping. It is thermal class B insulation(105^0C).

The figure 5.6 show the existing low voltage sandwich bus duct for 415volt, 800A. The insulation used is epoxy sleeve with thickness 1.6mm.

From the existing the low voltage sandwich bus duct the epoxy insulation is remove and glass mica epoxy insulation material is wrapped over the bus bar and is cured for 5 hours

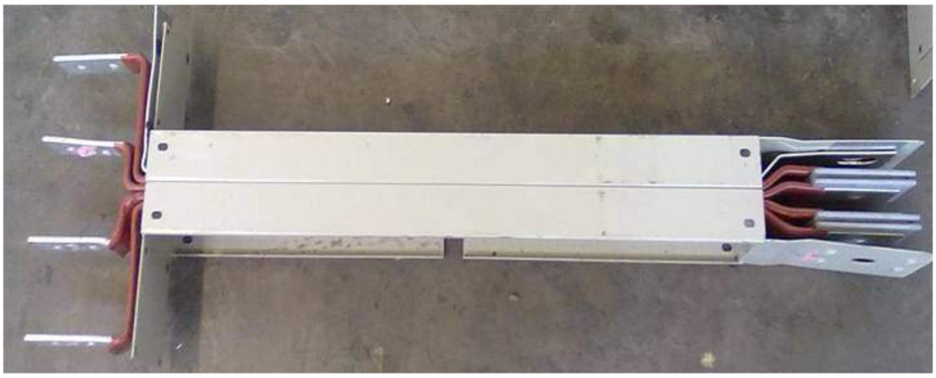
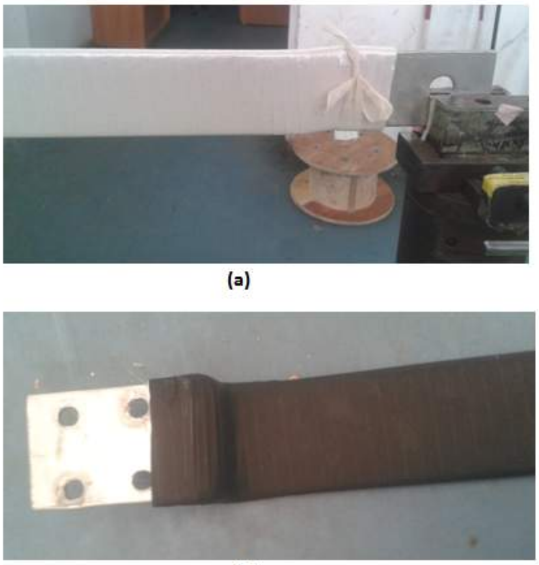


Figure 5.6: Existing Low voltage sandwich bus duct



(a)

(b)

Figure 5.7: Bus bar wrappped with (a)Glass mica epoxy tape (b) Conducting tape

at 150 ^0C as shown in figure shown in figure 5.7. Bus bar with the sharped edges the stress will be more at the sharped or(curved)edges so the chances of failure will be more from this edges. Stress control tape (i.e conducting tape) is used for the stress control and is wrapped over the insulatining material.

Bus bar wrapped with glass mica epoxy tape along with conducting tape is shown in figure 5.8. Bus bar after curing is shown in figure 5.9.

5.1 Dielectric Test

In dielectric test, the sandwich bus duct has to passed 20kV power frequency test for a one minute. It is tested at 20kV for different condition. First condition all phases are excited and

Figure 5.8: Bus bar with glass mica epoxy along with conducting tape before curing

Figure 5.9: Bus bar with insulation material after curing

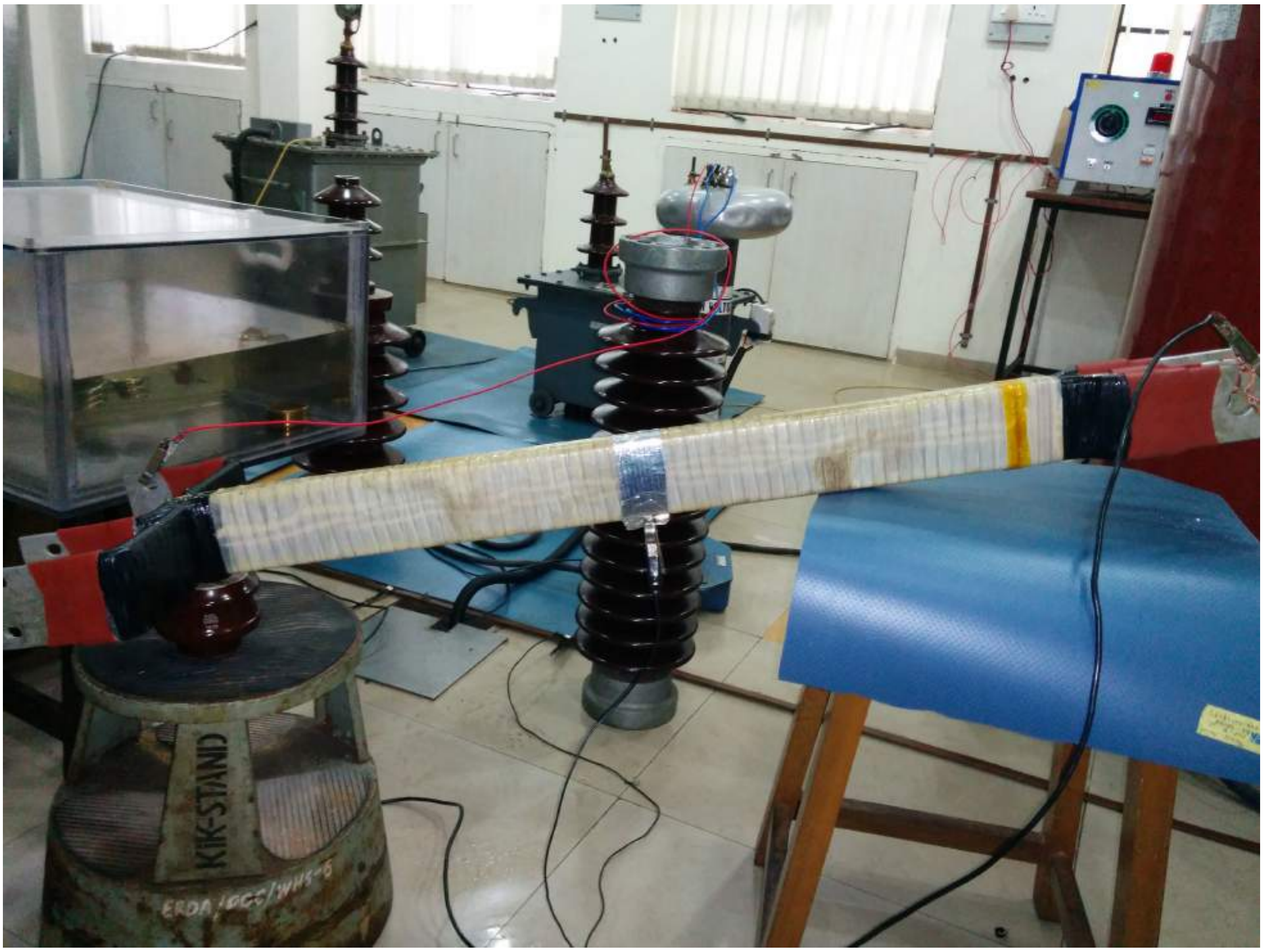


Figure 5.10: Dielectric test

enclosure is grounded and second condition each phase is excited one by one and enclosured is grounded. In this aluminium foil tape is wound on the middle of the bus bar and is grounded which act as a enclosure as shown in figure 5.10

After completing dielectric test the sandwich bus duct is tested for the temperature rise test.

5.2 Temperature Rise Test

The temperature rise test was conducted inside a closed room to avoid the undue cooling which should not affect termperature rise results. The temperature was measured with K-type thermocouple and it is placed on the bus bar and insulating material where there is more chances of hot spot. Thermocouple is connected to the data logger and measures the temperature in every half an hour. The temperature rise is carried out for the sufficent time for the temperature rise to reach a constant value and assumed steady state condition when the variation of the temperature of two succesive reading does not excced 1 $^0C/hr$. The ambient temperature during the test was measured by placing two thermocouples in two different location surrounding the assembly.For the temperature rise test bus duct has to be supported horizontally at approximately 1meter from the floor. The incoming terminals are connected with the two $240mm^2$ cable to low voltage high current source and other end terminals are short cicuited . The test is carried out for the three phase system. The test current is 800A per phase is flowing through the bus bar via cable and is monitored and recorded. Ambient temperature is always measured an recorded at particular time interval. The ambient temperature is 38.2^0C.

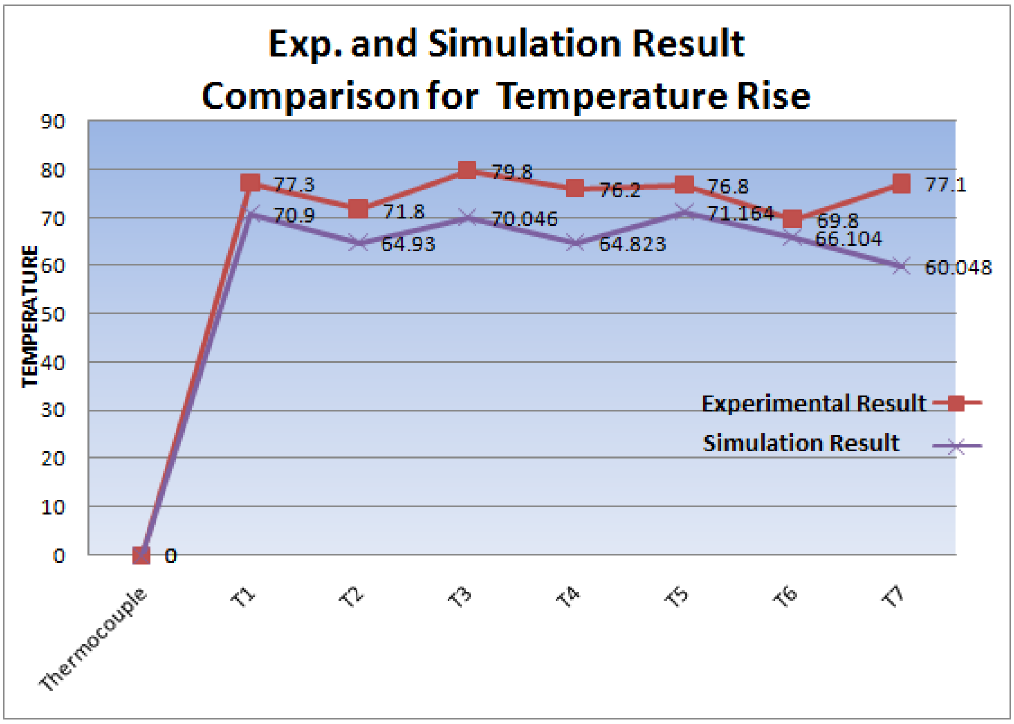


Figure 5.11: Comparison analysis between simulation and experimental result

After temperature rise test of the sandwich bus duct, temperature rise values from experiment test and simulation result of thermal analysis is shown in Table 5.1. Difference between experimental result and Simulation result is shown in Table 5.1

Figure 5.12: Temperature Rise Test

Table 5.1: Comparison of Experimental and Simulation result

Thermo-couple	Bus Bar	Experimental Value	Simulation Value	Temperature Difference
T1	R-phase conductor	77.3^0C.	70.9^0C.	6.4^0C.
T2	R-phase insulation	71.8^0C.	64.93^0C.	6.87^0C.
T3	Y-phase conductor	79.8^0C.	70.046^0C.	9.754^0C.
T4	Y-phase insulation	76.2^0C.	64.823^0C.	11.377^0C.
T5	B-phase conductor	76.8^0C.	71.164^0C.	5.636^0C.
T6	B-phase insulation	69.8^0C.	66.104^0C.	3.696^0C.
T7	Mica layer	77.1^0C.	60.048^0C.	17.05^0C.

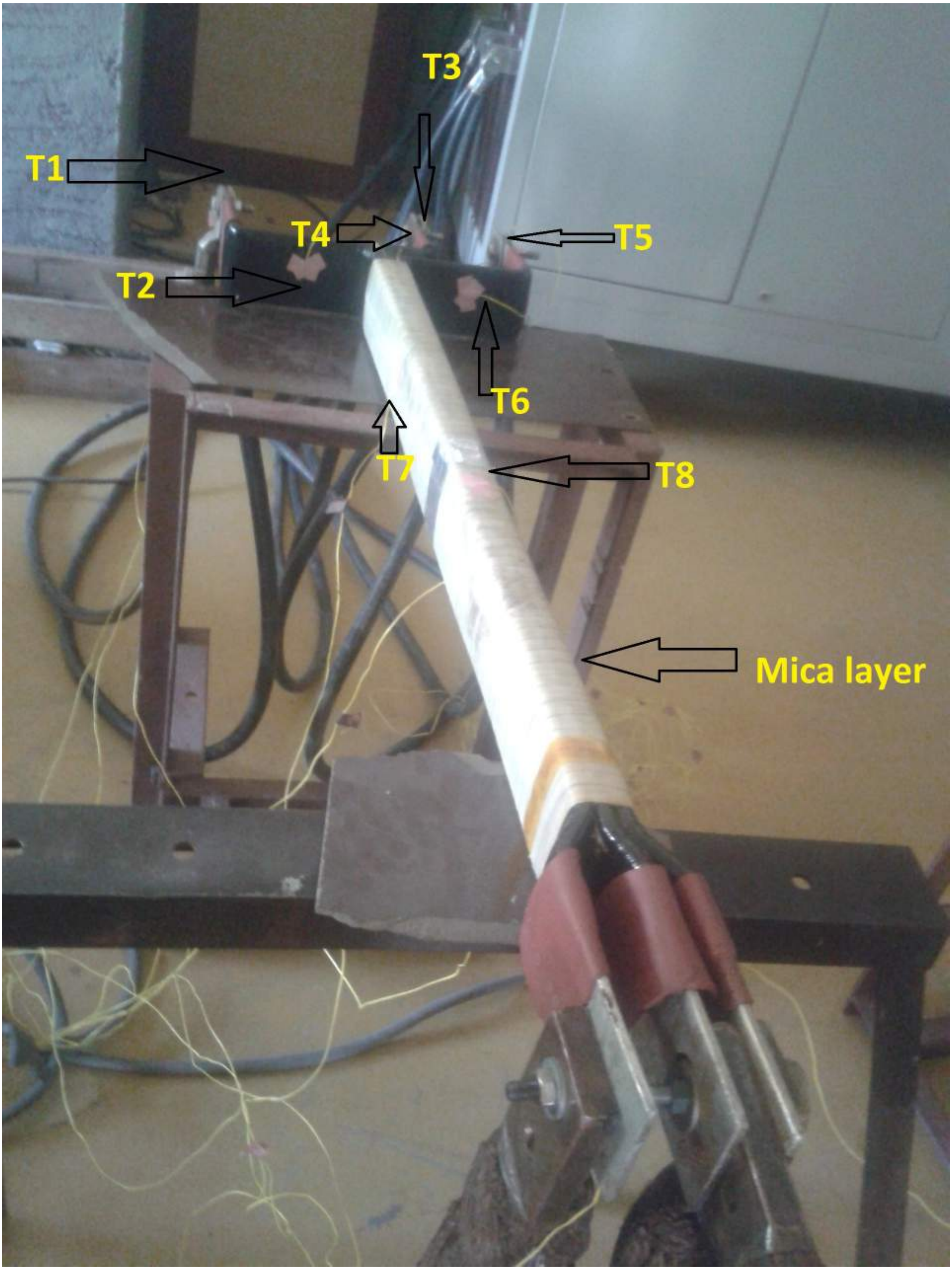


Figure 5.13: Temperature Rise Test setup

Chapter 6

Conclusion and Future work

6.1 Conclusions and current status of project work

Sandwich bus duct is normally used for the power distribution in large building which are recently available in the market with voltage rating ranging from 415V to 1000V A.C and 1500V D.C. Although IPBD and SPBD are conventionally use to transfer power in distribution system, it has been explored that sandwich bus duct system is giving better performance and compactness feature comparatively.

Specification considered for design and prototype developments of sandwich bus duct are 7.2kV, 800A (As per IS-8084). Performance improvement has been evaluated on the basis of ANSYS and ANSOFT MAXWELL simulation software and experimental testing.

From the simulation and experimental result, it has been found that for the same voltage and current rating percentage voltage drop and losses are lesser compared to conventional system as shown in table below. This results into efficient operation of the bus duct system.

Table 6.1: Comparison of Sandwich bus duct over AIPBD

Sr. No	Parameter	Sandwich Bus Duct	AIPBD
1	Flux Density	0.02T	0.009T
2	Mutual Inductance	6.243e-7H	4.8165e-7
3	Total Loss	220.71W/m	235.25W/m
4	Percentage Voltage drop	1.24%	1.535
5	Space required	1/3of AIPB	more
6	S.C withstand capacity	Large	Limited by coductor size
7	Initial cost	More	Less

For transferring same amount of power from H.T. cable, the ohmic loss are 132.48 W/m and EM losses are 66.24 W/m. Total losses are 198.72 W/m. Losses are less compared to sandwich bus duct but there are some disadvantages of cable over sandwich bus duct like S.C with stand capacity is lower, installation cost is more in cable, future expansion is limited by conductor size etc.

The inferences can be drawn from the present study:

- Losses are less in Sandwich bus duct compared to the air insulated bus duct. Voltage drop is also lower then air insulated bus duct.
- Due to improper surfaces of bus bar the surface discharge starts at 2kV and its value is 250 picocoloumb. Smooth surfaces and proper insulation wrapping techniques is required for precise designing of H.T sandwich bus duct.
- Best manufacturing technique can definitely help to construct partial discharge (PD) free H.T sandwich bus duct.

Payback period:- The payback method is a method of evaluating a project by measuring the time it will take to recover initial investment. It can be also define as the length of time required to recover the cost of an investment. The payback period of a given investment or project is an important determinant of whether to undertake the position or project, as longer payback periods are typically not desirable for investment positions. Shorter payback period are preferable to longer pay backperiod. Payback period as a tool of analysis is often used because it is easy to apply and easy to understand.

From Table 6.1, we can easily predict about the benefits of using sandwich bus duct over the air insulated bus duct with respect to losses and can calculate payback period. Let's comparinig the per meter length as a reference to calculatethe payback period based on the simulation and experimental result.
Initial cost of Sandwich bus duct(X) = Rs. 22000
Initial cost of Air insualted phase bus duct(Y)= Rs. 20000
Energy saving per day = 0.349kWh
Cost of saving over conventional air insulated phase bus duct (P) = Rs. 2.443 (1 unit kWh = Rs. 7)

So pay back period can be calculated as:-

$$Paybackperiod = \frac{X - Y}{PX365} \tag{6.1}$$

Pay back period =2.24 years

6.2 Future work

The following work is proposed in the future :

1. Suitable manufacturing techniques may be adopted for further precise designing of sandwich bus duct.
2. Different techniques are required to be explored for the insulation wrapping to control the temperature rise and partial discharge.
3. Proper Bus duct joint should be designed.
4. Appropriate changes in the present design of H.T sandwich bus duct may be carried out so that further higher current rating sandwich bus duct system can be developed.

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