



DESIGN AND ANALYSIS OF COOLING FINS FOR AN ELECTRICAL BUSBAR



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A PROJECT REPORT

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Department of Mechanical Engineering

PROJECT WORK

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This is to certify that the project entitled
**DESIGN AND ANALYSIS OF COOLING FINS
FOR AN ELECTRICAL BUSBAR**

is the bonafide record of project work done by

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ABSTRACT

In the current energy scenario, the average power consumption for any building is rapidly increasing due to usage of high power consuming equipments like air conditioners, room heaters and elevators. The transmission of power was through wires and cables all these days. But now, the wires and cables are being replaced by busbars in buildings which consume very high power. The electrical conductivity of busbars decreases if heat generated by it is not dissipated to the atmosphere. Maximum electrical conductivity is at the point when the heat generated by the busbar is equal to the heat dissipated by it. Our project is carrying out a thermal analysis on busbars using ANSYS 12.0 and to devise a method for faster heat dissipation from the busbars in order to increase its conductivity. If heat dissipation is through forced convection, the initial investment is higher due to the need for fans or blowers. Also there is additional power required for the fans. Hence, to make the mechanism economical and effective, the surface area is increased by providing fins, so that the rate of dissipation of heat is faster.

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CHAPTER 1

INTRODUCTION

CHAPTER - 1

INTRODUCTION

Electricity in general is transmitted through three types of conductors namely

- Wires
- Cables
- Busbars

WIRES

A wire is a single, cylindrical, flexible strand of metal which carry electricity. Wire is commonly produced by drawing the metal through a hole in a die or draw plate.

CABLES

A cable is most often two or more wires running side by side and bonded or twisted together to form a single assembly. Cables have higher current carrying capacity when compared to wires.

BUSBARS

Busbars are electrical conductors made of copper or aluminium and have high cross sectional areas in order to transmit such high levels of power which is not possible by using cables.

The average power consumption of all buildings is at an all time high and it is only increasing day by day. The usage of high power consuming equipments like air conditioners, room heaters and elevators has only increased the consumption of power. The power transmission all these days was through cables. But now all the cables are being replaced by bus bars. Busbars are made of solid rods or bars with larger cross sectional area to enable them to conduct high currents. Moreover, wiring of cables in such a huge space with innumerable electrical points is a very difficult task. But if bus bars are used, the installation is very easy and tap-off units can be used to draw power wherever required.

CHAPTER 2

BUSBARS

CHAPTER – 2

BUSBARS

2.1 INTRODUCTION TO BUSBARS:

A busbar in electrical power distribution refers to thick strips of copper or aluminium that conduct electricity within a switchboard, distribution board, substation, or other electrical apparatus. The size of the busbar is important in determining the maximum amount of current that can be safely carried. Busbars can have a cross-sectional area of as little as 10 mm² but electrical substations may use metal tubes of 50 mm in diameter. But the busbars become inefficient if the thickness exceeds 8 mm. So, hollow tubes are used in cases where the thickness is very high. Busbars are protected from accidental contact either by a metal enclosure or by elevation out of normal reach. Busbars are placed in metal casing with bolt-on tap-off units and fully enclosed diversions with protected contacts for maximum security. Busbars are usually of length 1.5 m or 3 m which can be cut to any length and the tap-off units can be placed at every 0.5m interval. A typical busbar system is shown below.

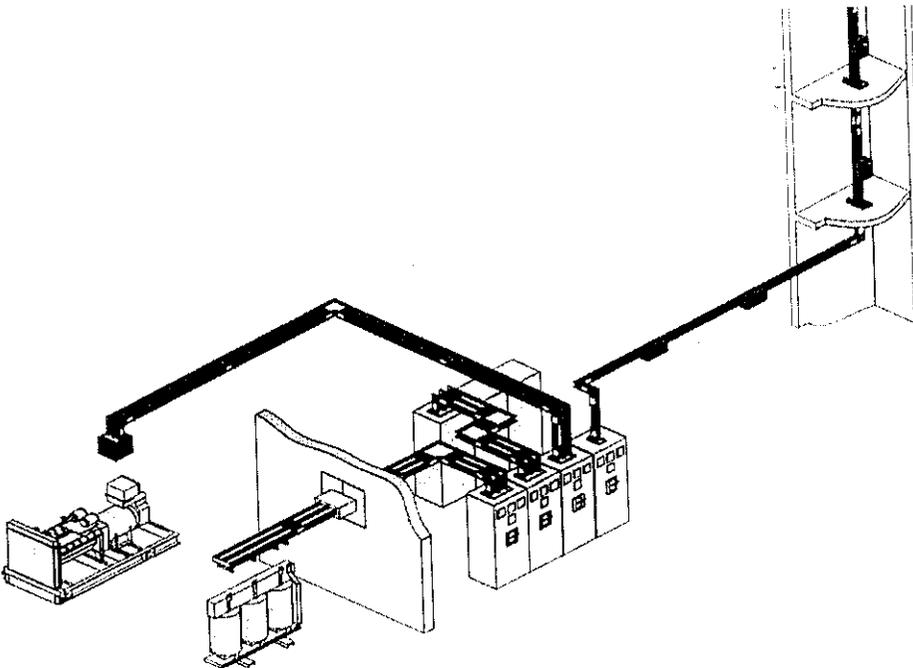


Fig 2.1 Busbar System

11	3.3 Convection	
11	3.3.1 Coefficient of heat transfer	
12	3.4 Fins	
12	3.4.1 Types of fins	
12	3.5 Heat generated in an electrical conductor	
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Current can be drawn from any point on the busbar using tap-off units. A tap-off unit along a busbar is shown below.



Fig 2.2 Busbar Showing Tap-Off Units

2.2 CLASSIFICATION OF BUSBARS:

2.2.1 Classification based on material:

- Copper busbar
- Aluminium busbar
- Aluminium-coated Copper busbar

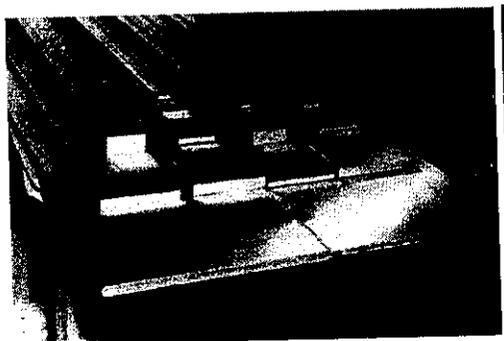


Fig 2.3 Copper Busbar

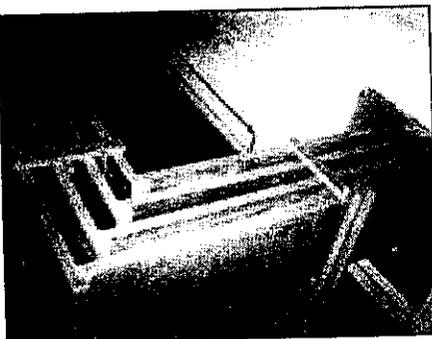


Fig 2.4 Aluminium Busbar

2.2.2 Classification based on geometry:

- Tubular busbar
- Flat busbar

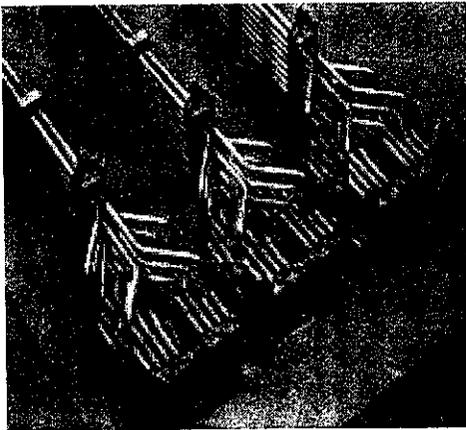


Fig 2.5 Tubular busbar



Fig. 2.6 Flat busbar

2.2.3 Classification based on type of insulation:

- Air insulated bus bars
- Sandwich type busbars

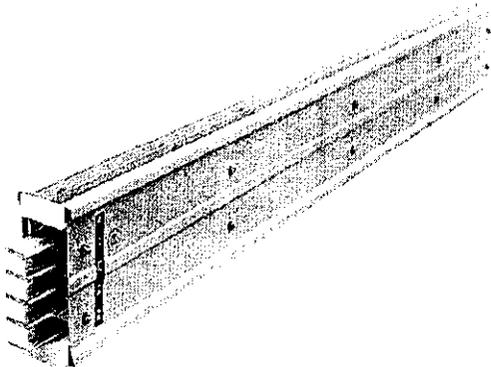


Fig. 2.7 Air insulated busbar

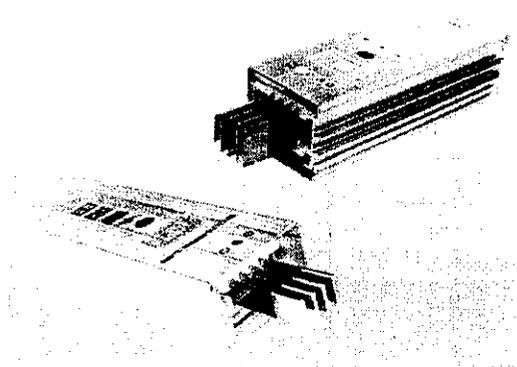


Fig. 2.8 Sandwich busbar

2.2.4 Classification based on Voltage Rating:

- Extra high voltage busbar
- High voltage busbar
- Medium voltage busbar
- Low voltage busbar

2.3 ADVANTAGES

- Improves reliability
- More compact and require very less space for the placement of switch boards
- Reduces installation time compared to cable systems which leads to saving of money and labour
- Flexibility in design , and in relation to future modifications
- Highly secure which is achieved through using of high quality materials and components
- Easy to tap-off at any section
- Provides wider variety of interconnection methods

2.4 APPLICATIONS

- High- rated electrical distribution and transmission systems
- Can be used underwater in the case of petrochemical industries
- Are mostly used in places of high voltage applications
- Laminated busbar configuration is used to distribute power in helicopter

2.5 MATERIAL SPECIFICATIONS AND DIMENSIONS:

The busbars considered in the project are made of copper. The metal casings in which the busbars are enclosed are made of aluminium. The fin material is also aluminium.

2.5.1 BUSBAR SPECIFICATIONS:

Density: 8960 kg/ m³

Thermal Conductivity: 386 W/ m-K

Specific Heat: 390 J/ kg-K

Resistivity: 1.68×10^{-8} Ω -m

2.5.2 CASING SPECIFICATIONS:

Density: 2700 kg/ m³

Thermal Conductivity: 204 W/ m-K

Specific Heat: 910 J/ kg-K

The casing and the fins are made of the same material. So, they have similar properties. The casings are hollow ducts with 1 mm thickness and the clearance between the busbars and the casing is 5 mm. The distance between each phase of the busbar is $\frac{1}{4}$ " (6.35 mm).

CHAPTER 3

HEAT TRANSFER

CHAPTER – 3

HEAT TRANSFER

3.1 DEFINITION OF HEAT TRANSFER:

The flow of heat from one body or substance to another is called heat transfer. Usually heat transfers from body at high energy(temperature) to body at low energy(temperature). There can be no heat transfer between two bodies at same energy(temperature). The temperature is the driving force for heat transfer, just as the voltage difference is the driving force for electric current flow and pressure difference is the driving force for fluid flow. There are three modes of heat transfer namely

- Conduction
- Convection
- Radiation

3.2 CONDUCTION

Conduction refers to the heat transfer that occurs across the medium. Medium can be solid or a fluid. Conduction can be imagined as a atomic or molecular activity which involves the transfer of energy from the more energetic to the less energetic particles of a substance due to interactions between the particles. The proportionality constant is a transport property known as the thermal conductivity.

3.2.1 Thermal Conductivity

The thermal conductivity of a material is the property of a materials ability to conduct heat. Heat transfer across materials of high thermal conductivity occurs at a higher rate than across materials of low thermal conductivity. Materials of low thermal conductivity are used as thermal insulation and also used as heat sink in cases of vice versa. Thermal conductivity of materials is temperature dependant.

3.3 CONVECTION

Convection refers to the heat transfer that will occur between a surface and a moving fluid when they are at different temperatures. Convection takes place when energy is transferred from a surface to a fluid flowing over it as a result of a difference between the temperatures of the surface and the fluid. Convection heat transfer mode is comprised of two mechanisms

- Energy transfer due to random molecular motion
- Energy transferred by the bulk motion of the fluid

Convection heat transfer may be classified according to the nature of the flow

- Forced convection takes place when the flow is caused by an external agent such as fan, pump or atmospheric winds.
- Natural convection takes place when the flow is induced by density differences caused by the temperature variations in the fluid.

3.3.1 Co-efficient of convective heat transfer

The heat transfer coefficient is used in calculating the heat transfer typically by convection or the phase change between a fluid and a solid:

$$h = Q / (A \cdot \Delta T)$$

where,

Q-Heat flow in input or lost(W)

h-Heat transfer coefficient(W/ m² – K)

A-Heat transfer surface area (m²)

T-difference in temperature between the solid surface and surrounding fluid area

3.4 FINS

In the study of heat transfer, a fin is a surface that extends from an object to increase the rate of heat transfer to or from the environment by increasing convection. The amount of conduction, convection or radiation of an object determines the amount of heat it transfers. Increasing the temperature difference between the object and the environment, increasing the convection heat transfer coefficient, or increasing the surface area of the object increases the heat transfer. Sometimes it is not economical or it is not economical or not feasible to change the first two options. Adding a fin to an object, however, increases the surface area and can sometimes be an economical solution to heat transfer problem.

3.4.1 Types of fins

- Triangular Fins
- Rectangular Fins
- Trapezoidal Fins
- Parabolic Fins
- Cylindrical Fins

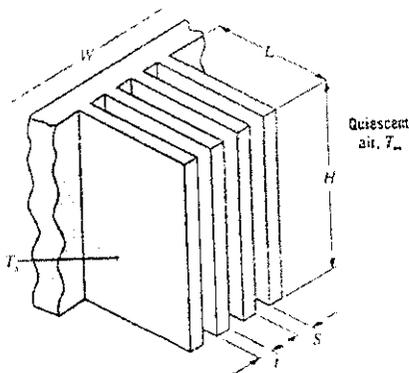


Fig. 3.1 Rectangular fin

3.5 HEAT GENERATED IN AN ELECTRICAL CONDUCTOR:

When electrical current flows through a conductor, heat is generated in the conductor. The amount of heat generated by a conductor is governed by Joule's law of heating.

3.5.1 JOULES LAW

According to Joule's law, the heat generated in a conductor is directly proportional to the square of the current flowing through it and the duration of conduction. The resistance of the conductor is the constant of proportionality.

$$Q \propto I^2 t$$

$$Q = RI^2 t$$

where

Q- Heat generated by constant current (W)

I - Constant current flowing in the conductor (A)

R- Electrical resistance of conductor (Ω)

T - Time interval (s)

CHAPTER – 4

FINITE ELEMENT

METHOD

CHAPTER – 4

FINITE ELEMENT METHOD

4.1 FINITE ELEMENT PROCESS

The different phases of finite element analysis are explained below in detail.

4.1.1 Pre- Processing:

In the pre- processing stage, the required component is modeled. The modeled component is meshed to carry out finite element analysis. Meshing is the process of dividing a component into elements, sub elements and nodes to apply boundary conditions, load conditions and constraints. Meshing makes the process simple as even complex profiles are converted into simple profiles like triangles or rectangles. The more refined the mesh, the more accurate the result is i.e., the accuracy of the result is directly proportional to the refinement of the mesh.

4.1.2 Solution:

The boundary conditions are applied to the model. Then the load conditions are applied along with other constraints to the model. The pre- processed model is analyzed and solutions are obtained using the governing equations of the specific problems. To make solving complex problems, there are many softwares available for elemental analysis which have the governing equations programmed in them. In this stage, the problem is solved and the results are solved.

4.1.3 Post- Processing:

Once the problem is solved and the results are obtained, the post processing work of plotting the results in charts or graphs is done and the result at various points in the component can be obtained by substituting the local variables in the governing equation. Most of the softwares used for post- processing are used only to indicate the maximum and minimum values of the resultant variable. The different ranges of values are represented in different colours or in different shades of grey in case of black and white images in the software.

4.2 THERMAL MODULE IN ANSYS

The software used for this project is ANSYS 12.0. The 'Steady State Thermal' module was used to carry out the analysis. The various steps involved in carrying out the analysis are explained below.

Step 1: Open ANSYS 12.0 Workbench and double click on 'Steady State Thermal' on the left pane of the window. The Project Schematic window appears on the right pane of the window.

Step 2: Right click on 'Geometry' and click Import Geometry → Browse. Then select the file which contains the model of the component and click OK.

Step 3: Double click on engineering data and enter all the material properties by selecting each property from the left pane of the window and click OK.

Step 4: Right click on Setup and click Edit. The Mechanical system window opens with the model which has been imported.

Step 5: Select Mesh from the menu. Select Mesh Control → Sizing. Change the Relevance from 'Coarse' to 'Fine.' Click Mesh → Generate Mesh. The meshed model is visible on the right pane of the window.

A sample meshed model is shown below.

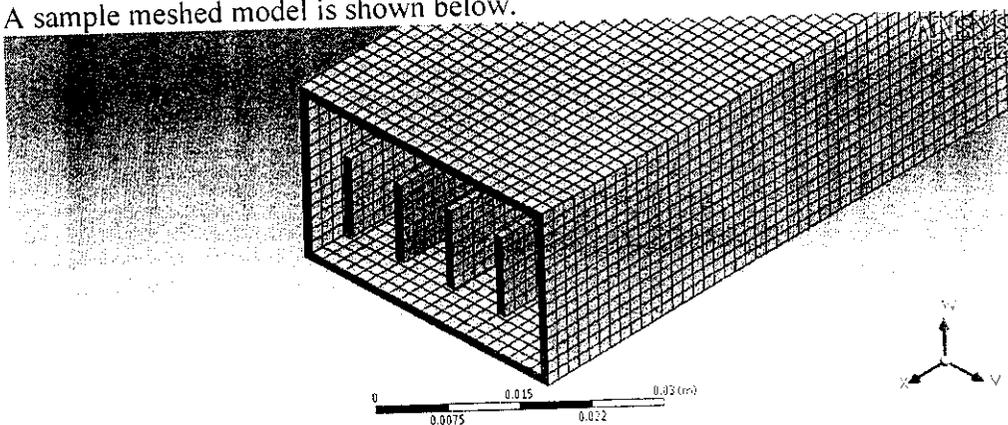


Fig. 4.1 Sample meshing in ANSYS 12.0

Step 6: Select Analysis Settings. Select Heat → Heat Generation. Select the volumes in which heat is generated and enter the value of the heat generated per unit volume and click Apply.

Step 7: Select Convection and then select all the areas through which convection occurs. Enter the heat transfer co-efficient(Film co-efficient) and the ambient temperature. Click Apply.

Step 8: Select Solution. Right click on it and select Insert → Temperature. Right click again on Solution and select Insert → Total Heat Flux.

Step 9: Right click on Temperature on the left pane and click 'Solve.' The temperature at various points in the component will be indicated with various colour codes.

Step 10: To know the heat flux at various points, click Total Heat Flux. The results will be directly shown as the problem is already solved.

Step 11: The results can be stored as a project and also as a picture(.jpg) file by clicking the 'Image to file' option in the solution window.

CHAPTER - 5
DESIGN CALCULATIONS

CHAPTER – 5

DESIGN CALCULATIONS

5.1 DESIGN ACCORDING TO THE STANDARD BUS BAR DIMENSIONS:

1) Cross-sectional area of the busbar:

$$A = 400 \times 0.785 \times 1 \times 1.05 \times 10^{-6} \times 25.4^2$$

For a conductor carrying 50 A,

$$A = 400 \times 0.785 \times 50 \times 1.05 \times 10^{-6} \times 25.4^2$$

$$A = 10.323 \text{ mm}^2$$

Similarly for conductor carrying 100 A,

$$A = 21.271 \text{ mm}^2$$

2) Dimensions of the busbar:

Standard thickness of busbars available:

0.508 mm, 1.016 mm, 1.574 mm, 2.362 mm, 3.175 mm, 4.75 mm

Area = thickness x width

$$\rightarrow \text{Width} = \text{area} / \text{thickness}$$

$$= 10.323 / 1.016$$

$$\text{Width} = 10.16 \text{ mm}$$

For the cross sectional area calculated, the possible dimensions of the busbar for:

50 A and 100 A are as follows.

Table 5.1 Dimensions of a busbar

Thickness	Width	
	50 A	100 A
0.508 mm	20.321 mm	41.872 mm
1.016 mm	10.160 mm	20.936 mm
1.574 mm	6.558 mm	13.513 mm
2.362 mm	4.370 mm	9.005 mm
3.175 mm	3.251 mm	6.700 mm
4.75 mm	2.173 mm	4.478 mm

3) Resistance of conductor:

$$R = \rho l / A$$

$$= 1.68 \times 10^{-8} \times 3 / (10.323 \times 10^{-6})$$

$$R = 4.882 \times 10^{-3} \Omega$$

4) Heat generated in the conductor:

$$Q = I^2 R$$

$$= 50^2 \times 4.882 \times 10^{-3}$$

$$Q = 12.23 \text{ W}$$

5) Heat generated per unit volume:

$$q = Q / V$$

$$= 12.23 / (10.323 \times 10^{-6} \times 3)$$

$$q = 3.958 \times 10^5 \text{ W/m}^3$$

Table 5.2 Heat transfer parameters of a busbar

Current (A)	C/S Area (mm ²)	Resistance (x 10 ⁻³ Ω)	Heat generated per bar (W)	Heat generated per unit volume (W/ m ³)
50	10.323	4.822	12.23	3.958 x 10 ⁵
100	21.271	2.369	23.69	3.713 x 10 ⁵

6) Temperature of busbar:

$$\begin{aligned}T_w &= T_{\infty} + qL/h \\ &= 22 + [(3.958 \times 10^5 \times 0.51 \times 10^{-3})/5] \\ T_w &= 62 \text{ }^\circ\text{C}\end{aligned}$$

7) Heat flux at the walls of busbar:

$$\begin{aligned}\text{Heat flux} &= q \times L = 3.958 \times 10^5 \times 0.51 \times 10^{-3} \\ \text{Heat flux} &= 210.22 \text{ W/ m}^2\end{aligned}$$

5.2 DESIGN OF FINS

The base temperature of the fin is equal to the temperature of the casing as the fins are placed on the casing.

$$\text{Heat dissipated per fin, } Q = (T_b - T_{\infty})(hPkA)^{0.5} \tanh(mL)$$

1) Fins on the sides of the casing for 50 A

Fin dimension: 20 mm x 1 mm (cross section)

$$\begin{aligned}m &= (hP/kA)^{0.5} \\ &= (5 \times 42 \times 0.001 / 204 \times 20 \times 10^{-6})^{0.5} \\ m &= 7.425\end{aligned}$$

$$Q = (321 - 295) \times 0.0289 \times \tanh(7.425 \times 20 \times 10^{-3})$$

$$Q = 0.112 \text{ W}$$

$$\begin{aligned}\text{Number of fins} &= \text{Total heat to be dissipated} / \text{Heat dissipated per fin} \\ &= 36.69 / 0.112 \\ &= 321 \text{ fins}\end{aligned}$$

Total length = 3000 mm.

Therefore, spacing between fins = 9.4 mm = 10 mm (approx.)

2) Fins on the top on bottom surfaces of the casing for 50 A

Fin dimensions: 25 mm x 1 mm (cross section)

$$m = (hP/kA)^{0.5}$$
$$= (5 \times 52 \times 0.001 / 204 \times 25 \times 10^{-6})^{0.5}$$

$$m = 7.21$$

$$Q = (321 - 295) \times 0.0361 \times \tanh(7.21 \times 20 \times 10^{-3})$$

$$Q = 0.14 \text{ W}$$

Number of fins = Total heat to be dissipated/ Heat dissipated per fin

$$= 36.69 / 0.14$$

$$= 263 \text{ fins}$$

Total length = 3000 mm.

Therefore, spacing between fins = 11 mm

3) Fins on the sides of the casing for 100 A

Fin dimension: 20 mm x 1 mm (cross section)

$$m = (hP/kA)^{0.5}$$
$$= (5 \times 42 \times 0.001 / 204 \times 20 \times 10^{-6})^{0.5}$$

$$m = 7.425$$

$$Q = (334 - 295) \times 0.0289 \times \tanh(7.425 \times 20 \times 10^{-3})$$

$$Q = 0.162 \text{ W}$$

Number of fins = Total heat to be dissipated/ Heat dissipated per fin

$$= 71.07 / 0.162$$

$$= 432 \text{ fins}$$

Total length = 3000 mm.

Therefore, spacing between fins = 7 mm

4) Fins on the top on bottom surfaces of the casing for 100 A

Fin dimensions: 25 mm x 1 mm (cross section)

$$m = (hP/kA)^{0.5}$$

$$= (5 \times 52 \times 0.001 / 204 \times 25 \times 10^{-6})^{0.5}$$

$$m = 7.21$$

$$Q = (334 - 295) \times 0.0361 \times \tanh(7.21 \times 20 \times 10^{-3})$$

$$Q = 0.201 \text{ W}$$

Number of fins = Total heat to be dissipated/ Heat dissipated per fin

$$= 71.07 / 0.14$$

$$= 352 \text{ fins}$$

Total length = 3000 mm.

Therefore, spacing between fins = 8.6 mm = 9 mm(approx.)

CHAPTER – 6
ANALYSIS RESULTS

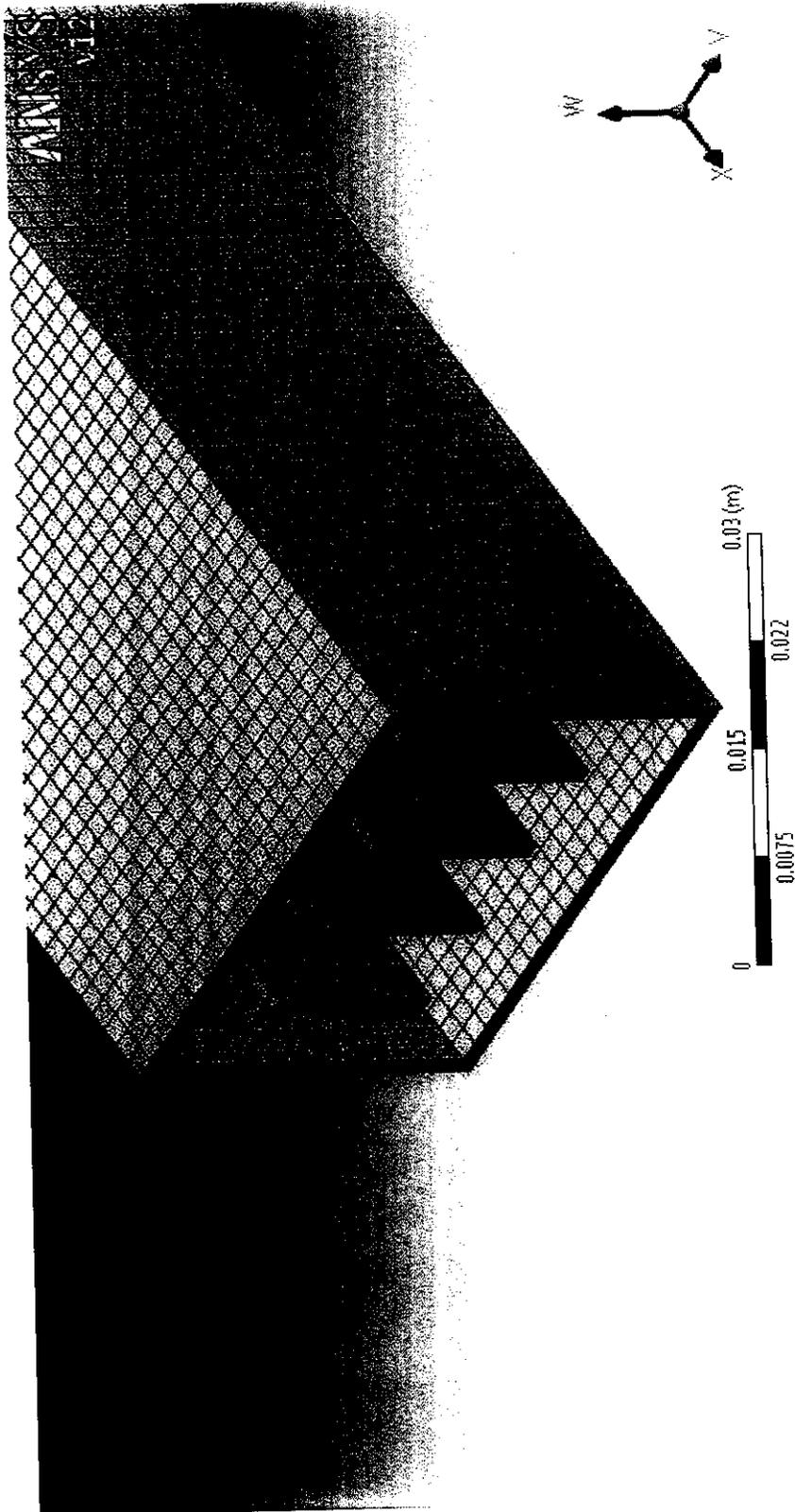


Figure 6.2 Meshed model of the busbar

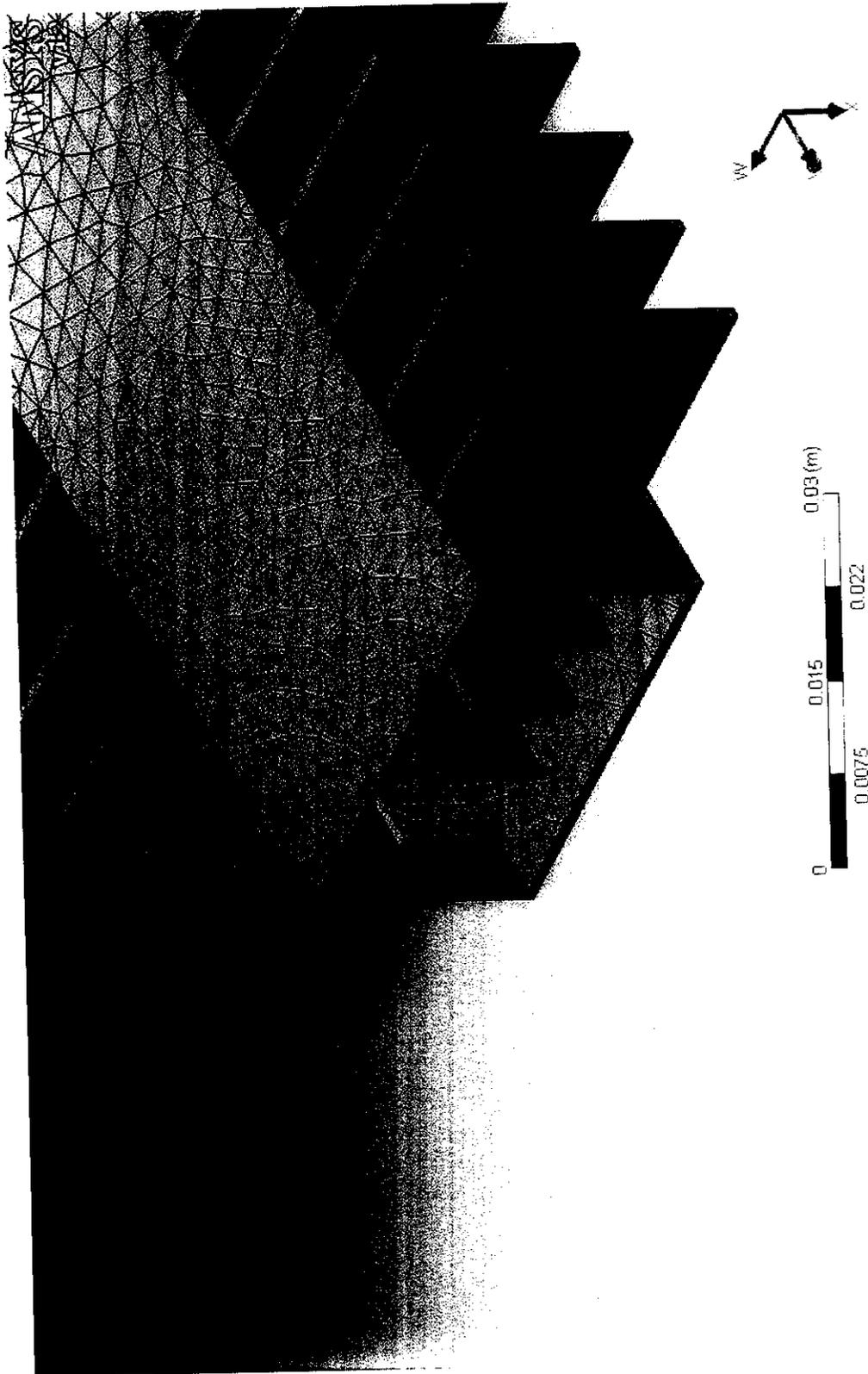


Figure 6.3 Meshed model of busbar with fins on surfaces on the sides

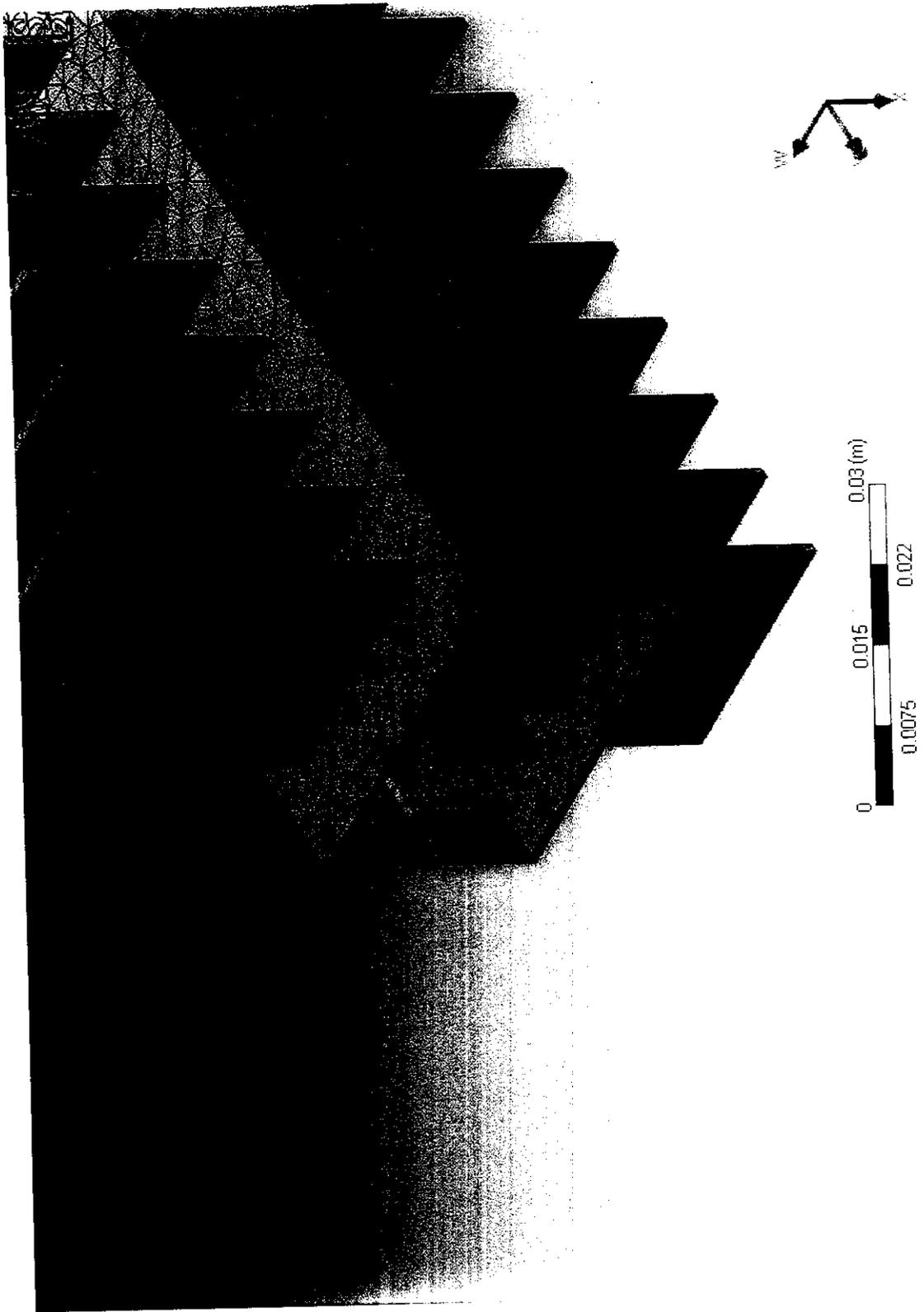


Figure 6.4 Meshed model of busbar with fins on top and bottom surfaces of the casing.

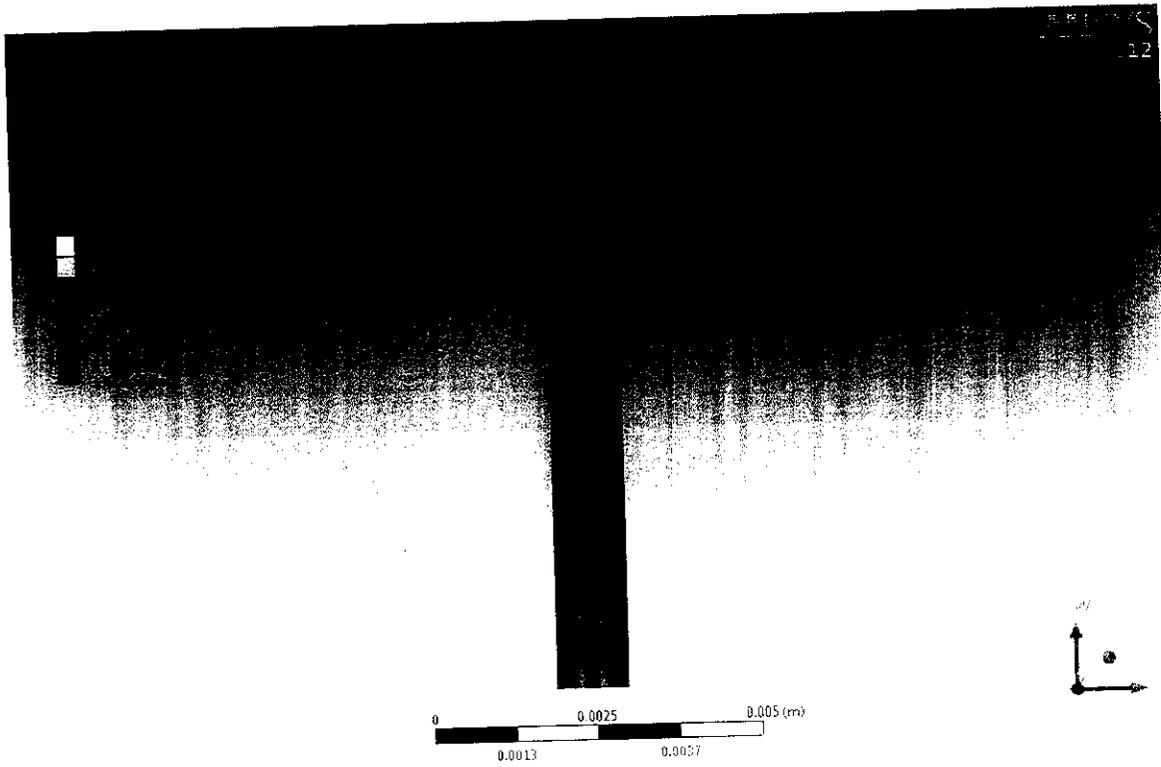
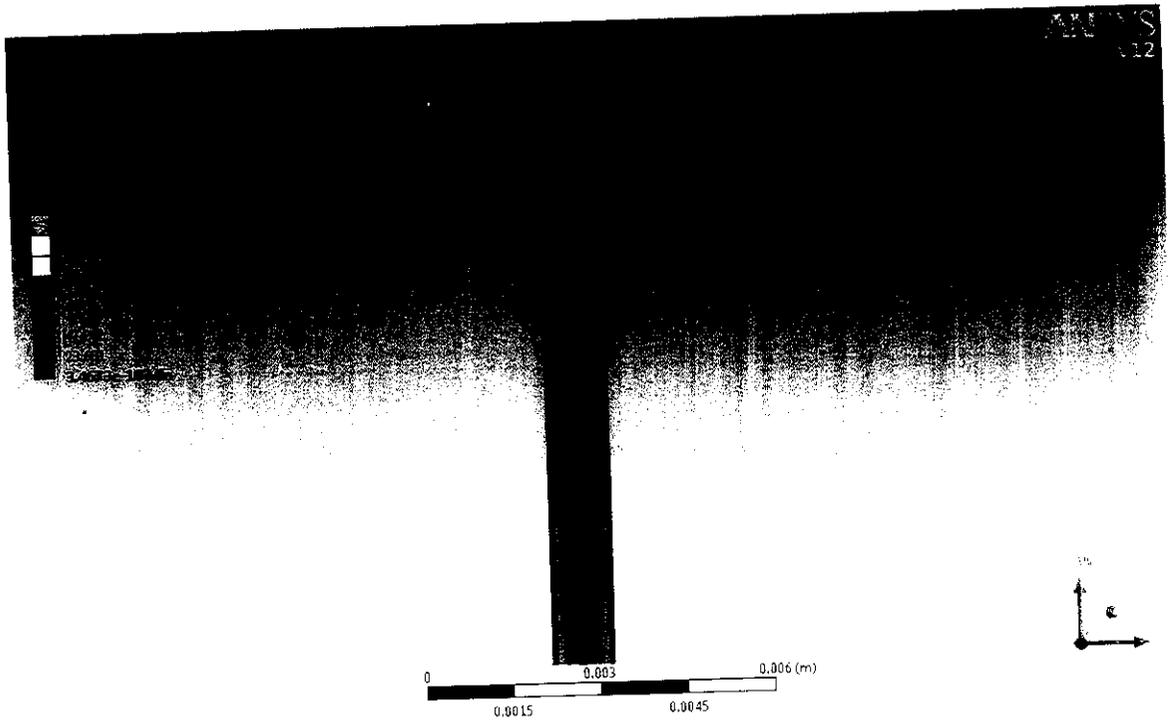


Fig. 6.5 Results showing the heat flux(top) and temperature of a busbar carrying 50 A

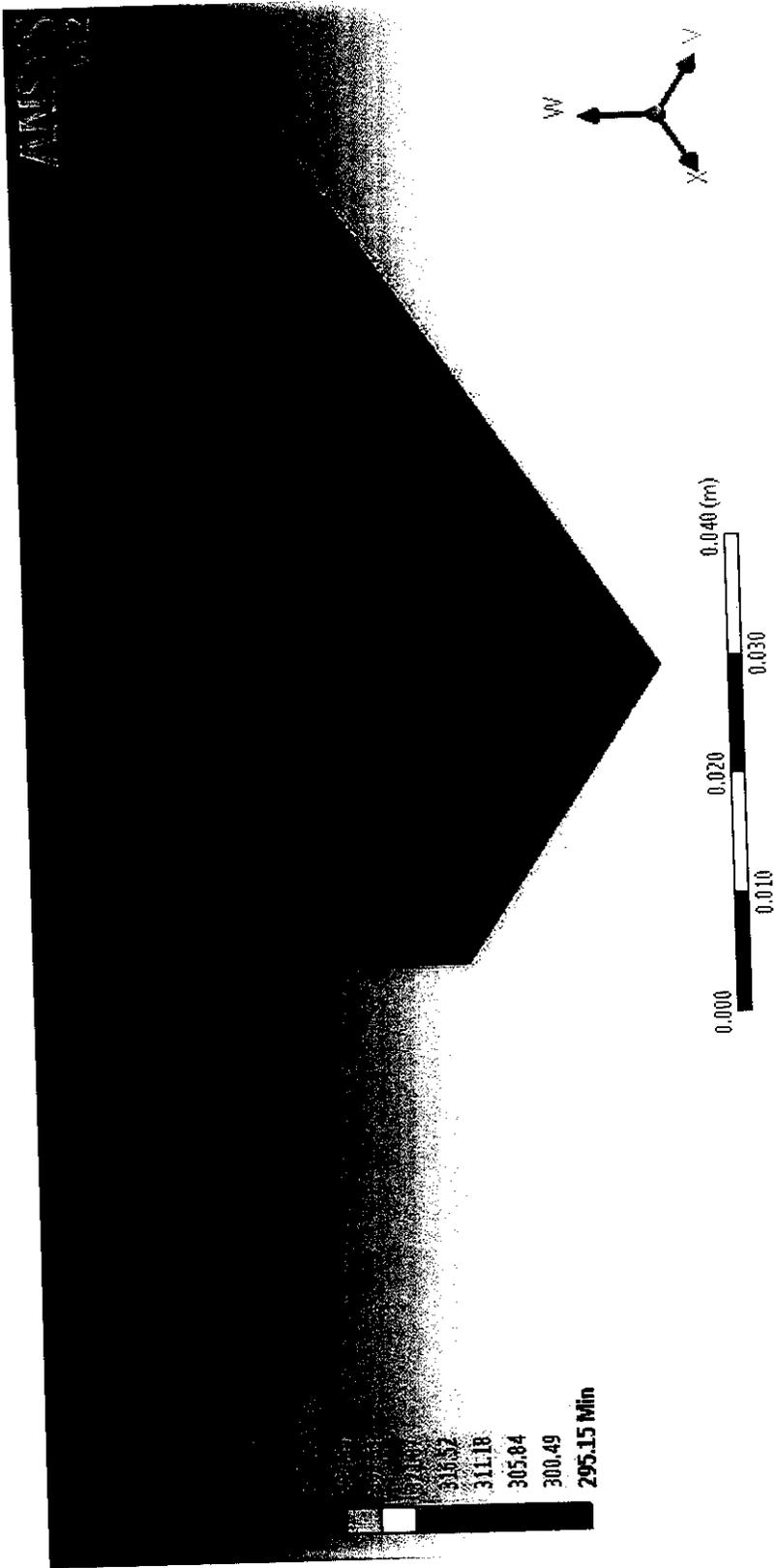


Figure 6.6 Temperature distribution on 50 A busbar placed in Al casing

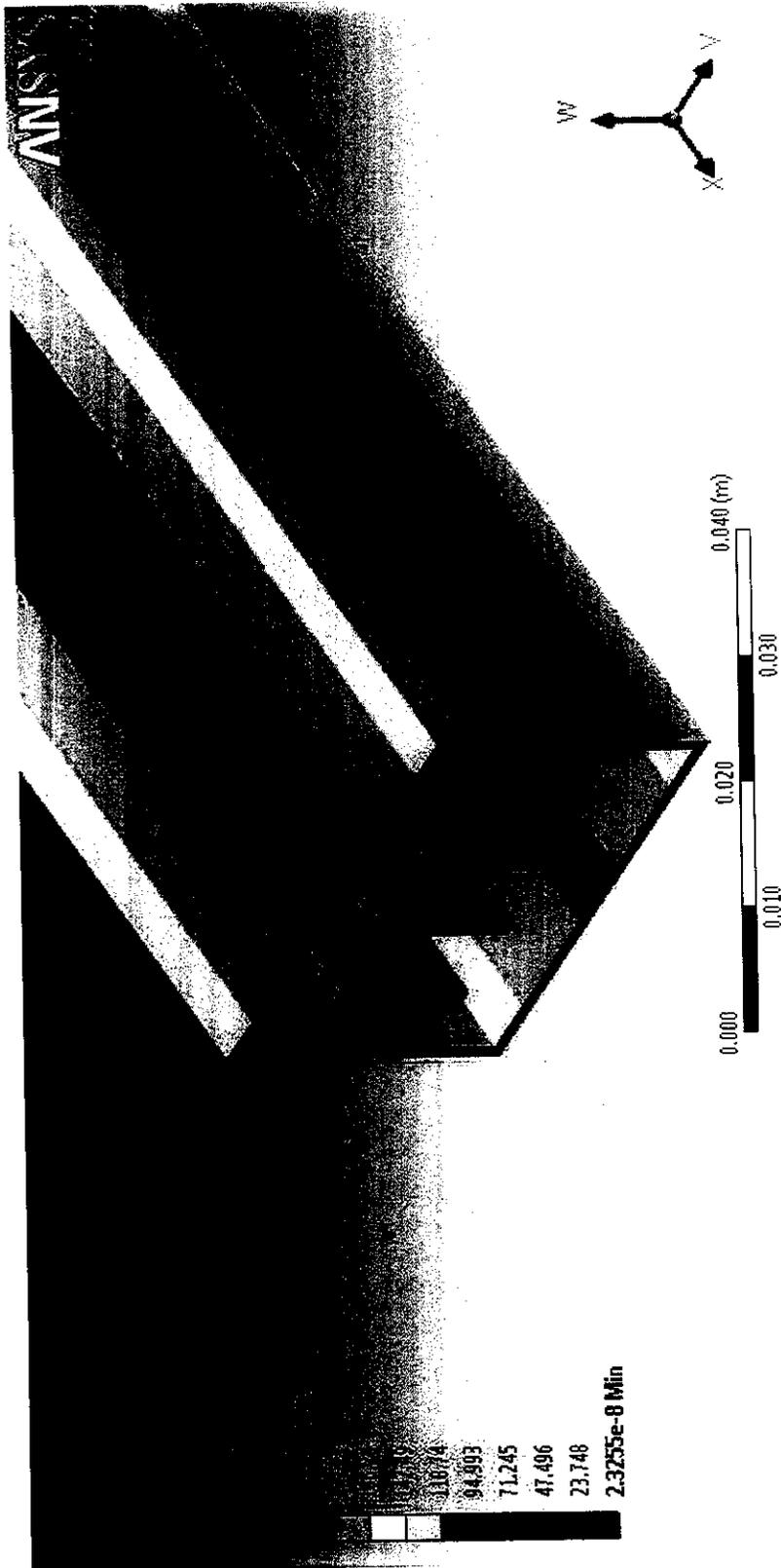


Figure 6.7 Heat flux distribution of 50 A busbar placed in Al casing

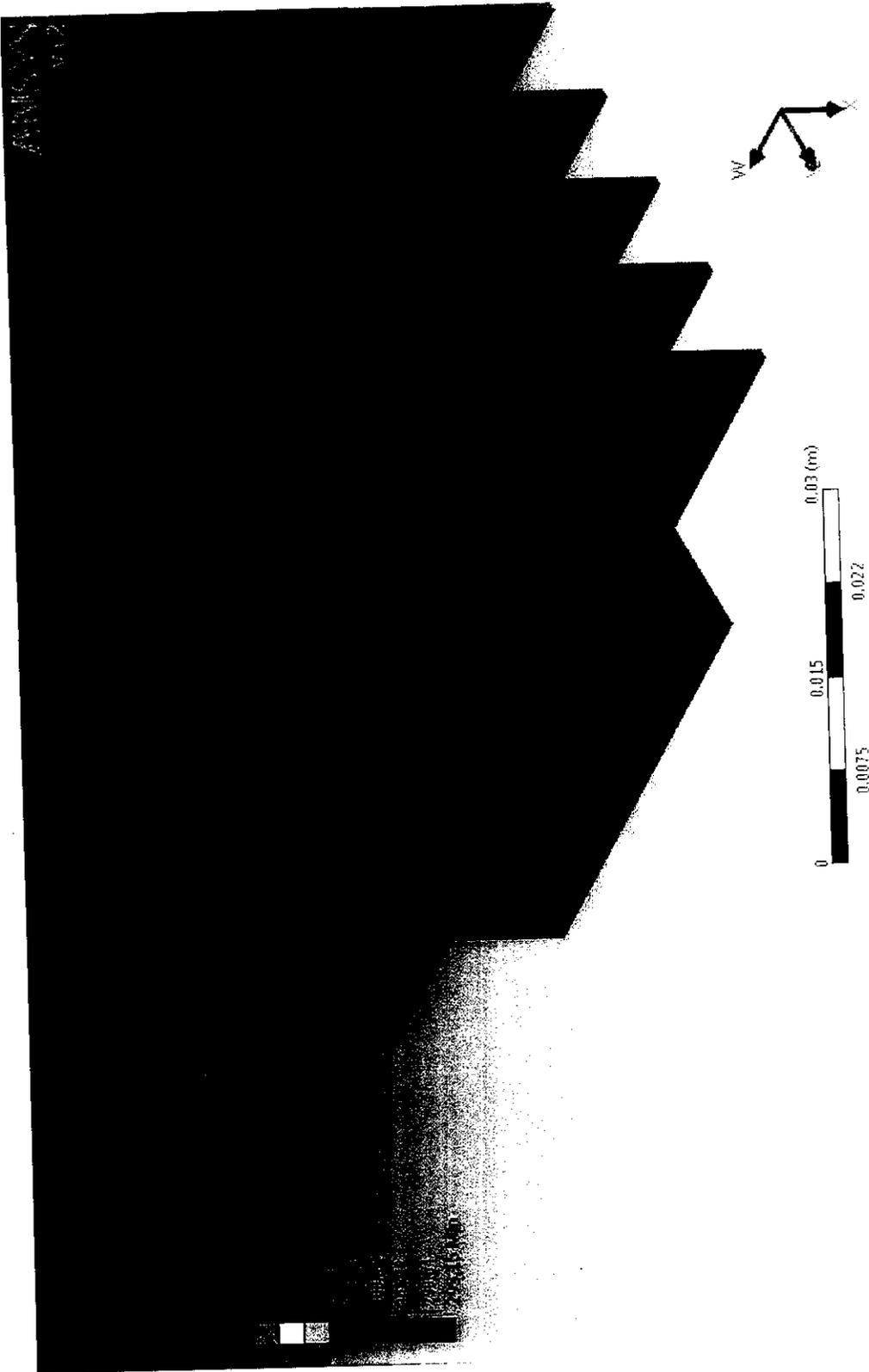


Figure 6.8 Temperature distribution on 50 A busbar with fins on the sides of casing

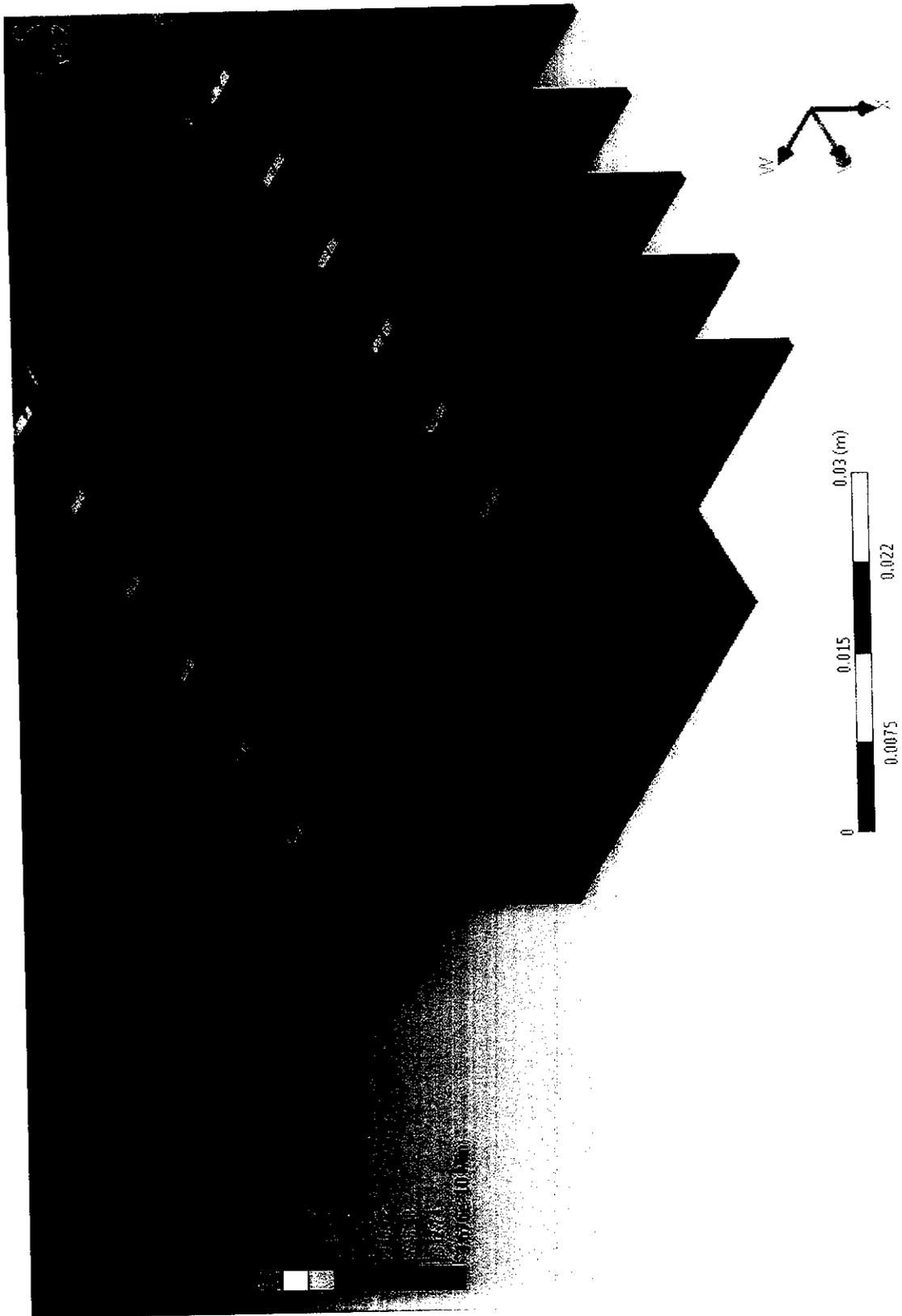


Figure 6.9 Heat flux of 50 A busbar with fins on sides of casing

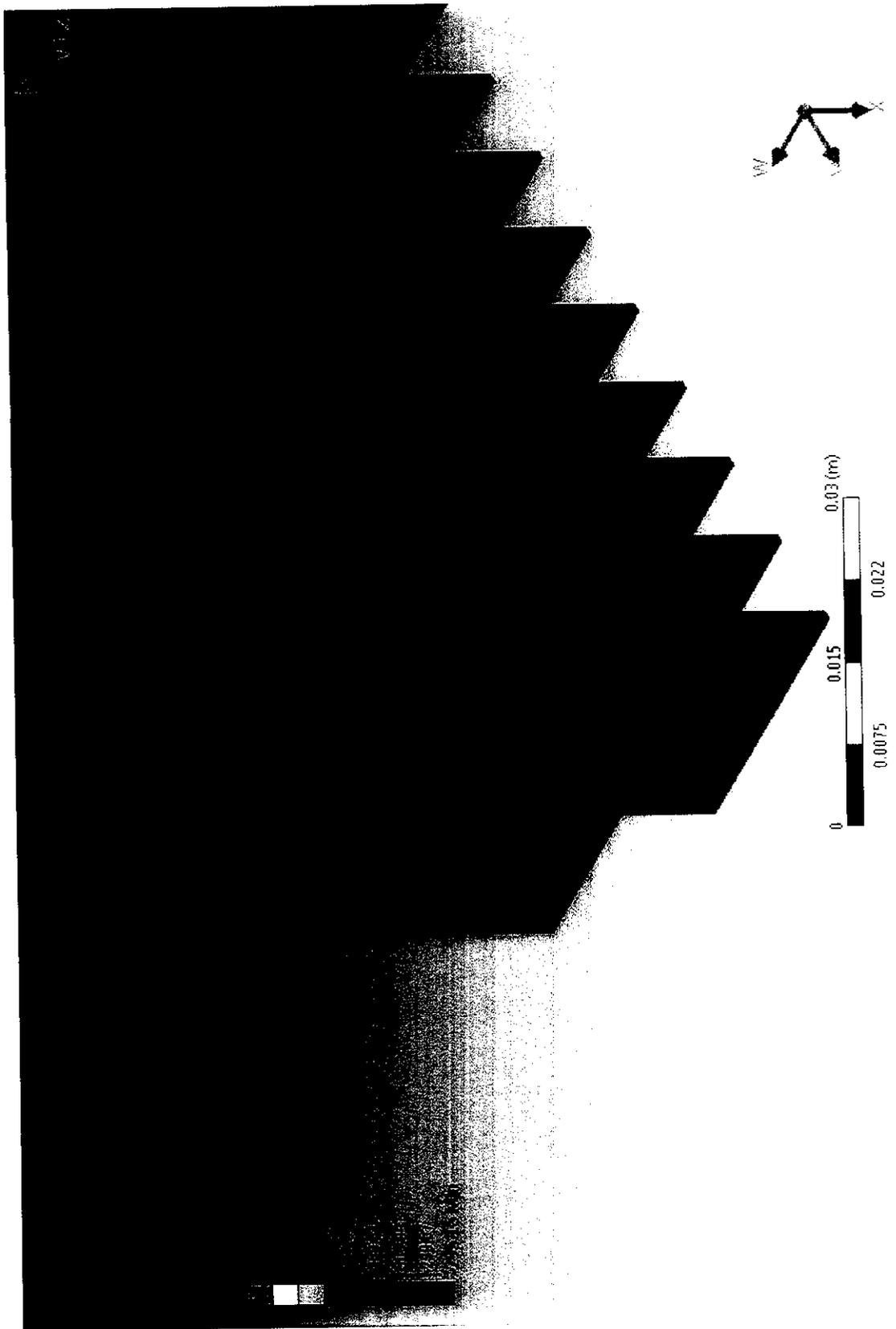


Figure 6.10 Temp. distribution for 50 A busbar with fins on top and bottom surfaces of the casing

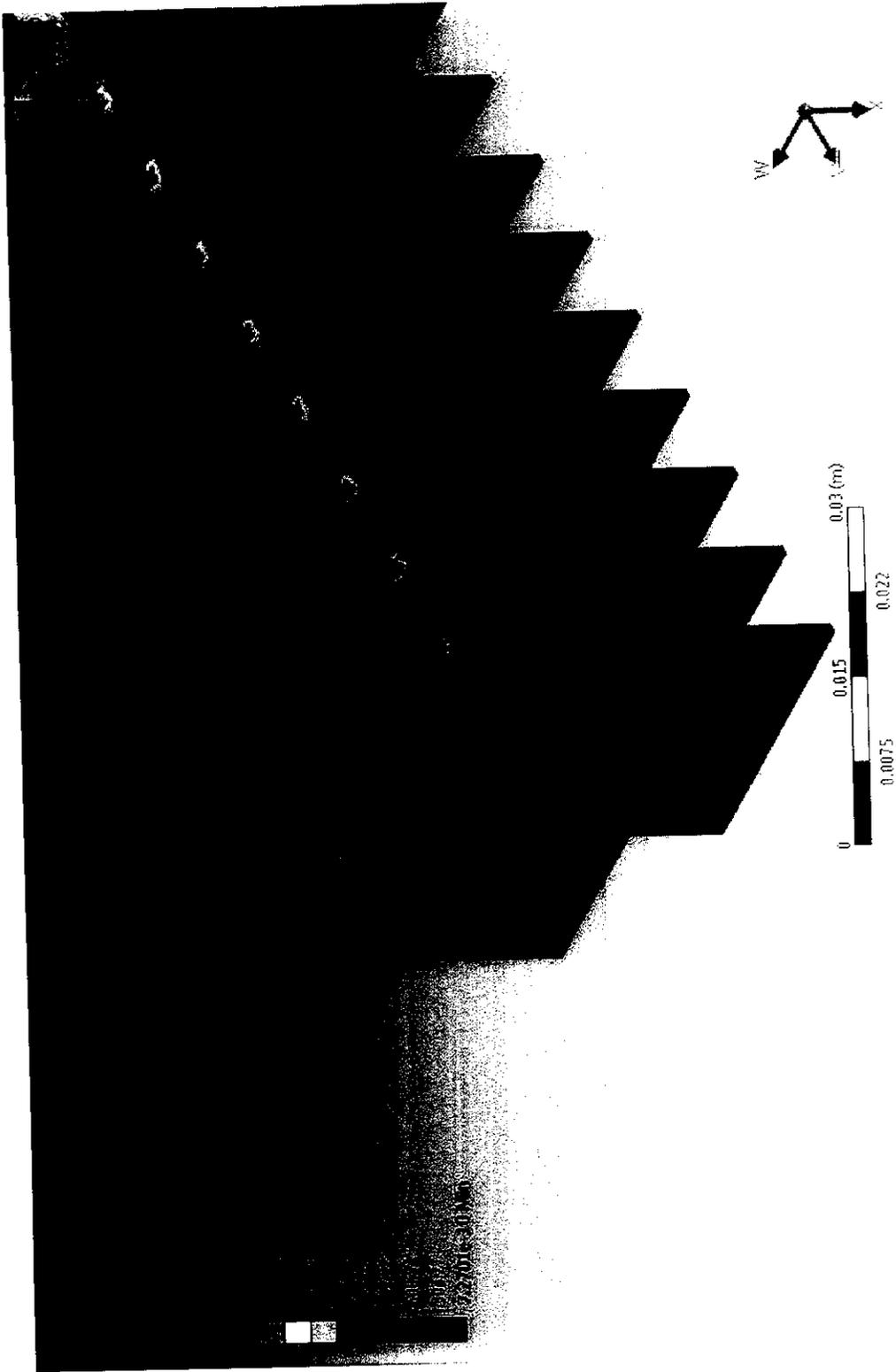


Figure 6.11 Heat flux for 50 A busbar with fins on top and bottom surfaces of the casing

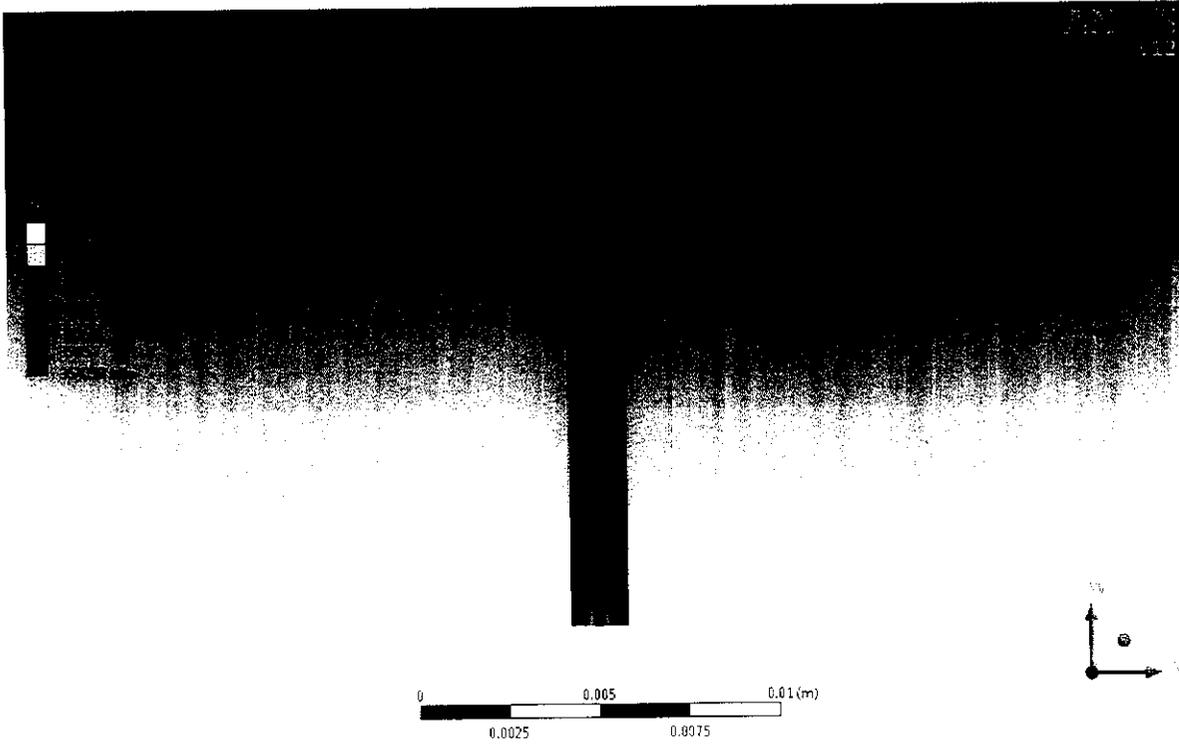
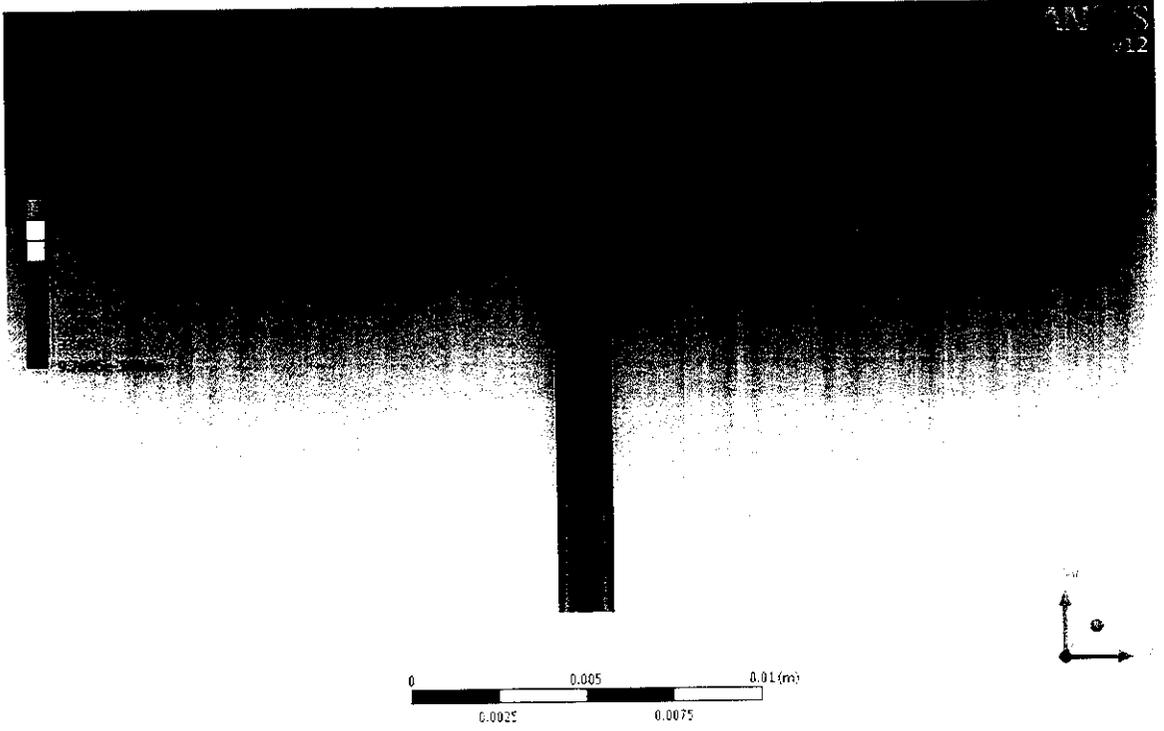


Figure 6.12 Temperature distribution(bottom) and heat flux distribution of busbar carrying 100 A

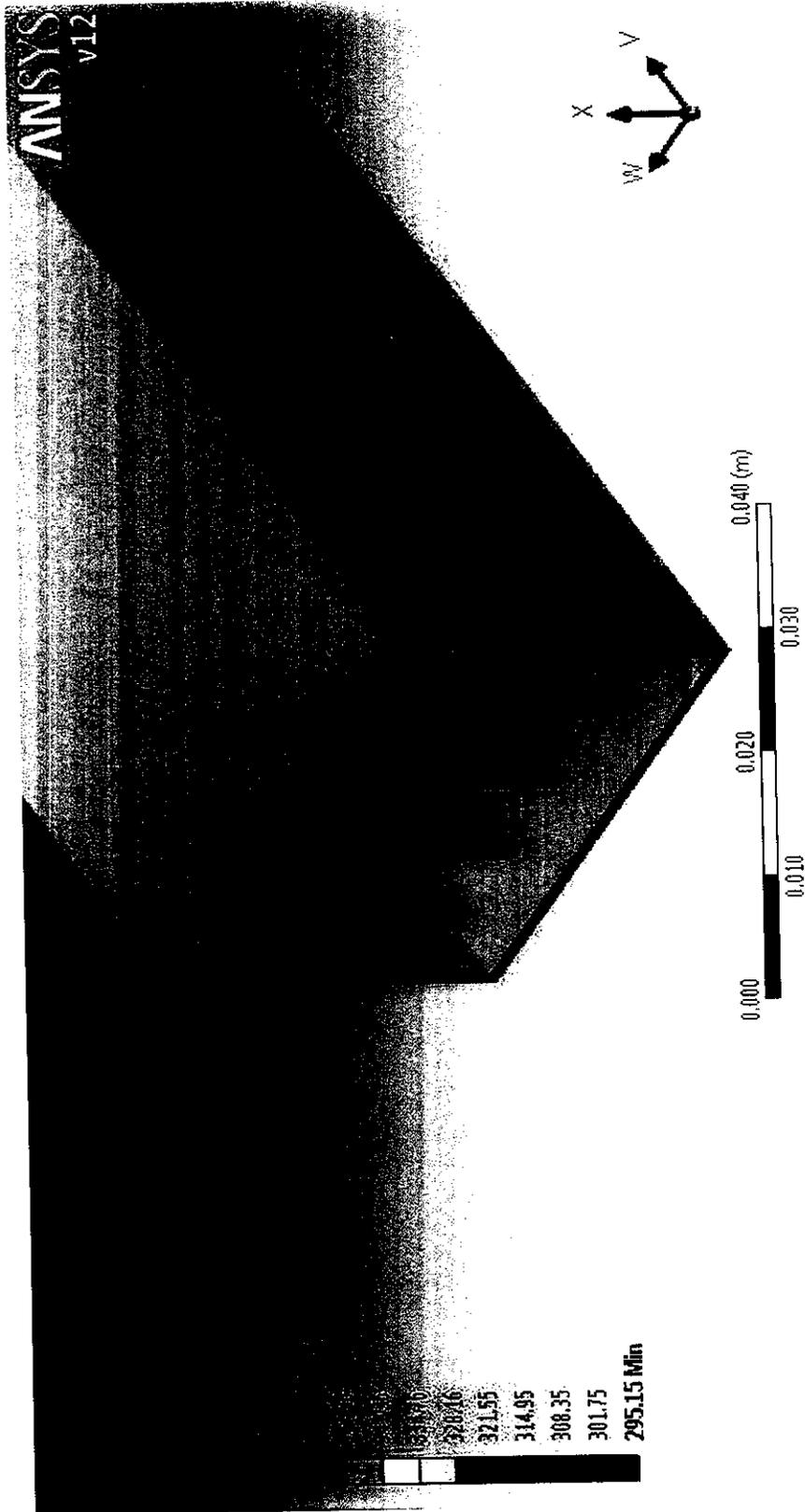


Figure 6.1.3 Temperature distribution of 100 A busbar placed in Al casing

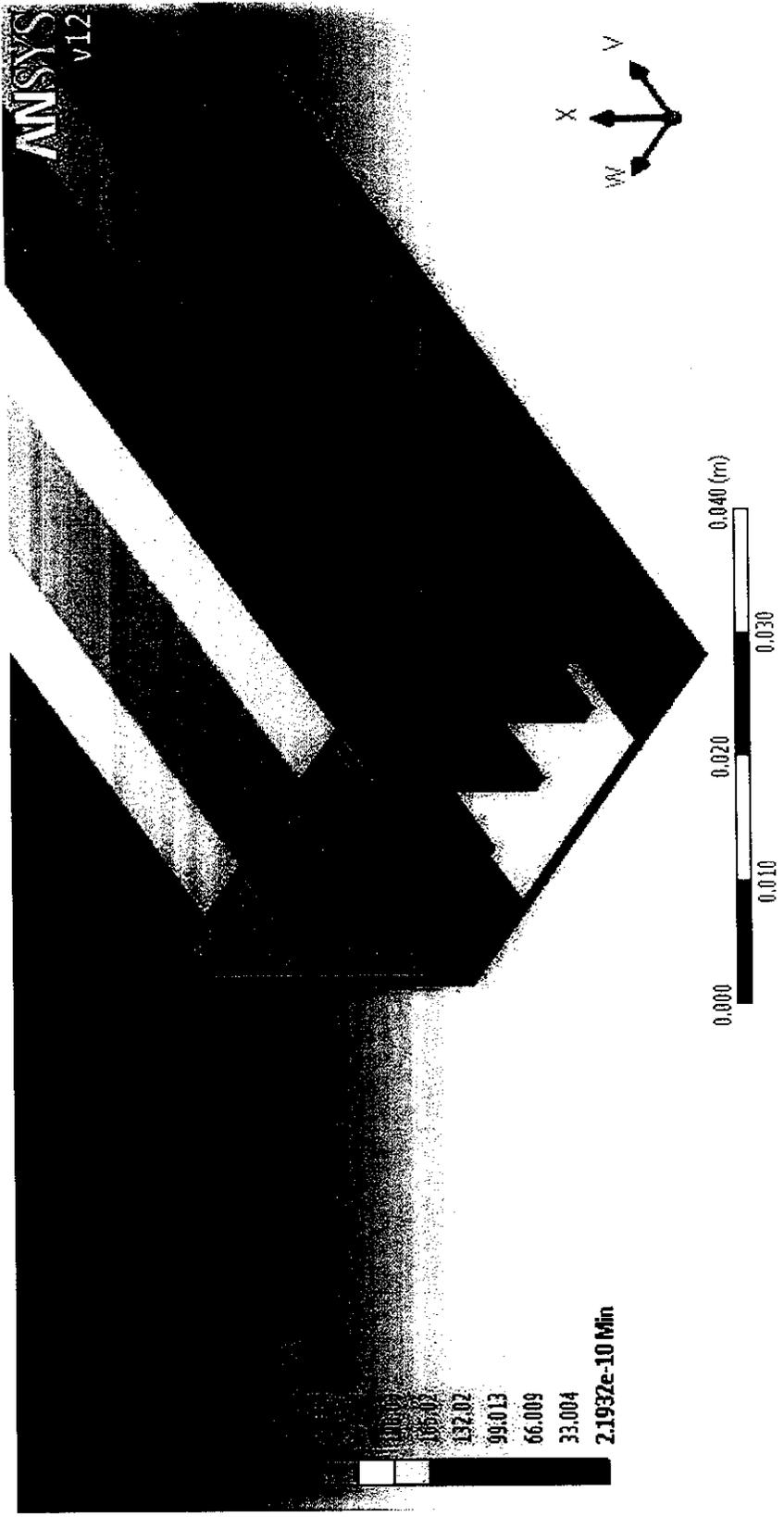


Figure 6.14 Heat flux of a busbar carrying 100 A placed in a casing.

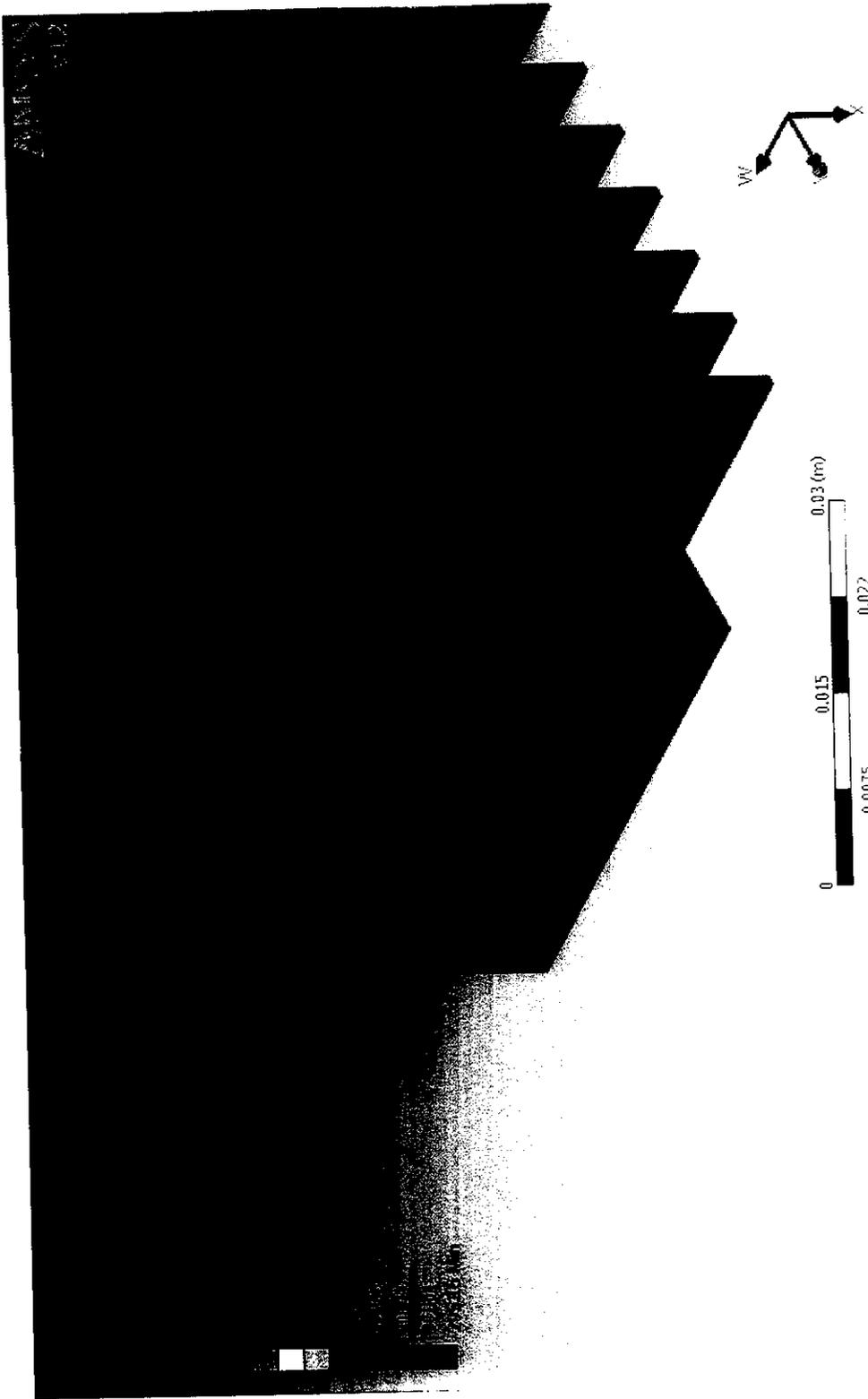


Figure 6.15 Temperature distribution on 100A busbar with fins on the sides of casing



Figure 6.16 Heat flux of 50 A busbar with fins on sides of casing

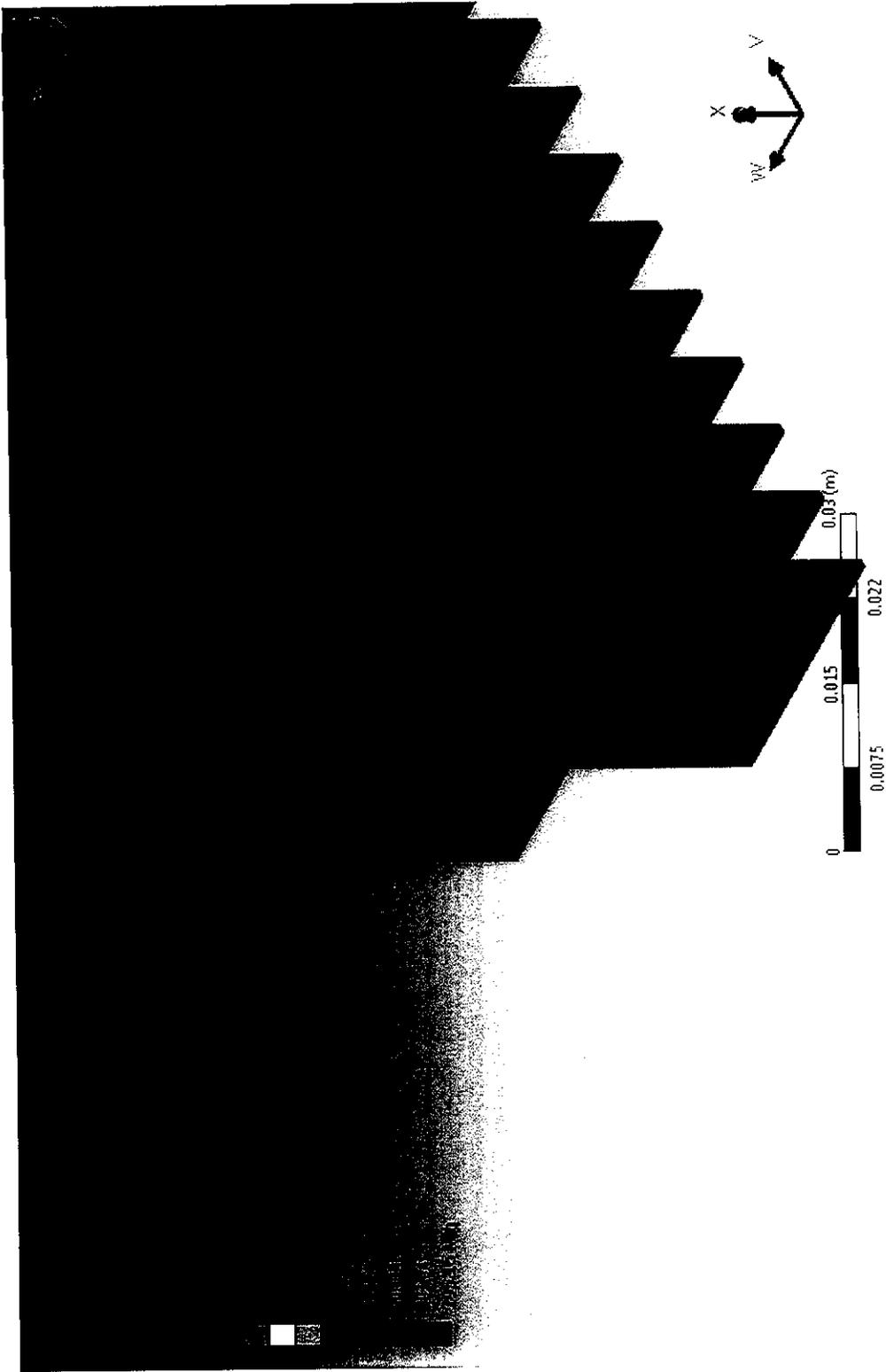


Figure 6.4/ Temp. distribution for 100 A busbar with fins on top & bottom surface of the casing

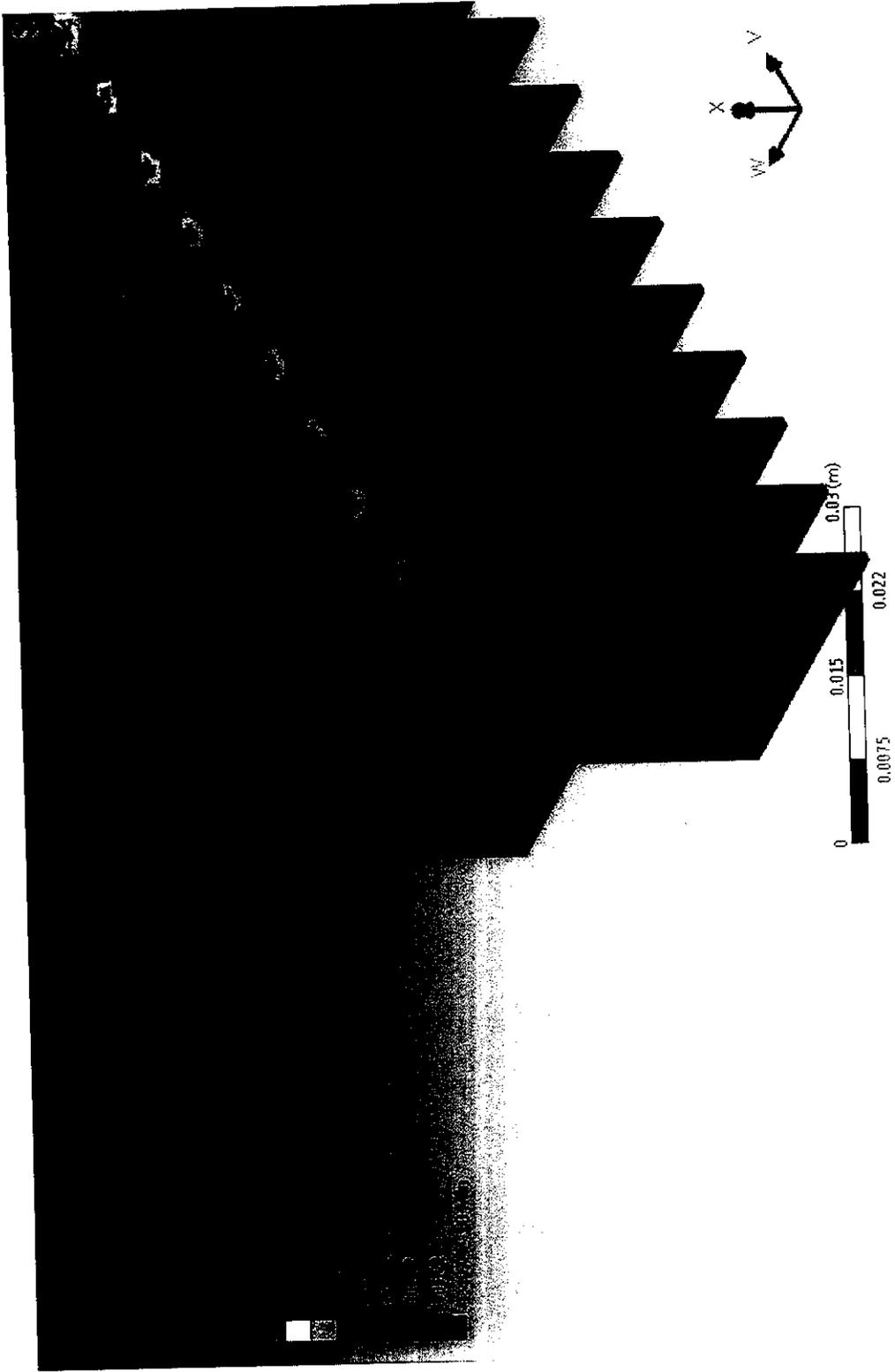


Figure 6.18 Heat flux for 100A busbar with fins on top and bottom surfaces of casing

Table 6.1 Summary of results for 50 A busbar

	Temperature of busbar (K)	Temperature of casing (K)
Without fins	337.9	321.87
With fins on sides of casing (20 mm x 1 mm – 10 mm spacing)	335.53	313.09
With fins on top and bottom surfaces of the casing (25 mm x 1 mm – 10 mm spacing)	334.93	303.99

Table 6.2 Summary of results for 100 A busbar

	Temperature of busbar (K)	Temperature of casing (K)
Without fins	354.56	334.76
With fins on sides of casing (20 mm x 1 mm – 7 mm spacing)	353.55	321.53
With fins on top and bottom surfaces of the casing (25 mm x 1 mm – 8.5 mm spacing)	353.55	308.13

CHAPTER – 7

CONCLUSION

CHAPTER – 7

CONCLUSION

Thermal analysis was carried out on the busbar placed inside a casing and the temperature distribution and heat flux were determined. Using the results of the analysis, rectangular fins were designed for two cases namely (i) fins on the vertical surfaces of the casing and (ii) fins on the horizontal surfaces of the casing. If the heat generated is not dissipated, the electrical conductivity of the busbar decreases. The busbars placed in the casing along with fins was analyzed and it was found that there was a decrease in temperature of the casing showing that heat is removed from the casing. As the heat generated is dissipated, the conductivity of the busbar is not affected. It is also found that faster dissipation of heat takes place if the fins are placed on the horizontal surfaces of the casing as the surface area is higher when placed on the horizontal surfaces.

FUTURE SCOPE OF THE PROJECT:

- Carry out analysis for sandwich-type busbar which have insulating material in between the three phases.
- Change the cross section of the fin and analyze the heat transfer through various types of fins.
- Analyze the heat transfer in L- angle connectors and T- connectors of a busbar system.
- Analyze the feasibility of forced convection for quicker heat transfer.

CHAPTER – 8

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(A value of approximately 400 circular mils per ampere is a traditional basis for design of single conductors. Since bus bars are not round, circular mils must be converted to mils squared (simply multiply the circular mils value by 0.785).
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