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Optimum configuration of busbar

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***Abstract*— Bus-bars are a vital component of electrical circuit ranging from high current to low current applications. The individual phases of busbar are found to be arranged in different configurations. They are mounted in an enclosed chamber. However the different configurations lack support in terms of standards or empirical data. As such, no particular configuration is known which is optimum or best suited. The current flowing through the busbar will lead to generation of heat due to the material resistance, which needs to be dissipated effectively. Natural convection is the only mode of heat transfer within the chamber. The inefficient heat dissipation affects the longevity of the busbar. In the present study, computational simulation of bus-bars in a closed chamber is done by using CFD tool. Comparison of the heat dissipation characteristics and temperature distribution is done for different configurations. Based upon these, the optimum configuration is identified.**

***Keywords*— Bus-bars, configuration, natural convection, CFD, heat dissipation**

I. Introduction

Bus-bars are vital component of an electrical circuit that are used for the distribution of electrical power from a supply point to numerous output circuits. Physically they are metallic strips/bars of copper or aluminium. However, numerous tapping are taken out from the bus-bars to supply it to loads of varying capacity. The current flowing through bus-bars is alternating current. The bus-bars used in large power stations or distribution systems carry high current of the order of thousands of amperes [1]. They form a part of high tension supply lines of the order of 33kV and more. As an effect of resistive heating in these high current carrying bus-bars, they lead to high temperature rise. This heat from the bus-bars needs to be dissipated to avoid thermal stresses else they reduce their service life and cause failure [2]. Keeping in view the safety factor, these high current carrying bus-bars are enclosed in a closed chamber. The bus-bars consist of individual phases viz. red, yellow, blue. A neutral phase is also provided at times. In general the number of bus-bars is 3 or 4.

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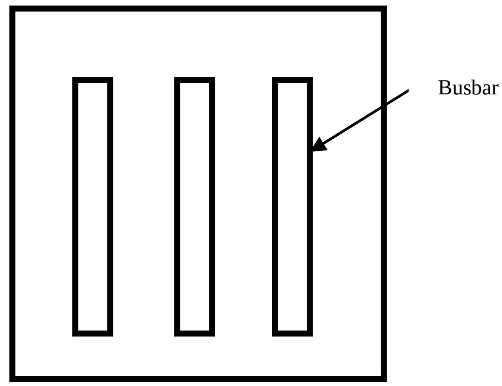

Figure 1. Schematic of busbar and chamber

However, the bus-bars may be of single run, double run, or triple run depending upon their design. The number of runs corresponds to the number of bus-bar strips per phase. The neutral phase of the bus-bar often is single run.

The individual bus-bar phases are mounted in different configurations [1]. The ease of access, the availability of space and safety, govern the mounting of bus-bars in various configurations. They could thus be mounted such a way as to have their longest dimension vertical. If the length is too large they may be mounted horizontally. In certain cases of high current carrying bus-bars, insulation is provided to electrically insulate them and also allow quick dissipation of heat. Some installations are also provided with a forced cooling arrangement.

The different configurations will certainly have different rates of heat dissipation. This study is aimed to find the optimum configuration with respect to efficient heat dissipation from the bus-bars. The configuration which leads to lesser temperatures in the bus-bar chambers would be suitable, since it will increase the service life of the bus-bars.

II. Physical Domain

The physical domain consists of bus-bars in an enclosed chamber as shown in Fig. 2. The dimension of the chamber is 500 × 350 mm, with the bus-bars dimensions as mentioned in Fig. 2. The bus-bars considered here are all of rectangular cross-section and the chamber is rectangular. The International Electrotechnical Commission (IEC) standard [3], is used to select the dimension of bus-bar and its equivalent chamber. The selected dimensions pertain to a current flow of 1000 amperes. The chamber is completed closed with no provision for forced convection. The heat that reaches the chamber wall is convected via the chamber walls to the atmosphere. Four configurations were used for comparison namely horizontal, vertical, L-shape and delta as shown in Fig 2. The 3D view of the geometry is shown in Fig 3.

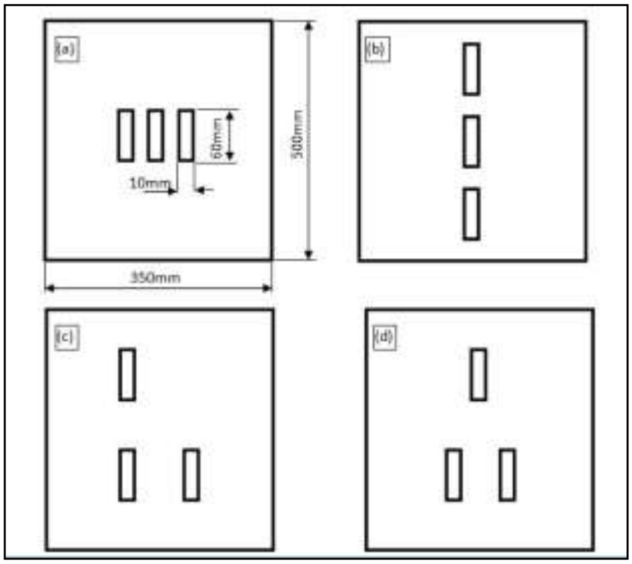

Figure 2. Cross-sectional view of bus-bars at different configurations namely (a) Horizontal (b) Vertical (c) L Shape and (d) Delta.

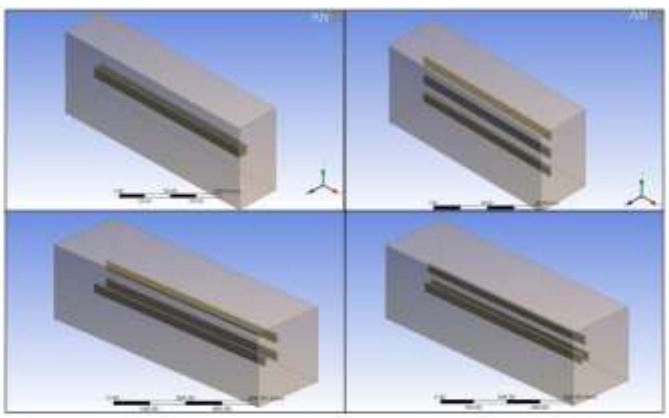

Figure 3. Cross-sectional view of bus-bars at different configurations namely (a) Horizontal (b) Vertical (c) L Shape and (d) Delta (clockwise from left)

III. Numerical Methodology:

The problem is modeled in a three dimensional domain as a steady state problem in FLUENT. To apply volumetric heat generation as source term, a conjugate heat transfer approach is taken to solve the problem. The modeling of the given problem as a conjugate heat transfer problem is described in the following.

To consider a normal heat transfer problem as conjugate heat transfer problem, it is required to have shadow walls at the interface of the solid and fluid region. Hence, geometry was modified slightly. The three bodies (i.e. 3 bus-bars + 1 domain) were combined to form a new part. This created shadow zones or two sided walls at the interaction regions of fluid and solid. The heat generated was modeled as source term in the cell-zone conditions. The whole bus-bar was specified as solid region. In the general settings the gravity is enabled and specified a value of -9.81 m/s^2. The energy equation was enabled. The flow was considered to be laminar. The chamber walls were specified a boundary condition of convection to the atmosphere. The SIMPLE algorithm was employed for the solution of the problem. For the boundary condition of convection, empirical relations to calculate convective heat transfer coefficient is used. The values of Rayleigh number, Grashoff number were calculated for the conditions in the physical domain. The material for the chamber was taken as aluminium.

A. *Meshing*

The meshing adopted was tetrahedral meshing with the sizing function on curvature and relevance center as fine. The natural convection boundary layer is found in a very close region around the bus-bar and hence, it was important to resolve the boundary layer by using a fine mesh in the region around bus-bar. The mesh refinement was hence carried out in fluent by using adaptation technique. Named selections were employed so as to facilitate the specification of boundary condition. The walls of the chamber and the busbar faces were named.

IV. Numerical Results

The results of temperature contour were plotted in the cfd-post processing tool. Planes were sliced containing the faces of the individual bus-bars. The resulting contour obtained fig.5 showed temperature distribution within and around the bus-bars. The natural convection loop was evident from the nature of the contours. The distribution was found symmetric about the direction of action of gravity. The lower part of the bus-bar showed temperatures which are less by at least 10 ˚K than while the higher temperatures found concentrated in the upper part of the bus-bar. Also, in the air domain or the chamber, as in the physical model the temperature was found to be more in the upper part. The horizontal configuration had the upper side temperature more by 47K while the other configurations show an increase by about 33K.

In order to have a criterion for comparison for results for the different configurations, the geometry dimensions, meshing methodology, boundary conditions all are kept constant. The temperature range obtained was found to be different for different configuration. The isotherms for the maximum temperature for the particular configuration were plotted as in Fig 5. The isotherms gave the relative volume in which this maximum temperature was seen to be concentrated.

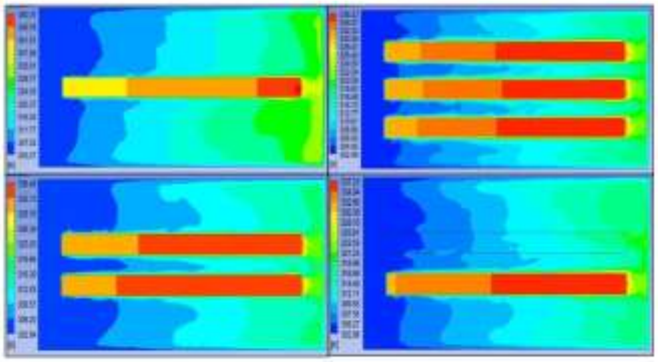

Figure 4. Temperature contours for different configuration a) Horizontal b) Vertical c) L-shape d) Delta

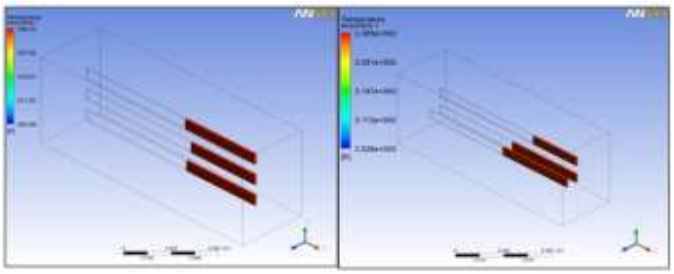

Figure 5. Isotherms for vertical and L-shape configuration

The top face of the bus-bar chamber was seen to be subjected to the maximum temperature and was seen to dissipate the maximum heat flux to the atmosphere. The temperature for horizontal configuration is 350K while for others it is about 335K. The high temperature results into a higher value of convective heat transfer co-efficient. The side and bottom walls of the bus-bar chamber were seen to be subjected to lower temperatures. It can be concluded that the selection of chamber material for bus-bar must be done with respect to the heat distribution on the top surface.

V. Optimum configuration

Temperature was the first criteria for study. The maximum temperature observed in all the 4 configurations showed that the horizontal configuration is exposed to the maximum temperature. The value was far higher as compared to other configurations. The lowest value was observed for vertical configuration. However, the L-shape configuration had its maximum temperature almost equal to vertical configuration. Hence a comparison of the maximum velocity of the two was done. Here again, the values fell quite in the neighborhood of each other. The isotherms were then plotted shown in fig 5. This revealed that the volume occupied by the temperature was more for vertical configuration. This effectively clarifies that the vertical configuration is found to be the optimum amongst the configurations under study.

TABLE I. RESULTS OF NUMERICAL SOLUTION

Sr. No.	Table Column Head			
	Configuration	*Max Temperature (K)*	*Chamber surface(K)*	*Velocity (m/s)*
1	Horizontal	350.01	330K	0.68
2	Vertical	336.23	315	0.41
3	L-shape	336.49	315	0.39
4	Delta	337.23	315	0.50

The values of total surface heat flux average Nusselt number and temperature were obtained in fluent as in table IV. Refer fig 6 for the naming convention. The cold and hot are the left and right edges respectively. The busbar in all the configurations were considered to be installed vertically. Hence, the hot side was the upper side of the busbar. The top and bottom are the top and bottom edges in the fig 6. Table II reveals that, the higher temperatures were being concentrated on the hot side of the chamber i.e. the upper side of the busbar (busbar are considered to be installed vertically). The other sides e.g. the top and bottom and front and back show the same values. The values are found to be higher on the hot side of the chamber. The heat flux is found to be 50 to 60% more on hot face than the other faces, while the Nusselt number is 40 to 50% more. Here, the cold face was not taken since the heat transfer would be obviously less since it was opposite to the direction of setup of natural convection currents.

TABLE II. VALUES AT DIFFERENT LOCATIONS

Location	Total heat transfer rate (W)	Area weighted average		
		Total surface heat flux (W/m^2)	Nusselt number	Temperature (K)
Horizontal				
Front	10.53	17.54	38.19	312.76
Back	10.69	17.81	39.68981	311.89
Top	5.37	17.90	41.52	311.56
Bottom	5.20	17.35	38.31	312.23
Cold	0.069	0.55	1.87	303.64
Hot	6.65	53.27	85.65	327.69
Vertical				
Front	10.74	17.54	38.19	312.76
Back	10.69	17.81	39.69	326.59
Top	5.37	17.90	41.52	310.37
Bottom	5.2	17.35	38.31	311.56
Cold	0.069	0.55	1.87	303.64
Hot	6.65	53.27	85.65	326.59
L-shape				
Front	9.88	16.48	40.43	310.25
Back	8.85	14.76	35.65	310.47
Top	6.71	15.99	40.57	309.37
Bottom	6.08	14.49	38.83	308.59
Cold	0.4	2.29	5.49	303.38
Hot	6.16	35.20	68.90	320.36
Delta				
Front	9.33	15.55	37.50	310.24
Back	9.22	15.37	36.60	310.59
Top	6.29	14.98	36.46	310.22
Bottom	6.71	15.985	39.29	309.83
Cold	0.23	1.35	4.54	303.88
Hot	6.35	36.29	70.32	320.36

VI. Validation with measurements

In order to validate the results of fluent the bus-bars from the substation of National Institute of Technology, Calicut were measured. Thus, actual working conditions of enclosed chamber were not maintained. The problem was hence modeled the same way in fluent and the results are validated as follows.

The bus-bars in the NITC substation are horizontal double run bus-bars made of aluminium. They are installed in a protective chamber also made of aluminium.

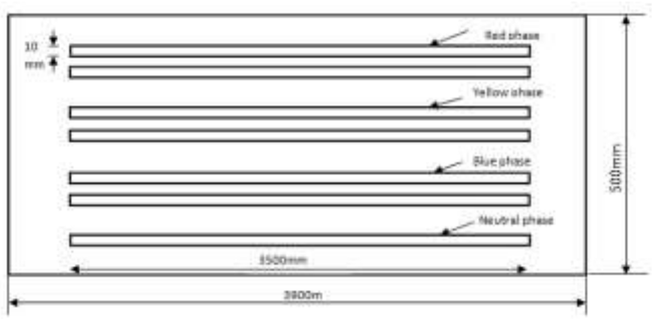

Figure 6. Schematic of substation bus-bar

TABLE III. DIMENSIONS OF BUS-BARS AT NITC SUBSTATION

Busbar	3000mm x 100mm x 10mm
Chamber	3400mm x 400mm x 400mm
Rated current	1000A
Actual current	500A
Voltage	400V

The insertion of thermocouples in the bus-bar chambers was not possible. Hence, a non-contact type infrared gun was employed for measurement of temperature. This necessitated the opening of the frontal lid of the chamber. To accommodate the change, the front face of the bus-bar chamber was given a boundary condition of pressure outlet. Table III shows the values of measured and the temperatures obtained by the numerical results

TABLE IV. COMPARISON BETWEEN MEASURED AND NUMERICAL VALUES

Sr. No.	*Location*	*Temperature (K)*	
		Measured	*Numerical*
1	Chamber: top	309.4	307.077
2	Chamber: back	309.4	308.679
3	Chamber: bottom	308.6	305.228
4	Red phase (bottom)	311	319.394
5	Red phase (top)	310.6	314.942
6	Yellow phase (bottom)	311.8	318.072
7	Yellow phase (top)	311.6	318.292
8	Blue phase(bottom)	310.6	316.457
9	Blue phase (top)	311.6	316.717
10	Neutral (top)	309.2	308.459

VII. Conclusion

The natural convection flow is modeled in Fluent. The results are validated with temperature measurements. The high temperature region is found in the top part of the busbar chamber. The top surface the chamber dissipates the maximum heat and is also subjected to maximum temperature. Thus, top surface of the busbar chamber is critical in the design of the chamber. Out of the four configurations under study, the vertical configuration is found to be the optimum one.

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