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Extensive review on Laminated bus bar for low and high power applications

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Abstract. This paper explains about wide range of applications for Laminated Bus Bar used for high and low power applications. Authors also explains ways to effective utilize laminated bus bar when compared to conventional bus bar. Laminated bus bars are designed with low stray inductance and high capacitance with a uniform current distribution in conducting plate. Parameters like Length, Width, material thickness and other miscellaneous parameters effect Laminated bus bar performance. With a proper design of Laminated bus bar it can best utilized , laminated bus bar are suitable for many low and high power applications which are discussed in this paper. Replacing conventional bus bar with laminated bus bar additional advantages are achieved like lighter weight, less space and lower maintenance.

1 Introduction

Conventional bus bars used these days require lot of space and also create hazardous situations in many cases. Many hazardous situations are due to weak connections between points or insulation failure and so on. Apart from arrangement they posses more stray inductance and low capacitance which make the bus bar to create spikes in transient cases. Laminated bus bars overcome these problems by maintaing lower stray inductance and high capacitance on using different material and sandwiching them in a suitable and required manner. Laminated bus bar are lighter when compared to conventional bus bar. Laminated bus bar there is minimal chance of sparking, wiring errors and heating effects [1] which can obtained by using a proper material. Many applications today demands for low stray inductance, low weight, safe to operate, lower maintenance, low space requirement which can be fulfilled by using laminated bus bars.

This paper describes laminated bus bars uses in different range of power applications and also how to modify Laminated bus bar based upon the performance obtained after simulations. Material used while designing a Laminated bus bar makes the performance vary a lot so special care need to be taken so, as obtain better performance. By selecting a suitable material requitred for operating temperature, operating voltage and good reliable better performance can be obtained easily. Certain models are described in section III. Models are designed and are modified to obtain uniform current distribution.

2 Laminated Bus Bar for Different Applications

2.1 Inverters

Inverters are used in many applications these days like power flow control, speed control of motors, power factor correction and so on. But due to wiring and soldering of switches parasitic value arises distorting the switching waves. Due to these parasitic values stray inductance becomes higher and disturbs the switch operations an distort the waveform. When replaced conventional PCB with laminated bus bar the stray inductance gets reduced which make the inverter operate as better and additionally capacitance is also increased. Due to high capacitance and low stray inductance, a smaller snubber circuit can be preferred and heat sink requirement also declines [3]. As a result, inverter weight and space requirement goes down. A switched oriented inverter bus bar is shown in Fig.1. Internally in Laminated bus bar the positive link and Negative link are isolated to avoid short circuit.

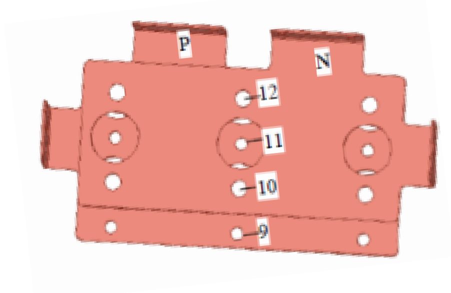

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Fig.1. Inverter PCB with Laminated bus bar

2.2 Battery Bank

Many applications make use of energy storage device to fulfill the excess demand power requirement or as primary power sources like Electric vehicles. For a dynamic grid and a renewable plant with dynamic power provider gives a challenging issue. With the growth in battery technology [4], it is possible to store fluctuating energy in battery and utilize it later. But dealing with such high power requires huge batteries and also create the transient peaks in voltages. Battery banks serve as a primary source of energy for electric vehicles [5] which are in KWH. With growth in Electric Vehicle (EV) technology and awareness of global warming [6] automobile industries are shifting toward electric vehicle with batteries as a primary energy source. Use of laminated bus bars in EV make the power source free from wiring problems occurring due to vibrations in heavy vehicles[7] and also a good quality source free from large transient spikes. Using the Laminated bus bar for battery bank makes them safer and allows for longer operating time and posses a lighter weight.

2.3Super Capacitor Banks

Supercapacitor (SC) have high power density and low response time when compared to other power source like batteries, Alternators, fuel cells and so on. SCs are used as a power source to fulfill high power demand in a short time generally at transient state. SC can also be used to meet dynamic power demand of the grid to balance divergence of power between power plants and loads with laminated bus bars possessing lower stray inductance and high capacitance provide spike free voltage in a short span of time. By using Laminated bus bars spike free voltage is pumped to the grid in a short span of time. SC banks are utilized as hybrid energy sources where weight is reduced [8] by replacing certain range of battery with SC and life of primary power source is also increased.

2.4 Data Centers

Data centers where data is stored in a voltaic memory which demands for a pure and constant voltage [9]. So, laminated bus bar as a power source distributer can make the transient spike lower and in turn make data centers safe by protecting them from fluctuations and providing spike free voltage waves. Use of laminated bus bar in data centers lead to safe and risk free operation, free from wiring hazard situations which can also be observed in conventional bus bars.

2.5 DC Links

DC links used in industries or for inverters with a conventional bus bar contains ripples and also add a spike in supply by which the wave disturbance disturbs the load or motor performance. The spike in the DC links is due to the high stray inductance [10]. By using Laminated bus bars with low stray inductance and also high capacitance the spikes are reduced. These two parameters make the spike lower under disturbance or transient state of operation.

2.6 Power Distribution

Higher power systems which carry more power faces issues like spark at joints, transient spike from supply, more weight and more space. To avoid such problems laminated bus bars can be used. Due to low stray inductance and high capacitance in laminated bus bar spikes are observed lower in transients state [11]. In industries, high power requirement makes the conventional bus bar requirement huge and add addition problems. Laminated bus bars occupy less space for same power constraints.

2.7 Industrial Automation

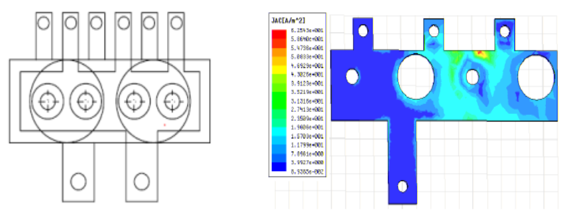
Robots which runs with huge power in industries uses conventional bus bars [12]. But due to high power bus bar weights high and being dynamic in nature of work makes potential create a hazard after a certain operation period of time. On replacing conventional bus bars with laminated bus bars, weight reduction and hazardous situations reduce. Due to lower weight, industry energy demands lower power for the same task. This makes the industries demands for lower energy and also reduce for hazard situation due to dynamic body behaviour of robut. Save in energy due to lighter laminated bus bar of same constraints make the lower power consumption lower te energy bills and power demand.

3 Effects on Laminated Bus Bar due to Various Parameters

3.1 Effect of Physical dimensions

3.1.1 Model A

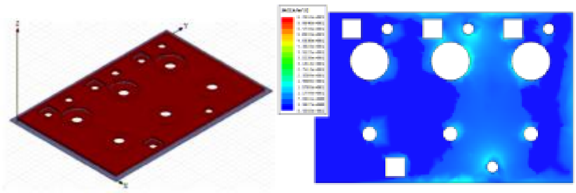
Generally models designed with lower dimension faces non-uniform crowing [13] of flux and current in conducting plates. Fig. 2a &b. shows a model and current plot for the model respectively. On observing the current distribution the current is non- uniformly distributed which can be seen in Fig. 2b.



(a) (b)

Fig. 2. Model with lower dimensions and current plot.

A new model was designed to make the current uniformly distributed. Fig. 3a&b. shows the modified model and current plots respectively. The current crowding is seen to be uniformly distributed and utilizing the whole conducting plate. Change in dimension make the plate to crowd uniformly and utilize effectively.



(a) (b)

Fig. 3. Modified model of lower dimension model and current plot

3.1.2 Model B

In another model based on current direction non uniform crowding can be observed [3]. In Fig.4. the current is seen to be distributed non-uniformly on positive and negative plates. The region nearer to the sink is crowded and remaining region is fewer crowded making the non-uniform crowding of the current.

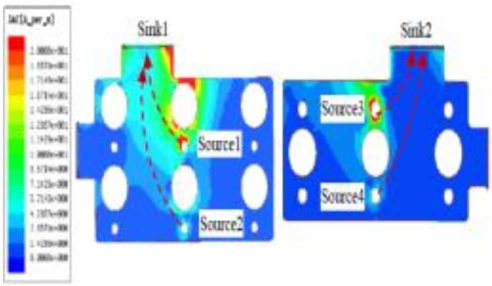


Fig. 4. Simulated current for plot model B

To make the density of current uniform, sink is made as source and vice-versa. The apertures seen in the model are bit farther from sink and creating a crowding of current. Either by designing the apertures as required or making the source as sink, the crowding of current problem can be reduced. Fig.5. describes the uniform current distribution as seen after operating source as sink and vice versa.

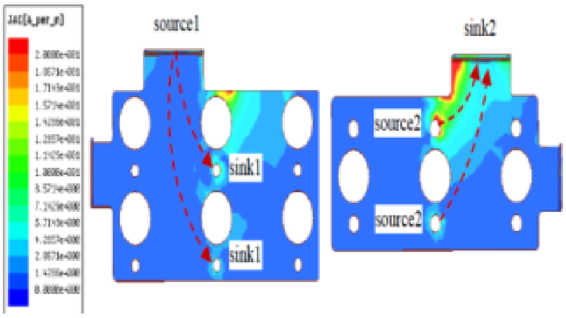


Fig. 5. Simulation of current plot for modified model B

3.2 Effects of Flexible Terminals

Apart from the physical structure and dimensions, some bus bar models have additional physical structures like flexible terminals acting as terminals of the bus bar, made of conducting material [14]. These terminals avoid current crowding and uniformly distribute the current. Flexible terminals are perpendicular to the plate so as make the terminal joints easy to connect. Fig.6. shows the flexible terminals perpendicular to the plate.

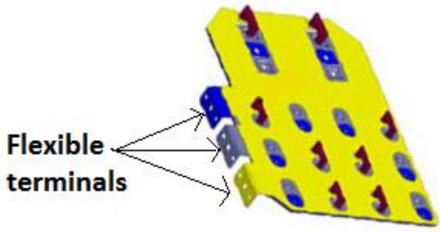


Fig. 6. Laminated bus bar with flexible terminals.

3.3 Effect of Apertures

3.3.1 Model A

Models are designed with apertures to maintain the uniform current flow, lower stray inductance and operate plate in heat limits. The apertures added in a model reduces material used, reduce operating temperatures, increase the durability and effectively use the plates [15].

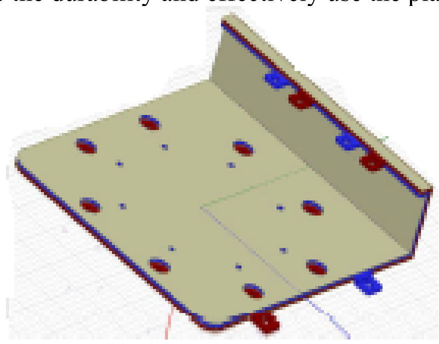


Fig. 7. Model A with no apertures

Fig.7. is a model with no aperture and a flexible terminal is included so as to make the model make uniform current distribution. Fig. 8. is a modified on Fig. 7. Which includes a big aperture in middle of plates. By adding a required aperture we could easily make the bas bar to uniformly current crowding.

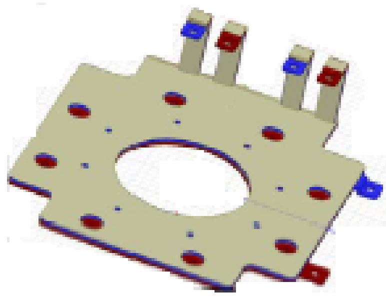


Fig. 8. Model A with apertures

3.3.2 Model B

Generally including apertures in the model doesn't have a significant effect on its current and inductance parameters. Apertures included in the model affect the stray inductance directly but material reduction takes

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place. The stray inductance variations can be seen but the change is not expected to be much [14]. These can depend on position of apertures from edges and diameter of apertures. In Fig.9. current crowding near apertures is high and when the aperture is divided into many smaller apertures, a decrease in the crowding of current can be seen in Fig.9.

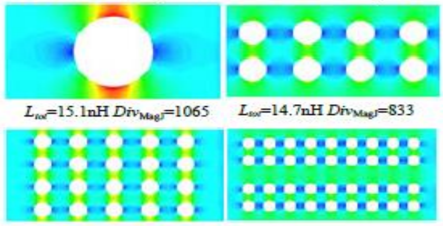


Fig. 9. Effect of stray inductance duet to apertures

To make the current uniform apertures were divided. On adding more apertures stray inductance is also affected, initially it was 17.1nH and it is reduced to 14nH. But a proper care need to be taken while adding a aperture so as to obtain a lower values of inductance and also uniform current distribution. Improper arrangement of aperture design make the inductance to increase rather than decreasing which can be seen in fig.8.

3.4 Effects of Stray Inductance

Laminated bus bars need to possess low stray inductance when compared to conventional bus bar. Laminated bus bar current and flux are not uniform. The stray inductance analytical formula [16] is given by

$$L = (31.9 \times l \times \frac{a}{d})\text{nH} \quad (1)$$

L= stray inductance of Laminated bus bar
l= length of Laminated bus bar in inches
a= dielectric thickness in inches
d= width of laminated bus bar in inches

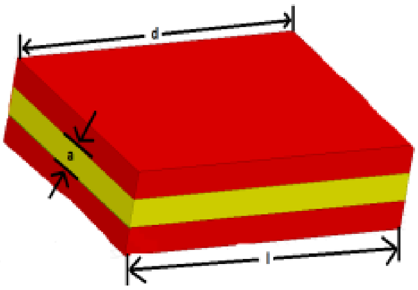
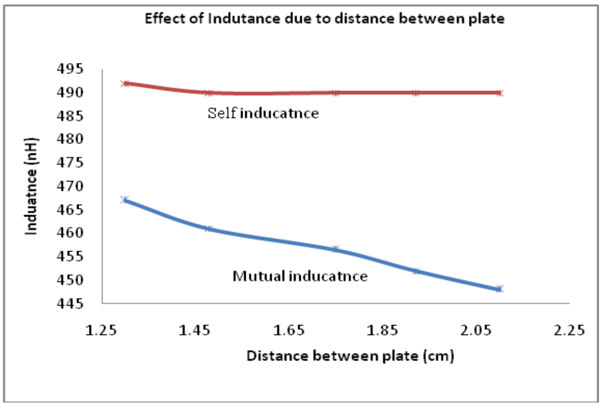
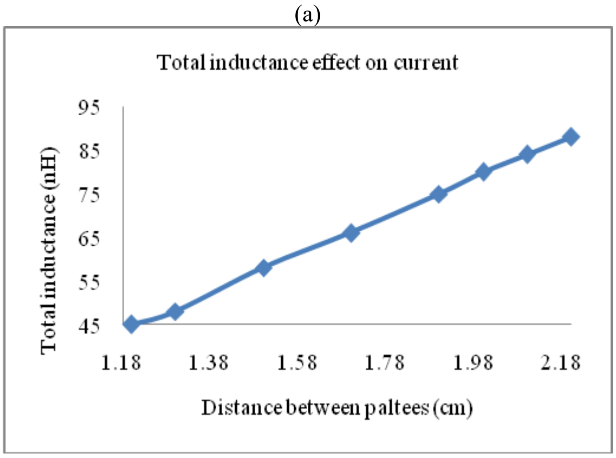


Fig. 10. Laminated bus model with insulation and conducting plate.

Fig.10. shows the Laminated bus bar arrangement red plates as conducting plate andd yelowas insulation material. Apart from stray inductance, mutual inductance also exists between the plates. Mutual inductance depends upon the distance between the plates. Fig.11 shows the variation of inductance due to change in distance between plates.



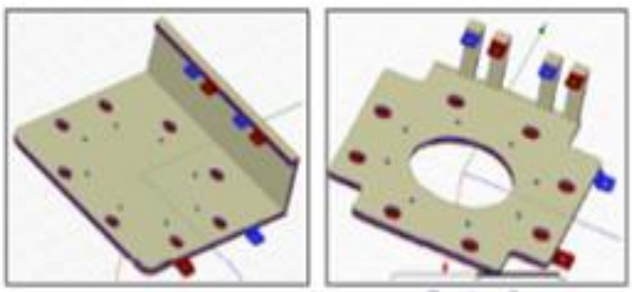
(a)



(b)

Fig. 11. Effect of distance between plate on stray inductance.

Apertures in model cause the inductance to reduce but only up to a certain limit. Fig. 9. shows a variation of stray inductance due to the apertures. Initially inductance had reduced to a 14.0nH from 17.1nH. In another model due to apertures, the effect of inductance variation can be seen due to change with frequency. Fig.12a &b. show the model and variation of inductance respectively between a apertures and a non-aperture model. Change in operating frequency make inductance to effect suitable material need to be designed to operated as required [15].



Design 1 Design 2

(a)

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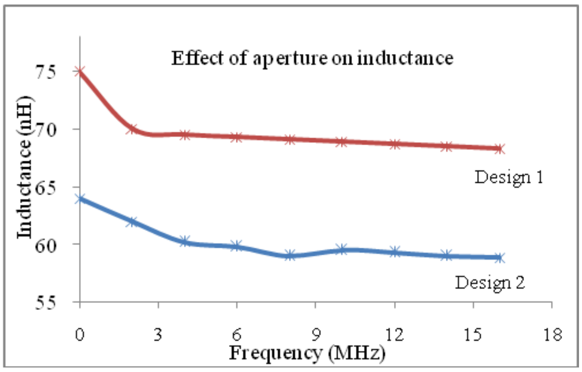


(b)

Fig. 12.Effect of aperture on inductance

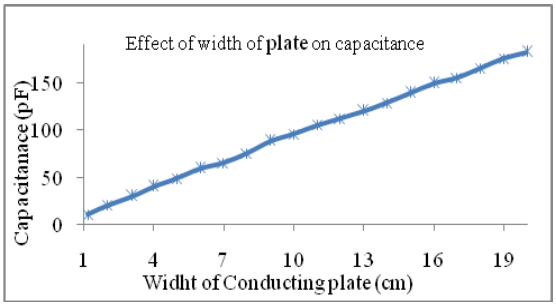
3.5 Effects of Capacitance

The capacitance for laminated bus bar is given by an analytical [16] formula-

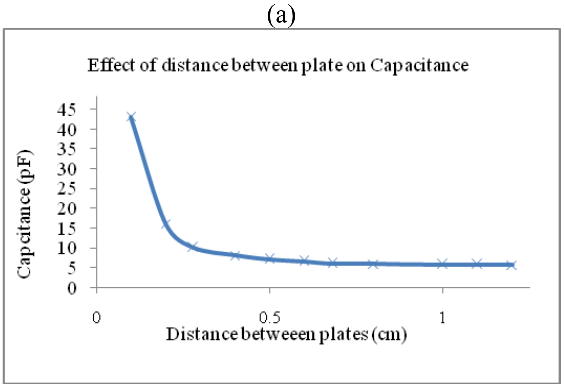
$$C = (.2225 \times l \times b \times \frac{Er}{a}) \text{ pF} \qquad (2)$$

C= stray inductance of laminated bus bar
l= length of laminated bus bar in inches
a= dielectric thickness in inches
b= Width of laminated bus bar in inches
E_r=Dielectric constant of dielectric material used in Laminated bus bar.

Change in area of plate, type of material used, thickness and distance between plate effects the capacitance [15]. Fig. 13a&b shows variation of capacitance due to width and distance between plates respectively. Apart from the plate area, the distance between the plates also affects the capacitance. Fig. 14. shows variation of capacitance due to change in material used in between conducting plates.



(a)



(b)

Fig. 13. Effect on capacitance due to width and distance between plate.

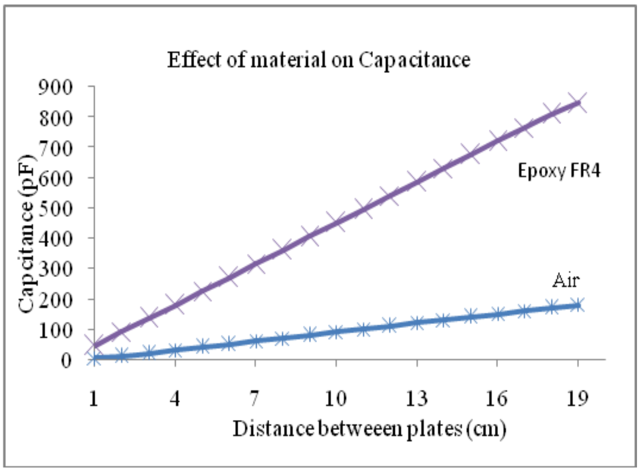


Fig. 14. Efect of material on capcitance

4. Effect of Other Parameters on Laminated Bus Bars

The stray inductance is mainly depended on the width to length (W:L) ratio. Current crowding is also indirectly related to W:Land also thermal effects [15]. Table 1. describes the effect of W:L ratio on stray inductance.

Table 1. Effect of W:L on Stray Inductance

Width (W) cm	Thickness (T) cm	W:T	Inductance (nH)
20	1	20	489.8
10	2	5	584.1
5	4	1.25	633.9
4	5	.08	633.7

Table 2. Effect of D:W on Stray Inductance and Capacitance

Diameter cm	D:W	Inductance (nH)	Capacitance (pF)
1	0.05	159.30	1.821
2	.1	159.27	1.751
4	.2	159.29	1.745
8	.4	160.18	1.618
10	.5	160.91	1.574
19.8	.99	182.81	1.101

5 Effect of Material on Laminated Bus Bar

Sometimes, laminated bus bar models designed perfectly even with optimal dimensions don't work as designed which could be due to material used. Based on working conditions like voltage, current, ambient temperature, working temperature and so on appropriate materials need to selected based on requirement [2]. Due to improper thickness used or excessive use of material may lead to improper respiration of Laminated bus bar. Many insulation materials are designed which have better properties than those currently used in wires or conventional bus bars. Table 4. lists different insulating materials used for laminated bus bars. Conducting materials used are generally copper and aluminum.

Table 3. Comparison of different materials used in laminated bus bar

Material	Dielectric constant	Dielectric strength V/mil	Minimum thickness	Continuous use temperature (° C)
Mylar	3.30	7500	.002	105
Epoxy glass	4	500	0.0025	~ 130
Kapton	3.70	4600	.001	400
Nomex	1.6	500	.003	220

CONCLUSION

Paper explains the applications of Laminated bus bar in modern world for low and high power applications. Design of Laminated bus bar plays a key role so as to effectively utilize its benefits. Aperture diameter and arrragement of the apperture in the plate make the non - current uniform and also disturb the stray inductance. Flexible terminal on adddition making the current uniform crowdinig. Change in frequency of the circuit effect the stray inductance. Suitable material used to make the model to operate in safer operating region. Change in material make the capcitance to increase. Proper design of model with apertures arrangement, material used, operating frequency, thickness and flexible terminals to operate effectively.

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