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Significance of Support Structure for Short Circuit withstand Strength of Bus-bar Assembly Panels - Experiences with Testing

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This paper describes short circuit withstand capability of Bus-bar assembly panels and the significance of Bus-bar support structures commercially available in use. Recent developments in Bus-bar support structures for assembly panels are also discussed. The performance comparisons of these support structures under the Short-circuit currents were given. Few failure cases are studied from the laboratory tested panels and appropriate recommendations were proposed. This can give an insight, while selecting the suitable bus-bars support structure. Theoretical Force calculations were compared for different Bus-bar geometrical configurations.

Keywords: *Bus-bar assembly panels, Bus-bar support structures, Short-circuit currents and Theoretical force calculations.*

1.0 INTRODUCTION

Power system substations serve as locations to step down voltage and distribute power to various locations. Normally this power is distributed by a three phase bus-bar structure which consists of three equally spaced parallel conductors (bus-bars) supported at various points by insulators. Two materials are commercially suitable for use as bus-bars, i.e. copper and aluminium. These bars may be exposed or enclosed which may have one or more joints to assure proper length and configuration and one or more take-off points connected to end-use equipment.

The power system is growing day by day to cater for increasing demand in electrical power. Interconnections between systems of various supply authorities are also increasing for improved reliability and voltage conditions. Because of this the short circuit levels and the frequency of occurrence of short-circuits have increased. Under normal operating conditions the load currents in the parallel bus-bars, through the interaction of the electromagnetic fields result in forces applied on the adjacent bus-bars. During short-circuit fault, the currents suddenly increase to many times the normal load currents applying very high instantaneous electro-magnetic forces on the bus-bars until the fault is cleared from the system. Unless the bus-bars are designed to withstand these forces failures can occur. i.e. these forces may bring about broken of bus supports or deformation or bent conductors which further may lead to shutdown of stations [1].

Hence to ascertain the withstand capability of these bus-bar panels to the short circuit forces which they experience during life period, they are subjected to short circuit test. The test procedure has been standardized [2] and short circuit test is conducted on bus-bar panels. So in order to withstand these mechanical stresses during short circuit currents the bus-bars shall be properly fixed with support structure in the panels. If short circuit current magnitudes are less and large spacing between conductors were maintained

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then a support to carry the weight of the conductor often was sufficient to withstand the stresses due to electromagnetic forces. If short circuit current magnitudes are high and with reduced spacing between the conductors then support structure shall play a major role in withstanding of short-circuit capacity.

2.0 BUS-BAR SUPPORT STRUCTURES

According to type of materials for support structure it is classified in to four categories.

1. FRP (fibre-reinforced plastic)
2. DMC (dough moulding compound)
3. SMC (sheet moulding compound)
4. EPOXY Resin cast

The different commercially available SMC/DMC bus-bar support insulators are in the form as given below

(i) Clonical

(ii) Hexagonal

(iii) Cylindrcal

(iv) Octagonal

(v) Single pole type support system

(vi) Finger type bus-bar support

(vii) Horizontal bus-bar mounting system

(ix) Three phase and neutral bus-bar supports

(x) Single pole, Three pole and four pole grip type supports

(xi) High tension post type insulators.

DMC insulators have replaced earlier concept of epoxy insulators. The shape of insulator is determined by location, capacity and rating of bus bar and environment conditions. Where short time current withstand capacity is not important, also not required, these DMC insulators are very much in use. Typical DMC bus-bar support is shown in Figure 1.

FIG. 1 DMC BUS-BAR SUPPORT.

Today concept of SMC horizontal and vertical bus bar supports are using in place of old conventional laminated sheet. SMC adopts unsaturated polyester resin as the bond, filled with glass fiber, pigment and other chemical agents, after being dipped, this is covered by film on both sides and finally supplied as the unsaturated polyester resin reinforced by glass fiber compounds in the shape of roll which gives heavy mechanical strength. Both SMC/DMC insulators have precision threaded brass inserts or steel inserts to minimize voltage gradients at the screw and to sustain the repeated connection stresses.

The advantages of these insulators are

- Flame resistant
- High durability
- Dimensional accuracy
- Light weight
- Superior thermal insulation
- Excellent mechanical strength

Typical SMC bus-bar support is shown in Figure 2.

These epoxy resin cast insulators are manufactured using high grade raw materials. These insulators are generally used for High voltage bus-bar panels because of their good insulation characteristics is shown in Figure 3.

FIG. 2 SMC BUS-BAR SUPPORT.

FIG. 3 EPOXY RESIN CAST BUS-BAR SUPPORT.

FRP stands for Fiber reinforced plastic. These are generally used at the low voltage bus-bar systems. A typical FRP bus-bar support is shown in the below in Figure 4.

The advantages of this support system are

- Good insulation characteristics
- No rust and High resistance to humidity

2.1 Recent Developments in Support Structures

Apart from the above different type of supports because of the developments that are happening in insulation materials recently people have been started using supports with polycarbonate material, nylon materials and other Fiber composite materials. In future these types of support systems will be replaced with the present available insulator supports because of their good performance both electrically and mechanically.

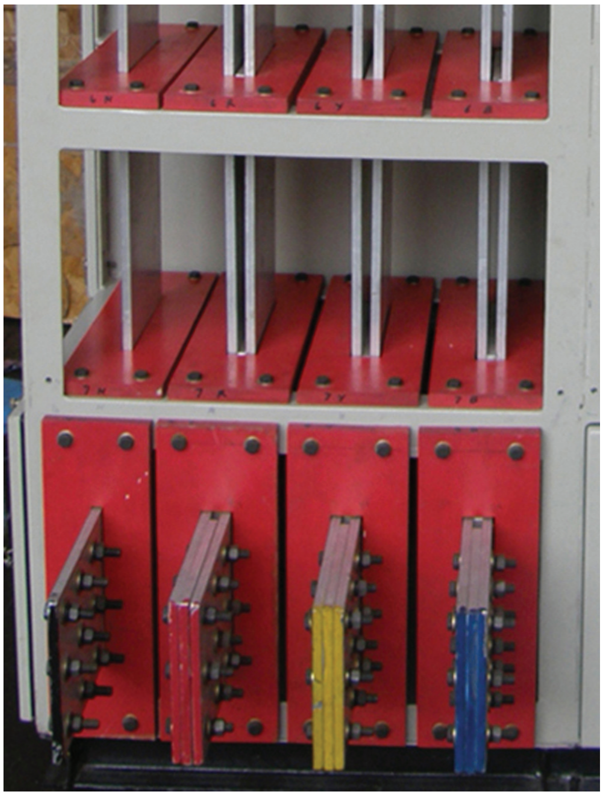


FIG. 4 FRP BUS-BAR SUPPORT.

Polycarbonate has the clarity of glass and the impact resistance of metal. It has good dimensional stability and rigidity. Polycarbonate is well suited for applications demanding high impact, excellent heat resistance, good chemical resistance, low moisture absorption and FDA compliance. The properties of Nylon material are environmentally friendly and great stability of electrical and mechanical parameters.

Typical Polycarbonate bus-bar support is shown in Figure 5.

Typical Nylon bus-bar support is shown in below in Figure 6.

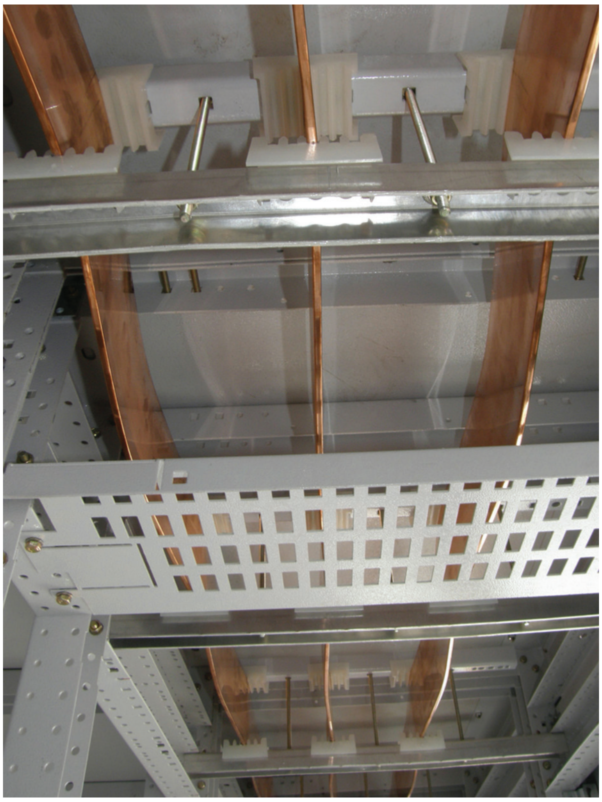


FIG. 5 POLYCARBONATE BUS-BAR SUPPORT.

FIG. 6 NYLON BUS-BAR SUPPORT.

The above all support structures are generally in direct contact with the bus-bars by using either bolted structure or direct gripping by cutting the small part of the support exactly suits with width of the bus-bar. Therefore the manufacturing process involves making an exact rack with good dimensional accuracy for sitting of the bus-bar.

In recent trends the support structure is developed with other forms also, having clamps (to hold the bus-bar) generally made up of MS which is connected to the main support by bolted structure as shown in the below Figure 7. Advantages of this supports structure are

- Racks i.e cutting of supports is not required
- Stresses will be shared for both clamps and supportive insulators during the short-circuits
- Halogen free and self-extinguishable
- Spacing requirements will be minimal
- Working temperatures are higher

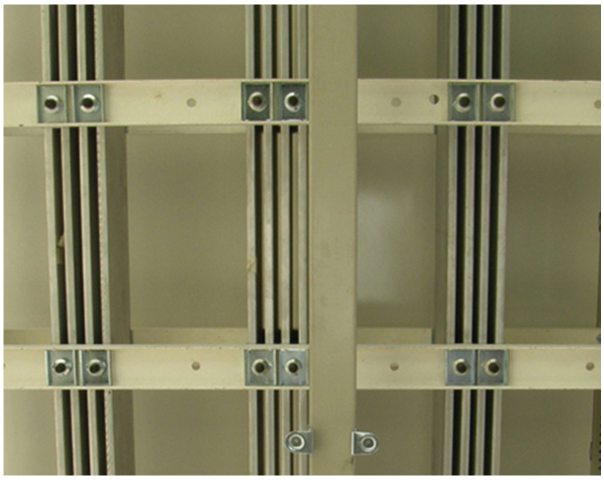


FIG. 7 SELF EXTINGUISHABLE FIBER MATERIAL BUS-BAR SUPPORT WITH MS CLAMPS.

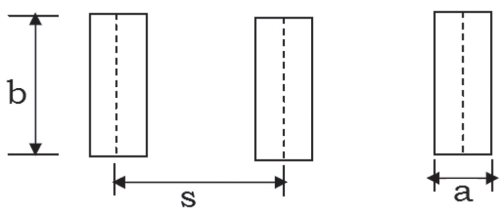
These bus-bar structures are costly than the SMC/ DMC & FRP due to its design which involving cost of the insulating material Fiber and its clamp structure.

3.0 THEORETICAL EVALUATION OF SHORT CIRCUIT FORCES OF DIFFERENT GEOMETRICAL BUS-BAR CONFIGURATIONS

The electromagnetic forces produced due to short-circuit currents create mechanical push or pull which causes the displacement of bus-bars from their normal position [3]. It is very important that the force acting on the bus-bars mainly depends on the geometrical configuration of the bus-bars.

Three of such typical geometrical configurations are shown below.

Configuration 1:



As we know, the parallel current flows cause attracting forces between two conductors and this force equals to

$F = 2 \times 10^{-7} \times (l/s) \times i_1 \times i_2$ N for a << s & s<<l

3.1 Balanced 3-Phase Short Circuit Stresses

A 3-phase system has its normal currents displaced by 120° and the instantaneous current in one phase is balanced by the currents in the other two phases. The directions of the currents are constantly changing and therefore the forces. The maximum forces are dependent on the point in the cycle at which the fault or short-circuit occurs.

For these circuits, because of the interaction between all conductors, the force acting on one of the conductor equals to the sum of force due to both the other conductors.

The maximum force [4] on the outer conductors can be calculated and is equals to F_{1max} or F_{3max} =

$13 \times 10^{-7} \times k \times [\{(l/s)^2+1\}^{1/2}-1] \times I^2_{sym}$ N

The maximum force on the centre conductor can be calculated which is equals to

$F_{2max} = 14 \times 10^{-7} \times k \times [\{(l/s)^2 + 1\}^{1/2}-1] \times I^2_{sym}$ N

Where k is correction factor for rectangular shape conductors

I_{sym}: Symmetrical rms current

l is length of rectangular bus-bar

s is distance between the centre axis of bus-bars

Assume a = 20 mm, b = 100 mm

Span, s = 200 mm

Length of the bus-bar, l = 1000 mm

I_{sym}= 50 kA, (s–a) / (a + b) = 1.5

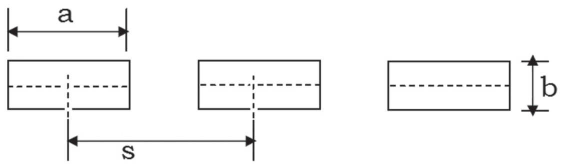
From the Correction factor graph from the literatures k = 0.955

F_{1max} or F_{3max} = 38 kN; F_{2max} = 41 kN

Since approximately the force magnitudes are equal we may go for the same type of support structure for all the conductor configurations.

Bus-bars arrangement in most of the bus-bar panels are like in Configuration 1.

Configuration 2:



Assume the above parameters,

(s–a) / (a + b) = 1.5

From the Correction factor graph from the literatures k = 1.05

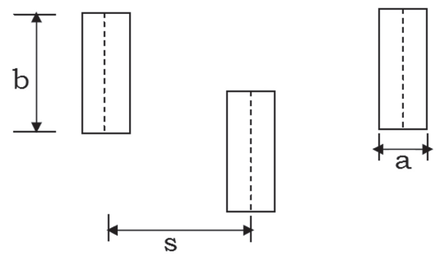
F_{1max} or F_{3max} = 42 kN; F_{2max} = 45 kN

If compare the force magnitudes for both the above configurations the force magnitudes are more for Configuration 2.

Stress on the supports can be calculated by considering the stress factor from which we can determine required support to withstand the stress and required spacing between one supports to another support.

In case of configuration1 the compressed type of forces will be developed. These forces will be transferred to whole support structure. But in case of Configuration 2 the forces are in the form of sheared which will not stress the whole support structure.

Configuration 3:



Generally this configuration will not be used in bus-bar panels because of the space requirements.

The force magnitudes are almost same with the configurations discussed.

4.0 PERFORMANCE COMPARISON OF DIFFERENT BUS-BAR SUPPORT STRUCTURES UNDER SHORT-CIRCUIT CONDITIONS – A CPRI EXPERIENCE

Generally all Low voltage bus-bar assembly panels are designed for 50 kA for 1 second short-circuit withstand strength.

The conductor therefore must have an adequate proof strength to carry these forces without permanent deformation as short-circuit forces have to be absorbed first by the conductor [5]. Apart from this the support structure and associated steel work must be well designed such that no deformation should be taken place in the bus-bars of the panel and no little breakage of the whole support system during the test. Therefore it is very important to select a suitable support structure for a given bus-bar design. Central Power Research Institute (CPRI) is Independent National testing Laboratory having experiences in short circuit testing on different LV and HV equipment for more than 40 years. Short circuit laboratory, CPRI specifically tested various types of panel assembly with different support structures for National / International customers. Figure 8 shows tested quantity of LV/HV panels versus recent years.

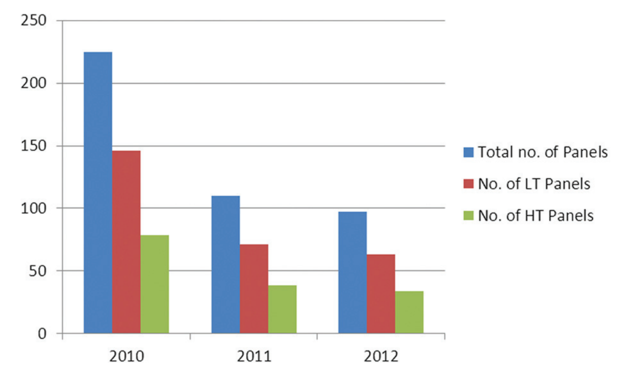


FIG. 8 TESTED QUANTITY Vs. YEAR.

4.1 Failures Observed with SMC/DMC Bus-bar structures

DMC Finger type of supports many times leads to failures in short-circuit withstand strength test because of the following reasons:

- Due to drawbacks in Its own design structure
- More mechanical tightening of the support to the bus-bar
- Not maintaining proper support to support distances
- Thickness of bus-bar is more than Finger width of support

It is not preferable to use Finger type DMC supports if width of bus-bars is more and short-circuit currents are very large in magnitudes. In that case it is recommended to use the SMC bus-bars.

SMC support structure design is same as the FRP supports. But the cuttings of a proper rack for the bus-bar to sit play a major role for the test to pass. These SMC supports will best suits for more widths of bus-bar and with more number of parallel conductors. The failure indications during short-circuit withstand strength test of SMC support is shown in Figure 9.

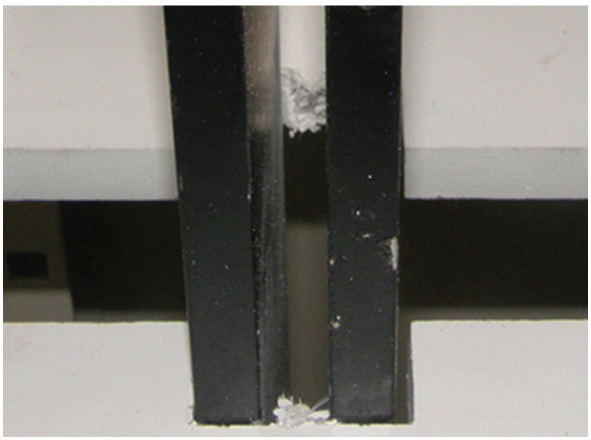


FIG. 9 BREAKAGE OF SMC SUPPORT.

FIG. 10 DEFORMATED BUS-BAR.

Figure 10 shows deformated bus-bars during short-circuit withstand strength test of a low voltage panel. This is happened due to longer support to support distance.

4.2 Necessary Steps for Designing a LT Panel

Typical recommended support to support distances are given in the Table 1.

Type of bus-bar support	Support to support distance
SMC	300 mm – 375 mm
DMC	200 mm – 225 mm

The failures in dielectric tests are very rare in case of LT panels.

Typical clearances between body to phase and phase to phase for LT panels are shown in Table 2.

LT panel	Clearance
Body to Phase	100 mm
Phase to Phase	100 mm

Type of bus-bar support	Performance under short-circuit
FRP	Good, 50 kA and above
Moulded type SMC/ DMC	Average, up to 30 kA
Nylon, Polycarbonate	Excellent, for 50 kA
Epoxy Resin cast	Good, Generally used for HT assemblies

5.0 CONCLUSIONS

In this paper study has been made for the different types of support structures properties and their performances under short-circuit conditions. It is observed that the failure rates are more with moulded type SMC/DMC support structures compared to FRP supports. Also with the recent developments in bus-bar support materials like Nylon, Polycarbonate, and Fiber materials performance under short-circuit currents are excellent than the previously used materials like Bakelite and DMC.

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