Reactance of Busbar Trunking System by Mathematical Modeling and FEMM Simulation

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Abstract— Busbar Trunking System involves distribution of electrical power using set of copper or aluminium busbars enclosed in suitable enclosure with high degree of protection against any ingress of foreign bodies. Due to time varying current within busbar induce magnetic fields. The resultant magnetic field in turn induces skin effect and proximity effect. In this paper, design a mathematical model for the calculation of reactance of busbar trunking system with the skin and proximity effects considered was developed. The mathematical model result also verified by using FEMM software. In this paper, a two-dimensional Finite Element Method of Magnetics field model for calculating the inductance in a sandwich BBT system is proposed. A two-dimensional model is used for this analysis. The numerical results of this method are verified with FEMM simulation result.

Key words: Busbar Trunking System (BBT), Finite Element Method of Magnetics (FEMM), Geometric Mean Distance

I. INTRODUCTION

BUSBAR TRUNKING SYSTEM (BBT) plays a vital role in electric power distribution system, due to recent development in the field of electric power distribution. BBT systems instead of cables are commonly used in low voltage and high current power distribution system [1]. Busbar Trunking System is an assembly comprising a system of conductors with one or more bars separated or supported by insulating material and contained in a conduit or similar casing [2]. The major reason behind popularity of the BBT is that they are cheap, rugged in construction, low maintenance cost, high efficiency, safe and ideal in operating condition.

The impedance of BBT is an important parameter in LV distribution system design. It is used to predict system performance, such as, voltage drop, voltage balance, power loss, Electrodynamic forces, temperature rise, current carrying capacity, etc. Traditionally, busbar system impedance is modeled by averaging phase resistance and effective reactance obtained by measurements [2]. It is found that trunking parameters, such as the material, thickness and size, have a significant influence on its shielding performance [3]. However, there are limitations using this approach. The major one is the inadequacy for determining the impedance for various busbar system configurations and sizes. There is the associated problem of making simultaneous measurements of high currents and small voltage values, unless the sample is rather long. Analytical calculation and computer simulation are alternative approaches for determining busbar impedance. These approaches have been investigated for several decades, and have been successfully applied to bare busbars without any metallic enclosure. The inductive part is deduced from self and mutual inductance computation using geometric mean distances. These approaches are suitable for simple configurations of bare bars.

Skin and proximity effects in single- or multi-conductor systems can notoriously affect the AC resistance in conductors intended for electrical power transmission and distribution systems and for electronic devices [4]. This increase of the AC resistance raises power loss and limits the conductors' current carrying capacity, being an important design parameter [4]. There are some internationally recognized exact and approximated formulas to calculate the AC resistance of conductors, whose accuracy and applicability is evaluated in this paper. However, since these formulas can be applied under a wide range of configurations and operating conditions, it is necessary to evaluate the applicability of these models. This is done by comparing the results with numerical evaluation and finite element method of magnetics (FEMM) simulation results. The results provided show that FEMM results are very accurate and more general than those provided by the formulas, since FEMM models can be applied to a wide range of conductor's configurations and electrical frequencies.

II. PROPOSED METHOD

A. Mathematical Modeling of BBT Model

The Busbar trunking system consists of three-phase rectangular busbars as shown in Fig. 1. The analysis presented in this paper is based on the following assumptions:

1) The Busbar trunking system is one meter long, so that the problem becomes a two-dimensional one.
2) Charges and displacement currents are disregarded.
3) The phase currents are sinusoidal and balanced.
4) All field quantities vary sinusoidally with time.
5) All materials have constant electrical properties.
6) The permeability of the Aluminium is constant.

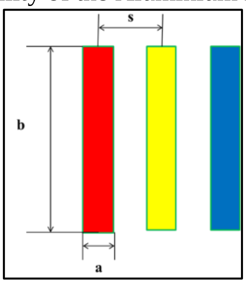

Fig. 1: Three-Phase Rectangular Busbars

For three phases R, Y and B, inductance may be calculated for each phase using the following method [5].

$$L_R = \left|2\times 10^{-3}\left[\{Log_e(1/D_s)\} + \{(-0.5+j0.866)\,Log_e(1/D_{mRY})\} + \{(-0.5-j0.866)\,Log_e(1/D_{mRB})\}\right]\right| \ \mu H/cm \quad (1.1)$$

$$L_Y = \left|2\times 10^{-3}\left[\{Log_e(1/D_{mRY})\} + \{(-0.5+j0.866)\,Log_e(1/D_s)\} + \{(-0.5-j0.866)\,Log_e(1/D_{mYB})\}\right]\right| \ \mu H/cm \quad (1.2)$$

$L_B=|2\times 10^{-3}$ [{Log_e (1/D_{mRB})} + {(-0.5-j0.866) Log_e (1/D_s)} +{(-0.5+j0.866) Log_e (1/D_{mYB})}]| μH/cm (1.3)

Here D_m represents the geometric mean distance between different phases. D_s represents the geometric mean radius of the conductor, unless each phase is made up of several conductors in which case it represents the distances between the conductors of the phase.

Geometric Mean Distance from Itself

$$Ds = 0.2235 (a + b) \quad (1.4)$$

Reactance can be calculated using the following formula,

$$X = 2 \times \pi \times f \times L \quad (1.5)$$

This technique provides a method for finding the Reactance aluminium conductor when alternating current flowing through the conductor. In table 1, provide the Basic Parameter For Calculate the reactance of Busbar Trunking System and table 2, provide the basic data of Aluminium conductor dimensions For 1600 A Sandwich Insulated Busbar Trunking System.

Sr. No.	Parameter	Symbol	Standard Value	Unit
1	Width	b		mm
2	Thickness	a		mm
3	Length	L		mm
4	Spacing between the Conductor	s		mm
5	area of cross section	A		mm^2
6	Frequency	f	50	Hz
7	Angular Frequency of the Current	w	100π	
8	Resistivity of the Aluminium conductor 20°C	ϱ	2.65×10^{-8}	Ωm
9	Permeability of free space	μ_0	$4\pi \times 10^{-7}$	H/m
10	Relative Permeability of Aluminium conductor	μ_r	1.000022	

Table 1: Basic Parameter For Calculate the Impedance of Busbar Trunking System.

Current Rating (A)	Width 'b' (mm)	Thickness 'a' (mm)	No. of conductors
1600	150	6	1

Table 2: Aluminium conductor dimensions For 1600 A Sandwich Insulated Busbar Trunking System.

B. Computer Simulations Approach of BBT Model

Computer simulations for busbar system reactance are performed with the aid of the FEMM software employing a two-dimensional boundary element procedure [6]. It solves for magnetic vector potential first, then calculates other derived quantities such as, magnetic field, induced current, the per unit length self-impedance and the mutual impedance of conductors as required. The applicability of this software for reactance calculation was investigated on a simple go-and-return rectangular busbar system, as illustrated in Fig. 2. Its accuracy was investigated by comparing the results with those calculated according to the geometric mean distance method [5]. For the purpose of comparison, conductivity of the Aluminum conductors was taken to be 0.35×10^8 S/m. The simulation results are presented in table 4, together with those calculated.

FEMM program is a Multiple Document Interface pre-processor and a post-processor for the various types of problems solved by FEMM [6]. Calculate the Reactance of busbar using FEMM software is very useful to compare the result with calculated value. The preprocessor is used for drawing the problems geometry, defining materials, and defining boundary conditions. The magnetics postprocessing functionality of FEMM is used to view solutions generated by the fkern solver. A magnetics postprocessor window can be opened either by loading some previously run analyses via File|Open on the main menu, or by pressing the "big magnifying glass" icon from within a preprocessor window to view a newly generated solution. Magnetics postprocessor data files stored on disk have the .ans prefix. In a preprocessor mode to draw the geometry of BBT system, choose the magnetic problem from create new problem menu. Define the problem, select the problem definitions menu and define the problem in planer or coordinates types. Choose the unit from the drop box for define the problem geometry. Specify the depth of problem geometry into page direction. Draw the geometry of three phase four wire rectangular BBT system as per dimension given in table 3 by using drawing tool in preprocessor mode. Enter the Material property in block property dialogue box and assign the material to the different parts in the geometry, also define the boundary condition for the problem. Figure 2 show the complete geometry in preprocessor mode for meshing the model, analyzing the model, and viewing the results. The magnetics postprocessing functionality of FEMM is used to view solutions generated by the fkern solver. Magnetics postprocessor data files stored on disk have the .ans prefix. The block has been defined; a variety of area and volume integrals can be taken over the defined sub domain. Integrals include stored energy (inductance), various kinds of losses, total current in the block, and so on. In Postprocessor mode select the integral menu to find the magnetic field energy. From the magnetic field energy, calculate the inductance stored in busbar.

Current Rating (A)		**Width 'b' (mm)**				**Thickness 'a' (mm)**	
1600		150				6	
Phase Conductor Coordinates							
R		**Y**		**B**		**N**	
x	**y**	**x**	**y**	**x**	**y**	**x**	**y**
0.3	0.3	0.3	6.9	0.3	13.5	0.3	20.1
0.3	6.3	0.3	12.9	0.3	19.5	0.3	26.1
150.3	0.3	150.3	6.9	150.3	13.5	150.3	20.1
150.3	6.3	150.3	12.9	150.3	19.5	150.3	26.1

Table 3: Dimension of the Problem Geometry

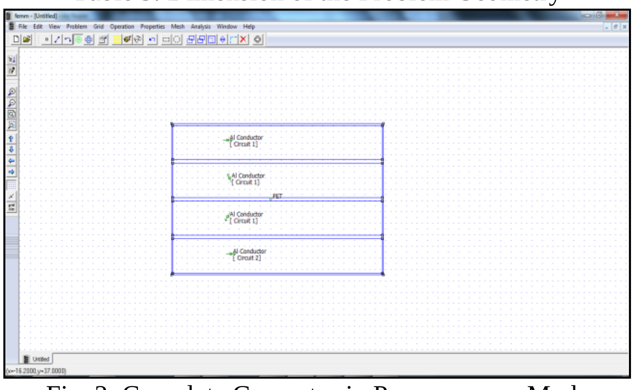

Fig. 2: Complete Geometry in Pre-processor Mode

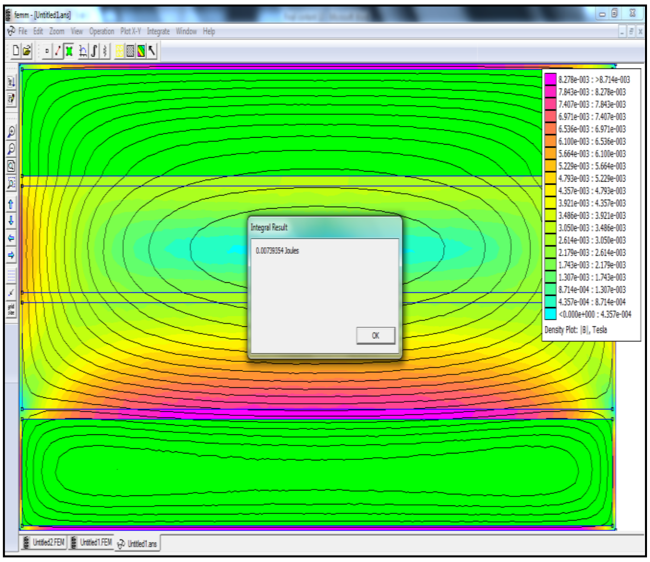

Fig. 3: Magnetic Field Energy in Busbar

III. COMPARISON OF RESULT

The overall significance of the paper was the overview obtained of the busbar trunking system and the thorough study made of various electrical characteristics of the busbar, the effects of standard electrical and mechanical phenomenon on the busbar, and a use of the knowledge obtained to develop theories, mathematical models, and compile all of this knowledge into a readily available format. The database thus being built, provides theoretical and mathematical backing for several results obtained by the design team, often through practical or simulation based methods.

The investigations have been developed on a system constituted by four equal and equidistant aluminium ducts (R, Y, B and N). Each bus, 1m long, has a rectangular solid busbar as shown in figure 2. The conductors can be supplied either as a three-phase system with neutral or as a single-phase configuration with two paralleled conductors for each polarity. Reactance of the BBT systems shown in Fig. 3 was simulated in the FEMM Software. It is found that the analytical values of reactance are very close to the computed values. These values have been calculated based on the final prepared FEMM model. The dimensions for cross-section of the busbar were obtained from the aluminium bus way catalogue for aluminium busbars operating at 50 Hz. All values here have been simulated for 1m length of the busbar. The simulated values have then been compared to the values given by mathematical model for reactance. The thickness has been assumed to be 6mm for busbars with one conductor per phase. Table 4:- Reactance Values of Aluminium Conductor for 1600 A Current Rating, compared with calculated and Simulated Values.

Current Rating	**Reactance**								
	XRcal	**XRsim**	**%**	**XYcal**	**XYsim**	**%**	**XBcal**	**XBsim**	**%**
1600	11.1652	9.564	14.3409	5.50146	4.098	25.5106	11.1653	9.564	14.341

Table 4: Result

IV. CONCLUSION

This paper has analyzed the behavior of different exact and approximate formulas to calculate the AC reactance of electrical conductors carrying AC currents in a constant frequency. The results provided by these formulas have been compared with computer simulated data and those obtained through FEMM simulations. Results presented show the analyzed formulas can deal with a various current configurations and the superior performance of the FEMM simulations due to their accuracy and wide range of geometries that the FEMM method allows analyzing. It is found that the analytical values of reactance are very close to the computed values. The relative error is generally less than 25%.

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