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Finite Element Method Application in Analyzing Magnetic Fields of High Current Bus Duct

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Abstract- The goal of paper is to present the magnetic field calculations in high current bus ducts. Finite element method is used to do this. Bus ducts under study have figure such as circle area. The calculations will be using mathematical relations, meshed geometric shape and analyzing them. Geometric mean will help us to determine value of magnetic field. COMSOL software is applied for simulation studies. Calculations have been analyzed in three phase state and also, simulations are implemented into the three dimension position. Demonstration procedure and numerical calculations are used for presentation the front of view of bus duct. Skin effect and connection configuration between bus ducts are considered in calculations. Aforementioned method can be used to the magnetic fields analyzing in transmission lines and electrical energy link which consist of insulator, easily. Typical bus duct which is applied in simulation studies produced by pars generator corporation, it has been installed in Ardebil substation.

Keywords*- High Current Bus Duct, Magnetic Field, Meshed-Finite Element, Gas Insulated Lines (GIL)*

I. INTRODUCTION

Usually, high level current systems use bus duct to transfer electrical energy. These systems in form of single or three phases can be located into the isolated cabinet. If, value of current is very high then, three parallel single phase line will be used. Also, geometric shapes of bus ducts are different. The connected Square figures in form of latticed or circular are different type of geometric figures. Most common and best state for high level current bus ducts will be the use of circular figures. Usually, bus ducts are constructed of copper or aluminum. Bus ducts configuration with regarded to equipment position will be vertically or horizontally. Often, location of this equipment is between generators and transformers connection. With regard to terminal voltage on the generator output is between 5kv to 30kv, therefore, current value in this location will be very high, between 1kA to 30kA approximately. These equipment's are more applicable in hydropower plants because of generator installation into the hydro tunnels path [1-2]. The usage of Gas Insulated transmission Line (GIL) technology is very appropriate for short time and longtime states [3]. Rated voltage and current of these lines can be between 20kV to 530kV and 1kA to 30kA, respectively. Insulator usually, is composed of 80% nitrogen and 20% sulfate hex florid, which is introduced N2-SF6 and or SF6 gas is applied. Use of GIL technology has been as a favorite technology (Transfer electrical energy to short and long distances). Recently, very modern projects are scheduling for more use of GIL technology in the European and china. The GIL systems are applied by different types, for example, passed due to ground, passed due to tunnel or channel, passed due to environment. Less transfer losses, high reliability, low capacitive load and environment with appropriate quality might be considered as advantages of use of this technology. Cupper or aluminum conductors, which are used in bus ducts construction, with regard to geometric shape will have variable range between 1m to multiple m. Passed, induced and eddy currents into the bus ducts will cause to magnetic fields generation with high values. These fields have effect on self-bus ducts, in addition to will have bad effect on equipment's and proximate humans. Indeed, bus duct singly is an electromagnetic interference source. EMI is considered as a basic menace for sensitive equipment's which are installed in power plants. Consider to importance of subject of electromagnetic fields in bus ducts, in this paper present an appropriate method to calculations. This is based on Finite Element method (FEM). Commercial software is produced in this domain, which will help us for improve in simulation performances. One of them is COMSOL multi physic software. Magnetic field analyzing in front of view state is considered for three phase network. Also, simulation has implemented by three dimension figure in COMSOL software environment.

II. MATHEMATICAL MODEL

A current path system with insulator is shown in figure (1). This presentation is top view of equipment and circuit. To calculation the exact field distribution in bus duct, all cases which is related to physics of subject should be considered. These cases consist of: (1) Value of passed current through conductor, (2) Resistance value and permeability in each filament which is independent from current value. (3) Mutual effects between phases with together. Filament Method is discussed for modeling in the reference [12]. Aforementioned method is recognized as one of the best method in high voltage cables and high level current bus duct. Based on this method each bus is divided to multiple filaments (Nc). Insulator and other point will divide to Ns filaments. Finally, for a three phase model will have N=3Nc+3Ns filament. Use of meshed method in finite element is based on these rules. Therefore, it can be used smaller mesh for more exact calculations. Thus, relation between plates and lack of uniformity are not considered [1].

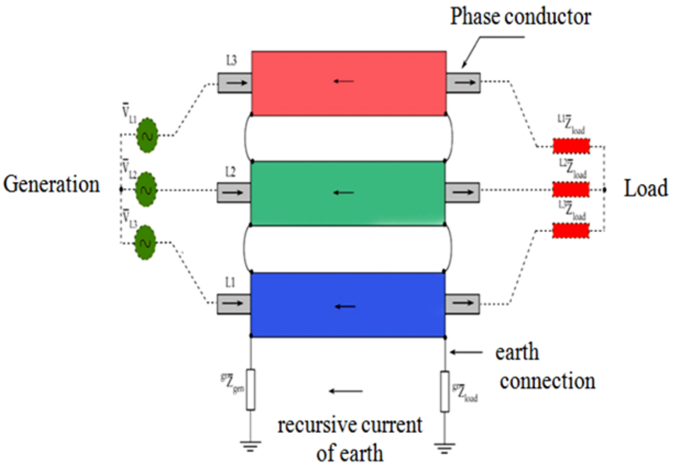

Figure (1): bus duct network in a power plant

Equation is governed on system will be according to bellow form (1).

$$\{V\} = [Z].\{I\} \tag{1}$$

{V} in relation (1) will express voltage vector in close loop between source and load. Matrix [z] is creation impedance. {I} is related to current matrix in close loop system. During impedance matrix building, it will need to geometric mean distance (GMD). Calculation this value will be very complicated. Value of GMD related to each filament (ith) will find by using relation (2). In relation (2), ai and bi will be dimension values of surface area.

$$d_{ii} = 0.22355.(a_i + b_i) \tag{2}$$

Also, GMD between each pair of bus duct system is given as a geometric distance among central points, for example, GMD between ith and kth filament is calculated by relation (3): x and y, which are related to position center of filaments.

$$d_{ik} = \sqrt{(x_i - x_k)^2 + (y_i - y_k)^2} \tag{3}$$

Introduced Bus duct system in figure (1) have earth system that will be shown by equation (4).

$$\begin{Bmatrix} \bar{V}_A \\ \bar{V}_B \\ \bar{V}_C \\ - \\ 0 \\ 0 \\ 0 \\ - \\ 0 \end{Bmatrix} = \left[\begin{array}{ccc|c|c} Z_{AA} & Z_{AB} & Z_{AB} & & 1 \\ Z^T{}_{AB} & Z_{BB} & Z_{BC} & Z_{CS} & \vdots \\ Z^T{}_{AC} & Z^T{}_{BC} & Z_{CC} & & 1 \\ \hline & & & & 0 \\ & Z^T_{CS} & & Z_{SS} & \vdots \\ & & & & 0 \\ \hline 1 & \cdots & 1 & 0 \ \cdots \ 0 & 0 \end{array}\right] \times \begin{bmatrix} I_1 \\ \vdots \\ I_N \\ - \\ \Delta\bar{V} \end{bmatrix} \tag{4}$$

Also, there are following relations:

$$\bar{V}_A = \{1\}^T.\bar{V}_{L1} \tag{5}$$

$$\bar{V}_B = \{1\}^T.\bar{V}_{L2} \tag{6}$$

$$\bar{V}_C = \{1\}^T.\bar{V}_{L3} \tag{7}$$

In these relations $\{1\}^T$ is as an identical transpose matrix. Matrix V_L is shown network voltage. Also, internal impedance matrix, impedance between filaments and impedance between network and earth are shown on above relations

It should be noted that, resistance in each phase and network part is function of temperature. In this paper for means of simplification, it is assumed that source side and load side are ideal. With previous definition and relations, we can study system in short circuit condition and also, load balance and unbalance conditions [4-7]. In equation (4), we can see that, there are N+1 known parameters while, there are many unknown variables (3Ns+3Nc). In addition to potential deference also will be part of problem variables. Determining current distribution in system and also, calculation the proximity effect with bus duct to other equipment's by using this method will be efficient. For analyzing field distribution in bus duct surrounding, geometry is presented in figure (2) will be use. Bus duct and surrounding space are shown in figure (2).

One typical point such as M in figure (2), for magnetic field caused by special point of bus duct such as T will be calculated. When these calculations are performed to all point of space and bus duct, it can be seen magnetic field as identically. Distance vectors and current have been depicted by polar coordinates. Different variables will define based on figure (2):

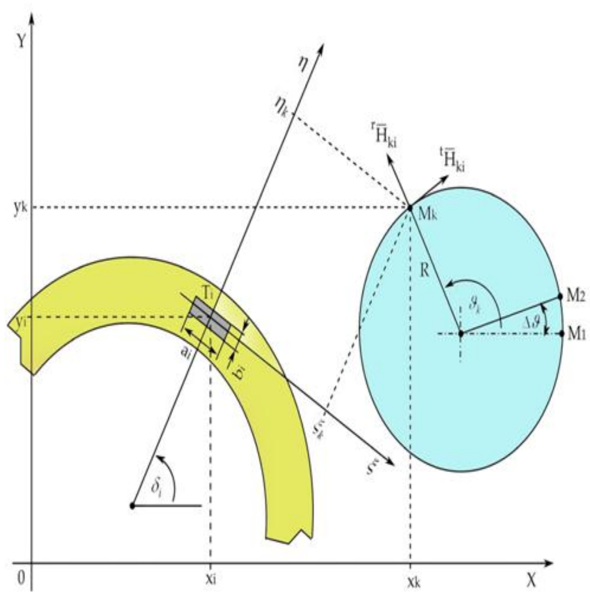

Figure (2): vector coordinates to calculation magnetic field

$$\xi_k = (x_k - x_i)\sin\delta_i - (y_k - y_i).\cos\delta_i \qquad (8)$$

$$\eta_k = (x_k - x_i).\cos\delta_i + (y_k - y_i).\sin\delta_i \qquad (9)$$

By use of bellow relationships the tangent and vertical parts of magnetic field will be known with polar coordinates.

$${}^{t}H_{ki} = {}^{\xi}H_{ki}.\cos(\vartheta_k - \delta_i) + {}^{\eta}H_{ki}.\sin(\vartheta_k - \delta_i) \qquad (10)$$

$${}^{r}H_{ki} = -{}^{\xi}H_{ki}.\sin(\vartheta_k - \delta_i) + {}^{\eta}H_{ki}.\sin(\vartheta_k - \delta_i) \qquad (11)$$

By use of busaver rules in electromagnetic discussion and defined relations based on figure (2) the severity of magnetic field in same direction of ξ axis will be as following relation (12). Similarly, by use of busaver rules the severity of magnetic field in same direction of η axis will find with relation (13).

$${}^{\xi}H_{ki} = -\frac{\bar{I}_i}{2\pi.a_i.b_i}.[\frac{1}{2}.\left(\zeta_k + \frac{a_i}{2}\right).\ln\frac{\left(\eta_k + \frac{b_i}{2}\right)^2 + \left(\xi_k + \frac{a_i}{2}\right)^2}{\left(\eta_k - \frac{b_i}{2}\right)^2 + \left(\xi_k + \frac{a_i}{2}\right)^2} -$$
$$\frac{1}{2}.\left(\zeta_k - \frac{a_i}{2}\right).\ln\frac{\left(\eta_k + \frac{b_i}{2}\right)^2 + \left(\xi_k - \frac{a_i}{2}\right)^2}{\left(\eta_k - \frac{b_i}{2}\right)^2 + \left(\xi_k - \frac{a_i}{2}\right)^2} +$$
$$.\left(\eta_k + \frac{b_i}{2}\right).\left(a\ \ \tan\frac{\zeta_k + \frac{a_i}{2}}{\eta_k + \frac{b_i}{2}} - a\ \ \tan\frac{\zeta_k - \frac{a_i}{2}}{\eta_k + \frac{b_i}{2}}\right)$$
$$-\left(\eta_k - \frac{b_i}{2}\right).\left(a\ \ \tan\frac{\zeta_k + \frac{a_i}{2}}{\eta_k - \frac{b_i}{2}} - a\ \ \tan\frac{\zeta_k - \frac{a_i}{2}}{\eta_k - \frac{b_i}{2}}\right)]$$

(12)

$${}^{\eta}H_{ki} = -\frac{\bar{I}_i}{2\pi.a_i.b_i}.[\frac{1}{2}.\left(\eta_k + \frac{a_i}{2}\right).\ln\frac{\left(\xi_k + \frac{b_i}{2}\right)^2 + \left(\eta_k + \frac{a_i}{2}\right)^2}{\left(\xi_k - \frac{b_i}{2}\right)^2 + \left(\eta_k + \frac{a_i}{2}\right)^2} -$$
$$\frac{1}{2}.\left(\eta_k - \frac{a_i}{2}\right).\ln\frac{\left(\xi_k + \frac{b_i}{2}\right)^2 + \left(\eta_k - \frac{a_i}{2}\right)^2}{\left(\xi_k - \frac{b_i}{2}\right)^2 + \left(\eta_k - \frac{a_i}{2}\right)^2} +$$
$$.\left(\xi_k + \frac{b_i}{2}\right).\left(a\ \ \tan\frac{\xi_k + \frac{a_i}{2}}{\xi_k + \frac{b_i}{2}} - a\ \ \tan\frac{\eta_k - \frac{a_i}{2}}{\xi_k + \frac{b_i}{2}}\right)$$
$$-\left(\xi_k - \frac{b_i}{2}\right).\left(a\ \ \tan\frac{\eta_k + \frac{a_i}{2}}{\xi_k - \frac{b_i}{2}} - a\ \ \tan\frac{\eta_k - \frac{a_i}{2}}{\xi_k - \frac{b_i}{2}}\right)]$$

(13)

Total value of magnetic flux density is calculated by summation all partial values according to relations (14) and (15).

$${}^{t}\overline{H}_k = \sum_{i=1}^{N} {}^{t}H_{ki} \qquad (14)$$

$${}^{r}\overline{H}_k = \sum_{i=1}^{N} {}^{r}H_{ki} \qquad (15)$$

Ampere rule can be used for presentation the phasor of severity of magnetic field and to calculate the total value of magnetic flux density according to relation (16).

$$H_k = \sqrt{\left(\left|{}^t H_K\right|^2 + \left|{}^r H_K\right|^2\right)} \quad (16)$$

Value of B by use of H value according to relation (17) can be calculated.

$$B_k = \mu_0 H_k \quad (17)$$

III. SIMULATION AND NUMERICAL RESULTS

Typical bus duct system for simulation studies is pars generator corporation product which, it has been installed on Ardebil substation. Test system is shown in figure (3).

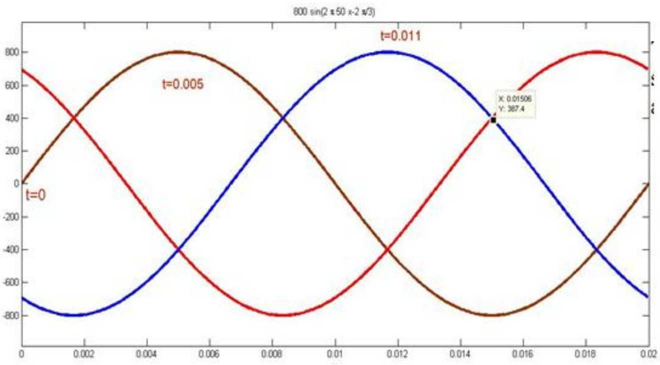

Figure (3): bus duct under studies

Effective level and impulse of bus duct voltage are equal to 38kV and 95kV, respectively. Rated current and power loss in each conductor are equal to 800A and 12W/m. Instantaneous current capability is equal to 500kA. Design of environment temperature for bus duct is 44°c. Permissible conductor temperature and insulator are 105°c and 80°c, respectively. The value of load resistance is 100Ω. Also, earth resistance has been neglected. Test network is simulated in the COMSOL environment by filament method [8]. The calculation will conduct with regard to 800A current in each phase. To achieve this goal, it is necessary that critical conditions and times which three phase composition create bad condition to bus duct and surrounding space, are analyzed. Three phase curve with 800A will be according to figure (4).

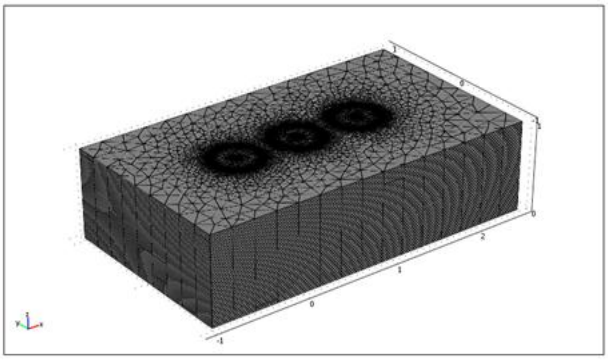

Figure (4): the curve of bus duct three phase current

Critical and sensitive values to simulation studies have been shown in table (1).

TABLE I: BUS DUCT CURRENT VALUES FOR DIFFERENT TIME

I_T	I_S	I_R	t
-692.8	692.8	0	0
-400	-400	800	0.005
800	-400	-400	0.011

With regard to that, there is current density requirement in calculations, it will compute based on the values of current and lateral surface area of bus duct according to table (2).

TABLE II: VALUE OF CURRENT DENSITY FOR DIFFERENT CURRENT

692.8	400	800	I
2450.7	1415	2829.9	J

By use of meshed method for bus duct, system will convert in many separate filaments and number of mesh should increase where is near to bus duct. In test system total number of mesh will equal to 32406.

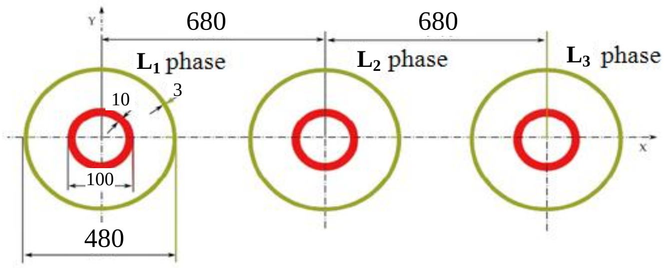

Figure (5): meshed environment in three dimension simulation

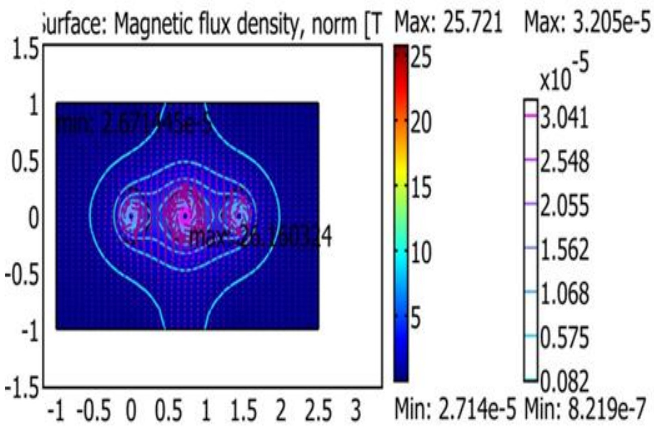

Figure (6): flux density and vectors of magnetic field

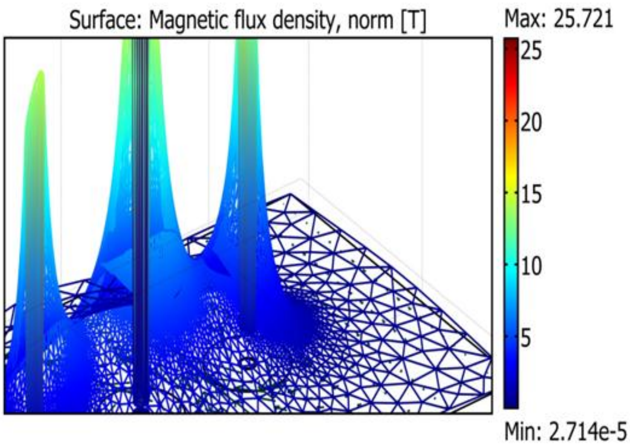

Figure (7): magnetic flux density with three dimension representation

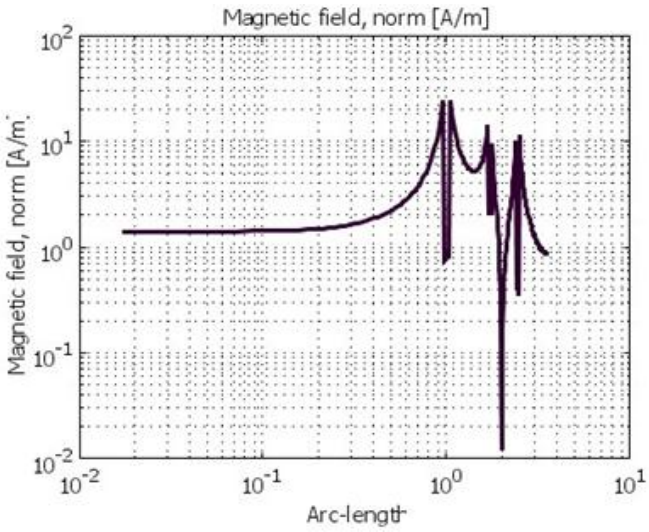

Figure (8): logarithmic representation of magnetic field based on distance of surrounding

By consider to earth system, current value of earth system will be equal to 1.2A. System power loss for different parts of system is according to table (3). Also, magnetic flux density profile in two states (1m and 0.5m distance), is shown in figure (9).

TABLE III: POWER LOSSES REPRESENTATION IN DIFFERENT PART OF SYSTEM

Power losses	**Losses (W/m)**		
	R	S	T
System conductors	11	11	11.
shell	12	12.	13
Total	0	73.7	0

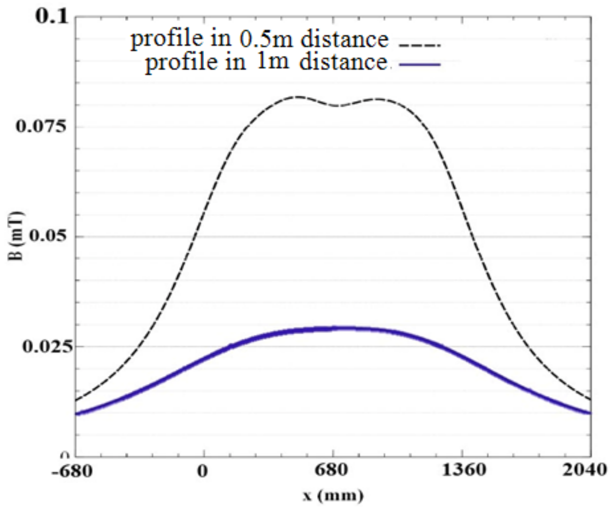

Figure (9): magnetic flux density profile in two states (1m and 0.5m distance)

If both side of bus duct are connected to earth system, value of flux density will be about 0.031623mT while, if one side of bus duct is connected to earth system and other side remain free, therefore maximum of flux density will equal to 0.5mT.

IV. CONCLUSION

There are different factors on the amount of bus duct undesirable effect such as total power losses, network over voltages and magnetic field on proximity equipment's. Better conditions will provide when, power losses and induced voltage on plate shell are minimized. Use of parallel bus duct in single phase cause to decrease in magnetic field which, decrement amount should be analyzed. Also, under real dimension and geometric shape conditions, calculation of electromagnetic field is very complicate therefore use of computational software in this field is an approach to overcome this problem. Numerical method and finite element are more common method in this software. Filament method as one of the best method has been proposed in this paper.

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