# Optimum Equivalent Models of Multi-Conductor Systems for the Study of Electromagnetic Signatures and Radiated Emissions from Electric Drives

A. Sarikhani, Student Member IEEE, M. Barzegaran, Student Member IEEE and
O. A. Mohammed, Fellow IEEE
Energy Systems Research Laboratory, Florida International University, Miami, Florida, USA

**Abstract — In this paper, we present optimum equivalent models for multi-machine environments, for the simulation and evaluation of radiated electromagnetic field emissions in electric drives. A full 3D finite element (3DFE) model of a 3 phase induction machine is simulated in a quasi-static electromagnetic domain. Based upon the simulated machine, an optimum equivalent model is determined. The identified equivalent model is validated in several examples by comparing its results of magnetic flux density and electric field with the full 3D finite element (3DFE) model of the actual machine systems. The calculated results show excellent accuracy with the full 3DFE model with significant reduction in computation time for evaluating the required field patterns. This makes the proposed model ideal for the development of accurate tools for the estimation of radiated electromagnetic field emissions from electric drives and multi conductor environments.**

## I. INTRODUCTION

Compliance with electromagnetic compatibility (EMC) standards and the evaluation of EMI issues is becoming a necessity with the increased utilization of high frequency switching in multi-source electric drives. Considering the EMC issues at the design and developments stages will help ensure safety, reliability, quality, and functionality of modern products and their utilization environments.

In the recent years, there has been an increased interest in the expansion of multi-level numerical simulation methods for investigation of EMC and EMI issue in the early stages of design of the electrical apparatus. There has been some studies evaluating signature patterns and radiated emissions from multi-machine environments. This represents a progress in this important area of product development and references [1-3] are examples. However, modeling of the EMC performance of multilayer systems, from the device level to the environment level, remains challenging for both of the technical and practical implementation reasons. As the number of the components within the system is increased, the complexity of the system within the device is also increased. The number and distributed nature of mutual coupling capacitances and inductances are increased exponentially. Therefore, a combination of small subsystems for creation of a system with lower number of components is needed for signature studies.

The goal of this paper is to provide an equivalent current loop model for an example induction machine. This model will make the simulation of low frequency fields in multi-machine environments simpler and faster using numerical models for signature studies. Since the study of far fields is usually measured at considerable distances from the components being studied, the elements of components which will not influence the field patterns at far distances can be simplified. For example, the rotor of a typical motor generally affect the flux pattern inside the machine structure but does not have a large effect at a far distance from the motor. Furthermore, as the observation point becomes far from the machine outer casing, the flux spectrum of multiple dipoles become one dipole. This allows simplification of the complex machine structure to one or several loops resulting in a more numerically reliable model for radiated field evaluations.

The proposed equivalent machine model for signature study is a cube as shown in figure 1. The sides of this cube carry current and the cube lengths (A, B, C) and the corresponding currents and voltages of the branches and nodes ($i_{x0},\ldots,i_{x3}$, $i_{y0}, \ldots i_{y3}$, $i_{z0}, \ldots i_{z3}$, $V_1$, $V_2$) are evaluated based upon an optimization process. The objective function of the optimization process which utilizes a PSO-GA algorithm is defined as:

$$\text{obj}=\text{mean}\left(\sum_{i=1}^{3}\left|B_i\left(x,y,z\right)_{3DFE}-B_i\left(x,y,z\right)_{Eq.model}\right|+\sum_{i=1}^{3}\left|E_i\left(x,y,z\right)_{3DFE}-E_i\left(x,y,z\right)_{Eq.model}\right|\right) \quad (1)$$

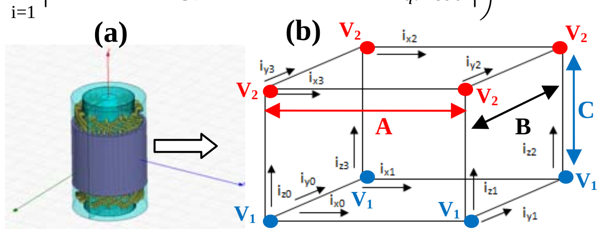


Fig.1. Prototype of the proposed machine (SCIM) in Finite Element Analysis (a), An equivalent current loop model for EMI and signature studies (b)

Where $B(x,y,z)$ and $E(x,y,z)$ are $N\times 3$ matrix that are calculated for three vector lines for the normal magnetic flux density and electric field along three lines in *x*, *y*, and *z* directions, as shown figure 3. The indices, *3DFE* and *Eq. model*, stands for real 3D motor model, and its corresponding equivalent model as depicted in figure 1. Here, $N$, stands for the number of samples along the x, y, and z lines.

## II. Simulation Results

For simulation purposes a 3-phase, 380-V, 10-A, 120-turn/phase induction machine with stack length of 0.15 (m) and outer diameter of 0.175 (m) is simulated in a 3D quasi-static FE domain for one time instance. The magnetic flux densities along three lines in the x, y, and z directions, $Bx, y, z_{motor}$, are calculated, and the optimization process runs to minimized the objective function.

After the optimization process, the side lengths are calculated as (A= 0.279 (m), B= 0.2 (m), C= 0.31(m)). The comparison between the normal magnetic flux densities of the full 3DFE model and the proposed cube model in one motor case is illustrated in figure 2.

For further validation of the proposed model, another case including a two-motor set in a multi-conductor environment, shown in fig. 3 was considered. The results of this model were then compared with the two-cube model. The dimensions, currents in each of the cube branches remain the same as the initial cube as well as the motors. The center of the coordinate system of each cube is set exactly the same as its corresponding 3D motor's model.

Figure 4 and 5, respectively show a comparison between the magnetic flux density and Electric field in the machine and the equivalent model for two-motor study cases. As can be seen from these figures, the magnetic flux densities and electric fields again follow the same patterns with the accepted accuracy. Although, the optimization process for finding the branch currents and node voltages is a time consuming process, the comparison between the various simulation times show that the proposed approach make the simulation time nearly 80 times faster than using the full 3DFE model without sacrificing accuracy. Moreover, we also observed that in case of evaluation of the field in just two directions, more accurate results can be obtained.

## III. Conclusion

In this paper, an equivalent current loop model of the multi conductor systems is presented as an a new and efficient approach toward the evaluation of radiated field patterns at far distances from the source. The proposed model was verified for a single and multi machine environments. This model allows us to evaluate products for their EMC/EMI compliance as well as their signature and radiation patterns during the development stage.

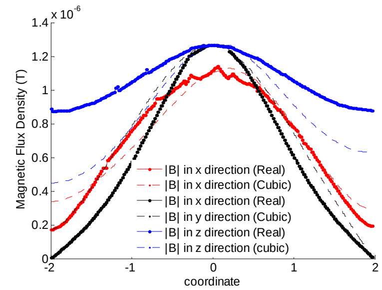


Fig. 2. Comparison between magnetic flux density in 3DFE and equivalent model for one motor

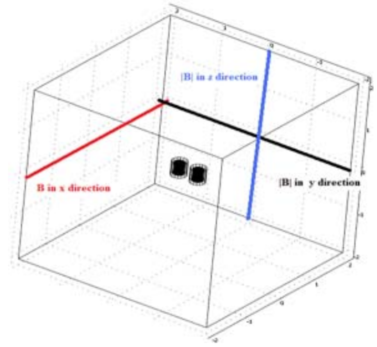


Fig. 3. Case of study for validation of the model, two motor

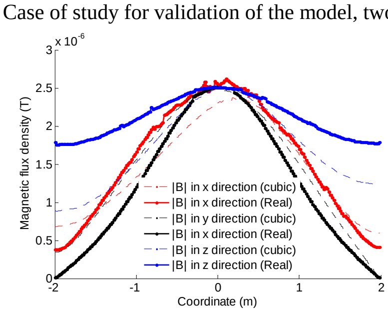


Fig. 4. Comparison between magnetic flux density in 3DFE and equivalent model, two motor compared with two equivalent models

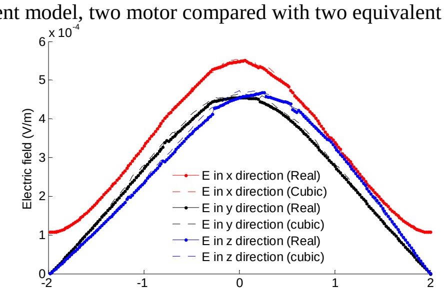


Fig. 5. Comparison between Electric filed in 3DFE and equivalent model, two motor compared with two equivalent models

## IV. References


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