Electromagnetic Signature Study of a Power Inverter Connected to an Electric Motor Drive

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Abstract— In this paper, a study of the radiated electromagnetic behavior of a power inverter is proposed. An inverter is simulated using three dimensional finite element (FE) modeling with a new approach in simulating the switching activity. The inverter is connected to an electric motor drive. For verification, the same setup was experimentally tested and the results show that the numerical simulation provides the exact field solution at a given distance. Furthermore, the correlation between the electromagnetic fields generated by each of the components was analyzed. The implication of this study is to evaluate electromagnetic field radiation for EMC compliance at the design stage.

***Index Terms*—Low Frequency Signature Study, Finite Element Analysis, Power Electronic Drives**

I. INTRODUCTION

With the increased development and utilization of power electronic drives, the evaluation of low frequency electromagnetic fields (DC to hundreds of kHz) in these devices become necessary. Power electronic drives have an electric system of significant power consisting of power converters, electric motors and electric loads.

Emission of low order harmonics can often be modeled using equivalent circuit modeling as current sources. This is while high order harmonics appear as voltage sources under normal conditions. In between these two simplified models there is naturally a more complex reality. Resonances may increase the complexity further. In addition, equivalent circuit modeling of power electronic drives doesn't show the radiated emission in the three dimensional areas around the drive. Therefore, the physics based modeling is proposed in this paper to evaluate the radiated field in the three dimensional space around the devices. In addition, the material properties of the devices and shape representation were investigated in this modeling process. On the other hand, time-varying electric and magnetic fields generate MMFs and EMFs that can sustain the fields that compromise the flux. Also, the currents and voltages in electric power systems are time-varying, which causes radiated electromagnetic fields. Therefore there is a need to model the EMI generated by these systems to develop designs meeting EMC standards. Several studies were performed in the area of radiated low frequency electromagnetic field (EMF) analysis of power electronic devices which some dealt with the impact of EMF on the environment and the others were conducted to implement attenuators and shielding of the radiated EMF [1], [2].

In this paper, three dimensional full finite element modeling of a typical power electronic drive at low frequency is analyzed. The frequency response of the drive was implemented in simulation as well as in the experimental setup. The results are compared and the application of this study was discussed.

II. RADIATED LOW FREQUENCY FIELD CALCULATION

Due to the Hertzian dipole and Maxwell equation, the electromagnetic potential of a dipole around the z-axis at a point P (r, θ, ϕ) is given by

$$\mathbf{A} = \frac{\mu I\, dl}{4\pi r}\mathbf{a}_z \qquad (1)$$

The time variant currants and the potential in (1) would lead to an inconstant field with Maxwell equation. The reason is that the time-variant fields give rise to wave propagation. Accordingly, the effect of the source current at a given value of time is felt at a distance *r* from the origin after a time delay of r/υ_p, where υ_p is the velocity of propagation of the wave. Considering this, the retarded magnetic vector potential is:

$$\mathbf{A} = \frac{\mu I_0\, dl}{4\pi r}\cos(\omega t - \beta r)\mathbf{a}_z \qquad (2)$$

where β is r/υ_p, the phase constant. The magnetic field **H** due to the Hertzian dipole is given by:

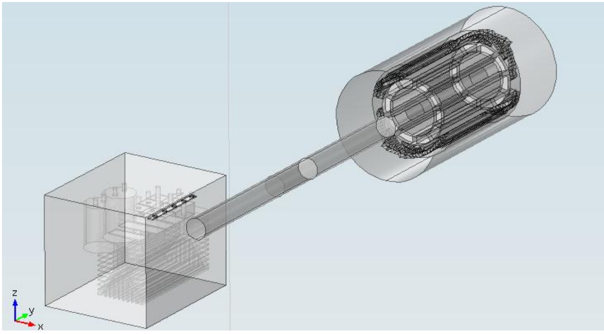
$$\mathbf{H} = \frac{\mu I_0\, dl \sin\theta}{4\pi}\left[\frac{\cos(\omega t - \beta r)}{r^2} - \frac{\beta \sin(\omega t - \beta r)}{r}\right]\mathbf{a}_\phi \qquad (3)$$

Equation (3) represents the radiated magnetic field due to the Hertzian dipole [2]. The radiated field of a complex model with thousands of dipoles, such as the proposed drive, needs the calculation of the field of each of these dipoles and having the whole field using a numerical method such as the FE method. The proposed model was accurately built in FE in which the above equation is calculated.

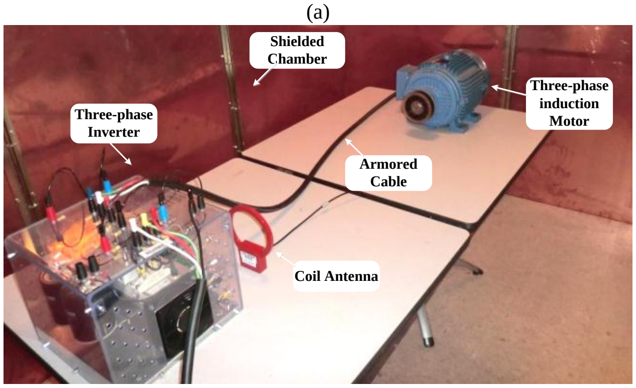
III. SIMULATION AND MEASUREMENT

In order to model the behavior of the IGBT for signature study, the switch is considered off and then it is turned on. In order to perform this in FE simulation, the plate between the load and the positive bus was considered a conductive plate for switch-ON case. Subsequently, this plate was considered non-conductive plate for the switch-OFF case. This alteration of the conductivity of the plate occurs 5000 times in a second due to the switching frequency. The simulation was computed in 6 hours with about 6 million degrees of freedom which means this leads to a good accuracy.

The proposed FE model is shown in fig.1 (a) and the similar test setup is shown in fig.1 (b). This electronic drive consists of an inverter, induction motor and the armored connection cable. The details of the devices are identified in Table1.



(a)



(b)

Fig.1. The scheme of the setup of case 2 (a) FE simulation (b) measurement

Table1. The details of the components in the tested setup

component	Characteristics
Inverter	**Three-phase, switching frequency: 5kHz , switching algorithm: SVM, length: 30cm, width: 30cm, height: 25cm, , nominal voltage: 320V, amp: 20A**
induction motor	**Three-phase, 5.5 kW, , length: 30cm, diameter: 20cm, , nominal voltage: 208V, number of poles: 4**
Connection cable	**XLPE, Diameter: 5cm, insulated and armored PVC sheathed cable**

In this setup, the inverter is connected to an induction motor. The aim is investigating the radiation of the harmonic fields from the inverter while the distance and the speed of the motor changes.

The magnetic field intensity (H-field) radiated from the setup in simulation is shown in fig. 2. The H-field is shown on a slice at 5 kHz frequency at 10 cm away from the setup.

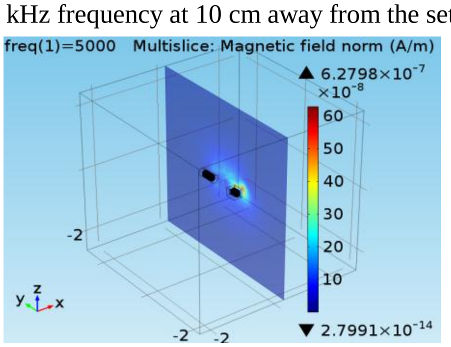


Fig.2. Radiated magnetic field intensity of the setup case2 at 5 kHz simulated in FE (μA/m)

Similarly, the setup was implemented experimentally and the frequency response from DC to 20 kHz was obtained. The experiment was implemented based on the MIL-STD-462D. The coil antenna which can detect magnetic field from 20Hz to 30MHz was located around the inverter to obtain the radiated fields. The fields are transferred to an EMI receiver with a cable of 50Ω impedance. The proposed EMI receiver can detect the fields from DC to 3GHz.

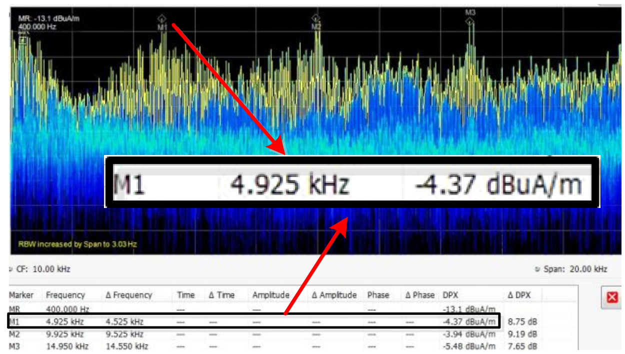


Fig.3. Measured frequency response of the radiated magnetic field intensity of the setup case2 from DC to 20 kHz (dBμA/m)

The unit of the simulation result is μA/m, while the unit of the experimental one is dBμA/m. The μA/m can be converted to dBμA/m by using (4) below. Using this equation, the peak at 5 kHz is -4.37 dBuA/m, would be 0.61 μA/m which is very close to the value in simulation, see fig.2.

$$\mu A/m = 10^{\frac{dB\mu A/m}{20}} \quad (4)$$

As shown in fig.3, the first peak located at very low frequency is propagated from the induction motor, since the motor is working at the power frequency, 60Hz. the working frequencies of the components are different. The behavior of each component can be investigated individually. This can be a very useful hint in monitoring the conditions as well as detecting the faults of the motor and the inverter. Note that, the peaks at 10 kHz and 15 kHz in fig.3 are due to the 2^{nd} and the 3^{rd} harmonic of the inverter. The frequency responses in between harmonics are noises and sub-harmonics.

IV. Conclusion

In this paper, 3-D full finite element modeling for the radiated EMI study of a typical power electronic drive was implemented. A new approach in simulating the switching activity was proposed. The measurement was also applied for verification on the numerical results as well as for investigating the radiated fields under different operating conditions. The results show that the FE model has a good accuracy for evaluating the radiated fields. The results also show that the frequency response of the field can be used for assessing shielding arrangements as well as for monitoring the conditions of the drive.

V. References

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