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Using the Matrix Pencil in order to analyze the disturbances induced by the radiation of static converters

M. Melit *, B. Nekhoul, B. Khelifi, N. Boudjerda

University of Jijel, BP 98 Ouled Aissa, 18000 Jijel, Algeria

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ABSTRACT

The Matrix Pencil method is used for extracting maximum information from the Electro-Magnetic disturbances emitted by power converters; these disturbances are manifested by an induced current in electric systems located in the power converter environs. The modeling of the power converter in time domain is realized by solving Maxwell's equations which allow determining the radiated electromagnetic field, Ampere's theorem is then used for computing the induced current in passive loops representing the victim system. In our work we also analyze the effect of the geometric configuration for both the passive loops and the power converter by extracting the poles and residues using Matrix Pencil method.

Introduction

The use of power electric converters is in large and extensive progress, both professional and military domain (embarked equipment, speed variation, heating, and control of energy...) and general public (domestic, automobile, computers...) are concerned. Electric functioning of power converters by means of the passage of electric currents in there circuits which constitute an Electro-Magnetic (EM) sources of disturbance that manifested by radiated electromagnetic fields. These disturbances, sometimes very constraining, lead the engineers of research towards a vast field commonly called ''Electro-Magnetic Compatibility''.

In practice, the power electronic converters are subject to the transient currents and voltages during standard functioning of the switch (turn-off and turn-on). For this reason, its important to quantify the EM field emitted by the converters in time domain and to know the signature of the electromagnetic disturbances manifested by induced currents in neighboring equipments or measurement devices or any more electrical system.

Let us consider the complex shape of the power electronic converters, an accurate modeling requires taking in consideration the different components forming the converters. Classically, numerical modeling in frequency domain is used with the marketed simulation codes (NEC, FEKO...); this modeling consists in the resolution of the integral equation by moment method [1], the Fast Fourier Transform allows the study in time domain. Modeling in time domain consists on the resolution of Maxwell equations by Finite Difference Time Domain (FDTD) [2].

In our work, we suggest an approach based on the resolution of Maxwell curl equations by FDTD and we compute the induced currents using Ampere's theorem. Next, we investigate these last by Pencil matrix method. The mathematical study of current induced by the electromagnetic field emitted by static converter using the parametric Pencil method will allow us to identify the dominant frequency in terms of energy carried by the disturbance to assist in the analysis of electromagnetic compatibility of the device and its environment.

In our study we treat the electromagnetic interaction between a power converter and electrical equipment located in its vicinity. Knowing that the coupling by radiation concerns essentially the conductive loops, we will represent the victim device by a simple passive loop. The mathematical analysis of the current with Pencil method will inform us about the role of the loop geometry.

Computation of electromagnetic field and induced currents

The geometry of a typical power converter circuit in the environs of passive loop is illustrated in Fig. 1; its composed of a voltage source V_s with an internal resistor R_s, and the load is represented by the resistor R.

Taking into account the geometries of the converter and the passive loop (Fig. 1), the computation of the radiated electromagnetic field distribution is not a fast task; this is due to the fact that it contains linear lumped elements (V_s, R), dielectric layer and PCB

* Corresponding author. Tel./fax: +213 34 50 15 87.
E-mail addresses: melit@univ-jijel.dz, mohamed.melit@lasmea.univ-bpclermont.fr (M. Melit).

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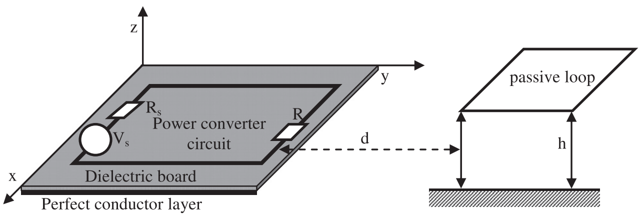

Fig. 1. The configuration of power converter and passive loop (victim) used in our work.

trace. In time domain, numerical computation can be obtained based on the resolution of Maxwell equations by FDTD method.

To do this, the following Maxwell curl equations can be used:

$$rot\,\vec{E} = -\mu \frac{\partial \vec{H}}{\partial t} \tag{1}$$

$$rot\,\vec{H} = \sigma\vec{E} + \varepsilon\frac{\partial \vec{E}}{\partial t} \tag{2}$$

where ε is the electric permittivity of the medium, μ the magnetic permeability of the medium, σ is the electrical conductivity of the medium.

By replacing the partial derivatives in Eqs. (1) and (2) by the finite differences in space and in time, Yee [2] deduces a set of equations equivalent to Maxwell's equations in the Cartesian coordinate system. In this set of equations Yee [2] evaluates the electric field $\vec{E}$ and the magnetic field $\vec{H}$ at alternate half-time steps.

Yee [2] introduces a set of finite difference equation for the scalar equations system, equivalent to Maxwell's equations in the Cartesian coordinate system, and to realize all of the space derivatives, he evaluates the electric field E and the magnetic field H at alternate half-time steps.

Any structure (3D, 2D or 1D) to be analyzed is discretized by an FDTD grid which extends to the limits of the considered structure if it is finite dimensional and clearly defined boundaries. Otherwise, truncation modeling is possible but remains with uncertain precision.

The modeling of open boundary structures is possible with some special conditions called absorbing boundary conditions [3].

Because of the limited computer memory and for the purpose of decreasing the computational time, the space of simulation must be taken as small as possible. Therefore, the simulation space must be truncated. If nothing were done to address this, some unpredictable reflections would be generated that would go back inward. This is the reason that absorbing boundary conditions (ABCs) have been an issue for as long as the FDTD has been used.

Absorbing boundary conditions

In the configurations of the power converters circuits treated in this paper, one of the six mesh boundaries of computation domain is a perfectly ground plane (Fig. 1), consequently its tangential electric field values are forced to be zero [4]. The tangential electric field components on the other five mesh walls must be specified in such a way that outgoing waves are not reflected using the absorbing boundary conditions [3].

In order to take account of open boundaries, the first approach is a very simple method proposed by Taflove [5] known as the retarded-time method which is based on the propagation of an electromagnetic wave in a single direction. This method was subsequently developed in two variants by Mur [3], which also suggested its implementation by FDTD.

Recently, a more accurate method called PML (Perfectly Matched Layer) has been proposed by Berenger [6,7]. It allows a very good absorption of electromagnetic waves. However, its implementation requires a relatively complicated digital processing. Another variant of this method has been proposed by Sullivan [8]. This last differs from that of Berenger [7] in two aspects: first, Sullivan [8] proposes using a fictitious conductivity associated with the electric displacement vector D instead of the electric field E, secondly, it makes adjustments to the parameters of the FDTD method instead of adjusting the conductivity or the spatial discretization proposed by Berenger [6].

Several studies have shown the effectiveness of different methods of absorbing boundary [9,10] for modeling structures with open boundaries. In a recent work, Gao [9] presents a comparison of different methods, where he showed the error and the simulation time required for each of them. The methods of Berenger [6] and Sullivan [8] need respectively a simulation time 12 and 30 times more than the Mur [3] method but with better accuracy. From this comparison we can see that the first-order Mur's [3] ABC is the most efficient.

In our work, knowing the nature of the treated devices in which we will only quantify the magnitude of the electromagnetic field, we have opted to use the first-order Mur's ABC [3] whose implementation is simpler and consumes less computation time with acceptable accuracy.

Some considerations for the implementation of the FDTD method on circuit components

FDTD method is extensively used for solving electromagnetic problems since Yee [2] first proposed it in 1966. In our work we apply FDTD method in 3-D for calculating the distribution of electromagnetic fields radiated by the power converter and the induced current in the passive loop. In this case, some problems must be solved. First, dealing with the printed circuit traces, second, handling the dielectric boards and third, some kinds of lumped loads. This approach is largely described in the literature [11].

Printed circuit traces

The PCB trace has a very high conductivity, so the electric conductors can be assumed to be perfectly conducting and have zero thickness, and simply treated by setting to zero the tangential electric field components on them [4]. Through numerical experiment testing, it is demonstrated that this method is suited to our applications.

Dielectric board

In 1988, Taflove [12] first proposed a method named contour integral approach and derived from the Maxwell's integral equations. This approach permits to derive the FDTD equation from the Maxwell's integral Eqs. (3) and (4) in an inhomogeneous medium which include the free space and dielectric board.

$$\oint_\ell \vec{H} d\vec{\ell} = \int\int_S \sigma\vec{E}\cdot d\vec{S} + \frac{\partial}{\partial t}\int\int_S \varepsilon\vec{E}\cdot d\vec{S} \tag{3}$$

$$\oint_\ell \vec{E} d\vec{\ell} = -\frac{\partial}{\partial t}\int\int_S \mu\vec{H}\cdot d\vec{S} \tag{4}$$

The derivation of FDTD equation in an inhomogeneous medium from Maxwell integral Eqs. (3) and (4) is detailed in [13].

Lumped components

The power converter circuit treated in this paper (Fig. 1) includes linear lumped elements (resistor, voltage source with internal resistance). Using FDTD method, lumped elements may be considered in Maxwell's equation by starting with Ampere's theorem [10].

If we consider that the elements of the converter are oriented in the direction of the x-axis as shown in Fig. 2, using the characteristic