THE USE OF CIRCUIT SIMULATION SOFTWARE FOR ANALYSIS OF CONDUCTED ELECTROMAGNETIC INTERFERENCE GENERATED AND PROPAGATED IN STATIC CONVERTERS

Luis C. M. Schlichting
GEELN/CEFETSC
88020-300
Florianópolis – SC – Brazil
schlicht@cefetsc.edu.br

Muriel B. de Liz
GEMCO/EEL/UFSC
C.P. 476 – Trindade – 88040-900
Florianópolis – SC – Brazil
muriel@eel.ufsc.br

Adroaldo Raizer
GEMCO/EEL/UFSC
C.P. 476 – Trindade – 88040-900
Florianópolis – SC – Brazil
raizer@eel.ufsc.br

Abstract — **The aim of this paper is to evaluate the use of circuit simulation software for prediction of conducted EMI generated by static converters. First, the conducted EMI generated by a flyback converter is measured using an artificial mains network. Afterward, the flyback circuit was modeled using circuit simulation software. Non-idealities inherent to a real circuit were added to the model in a step-by-step manner to evaluate their effect in the conducted EMI generated. Finally, the EMI measured through the simulated model gets very close to the measured EMI, assuring the advantage of using circuit simulation software to predict conducted EMI levels from static converters.**

KEYWORDS

Electromagnetic Interference, Electromagnetic Compatibility, Power electronics, Simulation software.

I. INTRODUCTION

The usual techniques for putting equipment in conformity with the Electromagnetic Compatibility (EMC) standards can be applied in the various stages of design. These techniques can act in the generation and/or the propagation of the Electromagnetic Interference (EMI). It is necessary a good understanding of the process of EMI generation and propagation to apply effectively these EMI reduction techniques.

An important tool in the study of the EMI related to static converters is their simulation via software. With this simulation tool, it is possible to predict the amount of generated EMI and the paths by which it is going to probably propagate. The accurate modeling of the components that compose the converters is a problematic issue in the reproduction of its operation. From the EMC viewpoint, it is necessary to consider the intrinsic non-idealities of semiconductors, resistors, inductors, capacitors, transformers, printed circuit board tracks, etc. These non-idealities are usually modeled as coupled capacitances and inductances, as well as intrinsic resistances of the components.

This paper presents the study, from the EMC viewpoint, of a static converter (220Vac/24Vdc, 24W) using *flyback* topology. This converter is analyzed using circuit simulator software. The obtained results and the models adopted in the simulation are validated with the converter practical implementation.

II. FLYBACK CONVERTER – EXPERIMENTAL RESULTS

For the experimental study, measurement of drain-source voltage in the power transistor and measurement of conducted EMI were carried out. These measurements will be compared with the results obtained via simulation. In Fig. 1, one can realize the waveform of the drain-source voltage acquired from the converter's MOSFET power transistor. In Fig. 2, one can realize the harmonic analysis of the drain-source voltage waveform. From Fig. 2, one can realize that the 16th harmonic component has a higher level than the precedent and subsequent harmonic components. In Fig. 3, the measurement of the conducted EMI generated by the converter is presented. One can realize that around the frequency of 508 kHz (16th harmonic component), there is an increase in the spectrum amplitude.

III. FLYBACK CONVERTER – SIMULATED RESULTS

For the simulations, it was used the circuit simulator software SPICE 8.0 (evaluation version). Fig. 4 and Fig. 5 present the converter schematic without non-idealities and with non-idealities, respectively. Fig. 5 also shows the inclusion of an artificial mains network (Line Impedance Stabilization Network – LISN), which acts as a transducer for EMI measurement.

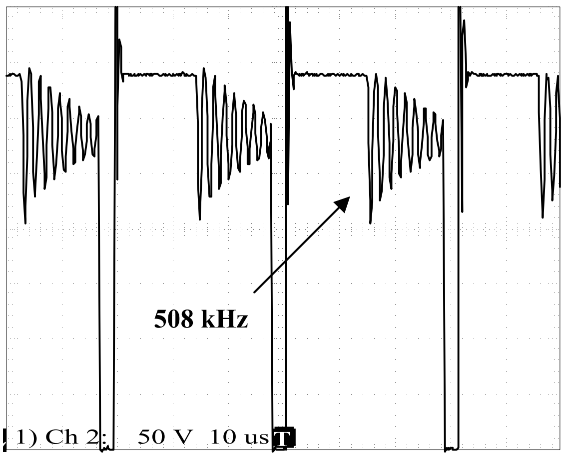

Fig. 1 – Drain-source voltage waveform.

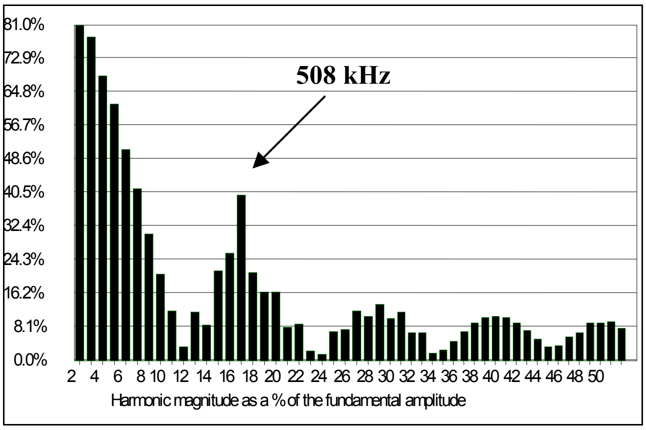

Fig. 2 – Harmonic Analysis of drain-source voltage waveform.

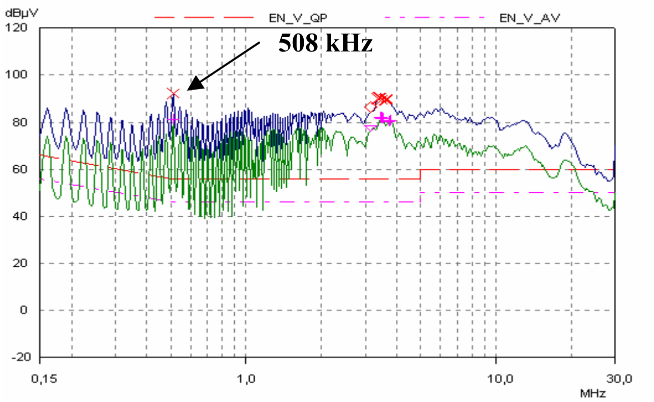

Fig. 3 – Frequency spectrum from the conducted EMI propagated through feeding cables.

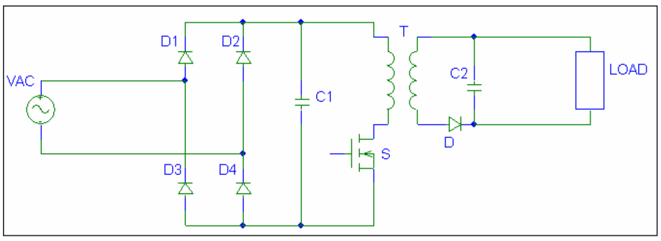

Fig .4 – Flyback converter schematic without non-idealities.

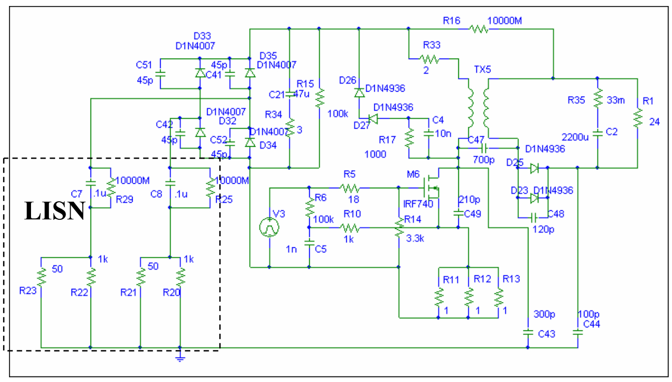

Fig. 5 – Flyback converter schematic with non-idealities.

For the simulation, it was used a simplified model and, when new elements concerning non-idealities were added, the conducted EMI was measured. Non-idealities adopted were:

- In the transformer circuit it was added the primary winding resistance (R33). The resistance of the secondary winding was negligible due to conductor gauge. Also, in the transformer it was added the capacitance (C47), which represents the capacitive coupling between the windings (inter-winding capacitance).
- The elements of the clamping circuit were added (D26, D27, R17, C4)
- Two diodes (D23, D25) were added because this was the actual configuration of the experimental converter. In parallel with these diodes, the capacitor (C48) was added representing its capacitances.
- Resistors (R11, R12, and R13) were added because they are in the experimental structure and are used for sensing the MOSFET (M6) drain-source current.
- Capacitor (C43) was added to represent the coupling: Drain/Heat sink/Ground.
- Resistor (R15) was added too, because it is in the experimental structure with the purpose of discharging the rectifier filter capacitor (C21). In this capacitor, its equivalent series resistance (R34) was added.
- The coupling factor of the transformer was changed.
- In the capacitor (C2), it was added its series resistance (R35).
- Parallel to the MOSFET (M6), it was added a capacitor (C49) to represent its output capacitance.
- It was added capacitor (C44) to represent the coupling output/ground.
- The power supply was omitted. Therefore, the noise generated by the converter will flow through resistor (R23). To accomplish this, capacitor (C21) starts with an initial condition.
- In parallel with each one of the rectifier bridge's diodes, capacitors (C41, C42, C51 and C52) were added to represent the parasitic capacitance between these element's terminals.
- Resistors (R16, R29 and R25) were added to prevent convergence problems from the circuit simulation software. As the additional resistance of these elements is of quite high value, they do not interfere with the simulation results obtained.

Fig 6 shows the first circuit simulated. Fig. 7 shows the drain-source voltage from power transistor (M6). Fig. 8 shows the harmonic analysis from the drain-source voltage of power transistor (M6). Finally, Fig. 9 shows the conducted EMI simulated, i.e., measured through the artificial mains network of Fig. 6. Also from Fig. 6, one can realize that the circuit already presents some non-idealities, which are indicated.

From Fig. 9 one can realize that the measured noise has a lower level when compared to the amplitude values given in Fig. 3 (conducted EMI, measured). However, the drain-source voltage waveform shown in Fig. 7 is similar to the waveform obtained through experiment. The EMI is being generated, but it is not propagating outside the converter.

Fig. 10 shows the second simulated circuit, and Fig. 11 shows the drain-source voltage waveform obtained. Fig. 12

shows the harmonic analysis of the drain-source voltage. Fig. 13 shows the conducted EMI simulated. Comparing Fig. 13 with Fig. 9, one can realize that the conducted EMI presented sensible changes. The EMI predicted via simulation is closer to the experimental values obtained.

Analyzing Fig. 11 and 12, one can realize that the drain-source voltage waveform is closer to the experimental waveform. The harmonic component of 600 kHz has increased. The noise in this frequency range is associated to the MOSFET power transistor (M6) commutation [1, 2].

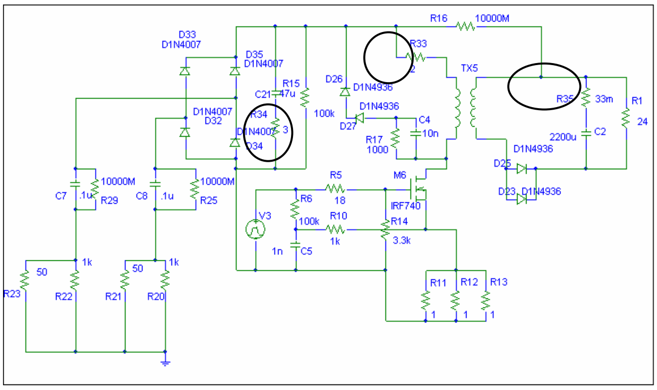

Fig. 6 – First circuit simulated.

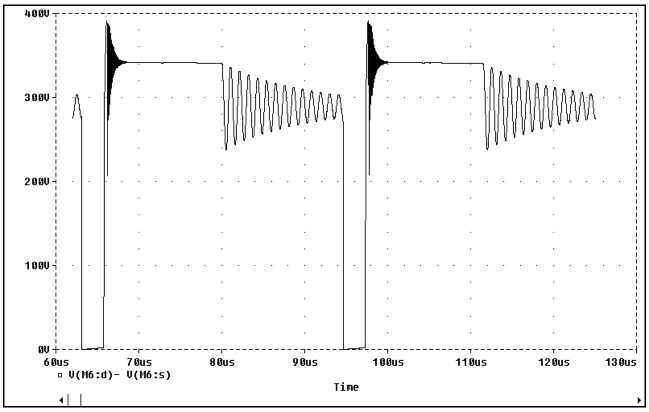

Fig. 7 – Drain-source voltage at transistor M6.

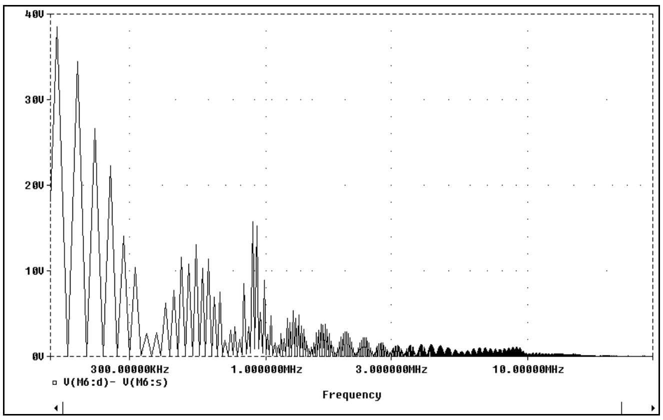

Fig. 8 – Harmonic analysis from drain-source voltage.

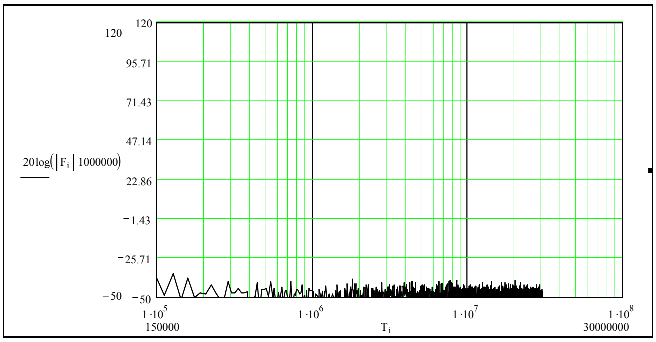

Fig. 9 – Conducted EMI measured in the artificial mains of the simulated circuit.

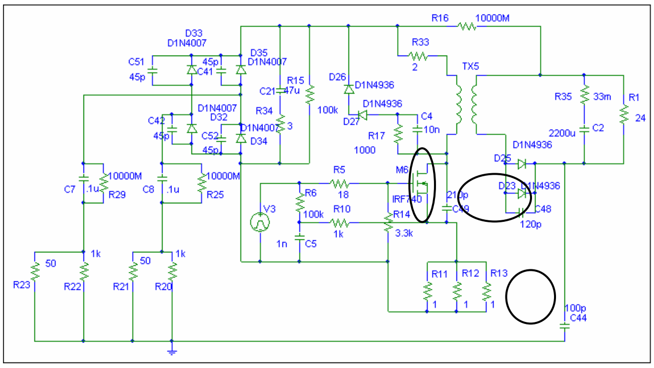

Fig. 10 – Second simulated circuit.

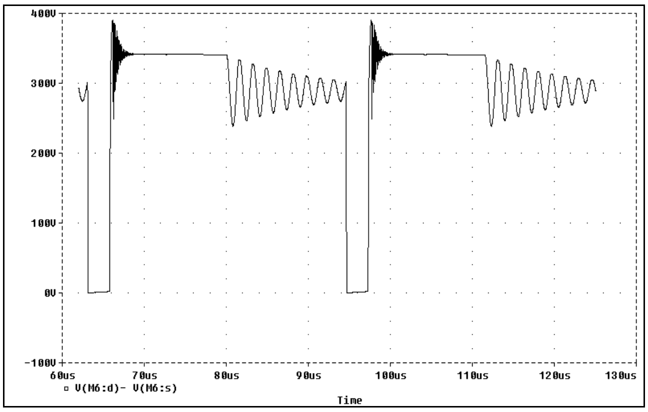

Fig. 11 – Drain-source voltage.

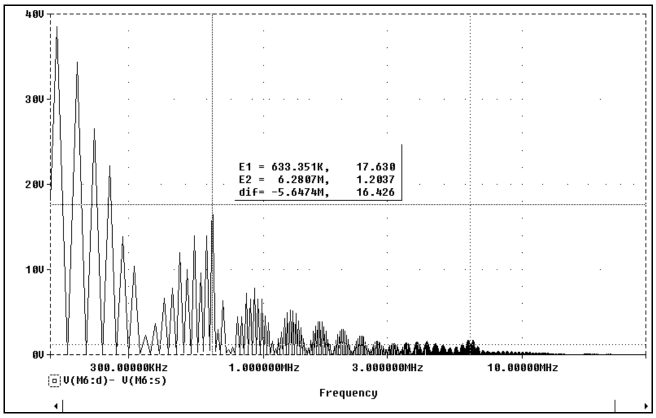

Fig. 12 – Harmonic analysis from drain-source voltage.

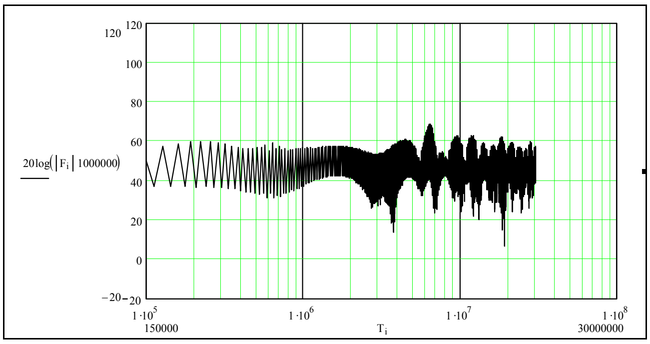

Fig. 13 – Conducted EMI measured in the artificial mains of the simulated circuit.

Fig. 14 shows the third simulated circuit. Fig. 15 shows the drain-source voltage waveform. Fig. 16 shows the harmonic analysis from the drain-source voltage and Fig. 17 shows the conducted EMI associated with circuit from Fig. 14.

Analyzing the result presented in Fig. 17, one can realize the influence of the inter-winding capacitance from the transformer in the conducted EMI. Also, one can realize that this capacitance (C47) has more influence in the high frequency range, particularly in the 3MHz to 30MHz frequency range. The influence of the inter-winding coupling capacitance in the EMI propagation is known [5]. However, this phenomenon is not easy to be isolated and treated. So, simulation demonstrates to be a useful tool in the prediction of the amount of conducted EMI generated by a static converter and the paths by which it is going to propagate.

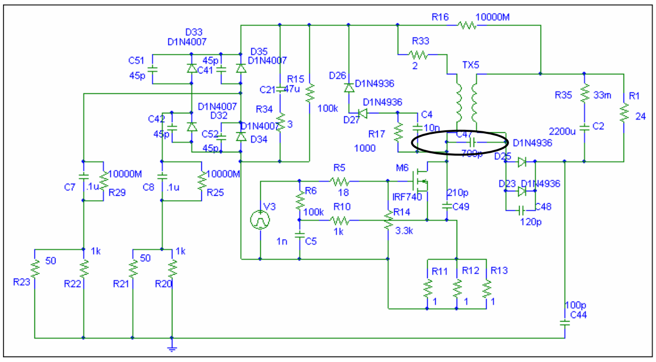
Fig. 14 – Third simulated circuit.

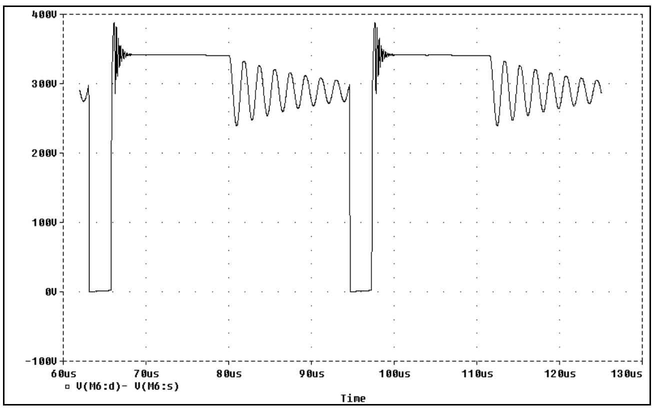

Fig. 15 – Drain-source voltage waveform.

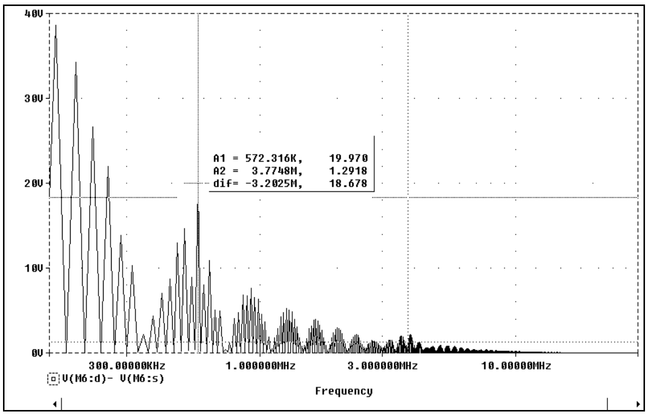

Fig. 16 – Harmonic analysis from drain-source voltage.

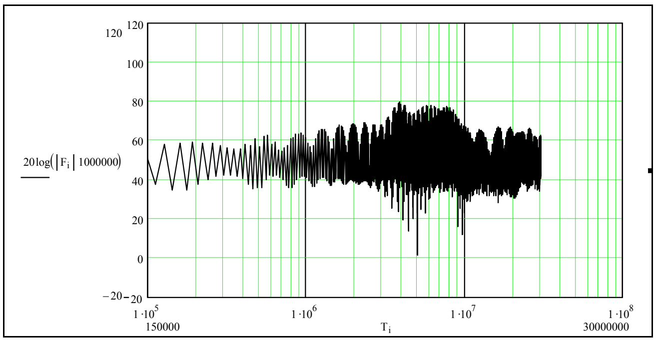

Fig 17 – Conducted EMI measured in the artificial mains of the simulated circuit.

Fig. 18 shows the last simulated circuit. Fig. 19 shows the drain-source voltage waveform from the MOSFET (M6). Fig. 20 shows the harmonic analysis from the drain-source voltage. Fig. 21 shows the conducted EMI associated to the Fig. 18 circuit.

From Fig. 21 one can realize that the conducted EMI simulated is very close to the measured result. The drain-source voltage presented in Fig. 19 and its respective harmonic analysis in Fig. 20 are very close to the experimental results. The harmonic component of 506 kHz is in evidence. The results show that capacitance (C43), which represents the capacitive coupling between drain/heat sink/ground, has a strong influence in the frequency range that extends from 150 kHz to 3 MHz, as in the case of the inter-winding capacitance in the transformer. The influence of the path associated to the drain/heat sink/ground capacitance now is known, but is hard to analyze.

IV. Conclusions

The presented results evidence the validity of simulation as a tool for studying the EMC generation and propagation mechanisms in static converters. The EMI generation and propagation in a static converter were reproduced with a high degree of similarity by using simulation software, like SPICE.

From the experimental and simulated results, one can realize the influence of commutation parameters in the generated EMI.

Also with the experimental and simulated results one can realize the influence of static converter components' non-idealities in the generated and propagated EMI.

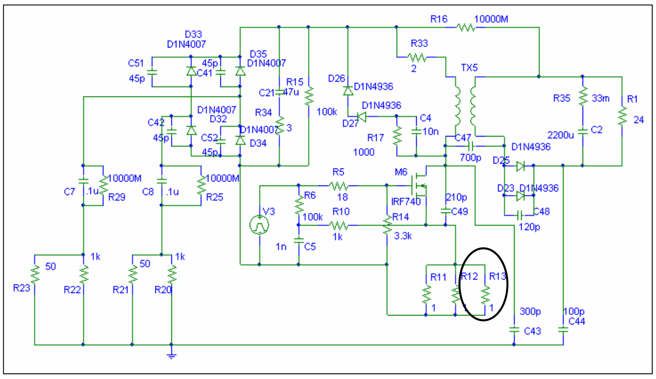

Fig. 18 – Last simulated circuit.

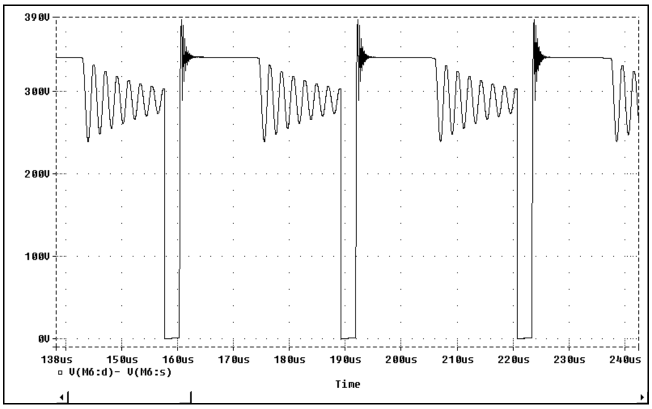

Fig. 19 – Drain-source voltage waveform.

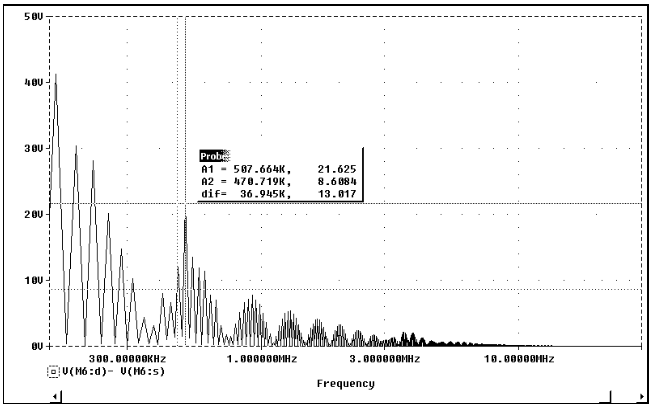

Fig. 20 – Harmonic analysis of drain-source voltage.

The simulation studies demonstrated the influence of inter-winding transformer and drain/heat sink/ground coupling capacitances in the propagated EMI. So, one knows which non-idealities must be treated to solve particular problems.

The study via simulation of EMI concerning static converters requires from the researcher a deep knowledge of the converter under analysis, of the simulation software parameters and of EMC and EMI.

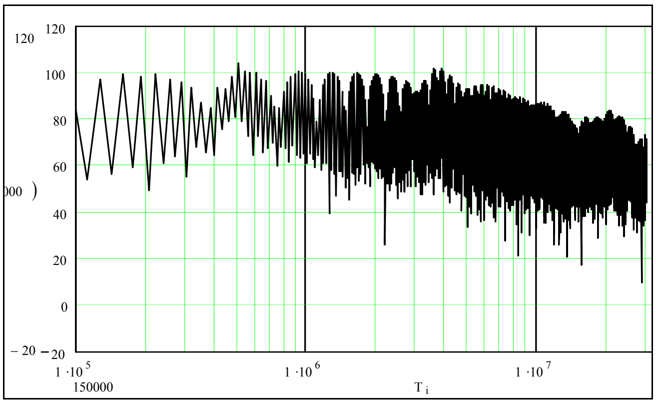

Fig. 21 – Conducted EMI measured from artificial mains of the Fig 18 circuit.

V. References

[1] BOWLES, B. A.; PAUL, C. R. Modeling Interference Properties of SMPS DC Power Distribution Buses. In: IEEE NATIONAL SYMPOSIUM ON ELECTROMAGNETIC COMPATIBILITY. 1989. p. 119-126.

[2] LABOURÉ, E.; COSTA, F.; GAUTIER, C. et al. Accurate Simulation of Conducted Interferences in Isolated DC to DC Converters Regarding to EMI Standards. In: POWER ELECTRONICS SPECIALISTS CONFERENCE – PESC'96 (27. : June 1996). v. 2. 1996. p. 1973-1978.

[3] TEULINGS, W.; SCHANEN, J. L.; ROUDET, J. A New Technique for Spectral Analysis of Conducted Noise of a SMPS Including Interconnects. In: POWER ELECTRONICS SPECIALISTS CONFERENCE – PESC'97 (28. : June 1997). v. 2. 1997. p. 1516-1521.

[4] DONGBING ZHANG; CHEN, D. Y.; NAVE, M. J. et al. Measurement of Noise Source Impedance of off-line Converters. In: APPLIED POWER ELECTRONICS CONFERENCE AND EXPOSITION – APEC'98 (13. : Feb. 1998). v. 2. 1998. p. 918-923.

[5] ROSSETTO, L.; TENTI, P.; ZUCCATO, A. Electromagnetic Compatibility of Industrial Equipment. In: CONGRESSO BRASILEIRO DE ELETRÔNICA DE POTÊNCIA – COBEP'97 (4. : 1997 : Belo Horizonte). Anais. p. 03-13.

[6] SCHLICHTING, L. C. M.; de LIZ, M. B.; RAIZER, A. Electromagnetic Interference in Static Converters Due to Switching Ringing. In: INDUSTRIAL APPLICATION CONFERENCE (4. : Nov. 2000 : Porto Alegre). Proceedings of the INDUSCON 2000. p. 640-645.

[7] SCHLICHTING, L. C. M.; de LIZ, M. B.; RAIZER, A. Impact of the Commutation on Electromagnetic Interference Generated in Static Converters. In: BRAZILIAN POWER ELECTRONICS CONFERENCE (6. : Nov. 2001 : Florianópolis, Brazil).

Proceedings of the COBEP 2001. p. 384-387.

[8] PEREZ, R. Handbook of Electromagnetic Compatibility. Academic Press Inc., 1995.

[9] TERRELL, D. L.; KEENAN, R. K. Digital Design for Interference Specifications: A Practical Handbook for EMI Suppression. Oxford : Butterworth-Heinemann, 2000.

[10] OTT, H. W. Noise Reduction Techniques in Electronic Systems. 2. ed. New York : Wiley-Interscience, 1988.