About Analysis of Emissions from a Switched Mode Power Supply

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Abstract**—The paper is dedicated to the analysis in the frequency domain of the currents (in common mode and differential mode) which generate conducted emissions in the supplying cable of the equipment containing a switch mode power supply (SMPS). The performed simulation considers the standard CISPR 16-1-2 which refers to specifications, methods and test apparatus for the measurements of disturbances and immunity to conducted emissions. One proposes solutions to limit and control the conducted emissions generated by the SMPS within the supplying cable that result into noise currents and high frequency currents within the range 150 kHz – 30 MHz that might interfere with other electric equipment. Various ways to limit the mentioned emissions are simulated and analyzed. The influence of the duty-cycle over the frequency spectrum from the conducted emissions range is considered, the worst case is determined. The conclusion is that the optimum filtering solution involves the use of an EMI filter, the results being compared to the CISPR 22 standard.**

Keywords— Conducted emissions, SMPS, LISN, DM – CM currents, Snubber, duty-cycle, EMI filter component

I. Introduction

Switched mode power supplies are the most widely used in electronic system in last decade. They use electronic semiconductor switches that operate in on or off state. Low power losses in these states represent their main advantage (considering the low voltage across the switch in on state and zero current through a switch in the off switch) [1]. SMPS operates in high frequency commutation, are light and can achieve high efficiency (90%). Unfortunately, high frequency commutations are accompanied by high level of electromagnetic interference (EMI), the major task of electronic designer therefore to identify and cancel it. Typically, SMPS generates two types of EMI: conducted emissions (150 kHz – 30 MHz) and radiated emissions (30 MHz – 1 GHz).

An important condition imposed by the electromagnetic compatibility (EMC) consists in the ability of an electronic circuit to operate properly in its electromagnetic environment without introducing unacceptable electromagnetic disturbances to anything in that environment. For this reason, there are many European (EN standards) and International (CISPR, IEC) agencies who specify the conducted and radiated limits for electronic products. Additionally, some standards give guidelines for measurement tests and instrumentations (CISPR 16). An important measurement instrument is the line stabilization network (LISN) inserted between AC power cord and the electronic system under test. The conducted emissions are measured with a spectrum analyzer attached to the LISN [2], [4].

As the conducted emissions level is directly influenced by the duty cycle, their limitation measures must consider it.

A solution to limit the conducted emissions consists in the use of a snubber, whose role is to limit the high values of *dv/dt* and *di/dt* from the switch.

The most efficient method to get SMPS conducted emissions limitations consists in filtering techniques. A power line filter helps SMPS to comply with regulatory conducted emissions requirements. The filter must provide attenuation for both common mode (CM) and differential mode (DM) noise currents [3].

II. DM and CM Conducted Emissions from SMPS

The conducted emissions' measurement was performed according to specific standards (CISPR 16), using a line stabilization impedance network (LISN) placed between the supplying network and the tested product. The visualization of the conducted emissions' spectrum (considering the frequency range (150 kHz – 30 MHz)) was performed by means of a spectrum analyzer connected to LISN, which is used to provide a constant 50 Ω impedance between a phase and ground and respectively between the null wire and ground, in order to prevent the influence of externally originated conducted noise signals.

A detailed schematic of the LISN and of the points used for the conducted emissions measurement is depicted by Fig. 1. The voltages denoted by V_P and V_N are measured between a phase and ground and respectively between the null wire and ground. Therefore, the conducted emissions are expressed in Volts whilst in fact the currents are those who present interest during the measurement of the conducted emissions.

Under these circumstances the equations presented below are valid, providing that within the frequency range (150 kHz

– 30 MHz) the capacitors from LISN behave like a short circuit and the coil behaves like an open circuit. According to Eq. (1), the measured voltages accurately express the currents generated by the product under test in both modes (DM and CM).

The voltage drops along the 50 Ω are to be measured and must meet the requirements imposed by standards [2]:

$$V_P = 50 \cdot I_P \qquad (1)$$

$$V_N = 50 \cdot I_N \qquad (2)$$

Fig.1 depicts the LISN and allows the identification of CM and DM currents. Eqs. (1) and (2) reveal the possibility to decompose I_P and I_N in two components: the DM component flows through the phase's conductor, returning through the null wire whilst the CM component flows through the phase

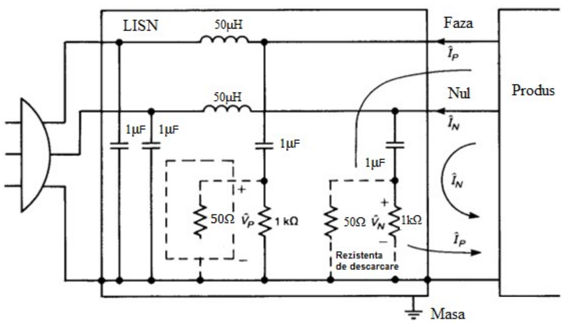

Fig. 1. DM and CM through LISN

and null wire and returns through ground [2]:

$$I_D = \frac{I_P - I_N}{2} \qquad (3)$$

$$I_C = \frac{I_P + I_N}{2} \qquad (4)$$

Therefore, the measured voltages will be:

$$V_P = 50(I_C + I_D) \qquad (5)$$

$$V_N = 50(I_C - I_D) \qquad (6)$$

At conducted emissions, the CM currents can get significant values, being possible for them to overcome those of the DM currents [2].

III. SMPS Conducted Emissions Simulation

For the conducted emissions simulation one choused a step-down voltage DC-DC buck converter.

Converter's parameters are given in Table I. The schematic from Fig. 2 includes the LISN model in SPICE used for the measurements of DM and CM voltages.

The ground wire is represented by a very high resistance. The schematic also contains a RC snubber, required for the limitations of switching losses associated to switching and for the limitation of conducted emissions generated by it respectively.

The SPICE schematic used to simulate the LISN is depicted by Fig. 3.

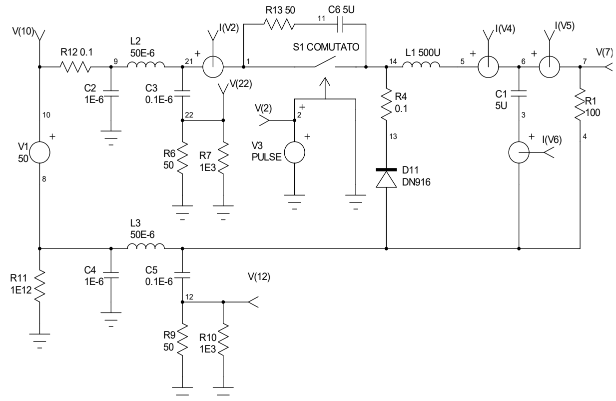

Fig. 2 SPICE schematic of the buck converter with LISN

TABLE I.
Specifications of the Buck Converter

Input Voltage	50 V_{dc}
Input Current	0.25 A_{rms}
Switching frequency of the switch	100 kHz
Inductance L	500 μH
Capacitance C	5 μF
Resistive load R	100 Ω

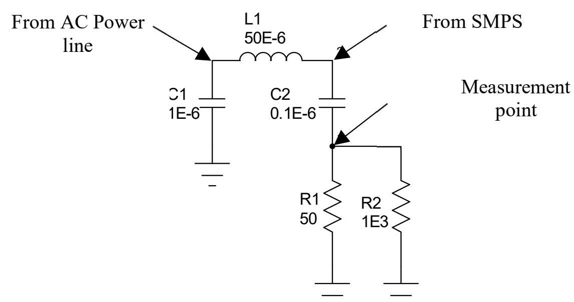

Fig. 3 SPICE schematic of LISN

Various scenarios regarding the conducted emissions produced by the buck converter were simulated, revealing the best, respectively the worst cases.

A. *Duty Cycle effects on conducted emissions*

Firstly, the influence of the duty-cycle ratio over the conducted emissions' level was studied. For this aim, simulations were performed considering three different values of the duty cycle ratio: 0.2, 0.5 and 0.8 respectively.

The level of the conducted emissions is displayed in the range of the conducted and simulated emissions, according to the test standards (CISPR 16).

To emphasize the different duty-cycle ratios, the output voltage was displayed according to [1]:

$$M \equiv \frac{V_{out}}{V_{dc}} = D \qquad (7)$$

Fig. 4 depicts the spectrum of the conducted emissions generated by SMPS when the duty-cycle ratio is 0.5.

The conducted emissions are significant, the RMS of the most significant harmonic (corresponding to 200 kHz which is a multiple of the switching frequency) being equal to 4.3V.

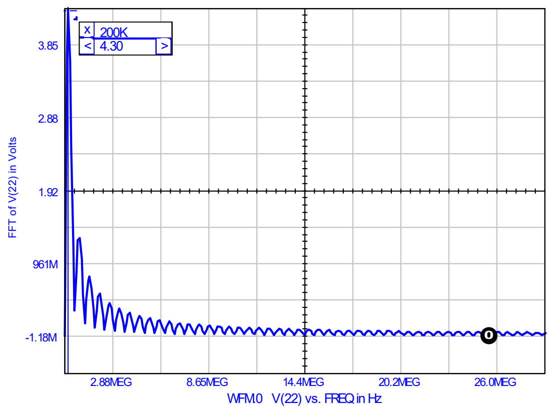

Fig. 4. Spectrum of conducted emissions for a duty-cycle ratio of 0.5

This value significantly overcomes the maximum value admitted by the compatibility standards. 132.67 dBμV correspond to this value, the maximum admitted value according to the standard CISPR 22 being 66 dBμV Quasi – peak for class B electronic and electric equipment.

When the simulation was performed for a duty-cycle ratio of 0.2 considering the same SMPS and the same operating conditions, the spectrum of conducted emissions for the specific frequency spectrum revealed that the most significant harmonic had a frequency of 200 kHz and a RMS of 1.43 V, to which a value of 123.1 dBμV is corresponding. Although lower than the value from the case considered in Fig. 4, this value is also significantly higher than the maximum level mentioned by standards (CISPR 22).

For a duty-cycle ratio of 0.8 the most significant harmonic had a frequency of 200 kHz, but its RMS was 1.51 V, corresponding to 123.58 dBμV.

The conclusion drawn from the simulations results is that the worst case when the conducted emissions are considered for the simulated SMPS appears when the duty-cycle ratio is equal to 0.5. Therefore, when the conducted emission reducing is intended, it is recommended to avoid the realization of this value [5].

B. Conducted emissions filtering

The most efficient method when conducted emissions limitation is intended consists in filtering. The EMC filters have a special configuration, imposed by standards' requirements.

The filters are generally low-pass filters of *L- C* type. The most common filters topology is depicted by Fig. 5. The symbols I_D and I_C are used to denote the DM current, respectively the CM current from filter's input, whilst the symbols I_D' and I_C' are used to denote the DM current, respectively the CM current from filter's output. The voltages expressed using the Eqs. (5) and (6) must be lower than the limits admitted by the conducted emissions all over the frequency range used for tests [2].

The capacitors C_{DL} and C_{DR} are used for the limitation of DM currents whilst the capacitors C_{CL} and C_{CR} are used to for the elimination of CM currents.

Another important element used in the filtering schematic is the common-mode choke represented by mutually coupled coils.

Based on this topology a filtering was performed, such as to limit the conducted emissions produced by the SMPS of buck type.

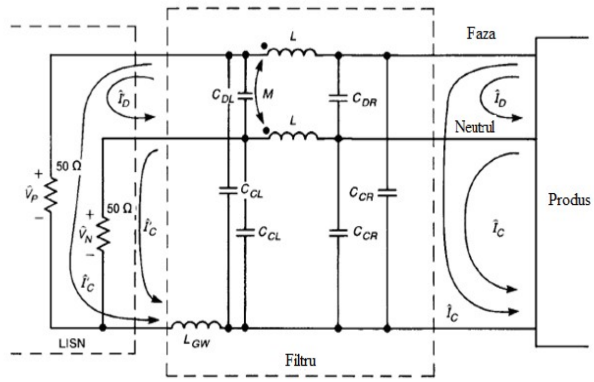

Fig. 5 Filter with a π schematic.

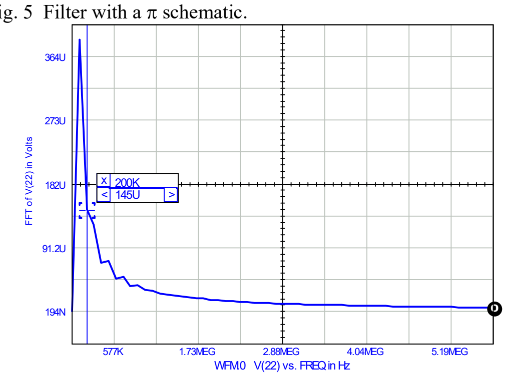

Fig. 6. Spectrum of conducted emissions when a filter is used

TABLE II.
LIMITS OF CONDUCTED EMISSIONS ACCORDING TO CISPR 22, CLASS B

Frequency range MHz	Limits dBμV	
	Quasi - peak	Average
0.15 – 0.5	66 - 56	56 - 46
0.5 - 5	56	46
5 - 30	60	50

The simulated waveform of the DM voltage, resulted from the filtering process, was afterward submitted to a Fourier analysis. In the spectrum from Fig. 6 one can see the most significant harmonic from the frequency range used for the measurement of conducted emissions. It has a value of 145 μV (63.22 dBμV) and therefore obeys the requirements from CISPR 22, class B [6].

The limits imposed by the standard CISPR 22 (or EN 55022) of the conducted emissions for class B equipment are gathered by Table II.

For a clearer emphasizing of the DM voltage obtained after filtering, a logarithmic representation of the voltage amplitude (expressed in dBμV) was used (Fig. 7).

As one can see from the conducted emissions from Fig. 7 and from the specifications and the standard CISPR 22 presented by Table II, the use of a dedicated EMC filter is compulsory in order to reduce the conducted emissions generated by a SMPS. The parasitic capacitances that might appear between the common mode choke windings were also considered in order to obtain results as close as possible to reality.

This way, the level of the conducted emissions generated by SMPS will be under the limits imposed by the mentioned standard.

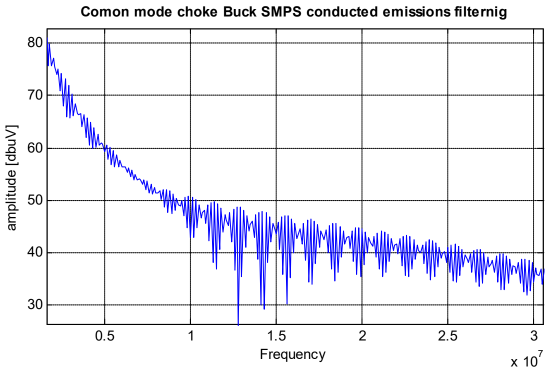

Fig. 7. Spectrum of conducted emissions expressed in dBμV when filtering is used

IV. Conclusions

A study was made with respect to the disturbances through conducted emissions generated by a SMPS which includes a switching element of type MOSFET operating at a switching frequency of 100 kHz.

The simulation of the studied conducted emissions was made according to the standard CISPR 16 and the SPICE schematic used for this scope includes a LISN circuit, whose role is to keep a constant impedance within the test spectrum of the conducted emissions.

Various cases were simulated and discussed as different operating cases and methods for the conducted emissions reduction were considered.

The conclusions were that one must avoid a value of 0.5 for the duty-cycle ratio, as this was proved to correspond to a maximum level of conducted emissions.

To obey the limits imposed by standards, one had to make a simulation of the entire system along with a specific filter for the limitation of the spectrum corresponding to the conducted emissions. For filter's simulation one took into consideration the parasitic capacitances of the common mode choke, as well as the magnetization resistance of the core [7].

A Fourier analysis of the measured disturbing signal was made and the results (expressed in dBμV) agree with the standards CISPR 22 (EN 55022). A filtering solution for SMPS can be conceived considering the simulations results. The filter efficiency is demonstrated by SPICE simulation results [8], [9], [10].

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