Noise Modeling and Improved Harmonic Spectrum for DC/DC Converter by RPWM Control

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Abstract – Higher operating frequency provides rising output power from modern power electronics devices. Nevertheless, the switch-mode operation results in EMI which is produced due to large di/dt and/or dv/dt. The methods to reduce EMI are the use of classic and expensive input filters or the addition of the active filter into the main circuits. In this paper, by using the randomized PWM the EMI effect can be reduced and implementation of the proposed control scheme into the forward converter can improve the harmonic spectrum as well.

1. Introduction

Power electronics provides the means by which electrical power is efficiently converted from one form to another by switching devices where the most important parameter is the switching frequency. Conventional PWM (Pulse Width Modulation) converters have been the fatal disadvantages, such as the switching losses and EMI (Electromagnetic Interference) problems according to the incremental switching frequency. EMI noises generally occur when semiconductor switching excites current and voltage to change suddenly. To overcome these problems, various counterplans have been made, such as the suppression of noise generating sources, the interception of transmission route, the shielding of electromagnetic wave, adequate ground, proper device layout, soft switching, adding snubber circuits, and filtering of conducted noise. In the past, EMC (Electromagnetic Compatibility) design remained a myth to the power electronics fields. EMI practices usually take last-minute, trial-and-error experimental methods without careful planning and design.[1, 2, 3]

A number of attempts have been reported to address the theoretical analysis of EMI noises for power supplies, and to perform an early-phase EMI design. However, they are limited to specific, simplified converter switching cells and it is difficult to apply to general complete power converters.

This study has built the EMI noise modeling for forward converter, predicted the transmission route of noise source, and built the couterplan as for each of CM(Common-Mode) conducted noise and DM(Differential-Mode) conducted noise.

The conducted noise emitted from SMPS (Switched-Mode Power Supplies) has usually periodicity with respect to switching frequency. Especially the noise spectrum of SMPS is located at the switching frequency and the harmonic frequencies. And the concentration of noise energy at these frequencies makes it harder to meet EMI regulations. Therefore in this paper by modulating of random switching frequency, the sidebands of those frequencies can be created, and the noise spectrum scattered. And the energy can be shattered into smaller pieces around many sidebands frequencies. This effect makes it easier to pass EMI regulations and to reduce the size of filter or/and total SMPS.

2. Conducted EMI test

Measuring of EMI Noise Source

Two generating causes of EMI in electronic equipment generally exist. The one is the natural noises, such as the noise due to natural phenomenon and thermal noise due to resistor. And the other is the artificial noises, such as di/dt, dv/dt due to sudden switching. The sudden surge is transmitted through the signal line or power line within electronic circuit, and then it generates the conducted noise.

Some noise sources which flow along line can be radiated in external circuit or other equipment by electromagnetic induction and electrostatic induction, and then they generate the radiated noises. This study deals only with the conducted noises.[2]

It is difficult to measure the noises generated at SMPS correctly, when EMI noises are invaded from the input power line. Therefore LISN(Line Impedance Stabilization Network) is set up between SMPS and input power line to prevent the influence of the noise of input power line. Fig. 1 shows the circuit of conducted EMI test equipment. LISN has two roles, in which LISN holds up constantly the impedance from SMPS and induces only the noises of SMPS for spectrum analyzer. The values of the reactive components inside LISN are such that for low line frequency, L is essentially shorted, and C1 and C2 are essentially open. For EMI noise frequency, however, L is essentially an open circuit, and C2 is essentially shorted. In other words, the input line power goes through LISN unaffected, and noises generated in the switching circuit can be measured at the 50 Ω impedance from each phase to ground. The 50 Ω resistance is normally the input impedance of the measuring spectrum analyzer.

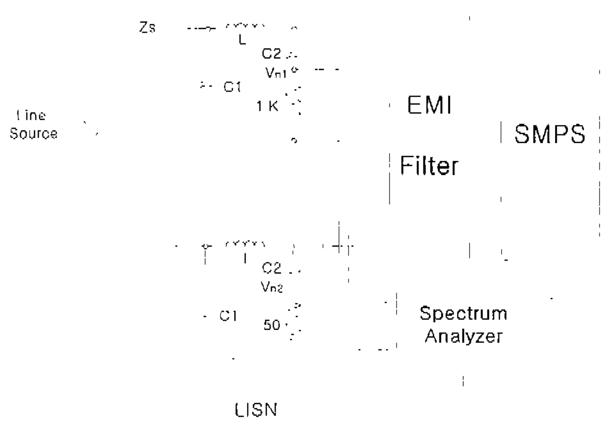


Fig. 1. The conducted EMI test equipment set

In Fig. 1, V_{n1} is the measured voltage in hot line through LISN and V_{n2} is that in return line. CM and DM conducted noises can be represented as follows.

CM conducted noise : $V_{CMnoise} = \frac{V_{n1}+V_{n2}}{2}$ (1)

DM conducted noise : $V_{DMnoise} = \frac{V_{n1}-V_{n2}}{2}$ (2)

Noise sources and coupling paths

Fig. 2 shows a circuit diagram depicting noise sources, noise coupling paths, and the noise-frequency equivalent circuit of the LISN. As stated earlier, the voltage measured across the 50 Ω LISN resistor is the measured conducted EMI noises.

There are two modes of current coupling to the 50 Ω resistor : DM and CM. DM noise is caused by sudden change of the pulsating switching current. Part of the pulsating switching current is shunted by bulk capacitor C, and the rest flows through the two 50 Ω resistors of LISN via hot-line and return-line. If the impedance of the capacitor C is very small compared to 100 Ω (50Ω + 50 Ω), then the DM noise coupling is small. The parasitic inductance of C must be kept low to avoid DM coupling at very high frequency operation. The route of DM Noise is made up closed loop through hotline – transformer primary winding – switch – return line – LISN return line noise measuring circuit – ground - LISN hot line noise measuring circuit – hot line. DM noise holds 180° phase margin between hot line and return line.

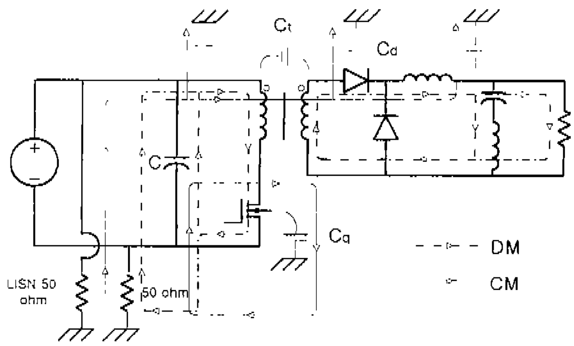


Fig. 2. Conducted noise emission sources for a forward converter circuit.

The CM noise is caused by sudden voltage change and ringing phenomenon originated at switching instant. C_d and C_q are the parasitic capacitors between semi- conductor and chassis, and C_t is the transformer winding capacitance. The voltages across the three parasitic capacitors are high-voltage high-frequency waveforms. Displacement current generated by these voltage waveforms flows through the 50 Ω resistors and causes the measured EMI emission. If the heat sinks used for semiconductor devices are physically tied to the chassis, then the values of C_q and C_d will be increased. From the discussion given above, it is clear why the circuit layout and component packaging affect the EMI performance of a circuit. Since the route of CM noise is coupled directly with hot line / return line and ground, CM noise holds the same phase between hot line and return line. [4, 5]

3. Principle of RPWM forward converter

Analysis of RPWM theory

Output voltage control in PWM DC/DC converters is achieved by modulating appropriate duty ratio of the converter switch. The duty ratio does not depend on the pulse position within the switching interval, nor on the length of the switching interval. If either the pulse position or the switching frequency is varied in a random manner, the power spectrum of output voltage of the converter acquires a continuous shape, while the discrete part is significantly reduced. This is the basic principle of the Random PWM, which has been the subject of intensive research during the last few years.

The following three basic concepts are proposed in the existing RPWM strategies : [1]

- Randomized switching frequency.
- Randomized pulse position.
- Random switching.

In this paper, it is main concern that noise voltage can be reduced for forward converter.

The conducted noise emitted from SMPS has periodicity with respect to switching frequency. Especially the noises of SMPS center at the switching frequency and the discrete harmonic frequencies. Concentration of noise energy at these discrete frequencies makes it harder to meet EMI regulations. Therefore by modulating switching frequency randomly, sidebands can be created and the noise spectrum can be smeared. And the energy is shattered into smaller pieces around many sidebands frequencies. This effect makes it easier to pass EMI regulations and to reduce the size of filter or/and total SMFS. [3, 4]

RPWM Controller

Fig. 3 shows the block diagram of RPWM controller. After it adds 1st reference voltage V_{ref1} to noise voltage generated in random noise generator, the triangular wave is generated. And then this triangular wave is compared with sensed output voltage V_{ref2}.

Input voltage Vi of the saw generator is defined by reference voltage V_{ref1} and by noise voltage V_{noise} as :

$$V_i = V_{ref1} \pm V_{noise} \quad (3)$$

which is kept constant within the switching interval Ts = RC. In conventional PWM (bold saw signal in Fig. 4) the output ramp voltage is :

$$V_o = \frac{1}{RC} V_{ref1} t \quad (4)$$

In RPWM when noise voltage V_{noise} is zero, time period is following ;

$$T = V_{peak} \times \frac{RC}{V_{ref1}} \quad (5)$$

When noise voltage V_{noise} is each positive or negative , time period is following ;

$$T = V_{peak} \times \frac{RC}{V_{ref1} + V_{noise}} \quad (6)$$

$$T = V_{peak} \times \frac{RC}{V_{ref1} - V_{noise}} \quad (7)$$

After all, ultimate random PWM wave is made and output voltage Vo is following ;

$$V_o = \frac{1}{RC}(V_{ref1} \pm V_{noise})t \quad (8)$$

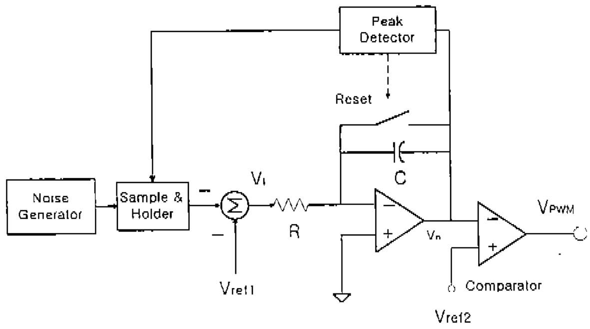


Fig. 3. The block diagram of RPWM controller

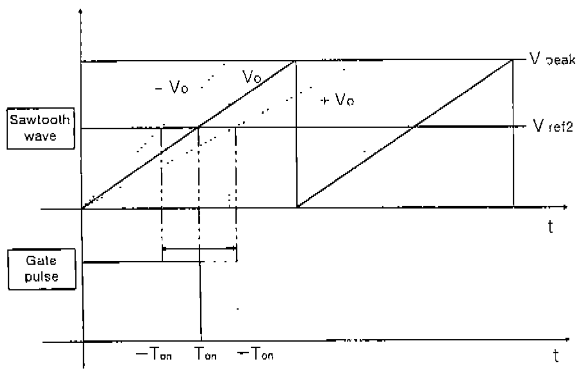


Fig. 4. Signal waveforms of the random PWM

4. Simulation of random PWM forward converter

Random PWM forward converter is designed and built to test the theory described above. A description of the converter is given below :

- Switching Frequency : 100 kHz nominal
- Frequency Variation : Adjustable but limited to 10 %
- Output Voltage : 15 V
- Output Current : 3 A
- Input Line Voltage : DC 30 V

Before practical forward converter shown in Fig. 2 was built, the simulation of random PWM forward converter was done. The idea of random PWM was verified by using Pspice simulation tool. Fig. 5 shows the controller diagram for random PWM forward converter.

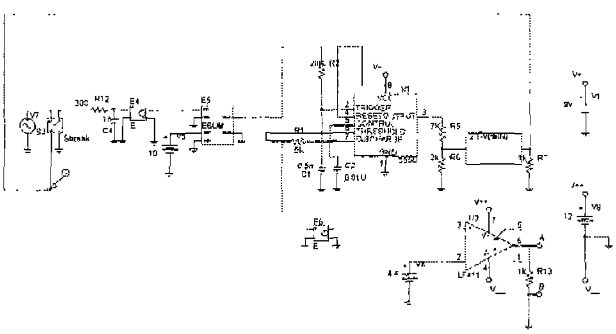
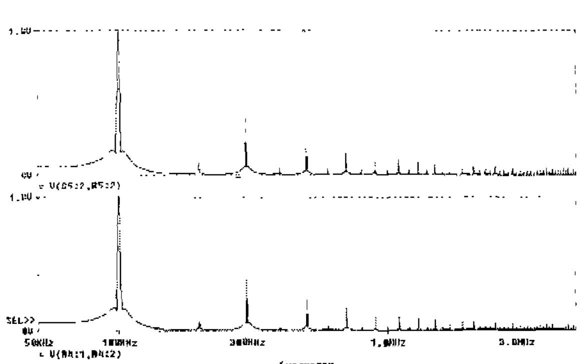


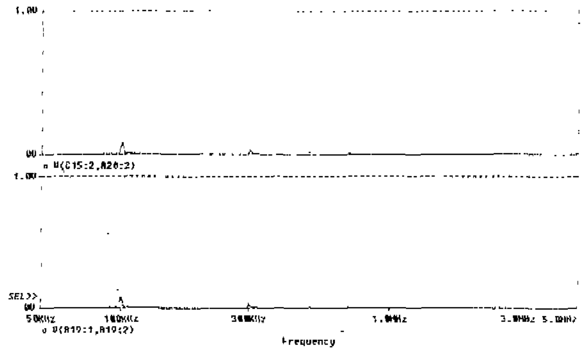
Fig. 5. Controller diagram for random PWM forward converter

Fig. 6(a) and (b) show the simulation noise voltage spectrums in forward converter without- and with- random PWM respectively. The noise voltage spectrum is normalized and shown in logarithmic scale. By using logarithm the high harmonic spectral lines were amplified and made more evident as well.

As can be seen in Fig. 6(a) (in conventional PWM), only odd components are present in noise voltage spectrum. In noise voltage spectrum of Fig. 6(b), it is evident that the introduction of random PWM reduce the higher order of harmonics considerably.



(a) without random PWM

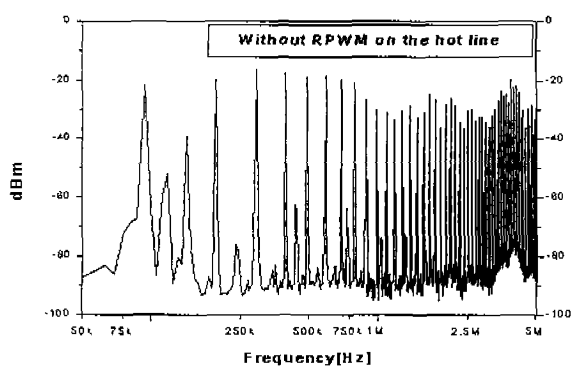


(b) with random PWM

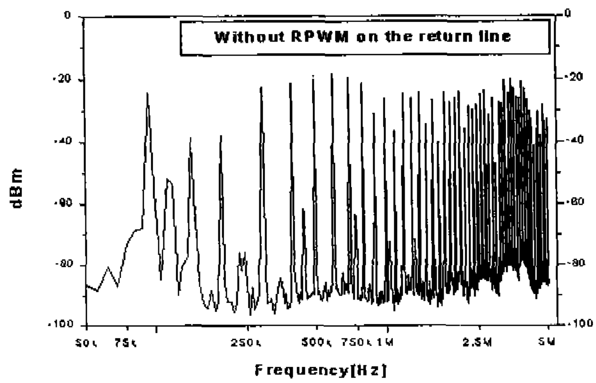
Fig. 6. Simulated noise voltage spectums in forward converter without- and with- random PWM

5. Experimental Results

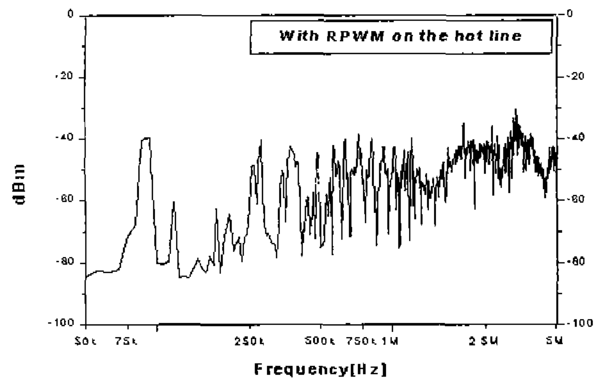
A Hewlett-Packard 4395A network/spectrum/impedance analyzer is used for EMI measurement. Measured noise voltage spectrum without- and with random PWM are shown in Fig. 7(a), (b), (c), and (d) respectively. It is clearly evident that the used random PWM has improve the harmonic spectrum and also reduce the EMI effect. Comparison with the simulation results also shows that the spectral lines are not so distinctive and in higher frequency range damped without added noise as well.



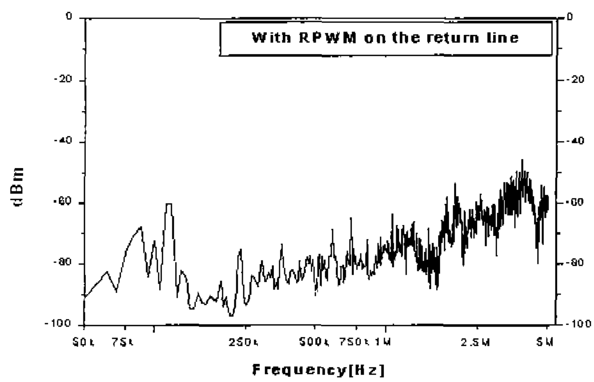
(a) Without random PWM on hot line



(b) Without random PWM on return line



(c) With random PWM on hot line



(d) Without random PWM on hot line

Fig. 7. Measured noise voltage spectrum

6. Conclusions

In this paper the random PWM was used in forward converter. This paper analyzed generating cause and source of EMI noise in SMPS, and predicted the conducted noise source as to separating CM and DM conducted noise source on the view of EMI noise for forward converter.

The conducted noise emitted from SMPS has periodicity according to switching frequency. Especially the spectrum of SMPS noise is located at the switching frequency and the discrete harmonic frequencies. Concentration of noise energy at these frequencies makes it harder to meet EMI regulations. As expected, by using the random PWM the sidebands were created along with these frequencies and the noise spectrum was smeared. And the energy was shattered into the smaller pieces around many sidebands frequencies. Therefore it was ascertained that this effect make it easier to pass EMI regulations and to reduce the size of filter or/and total SMPS.

7. References

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