

PERFORMANCE COMPARISON OF HARD AND SOFT SWITCHED POWER CONVERTERS IN SUPPRESSING HARMONICS USING CHAOS MODULATION

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Abstract: Switched mode power supplies are significant generator of harmonics and electromagnetic noise. This has always been a serious concern, as it adversely affects the operation of the system. In this paper, the effectiveness of soft switching in reducing harmonic noise is first investigated. Then external chaos is added to the soft switching and the combined effect in suppressing the harmonic noise and EMI is investigated. DC-DC buck converter is taken as case study and the comparative evaluation has been made using spectral analysis. Simulations are carried out for hard switching and soft switching techniques, with external chaos generator included, using Matlab. Results confirm that, compared with the conventional hard switching method with chaos modulation, the soft switching technique with chaos modulation substantially reduces the EMI in the power converter. The simulated results are compared with the experimental counterparts to verify the validity of the approach.

Key words: SMPS, harmonics, electromagnetic noise, chaos modulation, hard switching, soft switching, power density spectrum.

1. Introduction.

Switched mode power supplies are the efficient power supplies that are embedded in a variety of power electronic products and have wide applications in areas like commercial, automotive, military and telecommunications. However, they generate a large amount of electromagnetic noise owing to their fast acting switches with sharp switching rise and fall times [1]. Electromagnetic compatibility (EMC) is the ability of the system to function in the intended operating environment without causing performance degradation due to the unintentional EMI. Thus achieving EMC has become a requirement as important as meeting the power conversion specifications [2]. Especially, conducted emission is a major issue in most power electronic systems due to significant overvoltage and leakage current generated by fast switching and stray components of the system [3].

The solution to this problem lies in the design of SMPS with minimum EMI. Several methods have been proposed in literature [4]-[13] to reduce conducted EMI. The conducted EMI performance of the system can be improved by using a filter with larger component values or more complexity, but these measures usually increase the filter's cost. Various methods of amelioration have been proposed based on spread spectrum techniques.

The high dv/dt and di/dt involved in the switching operation of traditional hard-switched power electronic devices are the major sources of EMI emission. Recently, soft-switching techniques have been proposed to reduce the switching losses and the switching stress of switched mode power electronics circuits in order to improve the energy efficiency and reliability of power converters [14] – [17]. Essentially, soft-switching techniques create a zero-voltage and/or zero current conditions for the power switch to turn on or off so that the instantaneous power losses can be theoretically reduced or eliminated. The effect of the soft-switching techniques on the EMI emission has been reported in [18] and claims that the main reason for the superior EMC performance of the soft switched converters over the hard-switched ones is due to the reduction of switching transients in the soft-switched circuits.

Switched mode power converters are highly nonlinear systems exhibiting chaotic behavior [19] – [22]. It is reported in literature [23] that chaos can be used to suppress EMI by spreading the peaks over the entire frequency band which is called chaos modulation [24].

This paper aims at reducing the EMI by implementing soft switching in a dc-dc buck converter with chaotic modulation. The measurements of the conducted EMI spectrum of traditional hard switched chaotic buck converter and the proposed soft switched chaotic buck converter of the same power specifications are carried out and compared for EMI reduction.

2. Buck Converter Analysis.

This section discusses the principle of operation of hard and soft switched buck converters.

a. Hard switched buck converter

Fig.1 shows the block diagram of the hard switched buck converter that uses pulse width modulation (PWM) voltage loop that can display a variety of behavior as its parameters are disturbed.

When S is closed, the input voltage V_{in} is transferred to the low pass filter. When S is open, the inductor maintains its current flow, forcing D to conduct and ground the input of LC filter. The voltage V_o across

the load resistance R is applied to the non-inverting input of an amplifier with gain a ; A constant voltage V_{ref} is applied to the inverting input; the output of the amplifier is the control voltage V_{con} . This is applied to the inverting input of the comparator; the noninverting input is fed by an independently generated ramp voltage V_r . The comparator generates pulses by pulse width modulation (PWM) that drives the switch. The switch conducts whenever $V_{con} < V_r$, thus providing regulated output voltage.

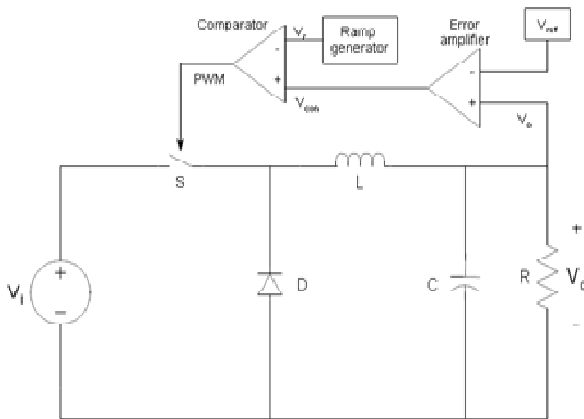


Fig. 1. Hard switched Buck converter schematic

b. Soft switched ZVS resonant buck converter

In these converters, the resonant capacitor provides a zero voltage condition for the switch to turn on and off. The topology is similar to the traditional non-resonant topology by replacing the conventional switch with resonant switch. In a ZV resonant switch, a capacitor C_r is connected in parallel with the switch S for achieving zero voltage switching (ZVS). Fig.2 shows the schematic of the soft switched ZVS resonant buck converter.

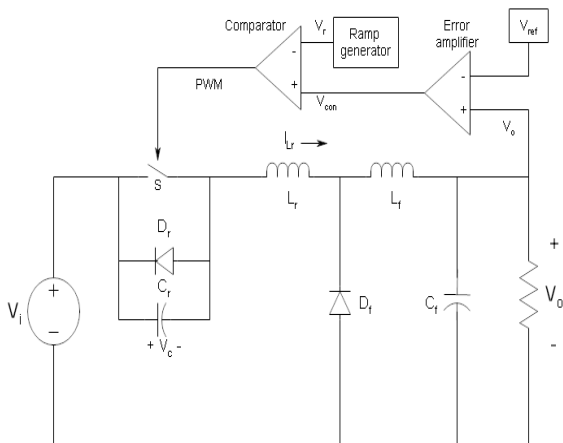


Fig.2. Soft switched Buck converter schematic

When switch S is turned on, it carries the output current I_o . The supply voltage V_i reverse biases the diode D_f . When the switch is zero voltage turned off, the output current starts to flow through the resonant capacitor C_r . When the resonant capacitor voltage V_{cr} is equal to V_i , D_f turns on. This starts the resonant stage. When V_{cr} equals zero, the antiparallel diode turns on. The resonant capacitor is shorted and the source voltage is applied to the resonant inductor L_r . The resonant inductor current I_{Lr} increases linearly until it reaches I_o . Then D_f turns off. In order to achieve ZVS, S should be triggered during the time when the antiparallel diode conducts. The peak amplitude of the resonant capacitor should be greater or equal to the input voltage [25].

3. Chaos study of Buck Converter – Experimental Results

The hard switched and soft switched converters are designed for 5 W applications. The experimental setup is shown in Fig.3.

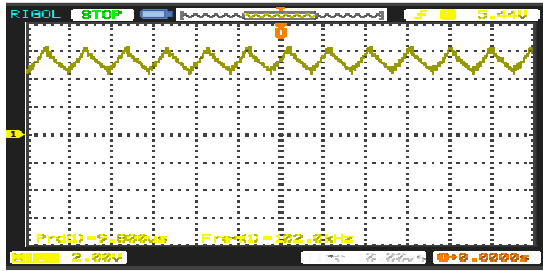


Fig. 3 Experimental setup

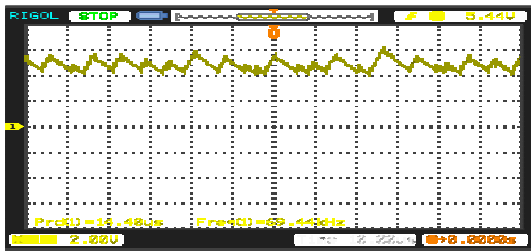
The circuit parameters for both the converters are $V_{in} = 5 \text{ V to } 30 \text{ V}$, $V_o = 5 \text{ V}$, Switching frequency $f_s = 100 \text{ KHz}$, $L = 50 \mu\text{H}$, $R = 5 \Omega$, $C = 10 \mu\text{F}$, $\text{ESR} = 0.25\Omega$. For the soft switched converter, the snubber circuit parameters are $L_r = 50 \mu\text{H}$ and $C_r = 50 \text{ nF}$.

a. Hard switched Buck converter

With the designed parameter values, as the input voltage V_{in} gets changed, the system undergoes bifurcation. The measured results of the hard switched buck converter are given in Fig.4.a and Fig.4.b respectively. It can be observed from figures that, for V_{in} of 7.8 V, the system behaves periodically. As V_{in} increases to 20 V, the system starts operating chaotically.



4.a. Periodic waveform

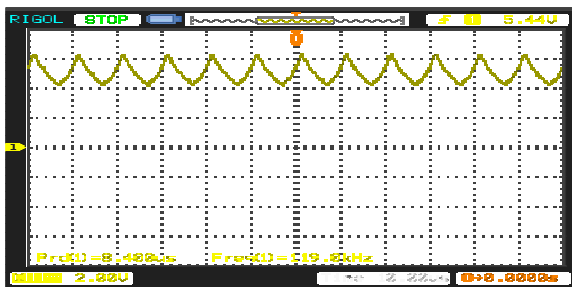


4.b. Chaotic waveform

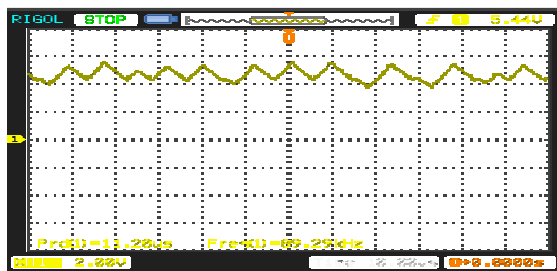
Fig. 4. Measured waveforms of hardswitched buck Converter

b. Soft switched buck converter

Similarly, the measured results of periodic and chaotic behavior of the soft switched buck converter at $V_{in}= 17 V$ and $V_{in}= 23 V$ are shown in Fig 5.a and Fig 5.b respectively.



5.a. Periodic waveform



5.b. Chaotic waveform at $V_{in}= 23 V$

Fig. 5. Measured waveforms of soft switched buck Converter

4. Spectral analysis of hard and soft switched buck converters – Results and Discussion

The Spectral analysis is carried out for hard and soft switched buck converter with Fast Fourier Transform (FFT) using Matlab.

a.Hard switched buck converter- Spectral analysis

The simulated and measured power density spectrums of the output voltage during periodic and chaotic state are measured for the hard switched buck converter. The comparison of both the spectrums is shown in Fig. 6.a and Fig.6.b respectively.

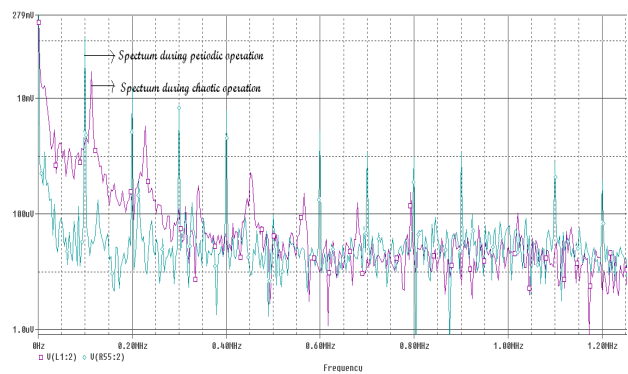


Fig 6.a. Hard switching – Simulated comparison of Periodic and Chaotic spectrum

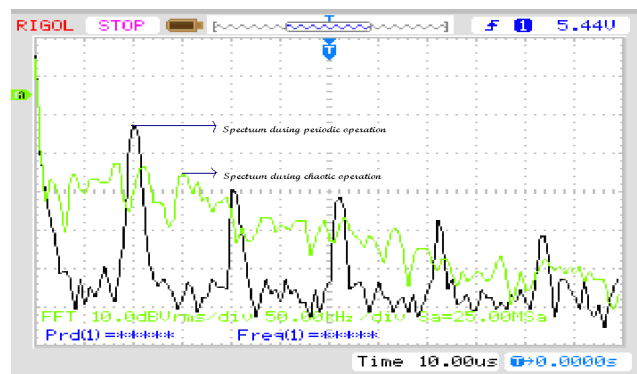


Fig 6.b. Hard switching – Measured comparison of Periodic and Chaotic spectrum

b. Soft switched buck converter- Spectral analysis

Similarly, the power density spectrums of the output voltage during periodic and chaotic state are simulated and measured for the soft switched buck converter. The comparison of both the spectrums is shown in Fig. 7.a and Fig.7.b respectively.

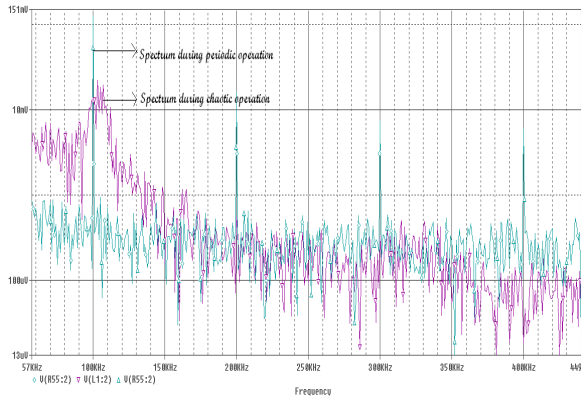


Fig. 7.a. Soft switching - Comparison of periodic and chaotic spectrum

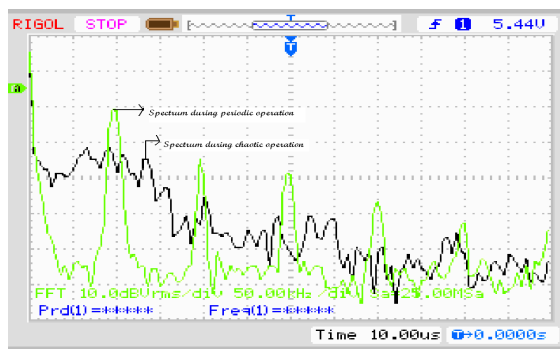


Fig. 7.b. Soft switching - Comparison of Periodic and Chaotic spectrum

It is found from the Fig.7, Fig.8, Fig.9 and Fig.10 that the power is densely concentrated at the fundamental frequency of 100 KHz and its harmonics (specific frequencies) during periodic operation whereas the spectrum is continuous and the amplitudes of the spectral peaks are reduced during chaotic operation. This is because the total emitted gets spread over a wider frequency range thereby reducing peak emissions.

The plot shows that operating the system in chaotic mode rather than in periodic mode is effective at lowering the peak level of both fundamental and harmonic peaks.

c. Comparison of Hard switching and Soft switching spectral analysis

The simulated and measured power density spectrums of the hard switched buck converter with chaos modulation and soft switched buck converter with chaos modulation are compared as shown in Fig 8 and Fig.9 respectively.

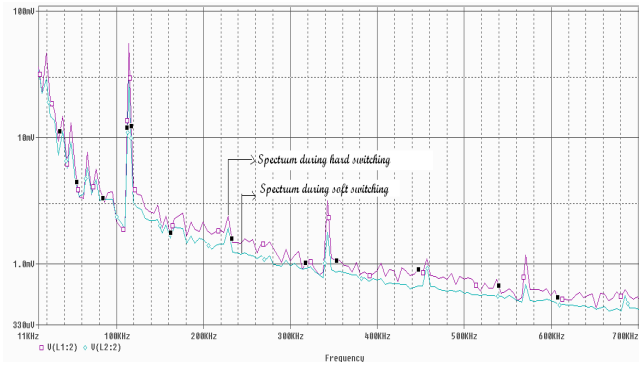


Fig. 8. Simulated comparison of chaotic spectrums of hard switched and soft switched buck converter

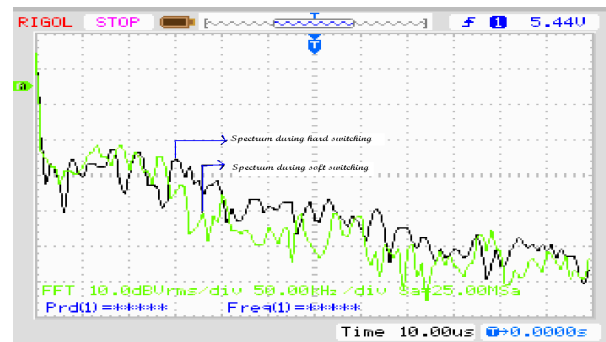


Fig. 9. Measured comparison of chaotic spectrums of hard switched and soft switched buck converter

It can be observed from the comparison that the net EMI emitted from the soft-switched converter has become significantly less than that from the hard-switched converter. The simulated results are found to be in well agreement with the experimental results.

5. Conclusion

In this paper, a hard-switched buck converter with chaos modulation and a soft switched buck converter with chaos modulation of same power ratings have been designed and analyzed for conducted EMI. It is found that the hard switch mode of operation results in large EMI emission and problem is minimized by turning on and off of the switch when the voltage across the switch is zero.

The simulated results are in well agreement with the simulated results. The spectral analysis indicates that the chaos modulated soft-switched converter operation is better than the chaos modulated hard-switched converter operation in terms of conducted EMI suppression.

It is observed that implementation of spread spectrum technique by operating the system in chaotic mode reduces the EMI and improves the system performance. Also the technique reduces the packaging and shielding costs.

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