Improved Line Imbalance of Single-Switch Converter by Double - Switch Converter for Common-Mode Noise Reduction

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Abstract

This paper aims to improve the system imbalance of the single - switch converters by employing the double -switch converter. The main objective is to analyze the cause of common mode noise generating in case of system imbalance and employing the double-switch converter for the common mode noise reduction. As the results, the ringing voltage and stress voltage of switching device are reduced. Finally, the experimental results in DC motor drive show the effectively improvement both time domain and frequency domain.

Keywords: single-switch converter, double-switch converter and common mode noise.

1. Introduction

The common mode noise which is generated from unbalance single-switch converter is the major source of RF. radiated emission, so it is important to reduce this noise to meet the standard of EMC regulation

There are several attempts to solve this problem. A common mode choke filter is widely used to suppress the conductive common mode noise, but it is not always effective and still has some problems [1] such as its insertion loss. The snubber circuit is employed to reduce dv/dt and di/dt by transferring the switching energy from the active switch to an energy storage element, such as a capacitor. [2]. The anti-phase windings [3], or the passive cancellation methods [4][5] needs the production of the compensation current which increase the size and total loss of circuit.

This paper proposes the technique of the system imbalance improvement of single-switch converter by using the double-switch converter. The synchronized switching of double-switch converter which can find out the series imbalance problem is applied. It is one of a efficient method for solving the problem of common mode noise emission.

2. Circuit Imbalance of Single-Switch Converter

The single-switch converter is a general type of converter. The structure consists of one switching device in the series connection a sending line or return line between a DC source and load, as shown in Fig.1. The operation, the impedance of sending line is varied from high to low with PWM frequency. This variation of line impedance specifically lead to circuit imbalance as series imbalance.

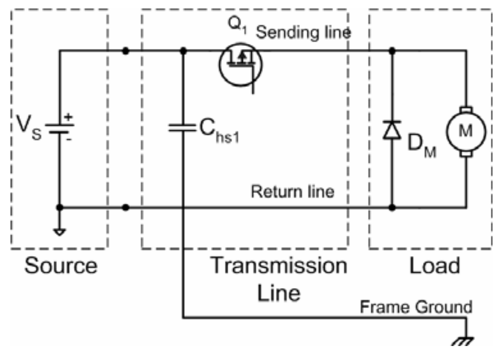

Fig. 1. The imbalanced circuit of single-switch converter.

Additionally, the parasitic capacitance of heat sink which connected to the frame ground is also the shunt imbalance. Consequently, the series and shunt imbalance are caused to generate a serious common-mode noise. The characteristic of circuit imbalance of the single-switch converter can be shown in Fig.2.

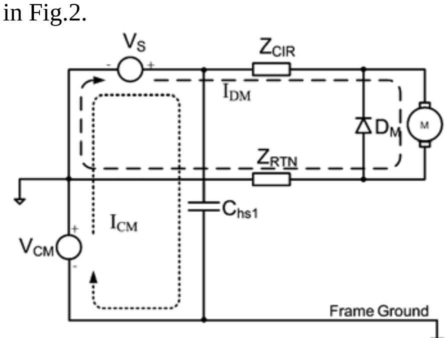

Fig. 2. Equivalent circuit of single - switch converter.

$$Z_{CIR} = Z_L + Z_{DS} \tag{1}$$

$$Z_{RTN} = Z_L$$

$$Z_{CIR} > Z_{RTN} \tag{2}$$

where

Z_{CIR} = sending line impedance, Z_{DS}= switching impedance, Z_{RTN} = return line impedance, Z_L = conductor impedance, C_{hs1}= parasitic capacitance of heat sink, I_{DM} =differential mode current, I_{CM} = common mode current.

3. Circuit Balance of Double - Converter

In order to solve the problem of imbalance circuit, the double-switch converter is applied by installing a low-side switching device in return line, as shown in Fig. 3.
These switches are synchronized with the PWM frequency. Thus, the impedance of sending line and return line is symmetrical and will respect to the frame ground for all switching time.

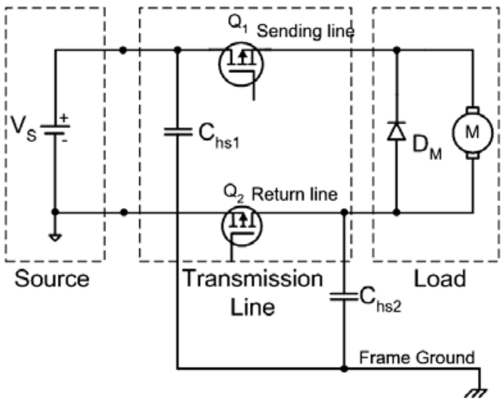

Fig. 3. Circuit balance of double-switch converter.

The double-switch converter is able to be improved the series imbalance of the single-switch converter since the parasitic capacitance between heat sink and frame ground of lower switch will be balanced the loop impedance of common mode noise circuit. Consequently, the common mode noise current of sending line is subtracted by common mode current of returning line. Fig. 4 shows the equivalent circuit of double-switch converter, the parasitic capacitance of both switching devices and the subtractive of both currents.

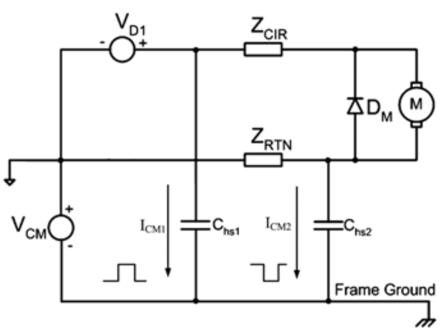

Fig. 4. Equivalent circuit of double-switch converter.

The impedance of sending line and returning line is explained by

$$Z_{CIR} = Z_L + Z_{DS1} \quad (3)$$

$$Z_{RTN} = Z_L + Z_{DS2} \quad (4)$$

then

$$Z_{CIR} = Z_{RTN} \quad (5)$$

Z_{DS1}=switching impedance of high-side switching device,
Z_{DS2}= switching impedance of low-side switching device.

As the series balance of double-switch converter, both common mode current which flow from high-side switch and low-side switch will be canceled due to the out of phase of common mode current waveform, as shown in Fig. 4.

4. Comparison of Single-Switch and Double-Switch of Instantaneous Voltage and Current

This section proposes the comparison between the waveform of instantaneous voltage of single-switch and double-switch in order to investigate the time domain response of both.
There are three cases of measurement;

a. Measure the on-off state waveform of terminal converter voltage and terminal converter current.

b. Measure the on-off state waveform of terminal converter voltage and switching device voltage (stress voltage of drain-source) .

c. Measure the waveform of noise voltage

The specification of the actual experiment.

- D.C. separately motor : 200 W., 30 V, rated speed 1250 r.p.m.
- D.C. power supply: 500 W., 0-60 volt,
- Digital storage oscilloscope : 150 MHz
- Current sensing (Hall sensing) 1:5 A/V.

Experimental conditions;

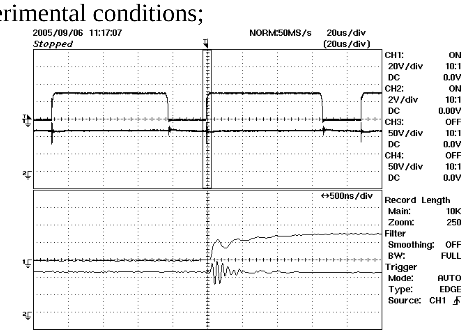

Fig. 5. The waveform of terminal voltage and load current of single-switch converter.

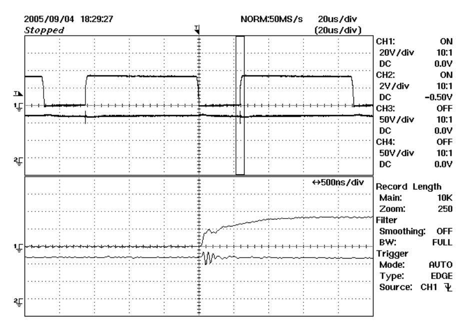

Fig. 6. The waveform of terminal voltage and load current of double- switch converter.

1. Set up the switching frequency from pulse width modulation circuit is 10 kHz., by manually initial the duty cycle is 80 %

2. Test the motor driving in no-load case by operate both single-switch converter and double-switch converter. Measure the output wave form voltage and load current and zoom the signal: 1:40. As can be seen from Fig. 5-6, there is more ringing in voltage and current in single-switch than double-switch converter.

3. Next, measure and compare the on-off state of terminal voltage and switching device voltage (or stress voltage of switching device). The waveform of both conditions show in Fig.7-8. The stress voltage for single-switch converter is equal to the supply voltage whereas it is a half of supply voltage in double-switch. Thus the energy loss from the dv/dt and di/dt and from the stress voltage is really reduced. Therefore, it is possible to employ the small size of switching device in double-switch converter.

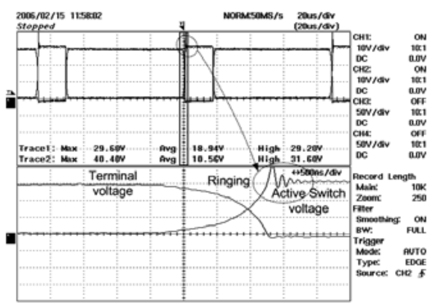

Fig. 7. The waveform of terminal voltage and switching device voltage of single –switch

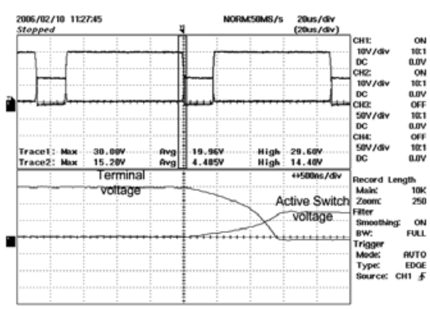

Fig. 8. The waveform of terminal voltage and switching device voltage of double-switch.

4. The next testing and measurement are carried out to confirm the symmetrical level of common mode voltage. The terminal voltage of load between the upper polarity (point A.) and the frame ground (point FG) as V_{AFG}, is compared with the load terminal voltage between lower polarity (point B) and frame ground as V_{BFG}, in the case of single-switch converter and double-switch converter, as shown in Fig. 9, and Fig 10 respectively. From the result of waveform in the case of single-switch converter, the upper waveform voltage (V_{AFG}) is larger than lower waveform voltage (V_{BFG}). And, the summation voltage result (V_{sum}) confirm that the both waveform voltage (V_{AFG}, V_{BFG}) in the case of double-switch converter is symmetrical.

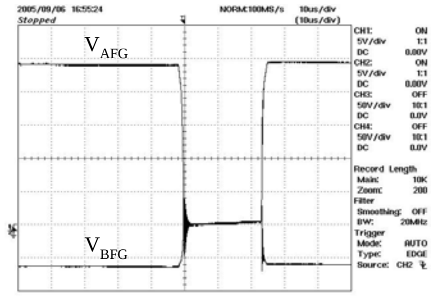

Fig. 9. The common-mode voltage of single-switch converter.

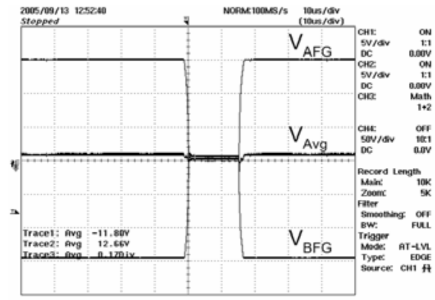

Fig. 10.. Common-mode voltages of the double-switch converter.

5. Confirmation of Common Mode Noise Reduction by Experiments

The single-switch converter and double-switch converter are investigated in case of frequency reduction of conductive common mode noise. This experiments based on the same operating condition: (f_s = 10 kHz., duty cycle = 0.8, V_s = 30 V, I_{out} = 1A, V_{out} = 24 V).

The conducted EMI measurement is made in a shielded enclosure in EMC laboratory, The conducted emission is measured from 9 kHz to 30 MHz according to CISPR standard. The measurement procedure requires EMI receiver and line impedance stabilization network (LISN) with impedance for testing. The LISN to be inserted between the equipment under test (EUT) and the ac utility line to provide a specified measuring impedance for noise voltage measurement, and to isolate the EUT and the measuring equipment from the utility at radio frequencies. A measured model of single-switch converter and double-switch converter is shown in Fig. 11.

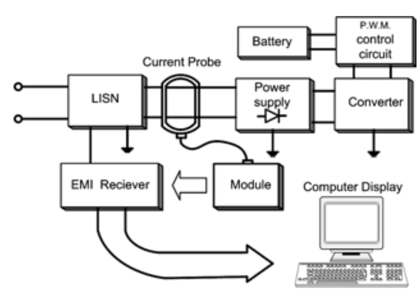

Fig. 11. Block diagram of system connection for measuring the conductive common mode noise.

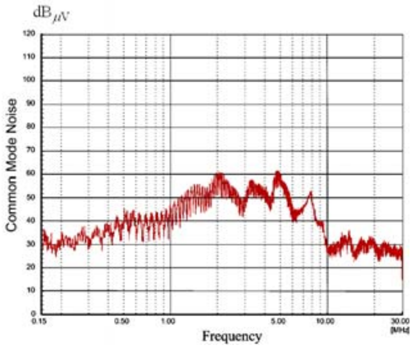

Fig. 12. The frequency spectrums of conductive common mode noise of single- switch converter.

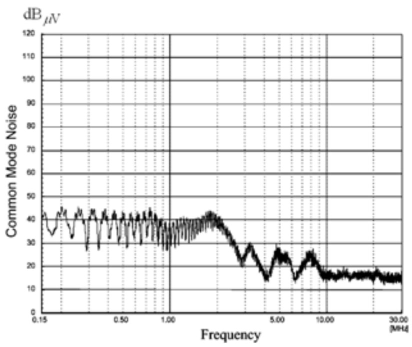

Fig. 13. The frequency spectrums of double-switch converter.

In the frequency region between 1 MHz. and 30 MHz., the difference between the common mode noise from the double-switch converter and it from the single-switch converter is large. The reason for the above results shown in Fig. 13 that the common mode noise in the above frequency region is influenced by the active switch of transmission line imbalance. However, it is not improved in the low frequency region. It is clarified that the conductive common mode noise of the single-switch converter is greatly improved by the double-switch converter.

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5. Conclusions

This paper aims to improve the system imbalance of the single - switch converter by employing the double -switch converter. As the experimental results, the common mode noise is reduced by the improving the circuit balance.
In additional, the stress voltage and ringing voltage are reduced. Finally, the frequency spectrum of conductive common mode noise confirm the effectively improvement.

Furthermore, the passive balance is able to improved in order to increase the degree of balance in converter circuit and inverter circuit.

References

[1] J. Mark Nave, Power Line Filter Design for Switched-Mode Power Supplied, Van Nosstrand Reinhold, pp.193-196, 1991.

[2] H.P. Yee, “An EMI Suppression MOSFET Driver,” Power Electronic Conference and Exposition, APEC’97 Conference Proceeding 1997, 12 th Annual meeting 1997, vol.1, pp. 242-248, 1997.

[3] W. Xin, M.H. Pong, Z.Y. Lu and Z.M. Qian, “Novel boost PFC with low common mode EMI: Modeling and design,” IEEE APEC Proc., pp. 178-181, 2000.

[4] D. Cochrane, D.Y. Chen, D. Boroyevic , “Passive Cancellation of Common-Mode Noise in Power Electronic Circuit,” IEEE Trans. on Power Electronics., vol.8, no.5, pp.756-763, 2003.

[5] S. Masahits , Ge Li, N. Tamotsu , “Balanced Switching Converter to Reduce Common-Mode Conducted Noise,” IEEE Trans. on Industrial Electronics, vol.50, no.6, pp. 1095-1099, 2003.

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