Study on Conducted Interference and Radiated Interference of Buck-Boost Converter in Electric Automobile

Jian Wang, Youqun Zhao, Liguo Zang and Wei Wang

Abstract Buck-boost converter is an important component of electric automobile, it is an important interference source in electric automobile, the study of the interference source is very important to restrain interference. The buck-boost converter in continuous conduction mode (CCM) is established by using circuit simulation software PSPICE. According to the request of GB18655-2002, the simulation study on common-mode conducted interference,differential-mode conducted interference and far-field radiated interference of buck-boost converter are given. The common-mode current radiation of buck-boost converter is simplified as an electric dipole radiation mode and the differential-mode current radiation is simplified as a rectangular loop antenna. In order to improve the electromagnetic compatibility of buck-boost converter in electric automobile, some measures to reduce the conducted interference and the radiated interference are proposed.

Keywords Buck-boost converter · Conducted interference · Radiated interference · PSPICE · Electric automobile

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J. Wang (✉) · Y. Zhao · L. Zang · W. Wang
College of Energy & Power Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China
e-mail: wangjian1987228@163.com

J. Wang · Y. Zhao · L. Zang · W. Wang
State Key Laboratory of Automotive Simulation and Control, Changchun 130025, China

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1 Introduction

The output voltage of buck-boost converter can be regulated above and/or below its input voltage with high efficiency [1]. Buck-boost converter has been widely used in power electronics and communication field. The battery pack of Chery electric vehicle consists of 100 lithium cells in series, one cell voltage is 3.6 V. Some low voltage electric systems such as dashboard system, lighting system, electric drive control system and car stereo system need 12 V voltage supply, the voltage can be regulated from 360 to 12 V by using buck-boost converter.

In this paper, the switching frequency of buck-boost converter is 20 kHz. The switching operation generates high *du/dt* and *di/dt,* and, consequently, wide disturbance bandwidths [2]. In such condition with high frequency, serious conducted interference and radiated interference are generated. According to the request of GB18655-2002, in the frequency range of interest (150–30 MHz), the conducted interference of buck-boost converter has been studied using Line Impedance Stabilization Network (LISN). The common-mode current radiation of buck-boost converter is simplified as an electric dipole radiation mode and the differential-mode current radiation is simplified as a rectangular loop antenna.

At present, some electromagnetic simulation softwares such as FEKO, HFSS, CST and EMC Studio are used to design and analyze antenna widely [3]. In this paper, EMC Studio is used to simulate the radiated interference of buck-boost converter, which is based on numerical calculation. Some measures to reduce the conducted interference and radiated interference are proposed in the following paper.

2 Working Principle of Buck-Boost Converter

The output voltage polarity is opposite to the input voltage in buck-boost converter. Buck-boost converter can shift from continuous conduction mode (CCM) to discontinuous conduction mode (DCM) with the variation of converter circuit parameters such as the input voltage and inductance value [4]. In this paper, buck-boost converter in CCM is studied.

Figure 1 shows the main circuit of buck-boost converter, it can be seen that the main circuit of buck-boost converter is composed of switching transistor, diode, inductor, capacitor and resistor.

Figure 2 shows the current path when the switching transistor Z works in switch-on. In this condition, the inductor L_f is charged by dc source and the load energy of R is given by the discharge of the capacitor C_f. Figure 3 shows the current path when the switching transistor Z works in switch-off. In the first stage, the inductor discharge energy to the capacitor and the load R. In the second stage, the load energy of R is given by the inductor L_f and the capacitor C_f.

The output voltage is given by

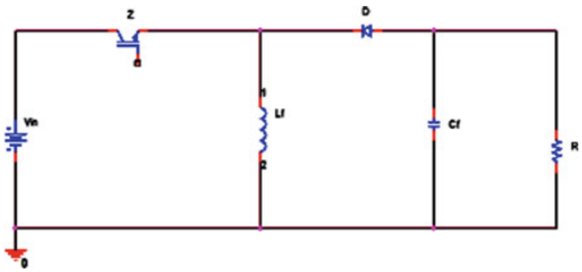


Fig. 1 Main circuit of buck-boost converter

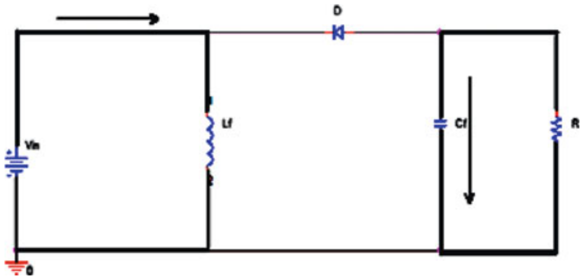


Fig. 2 Current path in switch-on

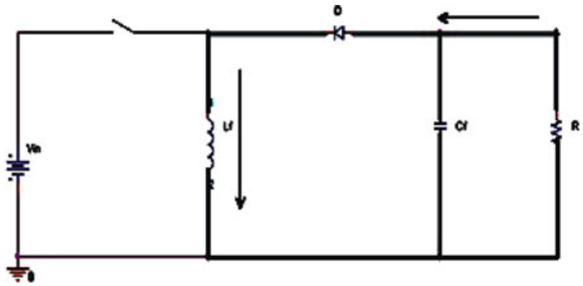


Fig. 3 Current path in switch-off

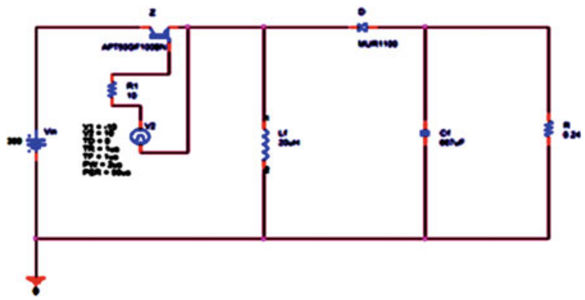
$$V_0 = \frac{D}{1 - D} V_{in} \tag{1}$$

where D is the duty cycle of buck-boost converter, V_{in} is the input voltage, V_o is the output voltage. The output voltage can be regulated by changing the duty cycle D, when $D < 0.5$, the output voltage is lower than the input voltage, when $D = 0.5$, the output voltage is equal to the input voltage, when $D > 0.5$, the output voltage is higher than the input voltage.

The critical inductance for the occurrence of transition from CCM to DCM can be obtained as follows:

$$L_f = \frac{R(1 - D)^2}{2f} = \frac{RV_{in}^2}{2f(V_{in} + V_0)^2} \tag{2}$$

Fig. 4 Buck-boost converter



where f is the switching frequency, R is the load resistor. If the inductance is less than L_f, the buck-boost converter will operate in DCM, otherwise the buck-boost converter will operate in CCM.

3 Simulation Study of Buck-Boost Converter

In this section, buck-boost converter is built by using circuit simulation software PSPICE. The value of input voltage is 360 V, the output voltage is 12 V, the switching frequency is 20 kHz and the output power is 600 W.

Figure 4 shows the simulation model of buck-boost converter, which is performed by using PSPICE software platform with the following parameters: $V_{in} = 360$ V, $L_f = 20$ uH, $C_f = 667$ uF, $R = 0.24\ \Omega$, $R_1 = 10\ \Omega$. With: Z: power switching tube APT50GF100BN, D: diode MUR100, R_1: current-limiting resistor. The transient analysis results of buck-boost converter circuit are obtained by using software PSPICE and the simulation time is 2 ms.

From Fig. 5, it can be seen that the inductor current is continuous.

Figure 6 shows the output voltage, it can be seen that the output voltage is -12 V. Figure 7 shows the output current which value is -50 A. From above results, it can be obtained that the output power of buck-boost converter is 600 W.

4 Study on Conducted Interference of Buck-Boost Converter

The drain-source voltage of switching tube can change in a short time, which produces high *du/dt*. The high *du/dt* spreads through the parasitic capacitance between the switching tube and ground, so the common-mode interference (CMI) is formed. High reverse recovery current is generated by diode when diode works from on state to off state. Because distributed capacitance and inductance are existed in the input and output wires, when high frequency surge current flow through the wires, the differential-mode interference (DMI) is formed. According to the request of GB18655-2002, in order to study the conducted interference,

Fig. 5 Inductor current

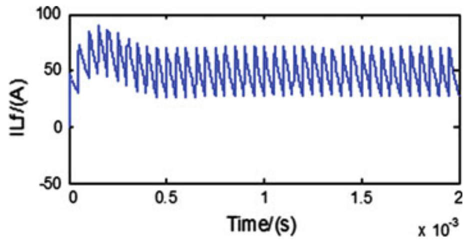


Fig. 6 Output voltage

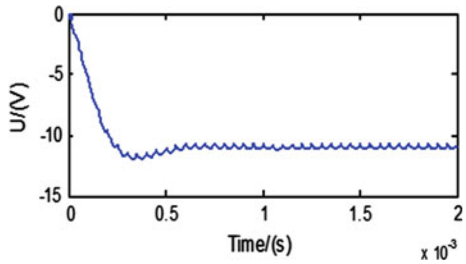
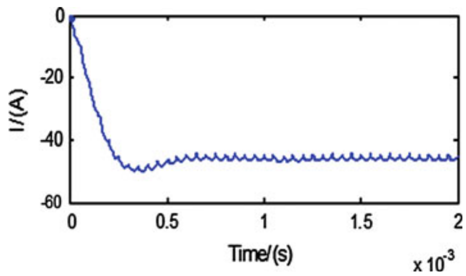


Fig. 7 Output current



Line Impedance Stabilization Network (LISN) installed between power supply and Equipment Under Test (EUT) is used.

Figure 8 shows the circuit of LISN, all the parameters are listed in the following: $L_2 = L_3 = 50$ uH, $C_2 = C_3 = 1$ uF, $C_4 = C_5 = 0.1$ uF, $R_3 = R_4 = 50\ \Omega$. Figures 9 and 10 shows the conduction path of CMI and DMI. The common-mode interference voltage and differential-mode interference voltage can be obtained on R_3 or R_4.

Figure 11 shows the relationship between the conducted interference voltage and frequency. According to the request of national standard GB18655-2002, the test results are compared with the standard limits given by the national standard.

From Fig. 12, it can be seen that the test results of the conducted interference exceed the national standard limits. Two methods are used to reduce the conducted interference. Firstly, an RCD snubber circuit is added in parallel with switching tube IGBT. Secondly, an RC snubber circuit is added in parallel with diode D.

Figure 13 shows measures for improving the circuit. After taking these measures, the test results of conducted interference are shown in Fig. 14.

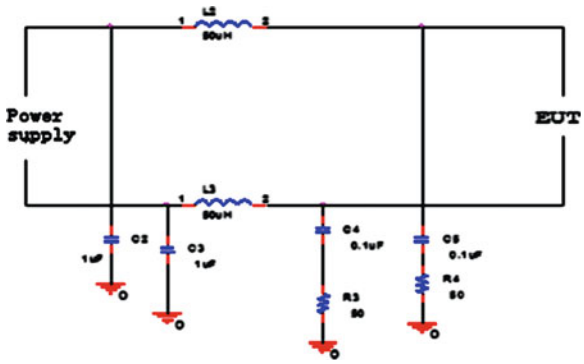


Fig. 8 Line impedance stabilization network

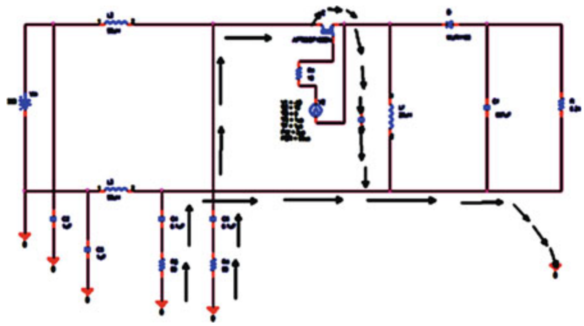


Fig. 9 Conduction path of CMI

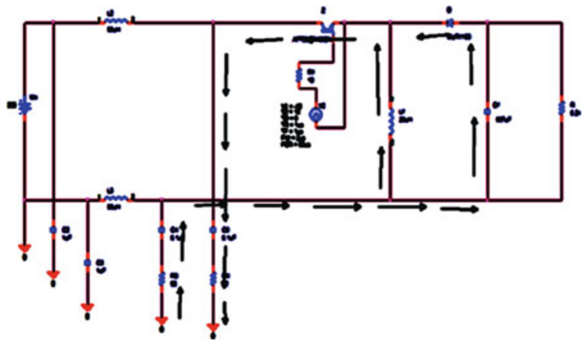


Fig. 10 Conduction path of DMI

5 Study on Radiated Interference of Buck-Boost Converter

Radiation field consists of far field and near field. High *du*/*dt* generates radiated electric field, high *di*/*dt* generates radiated magnetic field. In this paper, far-field radiation of common-mode interference and far-field radiation of differential-mode interference are studied. The relationship between conducted interference current and frequency is shown in Fig. 15.

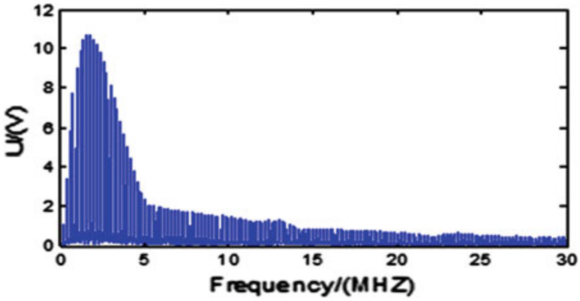


Fig. 11 The conducted interference voltage

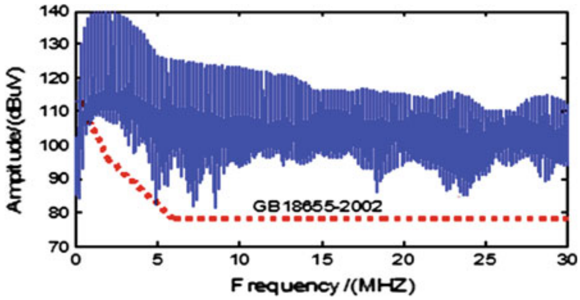


Fig. 12 Comparison results between test results and standard limits

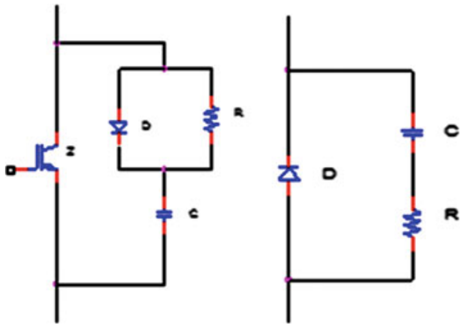


Fig. 13 Measures for improving the circuit

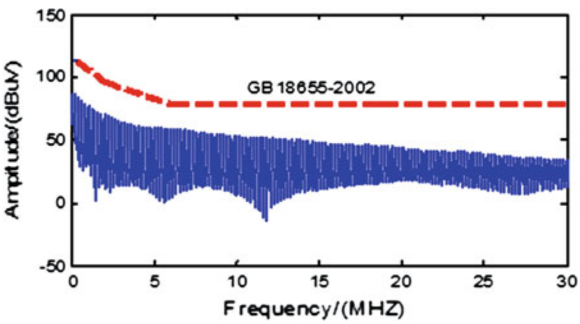


Fig. 14 Comparison between test results and standard limits

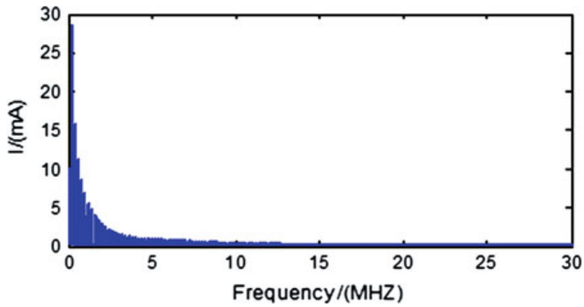


Fig. 15 Conducted interference current

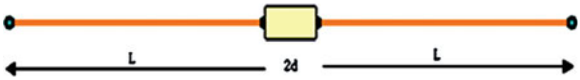


Fig. 16 Electric dipole mode

At the frequency from 150 kHz to 0.5 MHz, differential-mode conducted interference takes the main part. At the frequency from 5 to 30 MHz, common-mode conducted interference takes the main part.

In order to study the common-mode current far-field radiated interference, electromagnetic simulation software, EMC Studio, is used. The electric dipole radiation mode is built in EMC Studio (Fig. 16). L is the half length of the dipole, which is made of conductor. Where $2d = 1$ cm.

According to the request of GB18655-2002, the standard measurements of far-field radiated interference are done at a distance of 10 meters from the EUT and the measure frequency range vary from 30 to 500 MHz. Table 1 sums up the simulation parameters for electric dipole.

The electric field strength of common-mode current far-field radiation is given by

$$E = 1.26 \times 10^{-6} (fIL)(\frac{1}{r}) \quad (3)$$

where f is the frequency of common mode current, I is the value of common mode current, L is the path length of common mode current, r is the distance between test point and the interference source. In order to study the far-field radiation strength, different common mode current sizes and different path lengths are used to study the effects.

It can be seen that when the path length (common mode) L is under the same condition, the larger the common mode current, the stronger the electric field strength of far-field radiation will be (Fig. 17).

From Figure 18, it can be seen that when the common mode current I is under the same condition, the longer the path length (common mode), the stronger the electric field strength of far-field radiation is. In order to reduce the common mode current far-field radiation, reducing the common mode current size and the path length (common mode) are needed.

Table 1 Parameters for electric dipole

Common mode current (uA)	L_1 (cm)	L_2 (cm)	L_3 (cm)
800	5	10	15
600	5	10	15
400	5	10	15

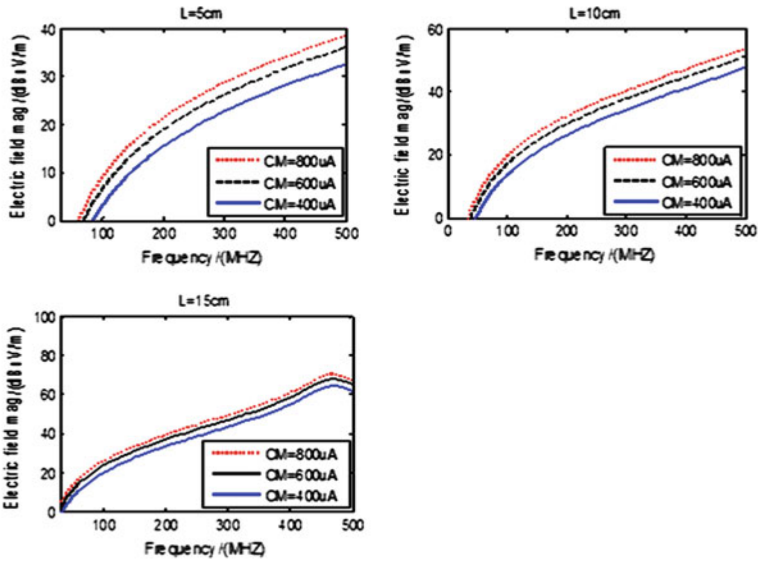


Fig. 17 The electric field magnitude

The differential-mode current far-field radiation is simplified as a rectangular loop antenna. The rectangular loop antenna is designed in electromagnetic simulation software EMC Studio (Fig. 19).

Figure 19 shows the rectangular loop antenna built in EMC Studio, where M is the width of the rectangular, L is the length of the rectangular. The electric field strength of differential mode current far-field radiation can be obtained as follows:

$$E = 1.316 \times 10^{-14}(f^2 SI)(\frac{1}{r}) \tag{4}$$

where f is the frequency of differential mode current, I is the value of differential mode current, S is the rectangular area, r is the distance between test point and interference source.

In order to study the effect of the rectangular area on the electric field strength, some parameters for rectangular loop antenna are shown in Table 2.

From Fig. 20, it can be seen that the larger the rectangular loop area, the stronger the electric field strength of far-field radiation is.

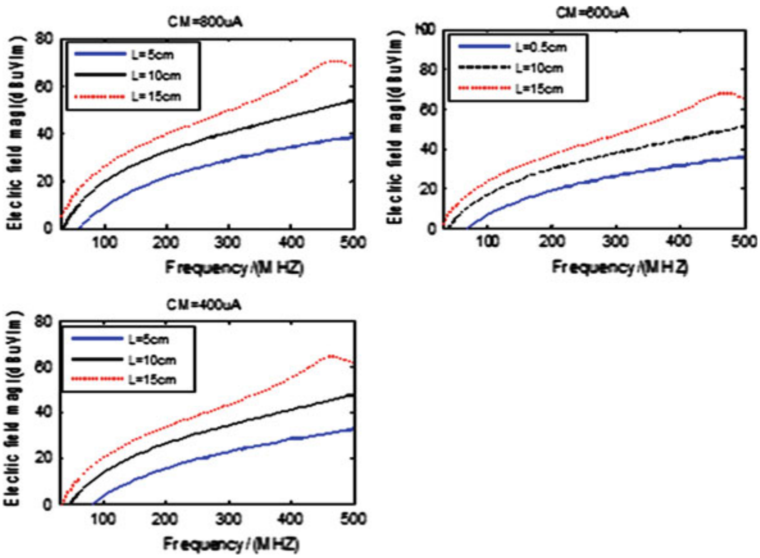


Fig. 18 The electric field magnitude

Fig. 19 Rectangular loop antenna

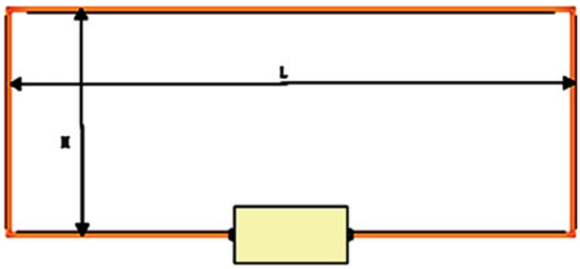


Table 2 Parameters for rectangular loop antenna

Loop area (cm^2)	L (cm)	M (cm)
9	3	3
16	4	4
25	5	5
9	2	4.5
16	2	8
25	2	12.5

Figure 21 shows when the rectangular loop area is equal to the square loop area, the electric field strength of rectangular loop is less than square loop. In order to reduce the differential mode current far-field radiation, reducing the rectangular loop area is needed. Using narrow rectangular loop instead of square loop can reduce the electric field strength of far-field radiation.

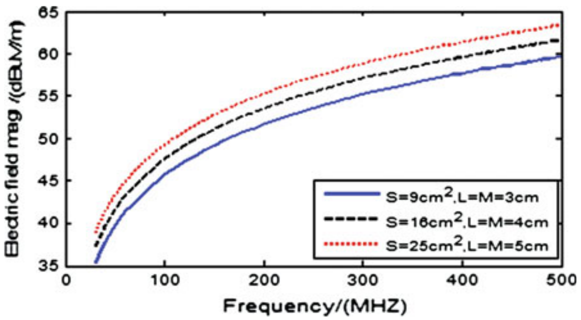


Fig. 20 Electric field magnitude

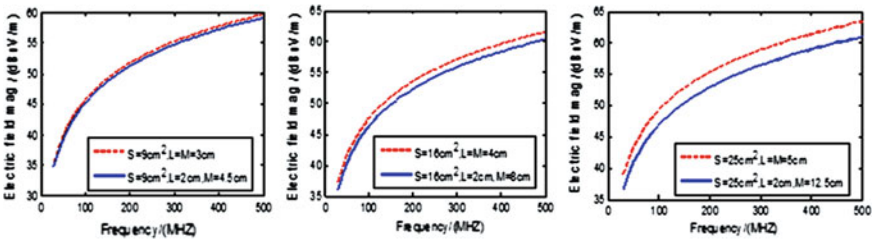


Fig. 21 Electric field strength comparison between rectangular loop and square loop

6 Conclusion

According to the request of GB18655-2002, the conducted interference and radiated interference have been studied. In order to reduce the conducted interference, RCD buffer circuit and RC buffer circuit are used. The methods of reducing the common mode current and shortening the path length of common mode are used to reduce the common mode current far-field radiation. The method of reducing the rectangular loop area and using narrow rectangular loop instead of square loop are adopted to decrease the differential mode current far-field radiation.

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