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Research on Common Mode Interference of PWM Inverter Driving System

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Abstract

In order to suppress electromagnetic interference of PWM driving system, electromagnetic interference characteristics ,system distribution and main influence factor in this system must be accurately mastered. Therefore this paper used conduction separation network to meter common mode interference of PWM inverter system ,and through comparison results of different conditions ,the author obtained the distribution of common mode interference on power side and load side . Then the team made analysis and improvement to the common-mode interference model, at last through theory analysis and calculation some suppression method to CM interference was found , which may provide certain theoretical guidance for EMI filter design.

***Keywords**: Common mode interference; interference model; electromagnetic interference*

1. Introduction

PWM inverter driving system are widely used in various fields of of industrial, agricultural,military and so on, by virtue of its better control of electrical energy through power conversion devices and can output variable voltage and current waveform; realized controllable speed through changing motor stator frequency, improving speed performance, while also saving energy. But with coexisting EMI (Electro Magnetic Interference) issues is becoming more and more serious, if can not be solved well, it will severely degrade system performance, and increase equipment fault, even causing tragedies [1-3].

In order to solve these problems, many scholars were analyzed,such as Ran of the University of Nottingham established a time domain simulation system model using Saber software, and accordingly obtained a simplified circuit model of three leading mode [4-8]. Scholars headed with A. L Julia from interference suppression aspects, according to the "Circuit balance" principle put forward a three-phase four-leg scheme for elimination of three-phase power converter output common-mode voltage [9-10]. A Takahashi et al proposed a completely eliminate common mode current active filter, in order to eliminate the common mode conducted EMI components of PWM motor drive system [11]. Meng Jin et al of Naval University of Engineering establish a high-frequency conducted interference model of PWM inverter drive system, in order to analyze the system conducted interference [12-14]. In this paper, through conduction separation network [15-18] of PWM drive system, distribution of common-mode interference and influence factors were studied, finally according to the improved interference model, the author has carried on the preliminary exploration on CM interference suppression method.

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2. Research Object

In this paper, the research object as shown in Figure 1, three-phase power supply to PWM inverter through LISN, the inverter connected three-phase asynchronous motor. G1, G, G2 are respectively the ground of LISN, inverter and motor, N is the drive chassis ground. The entire drive system includes two power conversion link: AC-DC three-phase uncontrolled rectifier bridge, DC-AC three-phase PWM inverter bridge. Therefore, the system exists of two interference sources, i.e., rectifier bridge and inverter bridge interference sources.

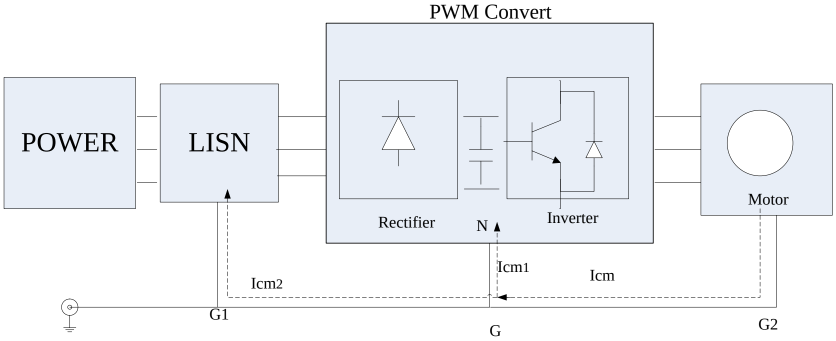


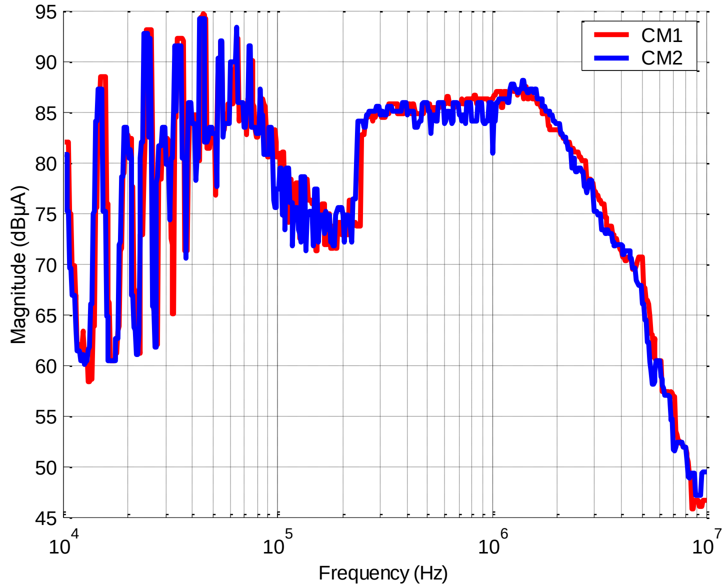
Figure 1. PWM Variable Frequency Driving System

3. Distribution of Interference

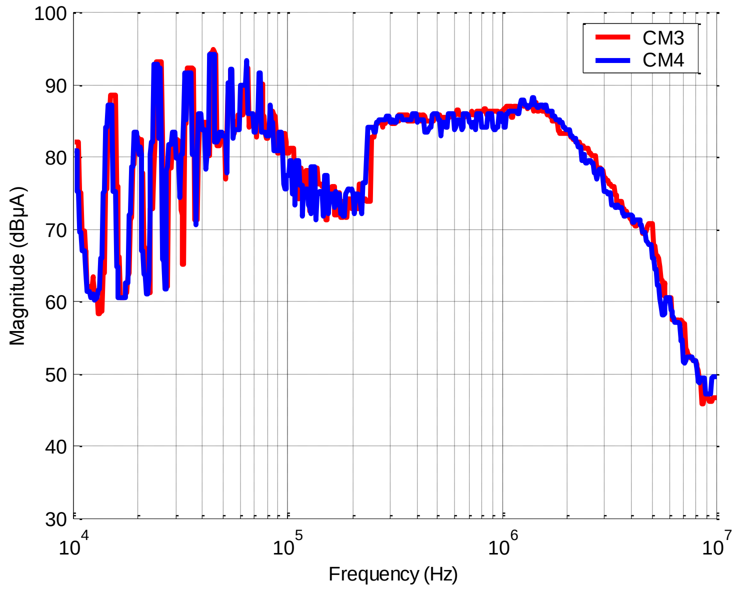
In order to investigate the main factors of influence on system CM interference distribution, test conditions as designed under different loads are shown in Table 1, wherein no-load refers to the load generator without excitation current, load refers to the generator have rated magnetizing current. The test results shown in Figure 2,and test data in Table 2.

Table 1.Test Conditions

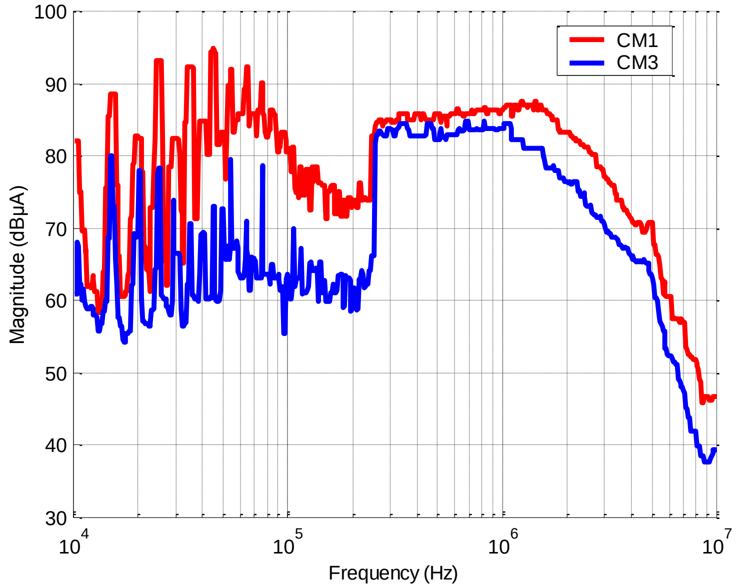
state	input voltage / V	inverter output voltage /(%)	inverter output current /A	motor working state	testing location	CM
1	380	100	12.8	no-load	power side	CM1
2	380	100	13.9	with-load	power side	CM2
3	380	50	4.9	no-load	power side	CM3
4	380	50	6.0	with -load	power side	CM4



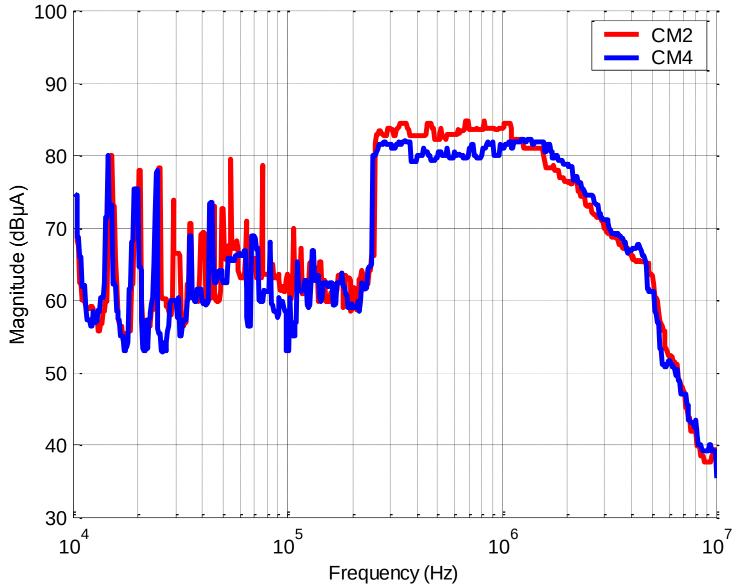
(a) Condition 1



(b) Condition 2



(c) Condition 3



(d) Condition 4

Figure 2. Common Mode Interference of Power Side under Different Conditions

Table 2. Part of Experimental Data

Interference	Frequency			
	10kHz	100kHz	1MHz	10MHz
CM1 (dBμA)	81.87	71 .55	83 .98	44.04
CM2 (dBμA)	82. 04	71.72	84. 6	44.37
CM3 (dBμA)	83 .82	70.72	80. 67	40. 59
CM4 (dBμA)	82.56	70.13	81 .92	41 .29

Comparing data in Table 2 , finding that, CM1 and CM2 are relatively close in the entire frequency band, furthermore CM3 and CM4 have the similar phenomenon, which shows that load has no obvious influence on common mode interference, but in contrast to CM1 and CM3 , CM2 to CM4, only a subtle influence on the individual point, the entire band remained the same. This shows that working conditions had no effect on distribution of common mode interference.

For working conditions are not the main factor of affecting common-mode interference, the following test conclusion can be extended to other conditions.

To understand the dominant system common mode interference sources, respectively, when under conditions 1 rectifier bridge working alone, common mode interference were tested on power side and load side, test results shown in Figure 3 to Figure 5.

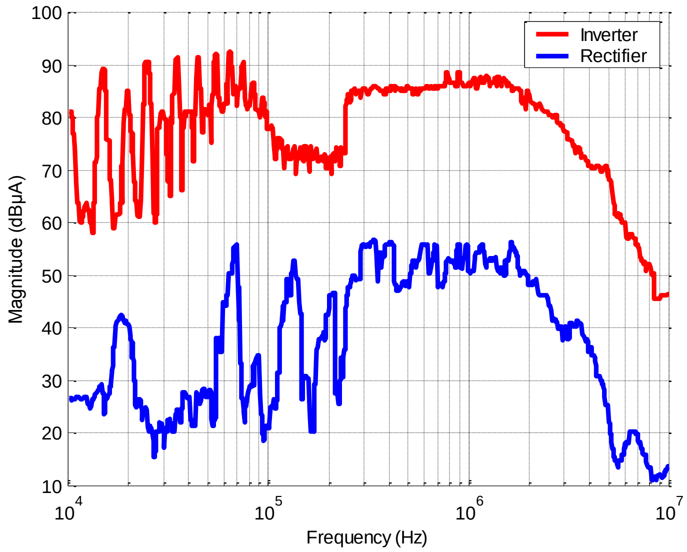


Figure 3. Common Mode Interference of Inverter and Rectifier on Power Side

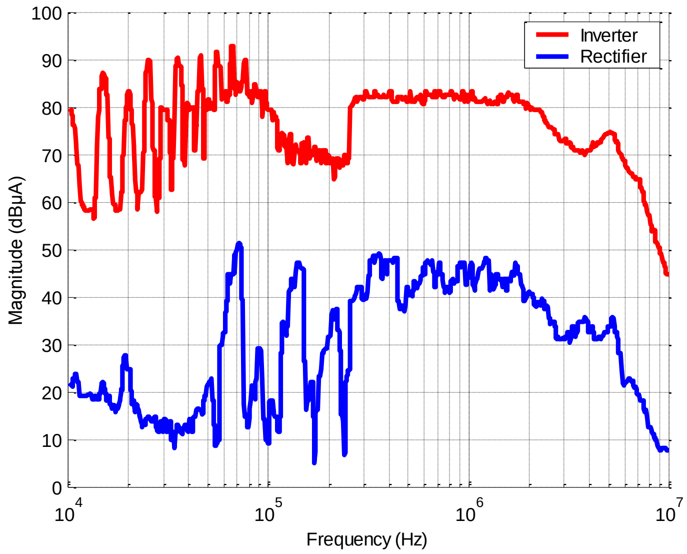


Figure 4. Common Mode Interference of Inverter and Rectifier on Load Side

As can be seen from Figure 3, in the entire frequency band, common mode interference generated by inverter is 30dB higher than rectifier. This indicates that relative to inverter, the common-mode interference generated by rectifier is negligible, the common-mode interference on power side is dominated by inverter. Similarly, it can be seen from Figure 4, the load-side common mode interference is also dominated by the inverter. Figure 5 shows a visual representation of common mode interference on power side and load side, you can see in the whole test band, common mode interference are basically consistent on both sides.

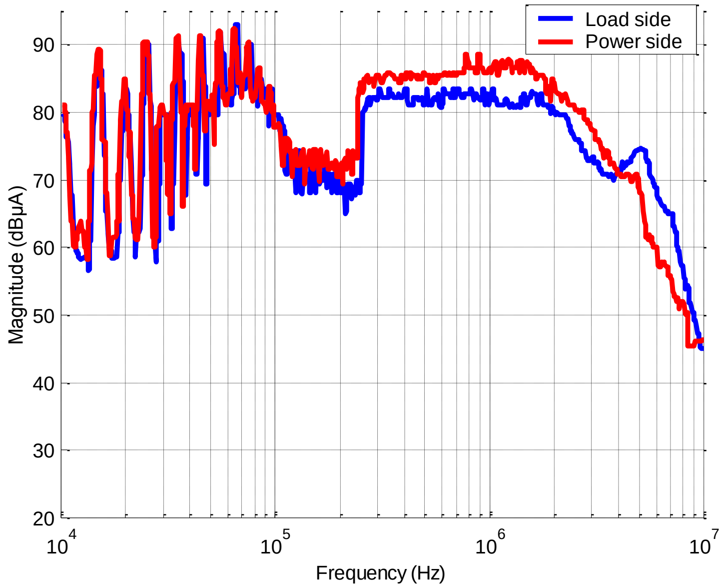


Figure 5. Common Mode Interference of Inverter on Power Side and Load Side

4. Interference Suppression

Through the above comparison test, concluded the regularity of common-mode interference distribution. The following will analyze main factors of common mode interference based on the interference model. Figure 6 is the common mode interference model proposed in literature [15]. Which, V_3 is common mode interference sources of rectifier, V_4 for common mode interference source of inverter bridge; L_1, L_2 DC bus parasitic inductance; R_5, L_5 for inverter outlet resistance and inductance; R_6, L_6 inverter line resistance and inductors; C_{rp}, C_{ip} inverter parasitic capacitance.

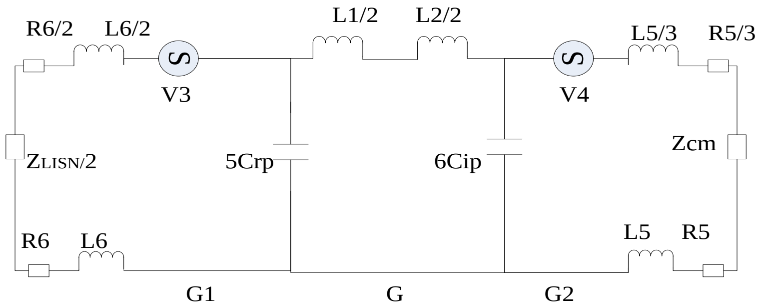


Figure 6. Equivalent Circuit of Common Mode Interference

Firstly we verify the correctness of the model: it can be seen from the model, to suppress common mode interference generated by inverter bridge, simply cut off the path of common mode interference on the load side, disconnected G2 in figure6, on power side there would be no common mode interference generated by inverter, only left common mode interference of rectifier. In this regard, cut off the ground wire G-G2 in figure 1, respectively test common mode interference on power side when rectifier and inverter working alone, and test results is shown in figure 7.

It can be clearly seen from Figure 7, when converter working common mode interference on power side bridge obviously contains interference points of inverter, and in addition to individual frequency, in the entire frequency band interference is 20dB larger than rectifier bridge. This fully shows that in the case of G-G2 cut off, common mode interference of inverter has conducted to the power side. Therefore, the model can not be used to explain the common mode interference path for this particular case, which requires improving the model.

Taking into account the dispersion of parasitic capacitance of converter, combined with the previous analysis, put forward the common mode interference model shown in figure 8. Wherein Z_3 is the power-side common mode interference equivalent impedance, which comprises the input line high-frequency inductance and resistance, as well as common mode impedance LISN. Z_4 for power-side common mode interference equivalent impedance, which contains the output line high-frequency inductance and resistance, as well as common mode impedance of motor windings. C_1 as the rectifier bridge capacitance to ground, C_2 for intermediate DC bus capacitance to ground, C_3 inverter bridge capacitance to ground. When disconnecting G-G2, the common mode current generated by inverter will now return to power side through capacitor C_3, which can better explain the phenomenon in figure 7.

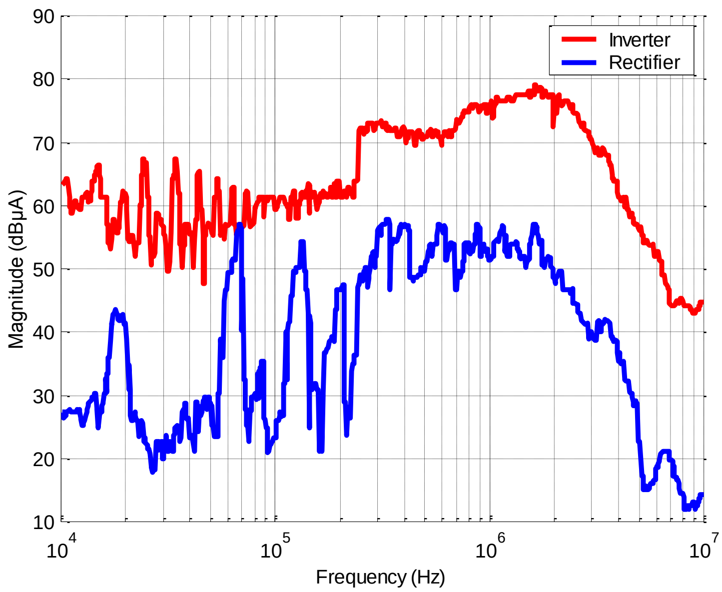


Figure 7. Common Mode Interference on Power Side Disconnecting G-G2

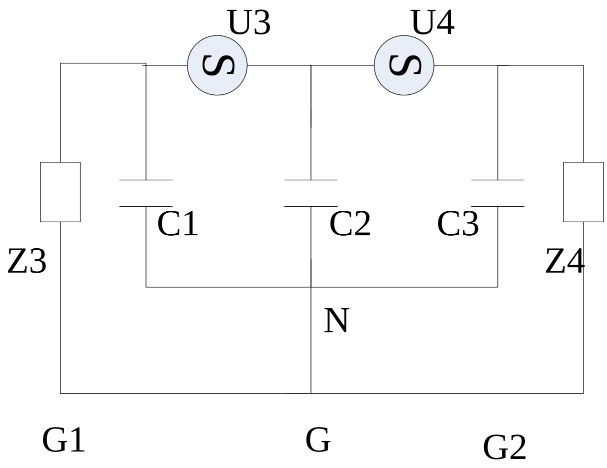


Figure 8. Common Mode Interference Model by Circuit Theory

$$I_{Z3} = \frac{U_3}{Z_4 // Z_{(C2+C3)} + Z_3 // Z_{c1}} \bullet \frac{Z_{c1}}{Z_3 + Z_{c1}} + \frac{U_4}{Z_3 // Z_{(C2+C1)} + Z_4 // Z_{c3}} \bullet \frac{Z_{(C2+C1)}}{Z_3 + Z_{(C2+C1)}} \tag{1}$$

$$I_{Z4} = \frac{U_3}{Z_4 // Z_{(C2+C3)} + Z_3 // Z_{c1}} \bullet \frac{Z_{(C2+C3)}}{Z_4 + Z_{(C2+C3)}} + \frac{U_4}{Z_3 // Z_{(C2+C1)} + Z_4 // Z_{c3}} \bullet \frac{Z_{C3}}{Z_4 + Z_{C3}} \tag{2}$$

Wherein: I_{Z3}, I_{Z4} − respectively common mode currents through Z_3 ,Z_4;
Z_{C1}, Z_{C2}, Z_{C3} − impedance of capacitors C_1, C_2, C_3;
$Z_{(C1+C2)}$, $Z_{(C2+C3)}$ − impedance of capacitance $C_1 + C_2$ and $C_2 + C_3$.

So long as we know parameters of the equation, we can analyze the system distribution of common-mode interference.

Figure 9, Figure 10 is the result of measurement and calculation, obtained Z_4, Z_{C1} impedance characteristics. As can be seen, in low frequency band Z_{C1} is much larger than the Z_3, Z_4. Since C_1, C_2, C_3 is of the same order of magnitude, the impedance can be approximately equal. Therefore, equation (1), equation (2) can be simplified to

$$I_{Z3} = I_{Z4} = \frac{U_3 + U_4}{Z_3 + Z_4} \tag{3}$$

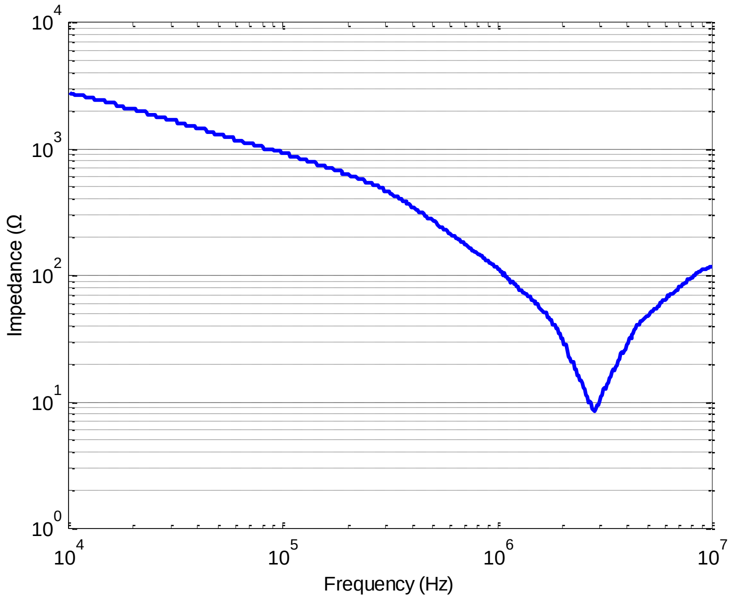


Figure 9. Impedance Z_{C1} of Parasitic Capacitance C_1

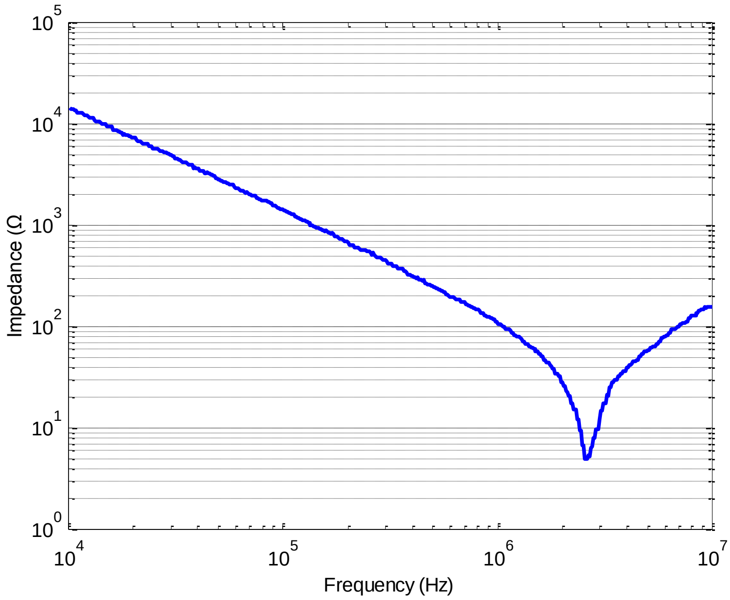


Figure 10. Load Impedance Z_4

From equation (3) can be seen, the common-mode currents on power-side and load side are equal, that matchs the phenomenon in Figure 6. At the same time, can also be seen that Z_3, Z_4 should be the main factors of common-mode interference. Therefore, direct cut off load ground line in the extreme cases, when $Z_4 = \infty$ common mode interference current on power side, the test results shown in CM7 of Figure 11, while CM1 for the common mode interference currents on power side as the system in condition 1.

It can be clearly found in 10kHz-2MHz, CM7 must be smaller than CM1, at 10kHz the difference is of -20dB, as the frequency increases, the difference decreases, indicating that in low-frequency band Z_4 is the main factors of common mode interference, but this effect decreases gradually with the increase of frequency. Overlap in the 3.7MHz, which indicated that Z_4 has no more influence on the common mode interference. For the definition of impact band scope, the decision is mainly composed of the relative size between Z_4 and Z_{C1}, Z_{C2}, Z_{C3}.

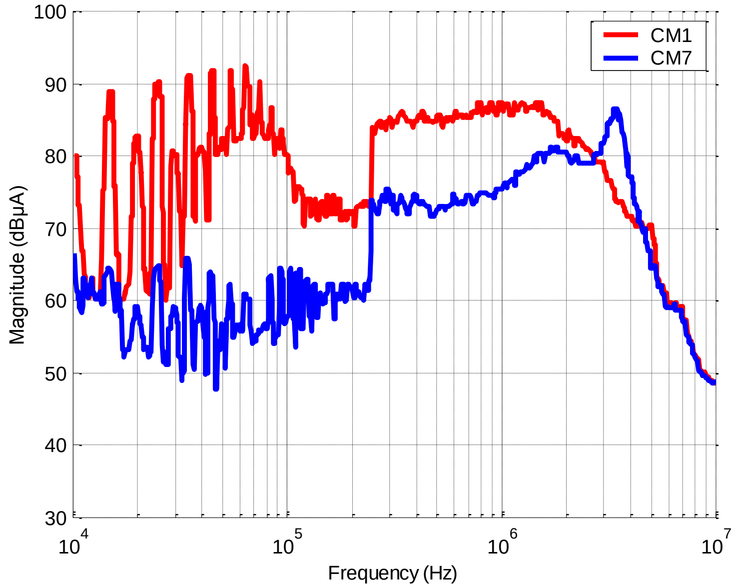
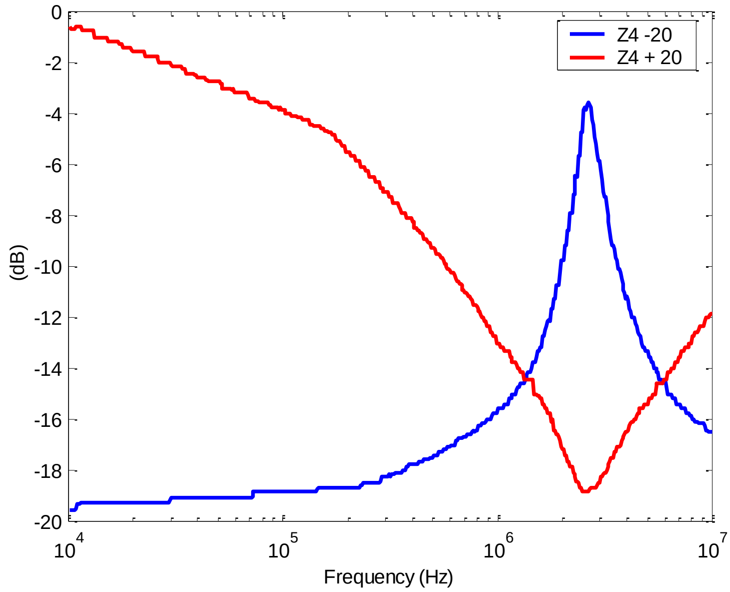


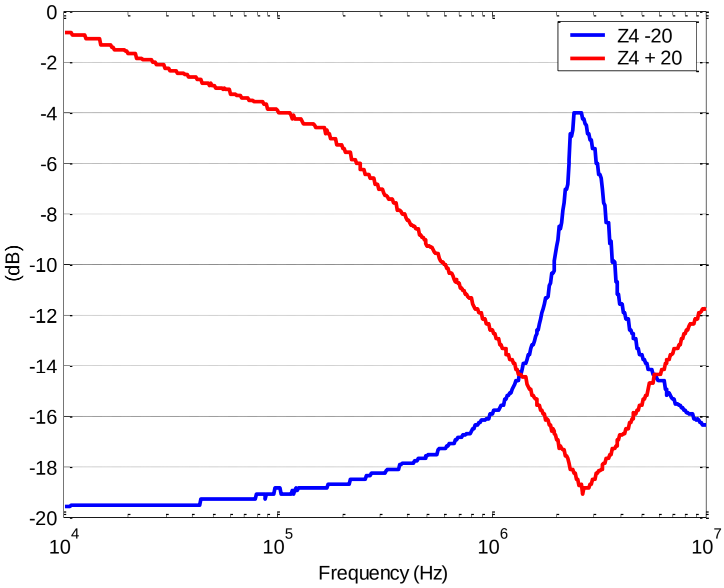
Figure 11. Common Mode Interference CM1, CM7 on Power Side

Also the similar method can be used to verify that Z_3 is the main factors of common mode interference in low frequency. Through the above model analysis, it can be concluded that in low frequency band, the main factors of affecting the common mode interference distribution is impedance Z_3, Z_4.

Z_3, Z_4 is the main factor affecting the distribution of common mode interference, respectively compared common mode interference suppression effect on power side and load side with common mode inductance and capacitance. Similarly, assuming that the power side inductance in series, so as to increase Z_3 to Z_3+ 20dB; parallel capacitor allows Z_3 to Z_3-20dB; load side series inductance, increased of Z_4 to Z_4 + 20dB, shunt capacitance makes Z_4 for Z_4 -20dB. Figure 12, Figure 13 is Z_3, Z_4 common mode interference curve calculated by the equation (1), the equation (2).

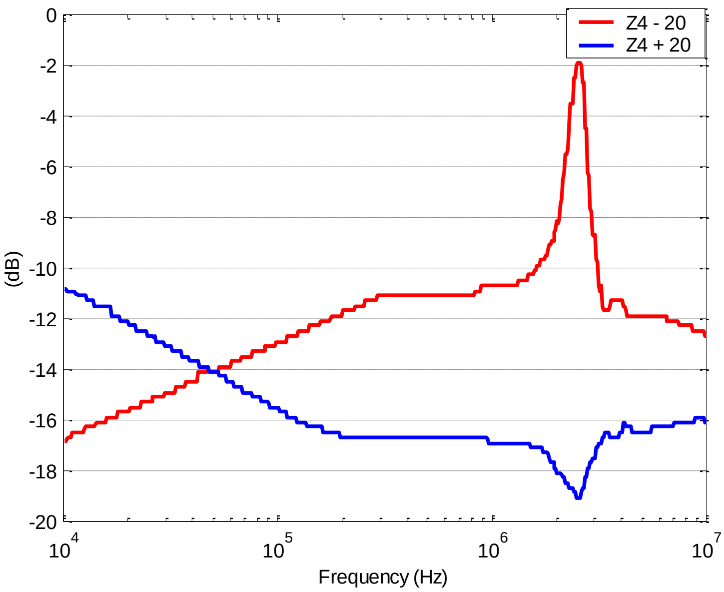


(a) U_3

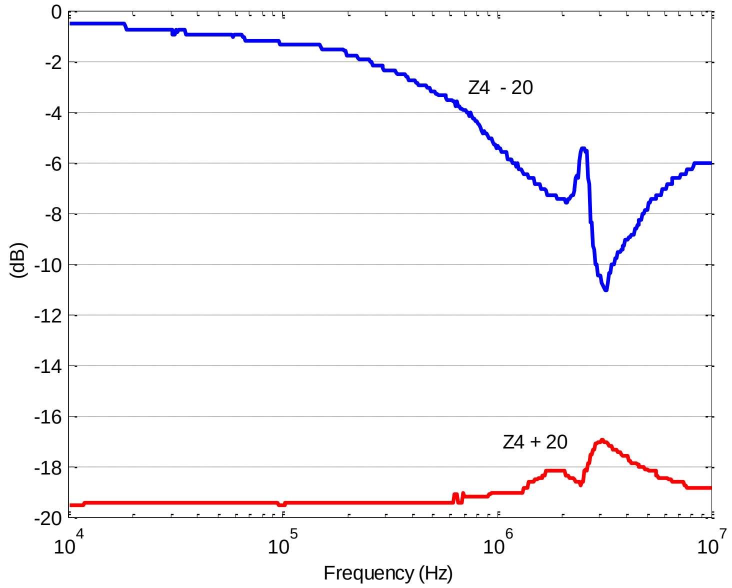


(b) U_4

Figure 12. Common Mode Interference Of U_3, U_4 on Power Side when Z_3 changing



(a) U_3



(b) U_4

Figure 13. Common Mode Interference of U_3, U_4 On Load Side when Z_4 Changing

As can be seen from Figure 12, in 1.5-6MHz with common mode inductance inhibitory effect is better than plus capacitance, while in other bands capacitor effect is better than inductance effect; through Figure. 13 showing that although 10-50kHz the inhibitory effect of shunt capacitance is better than the series inductance, combination with the actual situation of U_4 is much larger than U_3, on the whole, at load side the inductive effect is better than capacitance effect.

5. Conclusion

For PWM inverter drive systems EMI study is a very important issue. But most of the present study limited to simulation analysis, considerations is not comprehensive enough, not the actual conditions. In this paper,based on the actual system test comparative analysis, combined with interference model, interference suppression measures theoretical analysis and research on the theory, we get the following conclusions:

(1) common mode interference system for power side and load side are mainly produced by the inverter, and the common-mode interference on both sides are basically the same;

(2) to suppress common mode interference at power side ,in the low frequency parallel common mode capacitance is better than series common mode inductance; for the load side of common mode interference suppression, the series CM inductor is better.

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