Conducted EMI Circuits Modeling During Transient Phenomena on Three Phase Full-Bridge PWM Inverters

K. Karanun*,, W. Khan-ngern** and S. Nitta*****

* EMC Test Group, Operation and Standard Center, Electrical and Electronics Institute (EEI), Samutprakan, Thailand.

** Faculty of Engineering and EMC Laboratory,
Research Center for Communications and Information Technology (ReCCIT)
King Mongkut's Institute of Technology Ladkrabang (KMITL), Bangkok, 10520, Thailand
Phone/Fax: +662 737-3000 Ext. 3322, E-mail: kkomkrn@hotmail.com, kkveerac@kmitl.ac.th

*** Graduate School, Production System Engineering
Salesian Polytechnic, 2-35-11 Igusa Suginami, Tokyo, 167-0021, Japan
E-mail: nitta@cc.tuat.ac.jp

Abstract This paper presents the mechanism of common-mode (CM) conducted electromagnetic interference (EMI) on Three-phase full bridge pulse-width modulation (PWM) inverters. The circuits modeling of common-mode conducted EMI are proposed for the studying common-mode conducted EMI, which is generated by operating of the inverter. The circuit modeling is described by passive components, which the active component is replaced by passive components. The relationship between resonance frequency of the circuits and conducted EMI are explained. The circuit modeling is achieved by simulation, which refers to measured results and help to understanding the mechanism of conducted EMI.

1. Introduction

The operation of PWM inverter can generate noises into the system in both of conducted and radiated EMI. The high *dv/dt* and *di/dt* are caused of EMI [1]. The conducted EMI measurement which is succeed by Line Impedance Stabilization Network (LISN), from the investigation of input voltage waveform of the inverter, the waveform consists of fundamental signal and high frequency signals as shown in figure 1. The high frequency signals or ringing signal are undesigning signals which call noises. The ringing signals are detected by LISN. Then the ringing signals are noises, which are occurred by the operating of the switching devices of PWM inverter, during turn-on or turn-off condition. The ringing signal is affected by series RLC loop as shown in figure 2. When switch SW in figure 2 (a) turn-on, it can generate the ringing signal. The ringing signal can be explained by eq. (1) [2]. The waveform in figure 2(b) is achieved by eq. (1), which is one of EMI. In this paper the sinusoidal pulse-width modulation (SPWM) is used for consideration.

2. Three-Phase PWM Inverters

The three-phase PWM inverter is the dc-ac converter as shown in figure 3. The PWM inverter is to generate nearly sinusoidal current which it can be controlled. The voltage and current are controlled with 120º different in each phase. The controlling signals of three-phase PWM inverters have many pattern controls which it can be seen in paper and textbook of power electronics such as sinusoidal pluswidth modulation (SPWM) as shown in figure 4. Figure 4 shows controlling signals of three-phase PWM inverter in each phase. The operations three-phase inverter can be defined in eight modes [3] as shown in table I which shows status of each switch in each operations mode. From operations mode, the current cannot flow to load in mode #0 and #7 while current can flow to load in mode #1 to #6. Then, it can draw two equivalent circuits for operations mode which mode #1 operation is the same as of those #2 and #4 and mode #3 is the same as #5 and #6 as shown in figure 5.

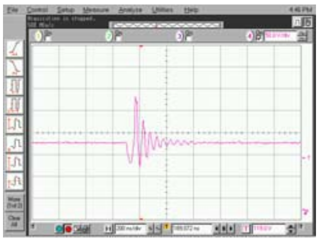
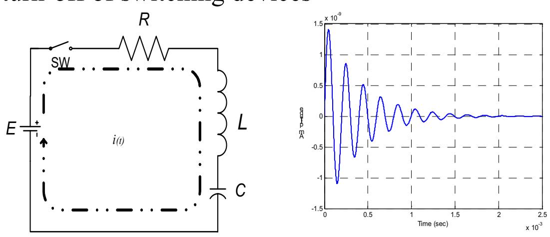


Figure 1. The ringing signal due to the turn-on or turn-off of switching devices



(a) Circuit diagram (b) Result of the Circuit

Figure 2. Series RLC loop

$$i(t)=\frac{2ELCe^{-\frac{R}{2L}t}}{\sqrt{4\frac{L}{C}-R^{2}}}\cdot \sin\left(\left(\frac{\sqrt{\frac{4L}{C}-R^{2}}}{2L}\right)\cdot t\right) \qquad (1)$$

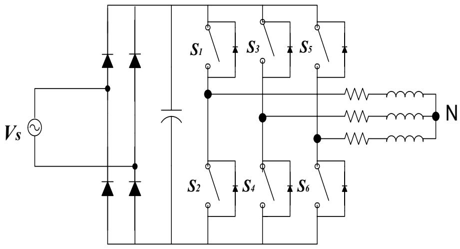


Figure 3. Three-phase voltage source inverters

Table I The operations mode of three-phase inverters

Mode	S_1	S_3	S_5	S_2	S_4	S_6
#0	0	0	0	1	1	1
#1	0	0	1	1	1	0
#2	0	1	0	1	0	1
#3	0	1	1	1	0	0
#4	1	0	0	0	1	1
#5	1	0	1	0	1	0
#6	1	1	0	0	0	1
#7	1	1	1	0	0	0

Remark: 1=switch close, 0=switch open

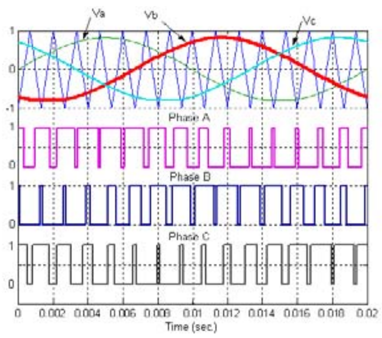
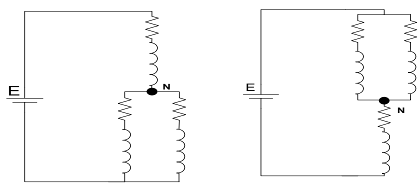


Figure 4. The controlling signals of SPWM three-phase inverters



(a) Mode #1, #2 and #4 (b) Mode #3, #5 and #6

Figure 5. Equivalent circuit of Three-phase inverter

3. Conducted EMI Circuit Modeling for Three-Phase Inverters

The conducted EMI circuit modeling of three-phase inverters, the parasitic component is concentrated in inverter circuit as shown in figure 6. The controlling signals of three-phase inverter in figure 3 is used in modeling structure of conducted EMI circuit which can be separated in six groups [3] as shown in figure 7. The operations mode can be defined in each group as shown in figure 7. Changing operation mode to another mode in each group, the switch status of inverter is changing only one switch which can be seen in each group.

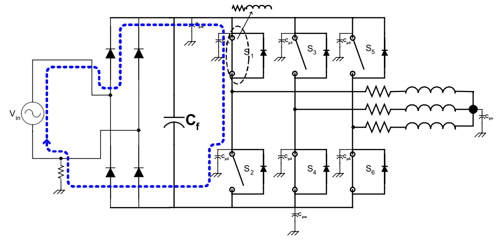


Figure 6. Three-phase inverters with parasitic circuit

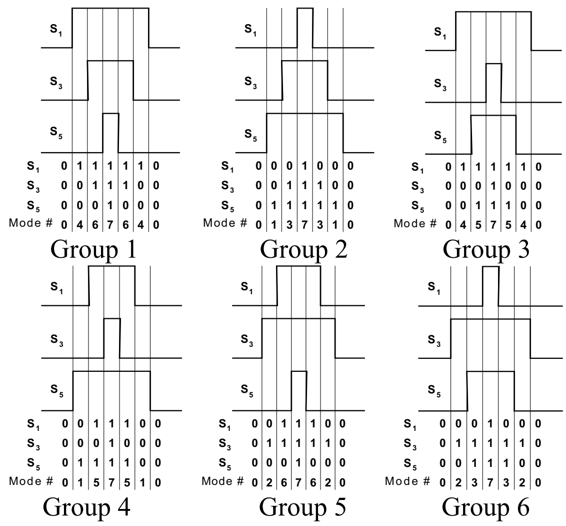


Figure 7. The operation group of controlling signals of Three-phase inverters

The conducted EMI modeling of three-phase inverters is considered from operation group which is separated in two statuses for turn-on and turn-off switching devices. In each status, it is separated for six cases. The changing switch status in each mode is the same as every group then it can be explained only one group for representation every group.

The turn-on status and turn-off status

<u>Case 1</u> Mode #0 → #4 ≡ #0 → #1 ≡ #0 → #2

<u>Case 2</u> Mode #4 → #6 ≡ #1 → #3 ≡ #4 → #5 ≡ #1 → #5 ≡ #2 → #6 ≡ #2 → #3

<u>Case 3</u> Mode #6 → #7 ≡ #3 → #7 ≡ #5 → #7

<u>Case 4</u> Mode #7 → #6 ≡ #7 → #3 ≡ #7 → #5

<u>Case 5</u> Mode #6 → #4 ≡ #3 → #1 ≡ #5 → #4 ≡ #5 → #1 ≡ #6 → #2 ≡ #3 → #2

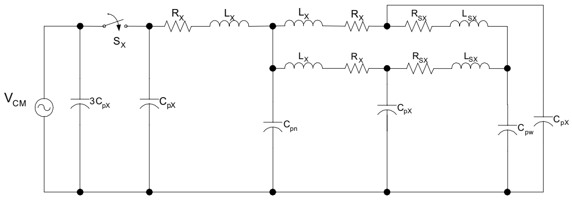
<u>Case 6</u> Mode #4 → #0 ≡ #1 → #0 ≡ #2 → #0

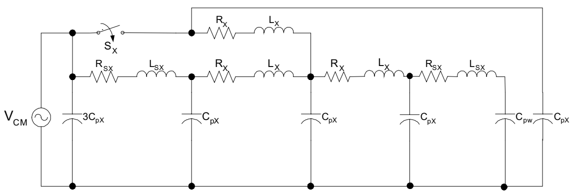
Remark: → is changing status to another mode
≡ is equivalent condition

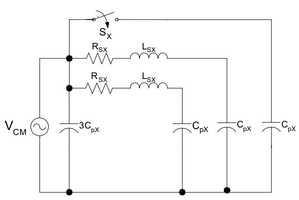
The turn-on and turn-off status in case1 and case 6 the main power current cannot flow to load, respectively. From the operations mode and three-phase inverters with parasitic circuit in figure 6, there can be created circuit modeling for conducted EMI of three-phase inverters in each case as shown in figure 8 and 9 respectively. Then, the circuit modeling is simulated for relationship between impedance and conducted EMI of each circuit.

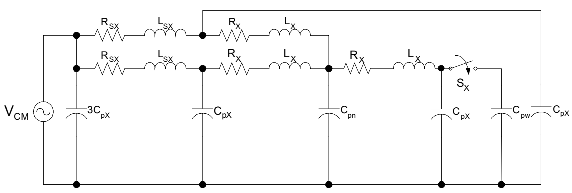
where R_{sx} is internal resistance of switching device
L_{sx} is internal inductance of switching device
R_x is load resistance
L_x is load inductance
C_{px} is parasitic capacitance between heat sink and switching device
C_{pw} is parasitic capacitance between conductor and ground plane
C_{pn} is parasitic capacitance between common-node of three phase load and ground plane
S_x is switch of three-phase inverters

Conducted EMI simulation of circuit modeling is assumed R_{SX} = 0.85 Ω, L_{SX} = 12nH, R_X = 79 Ω, L_X = 20 mH, C_{pX} = 50 pF, C_{pn} = 0.1 pF and C_{pW} = 0.5 pH. The simulated results of conducted EMI circuit modeling for turn-on in case1 and turn-off in case 2 shown in figures 10 and 11 respectively. Switching devices in three-phase inverters circuit are replaced by series R, L when switching device remains turn-on status. Figures 10 and 11 show impedance and conducted EMI during turn-on and turn-off, which is related to resonance point of circuit.


(a) Case1


(b) Case 2


(c) Case 3


(d) Case 4

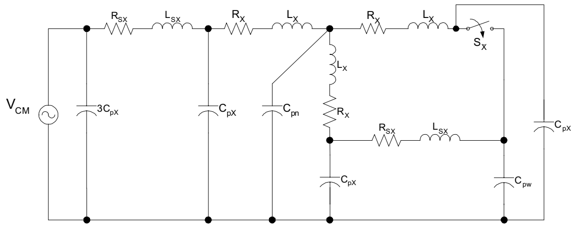
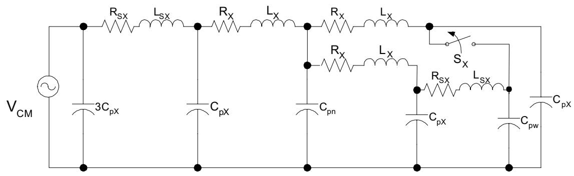
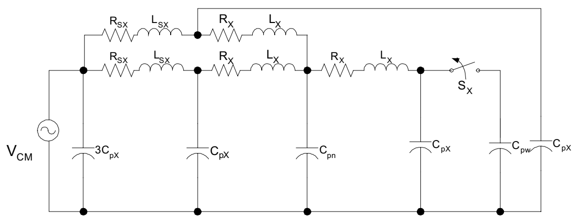
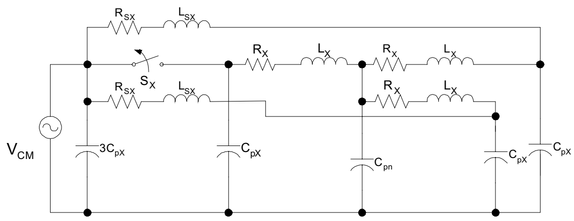
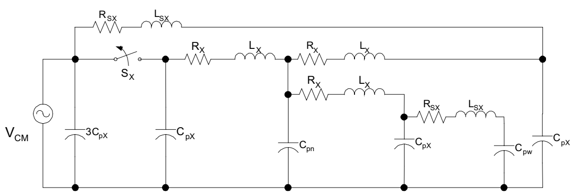

(e) Case 5

Figure 8. Circuit modeling for turn-on status


(a) Case 2


(b) Case 3


(c) Case 4


(d) Case 5

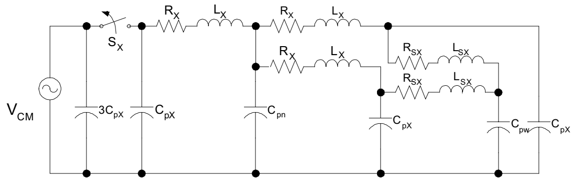
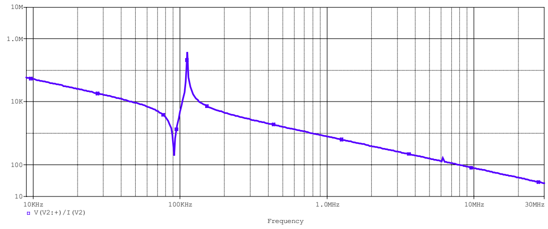
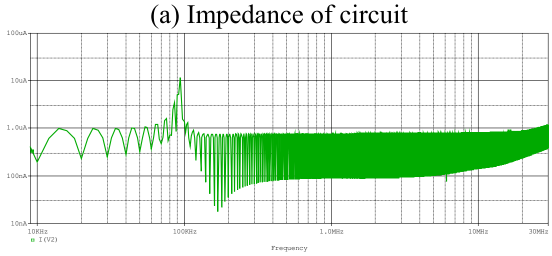

(e) Case 6

Figure 9. Circuit modeling for turn-off status

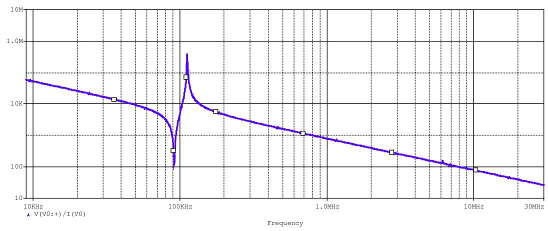


(a) Impedance of circuit

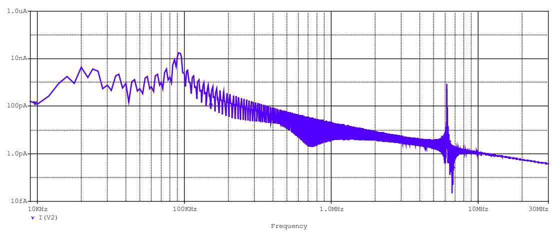


(b) Conducted EMI from circuit modeling

Figure 10. Simulated results for turn-on status in case1



(a) Impedance of circuit



(b) Conducted EMI from circuit modeling

Figure 11. Simulated results for turn-off status in case2

Simulated results during turn-on and turn-off in each case, the peak of conducted EMI corresponds the resonance frequency of circuit modeling. The resonance frequency can be seen simulated results of impedance in each case. For example, during turn-on the bottom of impedance (200Ω) at 90 kHz can create the EMI peak at 10 μA at the same frequency as shown the simulated results in figure 10 (a) and (b) respectively. For example, during turn-off the bottom of impedance (100Ω) at 90 kHz can create the EMI peak at 10 mA at the same frequency as shown the simulated results in figure 11 (a) and 11 (b) respectively.

During turn-on and turn-off of switching devices, it can generate high frequency signal (ringing signal) into system, which is oscillated at resonance frequency of circuit in during turn-on or turn-off as shown in circuit modeling transient phenomena on figures 8 and 9 for each case.

4. Conclusion

The circuit modeling can help to predict the process of conducted EMI emission during transient phenomena and to predict the peak of conducted EMI using PSPICE simulation. The circuit modeling for transient phenomena in this paper is alternated for conducted EMI explanation of three-phase inverters. The replacing switching devices by passive component (series R, L) are not quite corrected. The switching devices should be replaced by parasitic model of each switch type but it is complicated circuit and difficult to understanding. Then, switching devices are replaced by series R, L, which is status of switch, turn on for easy to explain and understand. Finally, the modeling during transient phenomena introduced and verified by impedance approach to predict the conducted EMI as supported by the simulated results.

Reference

[1] Shao, J; Lin, R.L.; Lee, F.C.; and Chan, D.Y. “Characterization of EMI Performance for Hard and Soft-Switched Inverters” Applied Power Electronics Conference and Exposition, 2000 APEC2000. Fifteenth Annual IEEE, Volume: 2, 2000 pp. 1009-1014.

[2] K. Karanun , W. Khan-ngern and S. Nitta. “The Analysis of Common-Mode EMI Emissions of a Three-Phase PWM Inverter” International Conference on Electromagnetic Compatibility: ICEMC2002. July 24th-27th, 2002 Bangkok, Thailand : pp. 278-283

[3] Komkrit Karanun, “The Analysis of Conducted Electromagnetic Interference Emission on Various Three Phase PWM Inverters”. Master thesis of Electrical Engineering Graduate School, King Mongkut’s Institute of Technology Ladkrabang. 2003.