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A control of the parallel IGBT Converter for Auxiliary Block of High Speed Train

Yeun-Chung Kim*, Geun-Woo Oh*, Chung-Yeun Won*,
Jong-Mook Choi**, Sang-Woo Kee**, Ki-Hoon Bae**
* : Sung Kyun Kwan Univ, ** : Korea Rolling Stock Corp.

ABSTRACT

Power factor and harmonics are increasingly important for high speed train auxiliary block.
This paper presents experimental results of the power factor and harmonic performance of two parallel PWM converter circuits, under various supply and load conditions. For reducing harmonics, the harmonic content is eliminated by the phase shift between two converters switching phase.
Experimental results show the usefulness of the proposed method and applicability to PWM converter in auxiliary block of high speed train.

1. Introduction

Auxiliary block of high speed train consists of ac/dc converters, VVVF inverters, battery chargers and CVCF inverters. Among this constitution, the ac/dc converters generally is in use thyristor phase controlled technique. This is the problem with respect to power factor and harmonics in the ac line.
In this paper, a PWM converter control method of which use high speed switching device such as IGBTs instead of thyristor are proposed for obtaining unit power factor.[1]
A method of reducing harmonics based on switching method is proposed. The parallel operation and control of a four quadrant PWM converter for increasing output power is proposed in this paper.
Simulation results verify that this control method is a practically available and effective way to reduce the harmonics.

2. PWM Converter

2.1 A parallel PWM converter

Fig. 1 shows the configuration of a parallel PWM converter.

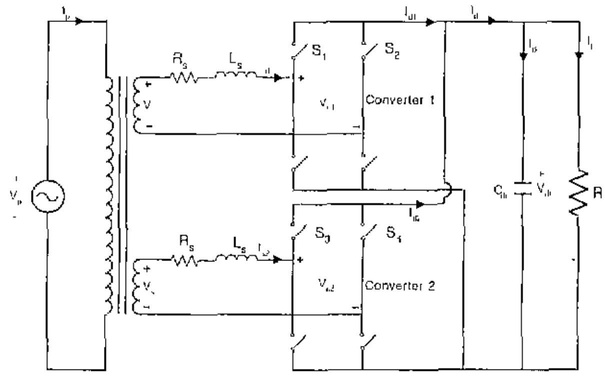


Fig. 1 Parallel PWM converter

The voltage equations of each terminal are given by eq. (1).

$$V_s = \begin{bmatrix} R_s + PL_s & 0 \\ 0 & R_s + PL_s \end{bmatrix} \begin{bmatrix} I_{s1} \\ I_{s2} \end{bmatrix} + \begin{bmatrix} V_{c1} \\ V_{c2} \end{bmatrix} \quad (1)$$

where, P is $\frac{d}{dt}$

Input voltage of the PWM converter V_{c1}, V_{c2} are determined by the output voltage V_{dc} and each switching state. V_{c1}, V_{c2} are expressed as

$$\begin{cases} V_{c1} = (S_1 - S_2) \cdot V_{dc} = S_{AD1} \cdot V_{dc} \\ V_{c2} = (S_3 - S_4) \cdot V_{dc} = S_{AD2} \cdot V_{dc} \end{cases} \quad (2)$$

Output current of the PWM converter becomes the eq. (3) by the input current of the PWM converter I_{s1}, I_{s2} and the switching state of each PWM converter.

$$I_d = S_{AD1} \cdot I_{s1} + S_{AD2} \cdot I_{s2} \qquad (3)$$

Output voltage of the PWM converter is given by eq.(4).

$$C\frac{dV_{dc}}{dt} = I_d - \frac{V_{dc}}{R} \qquad (4)$$

For equation (1), (2), (3), (4), the state equation of the parallel PWM converter becomes the eq. (5).[2-5]

$$\frac{d}{dt}\begin{bmatrix} V_{dc} \\ I_{s1} \\ I_{s2} \end{bmatrix} = \begin{bmatrix} -\frac{1}{RC_{dc}} & \frac{S_{AD1}}{C} & \frac{S_{AD2}}{C} \\ -\frac{S_{AD1}}{L} & -\frac{R}{L} & 0 \\ -\frac{S_{AD2}}{L} & 0 & -\frac{R}{L} \end{bmatrix}\begin{bmatrix} V_{dc} \\ I_{s1} \\ I_{s2} \end{bmatrix} + \frac{1}{L}\begin{bmatrix} 0 \\ V_s \\ V_s \end{bmatrix} \qquad (5)$$

Fig. 2 is the parallel PWM converter with the transfomer for deriving the differential equation of input current of the each PWM converter.

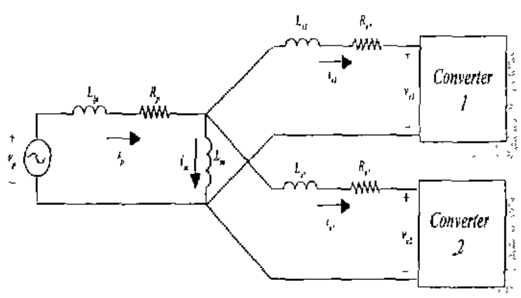


Fig. 2 Parallel PWM converter equivalent circuit

To simplify the analysis, it will be assumed that the transformer winding resistance R_p, R_{s1}, R_{s2} is zero and the inductance generating to the transformer secondary part is neglected. The voltage equation of the Fig.2 becomes the eq. (6).

$$\begin{aligned} v_p &= L_{lp}\frac{di_p}{dt} + L_m\frac{d(i_p - i_{s1} - i_{s2})}{dt} \\ v_{c1} &= -L_{ls1}\frac{di_{s1}}{dt} + L_m\frac{d(i_p - i_{s1} - i_{s2})}{dt} \\ v_{c2} &= -L_{ls2}\frac{di_{s1}}{dt} + L_m\frac{d(i_p - i_{s1} - i_{s2})}{dt} \end{aligned} \qquad (6)$$

Therefore, the differential equation of input current of the each PWM converter becomes the eq. (7).

$$\begin{aligned} \frac{di_{s1}}{dt} &= \frac{1}{L_{ls}D}\left[L_m L_{ls} \cdot v_p - (L_p L_s - L_m^2)v_{c1} + L_m L_{lp} \cdot v_{c2}\right] \\ \frac{di_{s2}}{dt} &= \frac{1}{L_{ls}D}\left[L_m L_{ls} \cdot v_p + L_m L_{lp} v_{c1} - (L_p L_s - L_m^2) \cdot v_{c2}\right] \end{aligned} \qquad (7)$$

where, $L_s = L_{ls} + L_m$, $L_p = L_{lp} + L_m$, $D = 2L_{lp}L_m + L_{ls}L_p$

2.2 Control of the parallel PWM converter

Fig. 3 shows a cross section of the transformer that is used in the experiment.

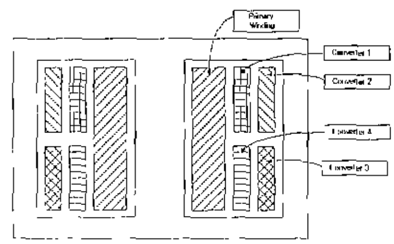


Fig. 3 Cross section of the transformer

Converter 2 effects converter 1's characteristic because windings are too close one another, while converter 3 and 4 have not effect on converter 1's operation. Therefore, non-interference algorithm should be adopted to between converter 1 and 2, 3 and 4 only.

Fig. 4 shows a control system of single phase PWM ac/dc converter.

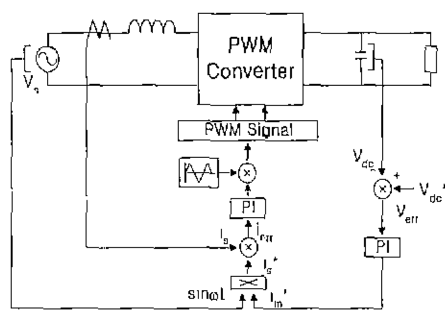


Fig. 4 Control system of single phase ac/dc converter

Fig. 5 describes the method which is reducing harmonic of the source current. It shifts reference current to reduce ripple of source current during parallel operation.

Non-interference algorithm was used to compensate effects of adjacent windings in transformer including converters. By using the two PI voltage controller, the divergence occurs because PI voltage controller integrates small error caused by that of sensor. To prevent divergence stated above, it is adopted a single voltage controller.[6]

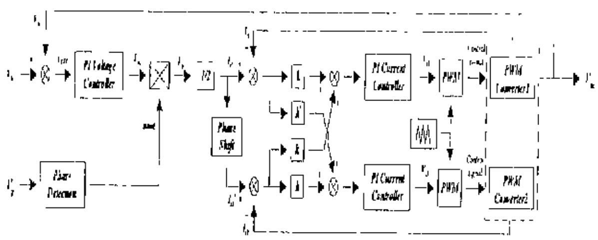


Fig. 5 Control block diagram

3. Simulation

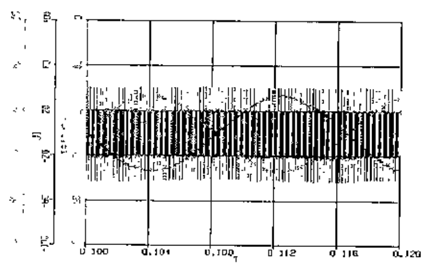
The system specification and parameters are shown in table 1.

Table 1. System specification and parameters

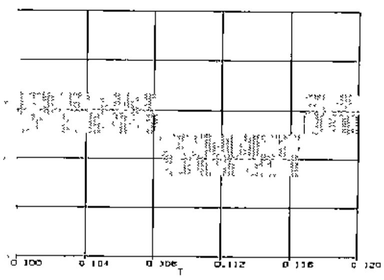
Input transformer turn ratio	220/220[V]
Primary leakage inductance	0.53[mH]
Secondary leakage inductance(L_{ls1})	1.62[mH]
Secondary leakage inductance(L_{ls2})	1.67[mH]
Mutual inductance	15.3[mH]
Output voltage	400[V]
DC Link capacitor	4700[μF]
Switching Frequency	5[kHz]

Fig. 6 is illustrated 3-level switching pattern. A period of the PWM converter is shifted 0.05 [ms] from the other, where the switching frequency is 5[kHz] and current control period is 100[μs]. As the results, source current harmonics can be reduced.

Fig 7 shows the transient responses of the output voltage of the parallel PWM converter in case of powering. The output voltage of the parallel PWM converter is perturbed for impact unload but it follows its reference rapidly by the voltage controller.



(a)



(b)

Fig. 6 Three-level switching pattern
(a) reference sine wave and carrier
(b) switching pattern

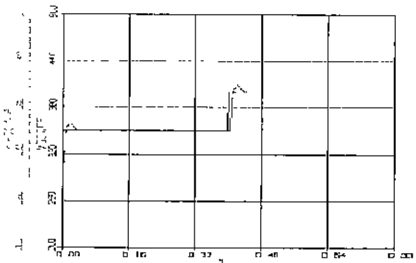


Fig. 7 Transient responses for impact unloading

Fig. 8 shows output voltage of the parallel PWM converter and load current waveform varying the load. It follows its reference rapidly by the voltage controller.

Fig. 9 illustrates that input voltage and current is the same phase. Therefore, power factor is near unity for input side.

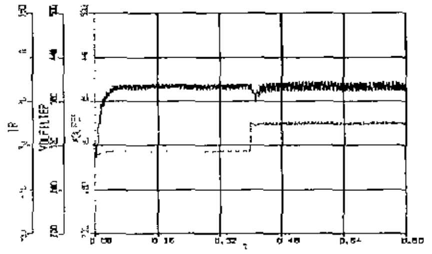


Fig. 8 Output voltage of PWM converter and load current

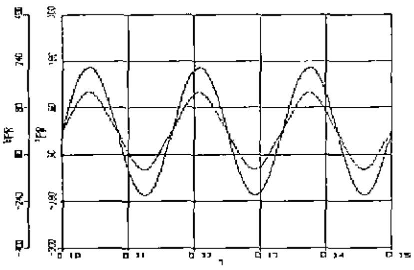
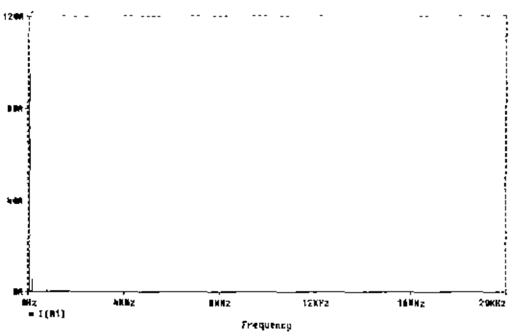
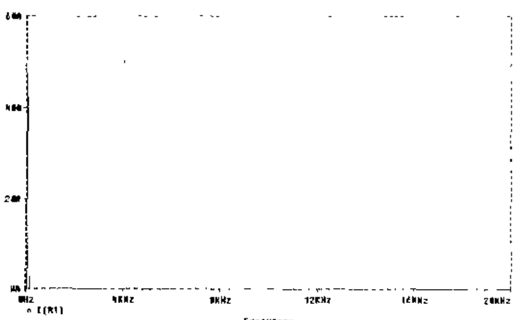


Fig. 9 Primary voltage and current.

Fig. 10 illustrates the harmonic spectrum of the converter current and the input current.



(a)



(b)

Fig. 10 Harmonic spectrum.
(a) primary current
(b) secondary current

4. Experimental Result

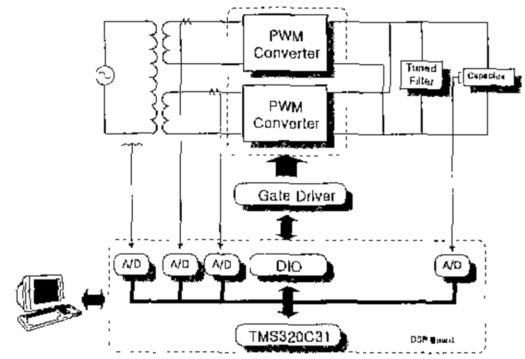


Fig. 11 System configuration

Fig. 11 shows the system configuration. The ac/dc IGBT PWM converter is connected through the inductor to sinusoidal voltage source(220V, 60Hz). The inductance and resistance of inductor are 1.5[mH] and 0.18[Ω]. The control circuit is constructed with DSP(TMS320C31). The input current and output voltage of the converter are detected by sensors and they are fed to 12bit A/D converter.

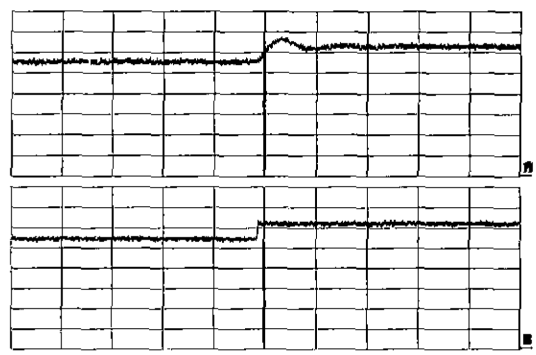


Fig. 12 Output voltage waveform of the parallel PWM converter varying the reference voltage
(X-axis : 0.2 s/div , Y-axis : 65V/div)

Fig. 12 is the output voltage waveform for the varying the reference voltage from 350[V] to 400[V]. The output voltage is well tracking the reference voltage.

Fig. 13 is the output voltage and the input current waveform of the parallel PWM converter for varying the load from 1.6[kW] to 3.2[kW]. Output voltage is tracking relative rapidly for the reference voltage.

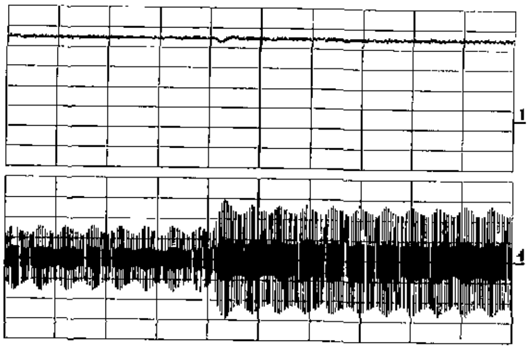


Fig. 13 Output voltage and current waveform of the parallel PWM converter varying the load
(X-axis : 0.5 s/div , Y-axis : 100V/div , 10A/div)

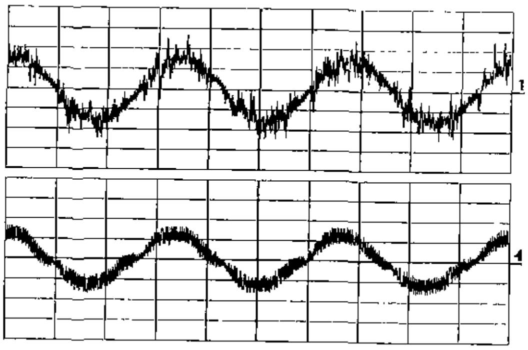


Fig. 14 The primary voltage and current waveform of transformer
(X-axis : 5 ms/div , Y-axis : 150V/div , 10A/div)

Fig. 14 is the primary voltage and current waveforms of the transformer for showing the power factor correction.

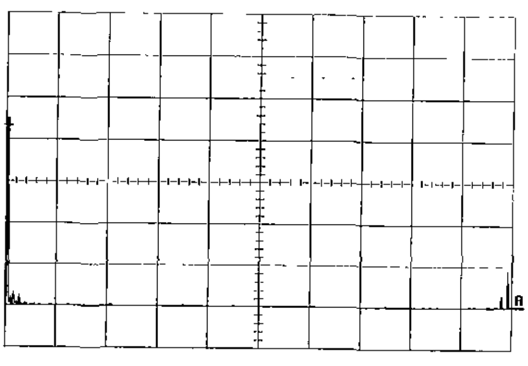


Fig. 15 FFT spectrum for the primary current of the transformer

Fig. 15 is the FFT spectrum for the primary current of the transformer.

5. Conclusions

In this paper we performed study on the harmonic reduction of single phase PWM converter for auxiliary power unit of high speed train. We obtained satisfactory results to the output voltage control and unit power factor control for parallel operation system of single phase IGBT PWM converter. The output voltage is perturbed for impact load but it follows its reference rapidly by voltage controller.

Experimental results for a prototype system of two parallel converter confirm the validity of the proposed algorithm.

Acknowledgement

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