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DC/DC Converter Design which Ensures Stable Motion of Ventilation Inverter

Young-Choon Kim[1], Ok-Hwan Kim[1*] and Moon-Taek Cho[2*]

[1] Dept. of Mechanical & Automotive Engineering, Kongju National University, 275 Budae-dong, Seobuk-gu, Cheonam-si, Chungnam, 31080, Korea
[2] Dept. of Electrical & Electronic Engineering, Daewon University College, 316 Daehak Road, Jecheon, Chungbuk, 27135, Korea
{yckim59,owkim}@kongju.ac.kr, mtcho@mail.daewon.ac.kr,

Abstract

When the ventilation inverter (ventilation inverter, VTI) of high-speed rolling stock normally receives power supply from stringing, it receives power from supplementary power device and supplies power to the ventilation fan. At this point, entry to neutral section blocks regeneration, burning the regeneration energy through resistance. Using a tap of resistance as VTI power at this point receives and converts input of rough electricity, causing consistent breakdown of VTI and ultimately leading to stop in operation. Also, entry to neutral point activates the chopper, burning energy through resistance. Switching the location of resistance and chopper solves many aspects, but it does not solve fundamental problems. As a result, this study solves the fundamental problem of VTI by installing DC/DC converter that receives input of DC Link 2800[V] and converts it into 670[V] when entry to neutral point occurs, enabling stable power supply.

***Keywords**: VTI, PWM, Power device, DC/DC, DC link, Power supply*

1. Introduction

The world is paying more and more attention to the high-speed railroad industry. Despite many disputes on intellectual properties, debt ratio, *etc.*, high-speed railroad industry stands out due to its connection to increased national competitiveness through faster transportation of passengers and goods, construction of eco-friendly transportation infrastructure, and sustainable keynotes for green growth.

The important factor in high-speed railroad is its comparative advantage in comparison other means of transportation in terms of speed, due to increasing speeds in overall means of transportation. It is natural that customers choose transportation with higher speed, because speed controls travel time of passengers and goods and determines efficiency of transportation. For such reasons, high-speed railroad will have absolute advantage compared to other transportations in terms of traffic distribution. Therefore, recognizing and understanding the flow of new change in railroad sector and making appropriate responses will become critical in determining future directions of technological development for high-speed railroad.

In addition, the area of next-generation electric vehicles shows increasing demands for technological development in various aspects for improved vehicle performance. Accordingly, propulsion control device requires efficiency and innovation in energy, as well as improved ride comfort.

When ventilation inverter (ventilation inverter, VTI) of high-speed rolling stock normally receives power supply from stringing, it receives power from supplementary power device and supplies power to ventilation fan. At this point, entry to neutral section blocks regeneration, burning the regeneration energy through resistance. Using a tap of

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resistance as VTI power at this point receives and converts input of rough electricity, causing consistent breakdown of VTI and ultimately leading to stop in operation.

Also, entry to neutral point activates the chopper, burning energy through resistance. Switching the location of resistance and chopper solves many aspects, but it does not solve fundamental problems. As a result, this study solves fundamental problem of VTI by installing DC/DC converter that receives input of DC Link 2800[V] and converts it into 670[V] when entry to neutral point occurs, enabling stable power supply.

2. Main Circuit of Ventilation Inverter Device

Ventilation inverter device is a DC/DC converter that uses IGBT (Insulated Gate Bipolar Transistor), the latest semiconductor device for power supply. This device stores history of malfunctioning and various data for convenience in maintenance, facilitating the work of repairer. Its composition makes it convenient for an engineer to repair the device, and it is separated into the main body of the converter and the output transformer. The DC/DC converter, which is loaded inside the main power conversion device, receives input of rating DC 2,850 [V] that is supplied at rheostatic brake on main power conversion device, and supplies power of DC 670 [V] to ventilation inverter.

2.1. Input Unit

4,000[V]/125[A] input fuse was installed to protect the system from input and current. Output rating of DDC is 26[kW], and input voltage is 2400[V] ~ 3100[V]. Therefore, input current I_{DC} at minimum input voltage can be obtained through equation (1).

$$I_{DC} = \frac{26[kW]}{2400[V]} = 10.8[A] \tag{1}$$

2.2 Converter Unit

With half-bridge composition, converter module consists of 1 IGBT and 2 DIODE in heat sink module, and is attached on the part with most excellent heat protection. Gate driver unit (GDU), IGBT, and heat sink have been directly molded for increased reliability. Switching frequency is 1[kHz] and turn ratio of transformer is 1400:887. Equation (2) shows primary and secondary rating current, equation (3) shows change in primary and secondary current, and equation (3) shows current that flows on IGBT.

$$I^1_{rated} = \frac{Rated\_Power}{V_{L}\_Primary\_Min} = 26[A] \tag{2}$$

$$I^2_{rated} = \frac{Rated\_Power}{V_{L}\_Secondary\_Min} = 41.2[A] \tag{3}$$

$$di\_Primary = \frac{V_{L}\_Primary}{L} \times T_{on} = 100[A] \tag{4}$$

$$di\_Secondary = \frac{V_{L}\_Secondary}{L} \times T_{on} = 158.4[A] \tag{5}$$

$$I_{pk}\_Primary = (I^1_{rated} + di\_Primary) = 126[A] \tag{6}$$

$$I_{pk}\_Secondary = (I^2_{rated} + di\_Secondary) = 200[A] \tag{7}$$

As current that flows on IGBT flows equivalently with $I_{pk}\_Primary$ current, MBM200H45E2-H(4,500[V]/200[A]) of Hitachi was selected. As current that flows on DIODE flows equivalently with $I_{pk}\_Secondary$ current, (3,300[V]/400[A]) of Infineon was selected.

Heat sink adopted forced air cooling system to ensure heat protection for IGBT and DIODE, semiconductor devices for power supply. For safety, electrical box of main power conversion device was grounded. Loss values calculated for IGBT and DIODE were used for size design and heat interpretation of heat sink. Heat interpretation showed that rating of five minutes results in change in temperature of below 55K, ensuring that there would be no heat increase due to error in heat sink design.

2.3 Gate Driver Unit

Control unit receives signal to turn IGBT, semiconductor device for power supply, on and off. It protects the device from combustion by overcurrent or short circuit current as much as possible by sensing potentials between collector and emitter of IGBT device. Maximum insulation voltage of GDU is 8.3[kV]. Since MBM200H45E2-H (4500 [V]/200[A]) of Hitachi was selected as IGBT, 2SC0635T of Concept, which satisfies 8.3[kV], the insulation internal pressure of GDU, while setting and controlling active clamp and protection level of IGBT, was selected.

2.4 Detection Sensor

DC current sensor of DC-DC convertor detects DC current and protects the convertor from combustion by DC overcurrent. AC current sensor detects AC current and protects the convertor from combustion by DC overcurrent. Since minimum DDC input voltage is 2400[V], current is $I_{dc} = 26[kW]/2400[V] = 10.8[A]$. Current that flows on direct current sensor is as shown in equation (4).

$$I_{pk}\_Primary = (I^{1}_{rated} + di\_Primary) = 126[A] \quad (4)$$

As a result, LA200-P (200[A]: 100[mA]) current source CT of LEM was selected as the current sensor..

DC voltage sensor detects unbalance of DC voltage. Maximum DDC input voltage is 3100[V]. Voltage sensor senses maximum input voltage/2 of input voltage. Maximum voltage measured by a single voltage sensor is 1550[V]. As a result, LV100-3000/SP12 (3000[V]/50[mA]) current source PT of LEM was selected.

2.5 Output Unit

Output DC current sensor on output unit detects output current to control current, and protects the system from output and current combustion. Since output voltage is 670[V], current is 26[kW]/670[V]=38.8[A]. As a result, LA200-P(200[A]:100[mA]) current source CT of LEM was selected as current sensor.

Output voltage sensor is a device that detects output voltage. It protects output from overvoltage and uses output voltage control FEEDBACK. Output voltage = TR turn ratio×(Maximum input voltage/2), turn ratio : TR voltage ratio (887 / 1,400 = 0.634), maximum input voltage = 3100[V], output voltage = 0.634×(3100[V]/2)=982.7[V]. As a result, DVL1500 (1500[V]:50[mA]) current source PT of LEM was selected.

Dummy resister is a resistor for stabilizing DDC output voltage through parallel connection on both sides of DDC output. Input voltage: DC 670[V], input capacitor: 2350 uF(4,700[uF] series × 2). Values shown in equation (5) have been obtained.

$$\begin{cases} I_{dummy} \cong 0.15[A] \\ R = \dfrac{V_{dc}}{I_{dummy}} \cong 4.5[k\Omega. \\ P = \dfrac{V^2}{R} \cong 00.75[W] \end{cases} \quad (5)$$

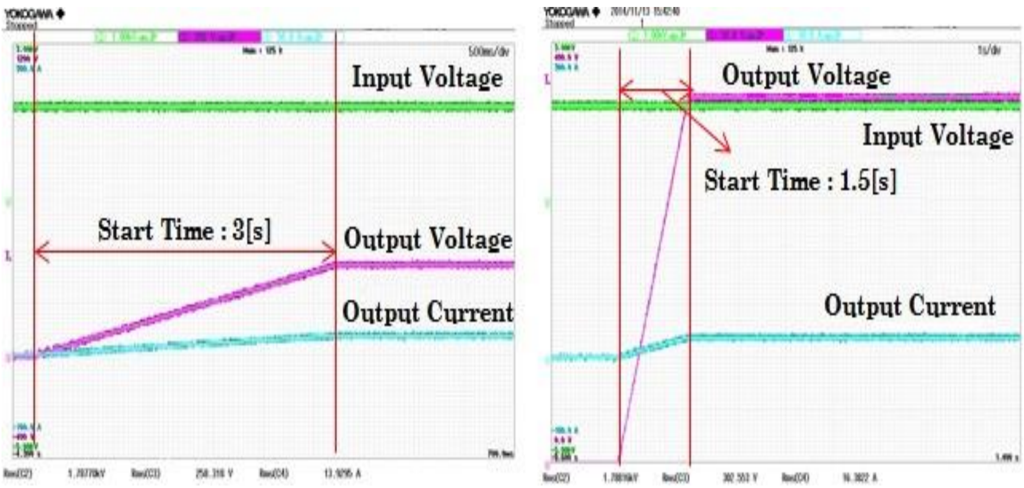
Based on this equation, it is thought that dummy resistor would have no problem in using series circuit of 2.25[kΩ], 500[W].

3. DC/DC Converter for Ventilation

3.1 DC/DC Converter

DC/DC convertor applied for stable power supply to ventilation inverter at resistance brake. 2 26[kVA] DC/DC convertors were installed inside one DC/DC convertor, which would supply power to ventilation inverter through parallel operation in normal case. If one DC/DC convertor becomes abnormal, the other normal DC/DC convertor will operate to supply power to ventilation inverter. In this case, power will be supplied only to ventilation fan of main power conversion device.

Figure 1 shows waveform of normal start test when start time is (a) 3 seconds and (b) 1.5 seconds at direct current input voltage of 1800[V]. Figure 2 shows output property test at load change after normal start. Also, Figure 3 shows waveform when starting 2 convertors simultaneously and applying load change. This shows that output voltage at load change is equivalent with single operation.



(a) Start Time: 3 Seconds (b) Start Time: 1.5 Seconds

Figure 1. Waveform of Normal Start Test at Direct Current Input Voltage of 1800[V] (Single Operation)

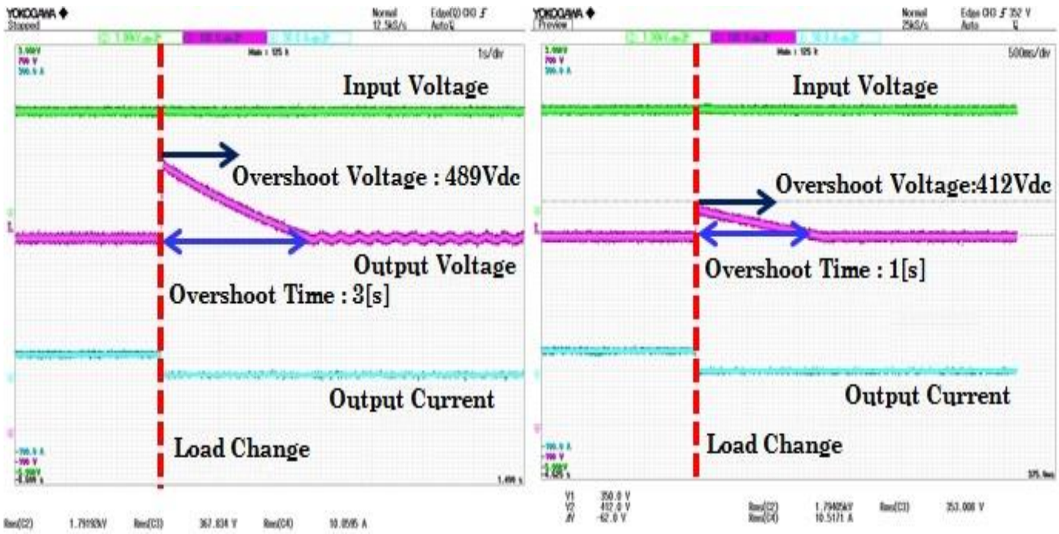


Figure 2. Waveform of Output Property at Load Change after Normal Start (Single Operation)

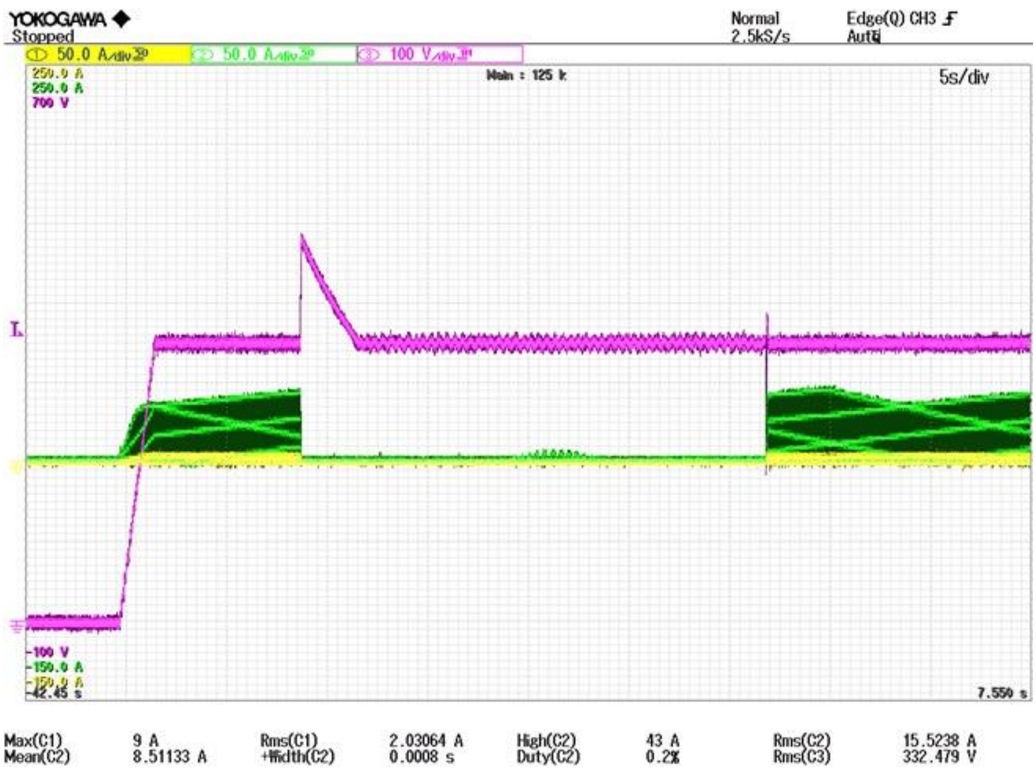


Figure 3. Waveform When Starting and Changing Load at Parallel Operation

The main circuit of the DC/DC convertor consists of half-wave bridge circuit, transformer, and full-wave rectifier.

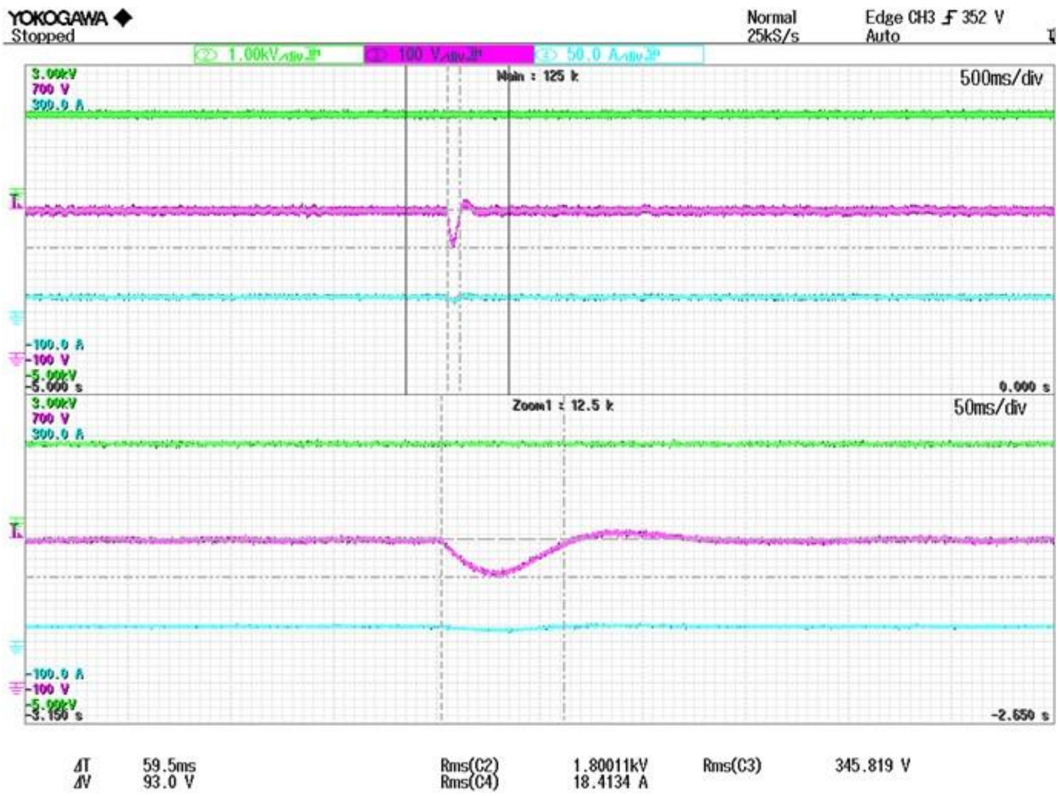


Figure 4. Waveform of Property Test when a Convertor Malfunctions at Parallel Operation

3.2 Resistance Brake

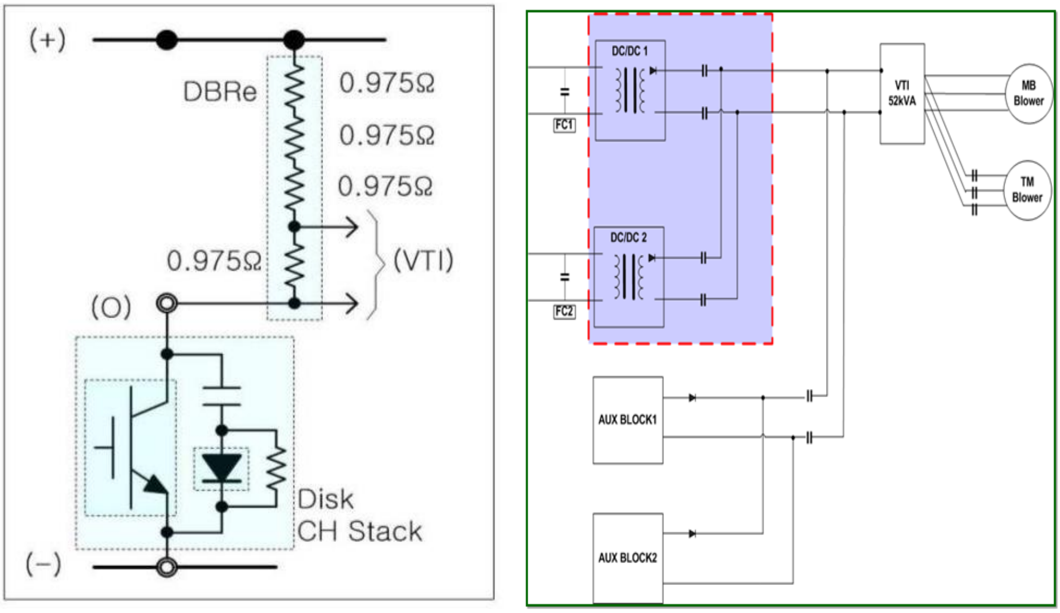
When advance notice signal for neutral section, stringing change section, *etc.*, arises during regenerative brake, regenerative brake automatically switches to resistance brake. When brake order from driver seat is delivered to main power conversion device while MCB and convertor device are on Gate Off, brake chopper is activated to secure resistance brake power while controlling DC link voltage consistently.

Resistance was produced with nickel-chrome class 1 to prevent corrosion and any property change by temperature. Brake resistance should have small change in resistance value by rise in temperature to facilitate current control, and should be non-magnetic so as not to attract any iron powders that are included in dust. Also, it should have moderate oxidation resistance and large high-temperature strength.

3.3. Improvement of Ventilation Fan Connection and Ventilation Inverter

Ground fault and ventilation fan/inverter malfunction are the major consistent malfunctions that occur in main power conversion device for high-speed railroad to this day. Their cause is that the circuits are supplied with input voltage (DC 670[V]) from brake resistor at dynamic braking as shown in Figure 5. Therefore, stray voltage due to Turn On/Off motion of chopper IGBT is supplied.

Accordingly, DC/DC converter should be applied to new high-speed rolling stocks in order to ensure stable power supply to ventilation inverter at dynamic braking, fundamentally solving the effect of stray voltage at dynamic braking, and ventilation fan with improved insulation capability should be applied in order to reduce failure rate.



(a) VTI Input Circuit (b) VTI Input Circuit for Suggested Rolling Stocks

Figure 5. Comparison of VTI Input Circuit for Existing Rolling Stocks and Suggested Rolling Stocks

For power circuits where main power conversion device works on resistance brake mode, resistance brake tap should be withdrawn and be supplied to ventilation inverter to be used as input power of ventilation inverter at brake chopper motion, as shown in Figure 6.

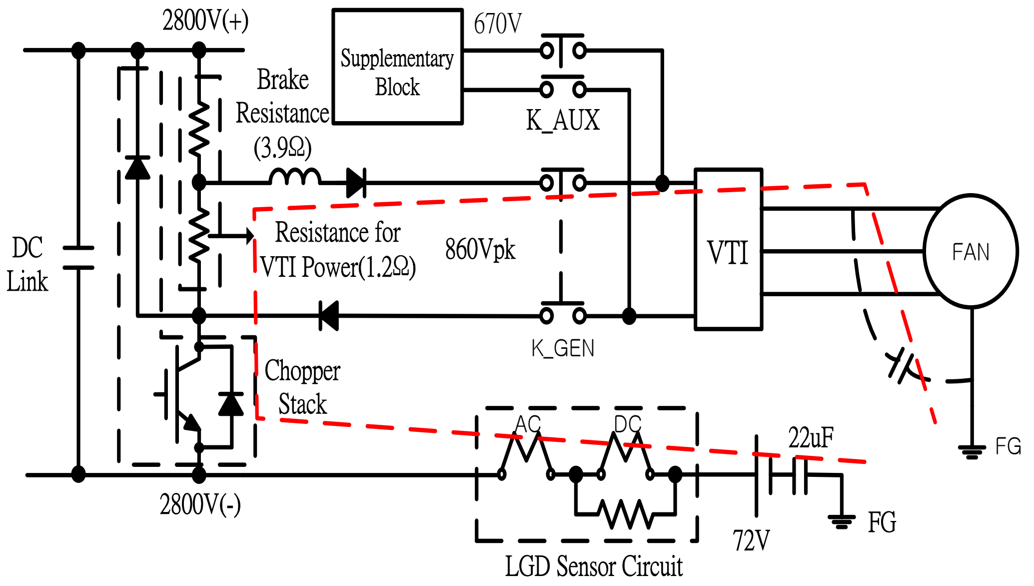


Figure 6. Power Circuit for KTX-Sancheon Main Power Conversion Device on Resistance Brake Mode (Prior to Improvement)

When the main power conversion device of ventilation inverter works on resistance brake mode, a PWM waveform with maximum of DC 700 [V] is supplied as input power. However, in brake resistance mode, chopper motion voltage of DC 2,800[V] Link switching voltage on resistance brake mode, such as the loop shown in dotted line on Figure 6, occurs as stray voltage on output terminal phase voltage and frame of ventilation fan as shown in Figure 7 by capacitance that exists between ventilation fan and frame. Ultimately, despite electrical insulation on FG (Frame Ground) by separating (insulating) ventilation fan of main power conversion device with main power conversion device frame, stray voltage that occurs whenever main power conversion device works on resistance brake mode consistently weakened insulation of electrical circuit components and ventilation fan inside ventilation inverter(VTI), causing frequent occurrences of malfunctioning ventilation inverter, malfunctioning ventilation fan insulation, and ground fault.

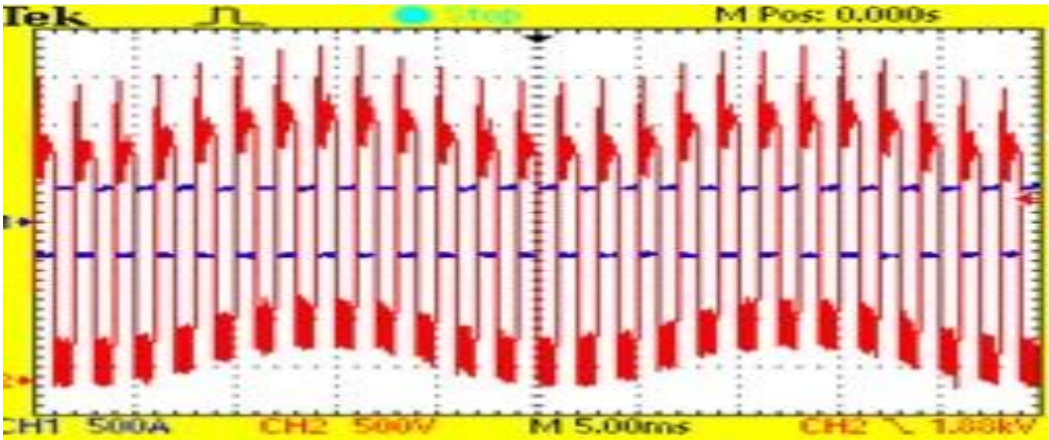


Figure 7. FG ↔ VTI U Voltage on Resistance Brake Mode of Motor Block (Prior to Improvement)

3.4. Major Control Properties of DC/DC Converter and VTI

PSIM software, a software broadly used in the field of electronics, was used on simulation as shown in Figure 8 in order to check control properties of DC/DC convertor. Results of major control properties are shown on Figure 9 and 10.

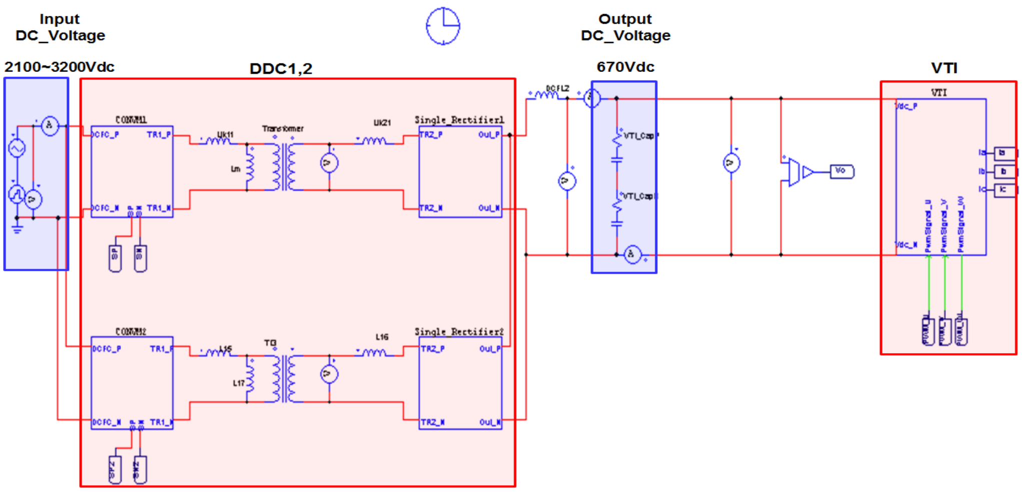


Figure 8. Simulation of DC/DC Converter and VTI Control Properties (PSIM)

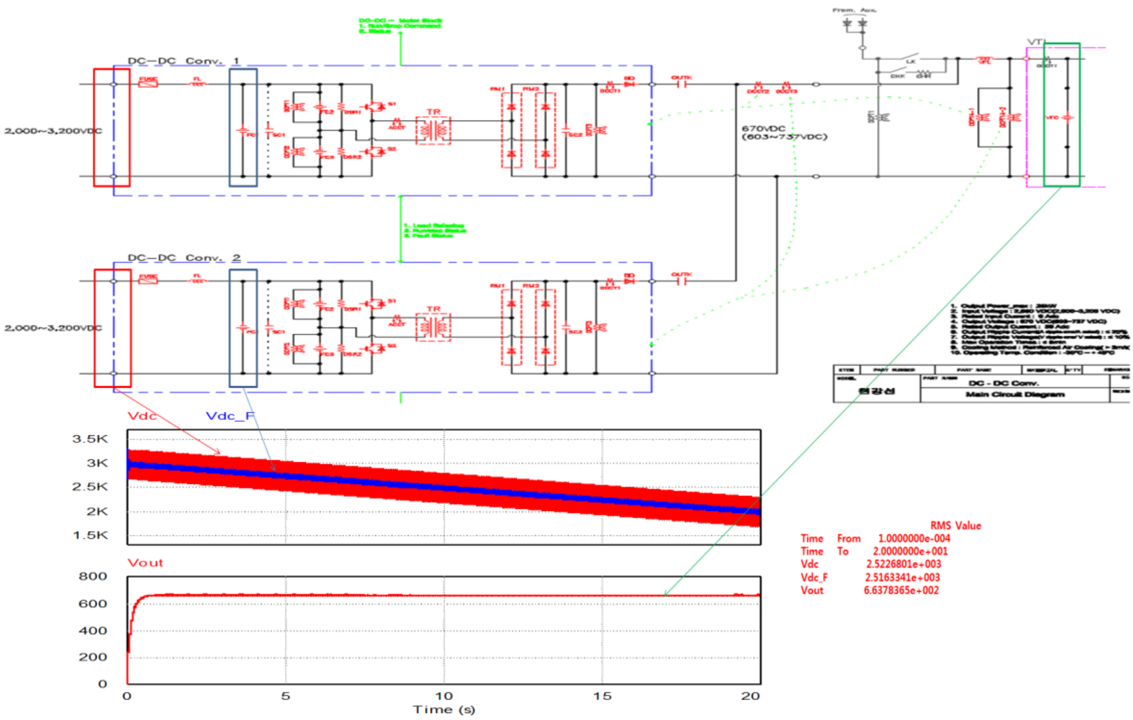


Figure 9. Properties of DC/DC Convertor Output Voltage Followed by Changes in Input Voltage

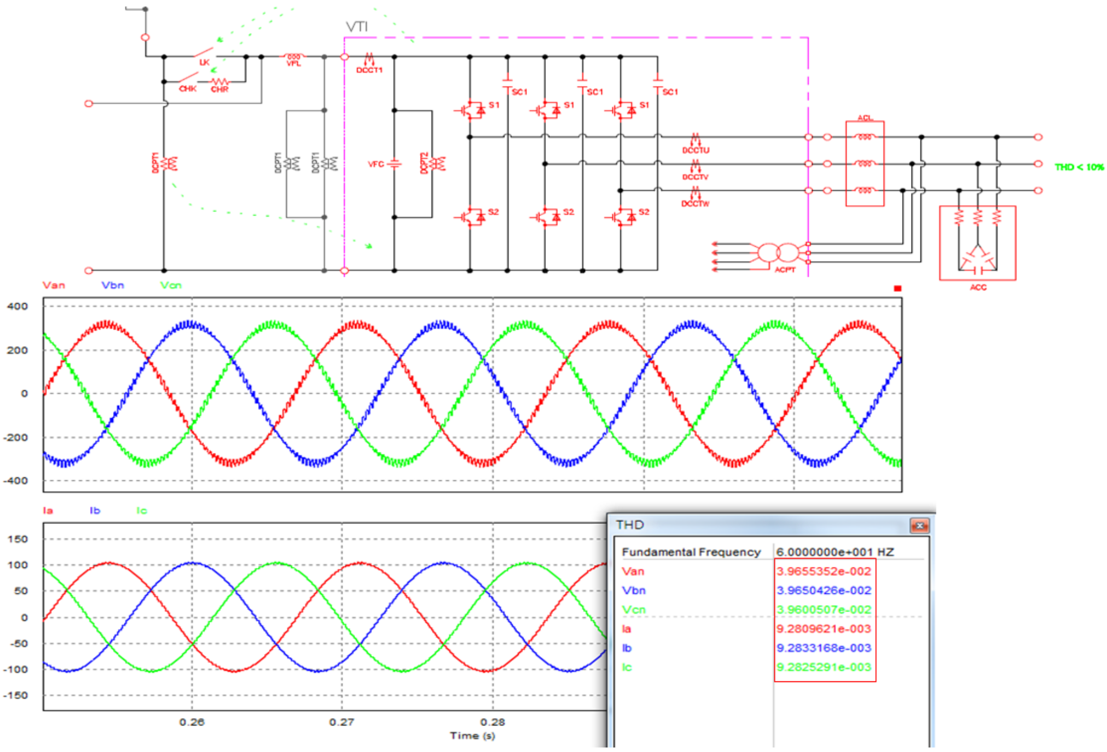


Figure 10. Final Output Voltage Properties of Ventilation Inverter

4. Conclusion

This paper suggested a method of ensuring stable power supply for the ventilation inverter (VTI) of high-speed rolling stocks by installing the DC/DC convertor.

By supplying input voltage of the ventilation inverter (VTI) to the DC/DC convertor from brake resistor at brake resistance in order to solve ground fault and ventilation fan malfunctioning through DC/DC convertor, the reliability of VTI, ventilation fan, and ground relay has been secured. Also, through fundamental solution on effects of stray voltage at dynamic braking in order to ensure stable power supply on ventilation inverter at dynamic braking, and by applying ventilation fan with improved insulation capability, the VTI input circuit of suggested rolling stock is thought to be effective in reducing failure rate.

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Authors

Young-Choon Kim, He was born in Korea on August 9, 1959. He received the ME. Eng. and Ph.D. degrees from Myongji University Korea in 1989 and 1997, respectively. Currently, he is a professor in the Kongju National Univ. Dept. of Mechanical & Automotive Eng., Korea. His special field of interest includes power electric, electrical machine, new renewable energy, PSPICE, Matlab, Fatigue and Fracture Mechanics.

Ok-Hwan Kim, He was born in Korea on January 3, 1960. He received the ME. Eng. and Ph.D. degrees from Yonsei University in Korea in 1982 and 1996, respectively. Currently, he is a professor in the Kongju National Univ. Dept. of Mechanical & Automotive Eng. Korea. His special field of interest includes machine design, electrical machine, fatigue analysis and fracture mechanics.

Moon-Taek Cho, He was born in Korea on February 23, 1965. He received the B.S., M.Eng. and Ph.D. degrees from Myongji Univ. Korea in 1988, 1990 and 1999, respectively. Currently, he is a professor in the Daewon University College Division of Electrical & Electronic Engineering, Korea. His special field of interest includes power electric, electrical machine, new renewable energy, super-capacitor, PSPICE, CASPOC.