International Journal of Internet, Broadcasting and Communication Vol.14 No.3 249-257 (2022)
http://dx.doi.org/10.7236/IJIBC.2022.14.3.249

IJIBC 22-3-29

On the Design of Power Supply System for Freight Train Reefer Container Based on Simulation

Joouk Kim*†, Sunwoo Hwang*, Jae-Bum Lee**, Jaemin Hwang*, Uri Chae*

**Advanced Logistics System Research Department, Korea Railroad Research Institute, Korea*
***Department of Railroad Electrical & Electronic Engineering, Korea National University of Transportation, Korea*
jookim@krri.re.kr, marcell93@krri.re.kr, leejb@ut.ac.kr, jmhwang@krri.re.kr, chaeuri@krri.re.kr

Abstract

In recent years, if we order food by easily accessing the online market with our smartphone, we can receive the product in a fresh state at dawn the next day. Cold chain is an industry that can create high added value because it has both the characteristics of general logistics and sensitivity to temperature. Based on the electrical specifications derived from the reefer container capacity requirement investigation, we proved that power supply to up to 33 reefer containers can be made by using three additional auxiliary power supplies which are applied for freight trains in Korea. In this paper, we conducted a research on a design of power supply system for freight train reefer container based on simulation as a basic research necessary for low-temperature distribution and cold chain construction based on the reefer container railroad. Consequently, the simulation was conducted using the three-phase inverter diagram in PSIM and the SVPWM (3-harmonic injection method) control technique, and it was verified that the required power voltage was satisfied with 622V_{dc}, which is lower than the input voltage of general SPWM of 718V_{dc}. The details of this paper could be used as a foundational study for constructing cold chains based on a reefer container dedicated to freight trains in the future.

Keywords: *Reefer Container, AC-DC Converter, 3-Phase-Inverter, Generator, Battery, Electrical Wiring*

1. Introduction

In recent years, if we order food by easily accessing the online market with our smartphone, we can receive the product in a fresh state at dawn the next day. Cold chain is an industry that can create high added value because it has both the characteristics of general logistics and sensitivity to temperature. In aspects of reefer containers are a key element used in railroad logistics for cold chains. Also, for a railroad-based cold chain logistics system, we need a key technology that can maintain frozen and refrigerated conditions in transporting fresh food from the production area to the logistics terminals is needed by utilizing railway infrastructure. In addition, recently, stably securing of fresh food is considered one of the important tasks, and accordingly, cold chain's presence is now growing due to the expansion of the online market and the growth of the contactless

Manuscript Received: July. 20, 2022 / Revised: July. 22, 2022 / Accepted: July. 25, 2022
Corresponding Author: jookim@krri.re.kr
Tel: +82-31-460-5168
Principal Researcher, Advanced Logistics System Research Department, Korea Railroad Research Institute, Korea

industry along with the needs for a pleasant and healthy life. However, distribution of most fresh foods such as agricultural and marine products is being made through road transportation, and due to the nature of road transportation, a large-scale transportation is impossible, and there are also issues related to efficiency, safety, and carbon emission. Therefore, the importance of management is emerging throughout the supply chain of cargo that requires low-temperature distribution such as food, medicine, and a refrigerated cargo. However, due to global warming and strengthening global environmental regulations, we believe that it is necessary to convert the existing road-centered logistics system into a railway-centered logistics system, a low-carbon transportation method. In addition, so far, cold chains are being studied only in the aspect of ground and sea transportation. When the reefer container for railroad transportation is commercialized, a large quantity of fresh food such as agricultural and marine products can be stably transported, and electricity supply and distribution system of freight trains can also be used for various electric equipment in addition to reefer containers. Therefore, in this paper, as a basic study necessary for establishing the low-temperature distribution and cold chain based on the reefer container railroad, we conducted a study on a simulation of power supply for reefer container operation.

2. Related Works

As previously mentioned before the importance of cold chains is increasing, research for enhancing the efficiency of reefer containers is being conducted in various fields. In this chapter, we intend to identify the core elements of reefer containers being applied in various fields. Kim et al. noted that container shipping companies are responding to the increase in global demand for fresh and frozen foods, and concluded that reefer container management companies should devise new services or businesses such as reefer container maintenance networks [1]. Recognizing the issue that despite the steadily increasing use of reefer containers, management of reefer containers that require continuous monitoring to prevent damage to cargo still relies on manpower, Lee et al. conducted a real-time reefer container monitoring system using Interrogation Port. As a result, some researchers proposed a system for collecting reefer container information in real time using interrogation port, which is a serial communication port attached to all reefer containers, and transmitting it to the server using TCP/IP communication [2]. Moon et al. conducted a study on the IoT-based reefer container real-time management system, after recognizing the issue that the PCT method, which is currently a representative method of monitoring reefer containers, cannot monitor in real time during a remote control of the set temperature of reefer container and during land transportation. As a result, we verified the test of monitoring the transportation process of the reefer container in real time by collecting real-time data of the reefer container using RS-232 communication and transmitting it to data collection middleware using WCDMA/GSM communication [3, 4]. Yang et al. developed an RF module-type vessel reefer container remote monitoring system to improve the safety and reduce cost of management personnel considering that they spend lots of time and effort visually checking and logging the condition and temperature of the reefer container to maintain the proper temperature on container ships or in container yards [5]. Lee et al. recognized an issue that a monitoring system using power line communication in accordance with the ISO-10368 standard is recommended, but that it is not much used in the field due to data loss when communicating between a reefer container and a master modem. Therefore, they researched on the mobile service for the reefer container monitoring system to conclude that mobile service for the reefer container monitoring system will be much utilized as monitoring work becomes possible while moving [6]. Moon et al. conducted a study on the reefer container temperature control algorithm after recognizing issues such as decomposition of fresh cargo during sea transportation due to large temperature deviation inside the section with cargo loaded using reefer containers. The result showed that the maintained a constant temperature within a maximum of 0.5°C based on the set-point of 4.0°C inside reefer container [7]. Recognizing the issue that it is impossible to immediately respond to problems in cargo because the temperature inside the container cannot be monitored in real time, Lee et al. conducted a study on the design of a reefer container monitoring system using a wireless sensor network. As a result of this, some researchers proposed a system for monitoring the temperature inside the container in real time by mounting a sensor node on a reefer container and using a wireless sensor network proposed [8]. In order to reduce the risk in monitoring reefer containers, Choi et al. presented an IoT-based real-time reefer container controlling and monitoring system, after recognizing that systems using PLC Modem are recommended by International Marine Organization but most of them are not activated [9]. Yoon conducted feed system modeling of railroad using fuel cell power generation system. As a result, he announced that the plan to link the fuel cell power generation system railroad power supply system must was linked to the power supply system that supplies power to the railroad, unlike solar and wind power [10]. As described above, nowadays research on reefer containers is being conducted in various fields, and in this paper, after learning the conclusions of related literature studies we studied the method of supplying power to the reefer container as a basic research necessary for low-temperature distribution and cold chain construction based on the reefer container railway. Also, Kim et al. studied that the capacity required for a reefer container is investigated the power supply and specifications of a reefer container and compare the size and volume of the reefer container when a catenary, battery, and generator are applied as a power supply source [11]. However, the results of this study studied the power supply method by calculating only volume and capacity. Based on it, our research team conducted a study on reefer container power simulation and improved the results.

3. Verification for Power Supply based on Simulation

A three-phase inverter is a device that converts a DC voltage into a three-phase AC voltage, and generally, it is configured by combining six switch devices. As shown in Figure 1, two DC Link capacitors at the inverter input terminal were used to consider the virtual neutral point. Q1, Q4, which are switching elements of the phase, operate as complementary, and a, b, and c phases are generally controlled by a 180° conduction method (a method of generating a signal of On and Off for the accompaniment period) among one cycle having a phase difference of 120°. The line-to-line voltage applied to the motor may be represented by a difference in phase voltages and may be represented by $V_{ab} = V_{ap} - V_{bp}$.

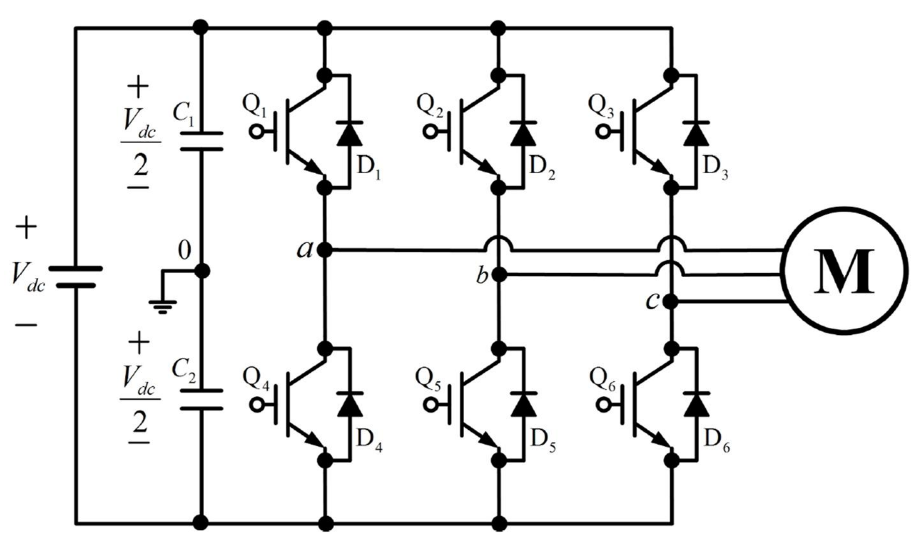

Figure 1. 3-phase inverter circuit diagram

In the three-phase inverter circuit designed above, a three-phase AC voltage can be generated by controlling the ON/OFF gate signals to six switches. There are three methods of controlling gate signals of six switches: 1. 6-step control technique, 2. Sinusoidal-PWM (SPWM), and 3.3-High frequency input SVPWM.

1. The 6-step control method is the simplest switching method of a 3-phase inverter, and as shown in the waveform in Figure 2, the gate signals on A, B, and C have a phase difference of 120° to make a spherical wave with a phase difference of 120°. In the square wave line voltage, the magnitude of the maximum phase voltage of the basic wave is $2V_{dc}/\pi$. Although there is an advantage of generating the largest output power voltage compared to the input voltage, there is a disadvantage in that the voltage is transmitted toward the load by including a lot of seventh, ninth, and high-order harmonics.

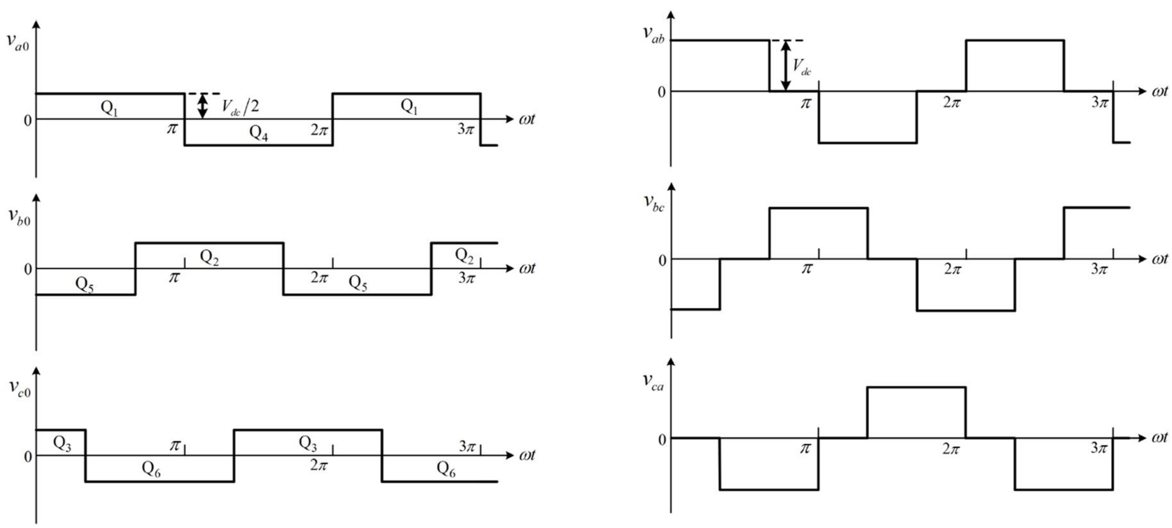

Figure 2. 3-phase inverter pole voltage and line voltage

2. SPWM control technology cannot output direct AC voltage, but it controls the average voltage for each period to be sinusoidal. A basic principle of pulse width modulation (PWM) operation is described in Figure 3, where V_r (carrier voltage) is greater than V_c, a high voltage is applied to a gate ($V_c/2$). If a value of V_r is less than the value of V_r, a low signal is applied to a gate so that a voltage of -$V_{dc}/2$ is applied to V_p (phase voltage). Assuming that the frequency of the triangular wave is 15 times or more large, if controlled in the above manner, V_r (command voltage) will be the same as the average value of the voltage applied to Vp (phase voltage). Therefore, if the command voltages with a phase difference of 120° are compared with Vc (triangle wave), as shown in Figure 4, the average of the power voltages of each phase is also as V_u*, V_v*, and V_w*. Since SPWM transmits the output power voltage to the average of the widths of each pulse, the harmonic components are much reduced compared to the case of using the 6-step control method. However, if the magnitude of V_r (command voltage) is larger than V_c (carrier), over-modulation occurs, and thus the relationship between the command voltage and the power voltage is not linear, so when the same power voltage is required, SPWM control requires more Vdc voltage than 6-step control. The increase in the input side Vdc voltage means that the voltage breakdown voltage specification of the switch device increases, so even if other conditions are the same, a switch with a higher voltage breakdown voltage should be used. There is a disadvantage in that the higher the voltage internal voltage of the switch, the larger the R_{ds_on} resistance, which results in a larger loss.

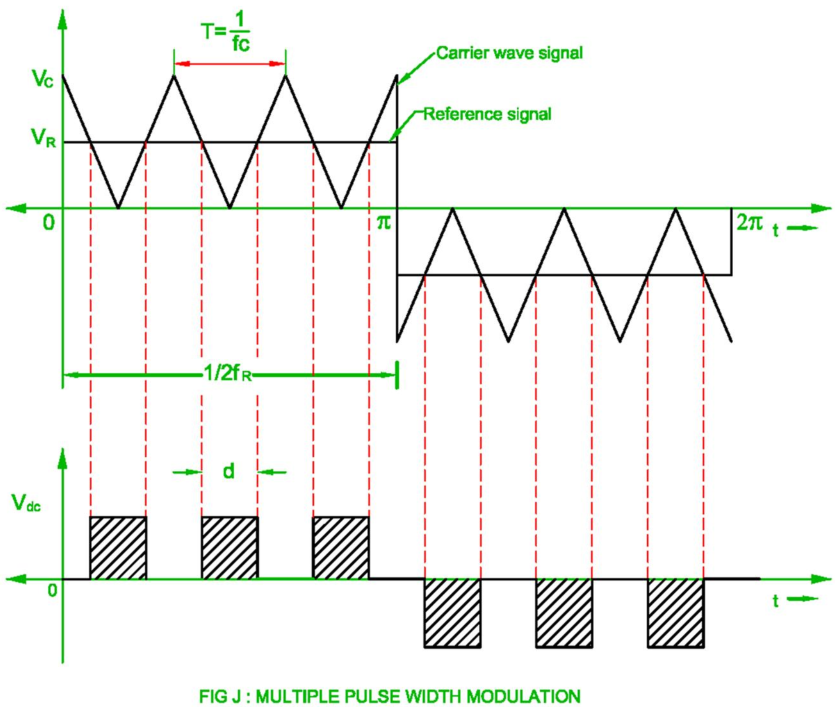

Figure 3. Waveform of PWM

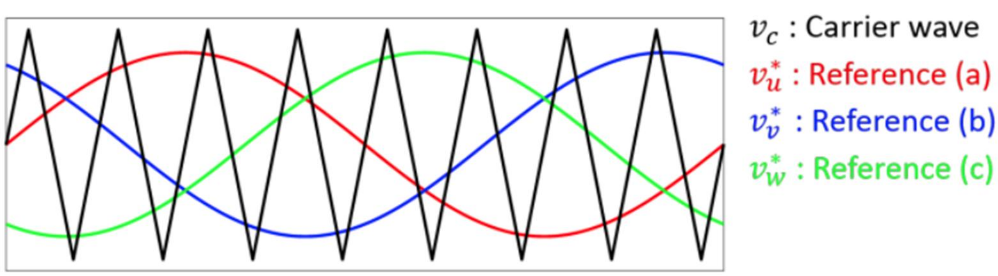

Figure 4. Waveform of SPWM

Therefore, there is an SVPWM (high harmonic injection) control method that can reduce harmonic as it is and increase the size of the output voltage compared to the input voltage. the 3rd harmonic of the command voltage V_r is added so that the maximum value of the existing command voltage is smaller than that of the carrier, and thus a voltage larger than SPWM is generated with the same V_{dc} voltage. Since the corresponding tertiary harmonic is offset and disappeared from each other when calculating the line-to-line voltage of the load, there is no problem in that the injected tertiary harmonic is transmitted to the load. The maximum phase voltage of basic waves for each inverter control method is specified in Table 1, and it was determined that the SVPWM (3-harmonic injection) method, which includes less harmonics and has a higher maximum phase voltage than SPWM, is most suitable for a three-phase inverter for a reefer container. Therefore, the load capacity simulation of the reefer container was conducted by applying the SVPWM (3-harmonic injection) method in PSIM.

Table 1. Utilization comparison of catenary, battery, generator

Category	Maximum standard wave	Comparison of square wave
6-Step	$\frac{2V_{dc}}{\pi}$	100%
SPWM	$\frac{V_{dc}}{2}$	78.5%
SVPWM(3-Phase)	$\frac{V_{dc}}{\sqrt{3}}$	90.7%

Figure 5 shows a circuit diagram connected to the SVPWM inverter (3-harmonic injection) by a three-phase Y-connection. The red part is a power unit, in which two switches are connected to one leg and a total of three legs are connected to the input voltage. In the middle of each leg, a Y-connection is connected to the load side by A, B, and C phases. The blue part is a part that generates a PWM Gate signal, has a phase difference of 120 degrees, and when three sine waves are a higher voltage than triangular waves having a Vdc size, the high signal is generated in the switch of the corresponding leg.

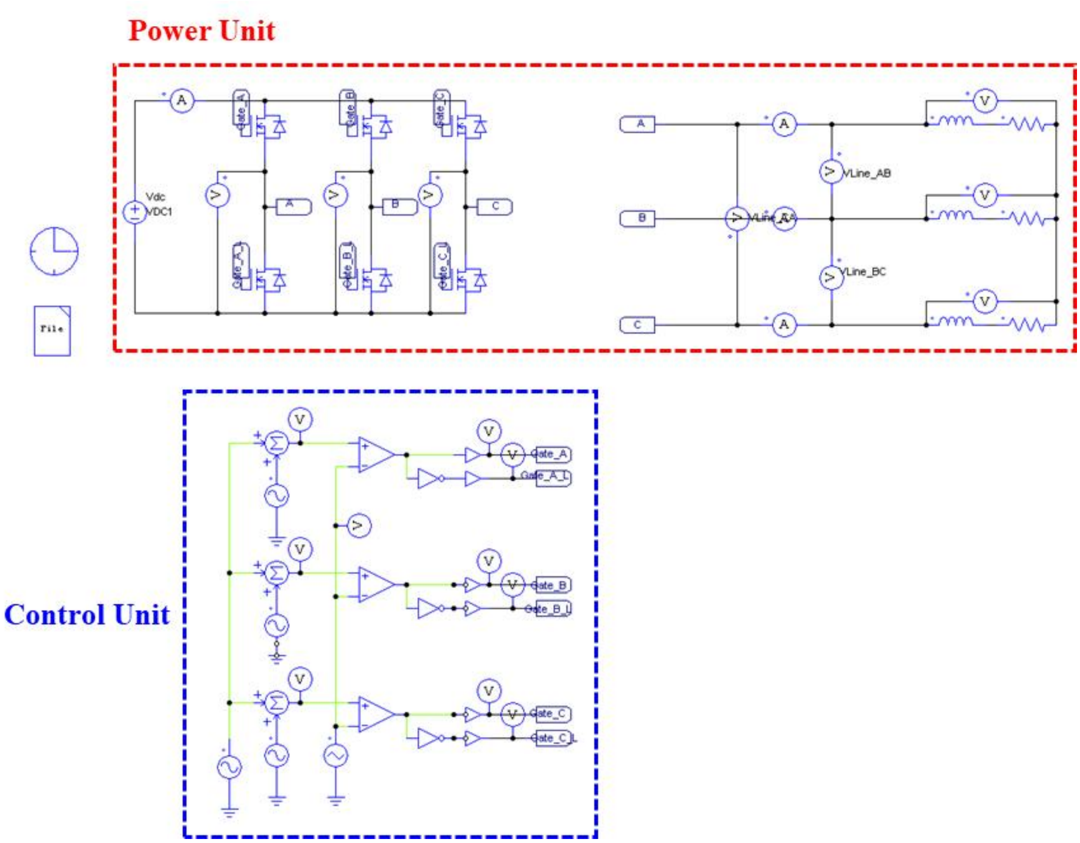

Figure 5. 3-phase SPWM inverter Y-connection load connection circuit diagram

As shown in Figure 6 the result of the simulation based on the calculated load. At the top, three-phase sine wave and triangular wave used in the comparator on the control unit side are shown. Since the 3 harmonic injection method is used, it can be seen that the vertex of the 3-phase sine wave entering the comparator is flat.

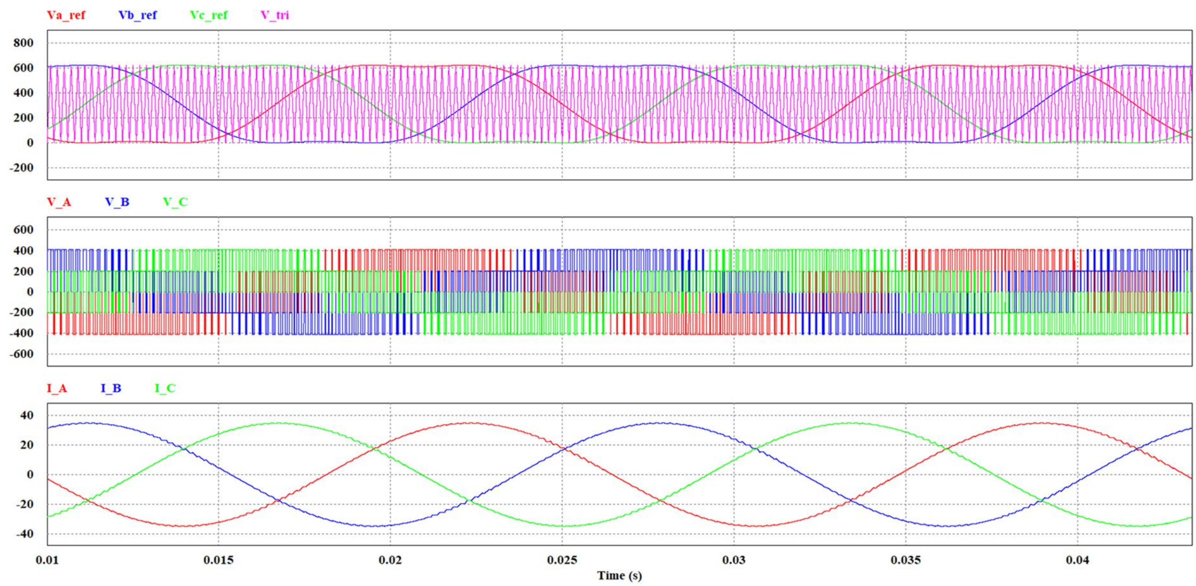

Figure 6. Reefer container 1 mass load reference phase voltage, phase current waveform

4. Functional / Structural Design for Power Supply

Consequently, the simulation was conducted using the three-phase inverter diagram in PSIM and the SVPWM (3 harmonic injection method) control technique, and it was verified that the required power voltage was satisfied with 622V_{dc}, which is lower than the input voltage of general SPWM of 718V_{dc}. From the previous process, it was concluded that the method of supplying the power required for the reefer container was most suitable to convert the voltage of the catenary to 760V_{dc} and supply the 760V_{dc} converted from the AC-DC converter to the reefer container through the inverter. Figure 7 shows the propulsion and auxiliary power supply configuration of an electric locomotive. The peripheral pressure has a capacity of 8,000kVA and receives a voltage of 60Hz and 25 kV_{rms} from the primary winding through the current collector, converts 1,400 V_{rms} from the secondary winding and 408V_{rms} from the tertiary winding. Two main converters with a capacity of 3,300kW receive an AC 1400V_{rms} from the secondary winding of the main transformer to the AC-DC converter, convert it to a DC 2,600Vdc, and convert it to a 3-phase AC line voltage of 0 to 2000V_{rms} (L-L) to transfer 1,100kW to the motor. The two auxiliary power supplies (APU) receive AC 408V_{rms} from the tertiary winding of the peripheral pressure, convert it into a DC voltage of 760V_{dc}, and then convert 760V_{dc} into a three-phase AC line-to-line voltage of 440V_{rms} (L-L) through a three-phase inverter. One of the two auxiliary power units (APU) delivers an alternating current voltage of 440V_{rms} (L-L) and a 60Hz frequency to the cooling pump, battery charger, air compressor and air conditioner in a CVCF (Constant Voltage Constant Frequency) manner; the other varies the voltage size and frequency to the 440V_{rms} (Variable) transmission.

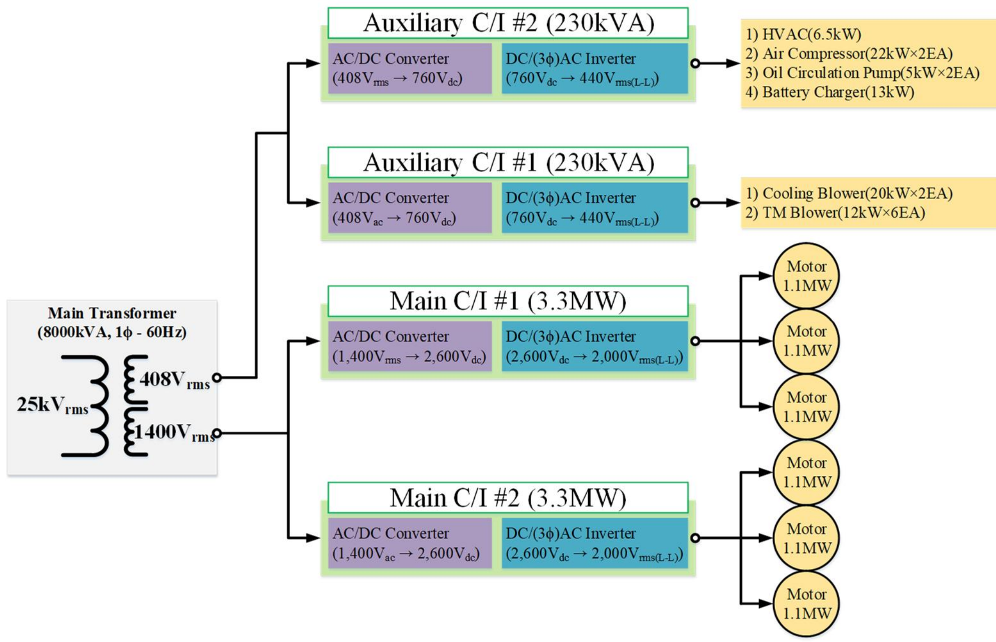

Figure 7. Electric locomotive propulsion/supplementary power supply configuration

5. Conclusion

When the reefer container for railroad transportation is commercialized, fresh food such as a large amount of agricultural and marine products can be delivered, and electricity supply and distribution of freight trains can be used not only for reefer containers but also various electric equipment. Based on the electrical specifications derived from the reefer container capacity requirement investigation, we proved that power supply to up to 33 reefer containers can be made by using three additional auxiliary power supplies which are applied for freight trains in Korea. In this paper, we conducted a research on a design of power supply system for freight train reefer container based on simulation as a basic research necessary for low-temperature distribution and cold chain construction based on the reefer container railroad. The existing researchers studied that the capacity required for a reefer container is investigated the power supply and specifications of a reefer container and compare the size and volume of the reefer container when a catenary, battery, and generator are applied as a power supply source. However, the results of this study studied the power supply method by calculating only volume and capacity. Based on it, our research team conducted a study on reefer container power simulation and improved the results. A three-phase inverter is a device that converts a DC voltage into a three-phase AC voltage, and generally, it is configured by combining six switch devices. Also, we proposed the result of the simulation based on the calculated load. At the top, three-phase sine wave and triangular wave used in the comparator on the control unit side are shown. Since the 3-harmonic injection method is used, it can be seen that the vertex of the 3-phase sine wave entering the comparator is flat. Consequently, the simulation was conducted using the three-phase inverter diagram in PSIM and the SVPWM (3 harmonic injection method) control technique, and it was verified that the required power voltage was satisfied with $622V_{dc}$, which is lower than the input voltage of general SPWM of $718V_{dc}$. The details of this paper could be used as a foundational study for constructing cold chains based on a reefer container dedicated to freight trains in the future.

Acknowledgement

This research was supported by a grant from R&D Program(Development of core technology for digital rail freight station, PK2202C3) of the Korea Railroad Research Institute.

References

[1] K. T. Kim and S. H. Roh, "A Study on the Improvement of Reefer Container Maintenance Industry", *Industrial innovation research*, Vol. 27, No. 4, pp. 53-85, Dec 2017.
DOI: https://doi.org/10.22793/indinn.2011.27.4.003

[2] W. C. Lee and S. J. Lee, "Real Time Reefer Container Monitoring System Using Interrogation Ports", *The Journal of Korean Institute of Information Technology*, Vol. 10, No. 1, pp. 13-19, Jan 2017.
DOI(UCI): G704-001947.2012.10.01.027

[3] Y. S. Moon, J. W. Jung, S. P. Choi, T. H. Kim, B. H. Lee, J. J. Kim and H. L. Choi, "Real-Time Management System of Reefer Container based on IoT", *Journal of the Korea Institute of Information and Communication Engineering*, Vol. 19, No. 9, pp. 2093-2099, Sep 2017.
DOI: https://doi.org/ 10.6109/jkiice.2015.19.9.2093

[4] Y. S. Moon, J. W. Jung, S. P. Choi, T. H. Kim, B. H. Lee, J. J. Kim and H. L. Choi, "Real-time Reefer Container Monitoring System based on IoT", *Journal of the Korea Institute of Information and Communication Engineering*, Vol. 19, No. 3, pp. 629-635, Mar 2017.
DOI: https://doi.org/ 10.6109/jkiice.2015.19.3.629

[5] H. S. Yang, H. J. Lim, K. W. Kim, Y. G. Kwon, D. M. Kim and S. G Lee, "Development of Refer-container Remote Monitoring System for Ship using RF Module", *Journal of the Korean Society of Marine Engineering*, Vol. 31, No. 4, pp. 425-432, May 2017.
DOI(UCI): G704-000602.2007.31.4.025

[6] S. J. Lee and W. C. Lee, "Mobile Service for Reefer Container Monitoring System", *The Journal of Korean Institute of Information Technology*, Vol. 10, No. 7, pp. 125-131, Jul 2017.
DOI(UCI): G704-001947.2012.10.7.022

[7] Y. S. Moon, S. J. Park, J. W. Jung, H. R Choi and J. J. Kim, "Temperature Control Algorithm for Reefer Container", *Journal of the Korea Institute of Information and Communication Engineering*, Vol. 21, No. 12, pp. 2380-2386, Dec 2017.
DOI: https://doi.org/ 10.6109/jkiice.2017.21.12.2380

[8] K. W. Lee and J. Y. Kim, "Design of Reefer Container Monitoring System based on Wireless Sensor Network", *Journal of the Korea Society of Computer and Information*, Vol. 12, No. 5, pp. 321-326, Nov 2007.
DOI(UCI): G704-001619.2007.12.5.027

[9] S. P. Choi, J. W. Jung, Y. S. Moon, T. H. Kim, B. H. Lee, J. J. Kim, H. L. Choi and E. K. Lee, "Development of Reefer Container Real-time Management System", *Journal of the Korea Institute of Information and Communication Engineering*, Vol. 19, No. 12, pp. 2917-2923, Dec 2015.
DOI: https://doi.org/ 10.6109/jkiice.2015.19.12.2917

[10] Y. H. Yoon, "Feed System Modeling of Railroad using Fuel Cell Power Generation System", *The Journal of The Institute of Internet, Broadcasting and Communication*, Vol. 20, No. 4, pp. 195-200, Aug 2020.
DOI: https:// 10.7236/JIIBC.2020.20.4.195

[11] J. U. Kim, S. W. Hwang, J. B. Lee and Y. M. Kim, "On the Calculation of Energy Requirement for Freight Train Reefer Containerand Methods of Supplying the Power", *International Journal of Internet, Broadcasting and Communication*, Vol. 14, No. 2, pp. 79-88, May 2022.
DOI: https://doi.org/ 10.7236/IJIBC.2022.14.2.79