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On the Calculation of Energy Requirement for Freight Train Reefer Container and Methods of Supplying the Power

Joouk Kim*†, Sunwoo Hwang*, Jae-Bum Lee**, Youngmin Kim***

**Advanced Logistics System Research Department, Korea Railroad Research Institute, Korea*
***Department of Railroad Electrical & Electronic Engineering, Korea National University of Transportation, Korea*
****Department of Systems Engineering, Ajou University, Korea*
jookim@krri.re.kr, marcell93@krri.re.kr, leejb@ut.ac.kr, pretty0m@ajou.ac.kr

Abstract

Recently, securing stable supply of fresh food is deemed as one of the important tasks. Accordingly, now the presence of cold chain along with the needs of a comfortable and healthy life is growing as the online market expands and the contactless industry grows, however, cold chain is being studied only in the aspect of ground and sea transportation. And, 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 means. Therefore, in this paper we calculated the maximum energy required by the reefer container as a basic research necessary for constructing the low temperature distribution and cold chain based on the reefer container railway, and conducted a study on methods of supplying the reefer container power utilizing 1. tramline, 2. battery, 3. generator. The results of this paper can be utilized as a foundational study for building a cold chain 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

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 industry along with the needs for a pleasant and healthy life. 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. And one of the main reasons behind the expansion of the online logistics market like this is that the contactless industry is rapidly growing due to the COVID-19 pandemic. Cold chain is an industry that can create high added value because it has both the characteristics of general logistics and sensitivity to temperature. 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, distribution of most fresh

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Corresponding Author: jookim@krri.re.kr
Tel: +82-31-460-5168
Principal Researcher, Advanced Logistics System Research Department, Korea Railroad Research Institute, Korea

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. In addition, so far, cold chains are being studied only in the aspect of ground and sea transportation. 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. 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. Reefer containers are a key element used in railroad logistics for cold chains. 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 power supply method for the reefer container. 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.

2. Relevant research

As previously mentioned in the introduction of this paper, according as the importance of cold chains is highlighted, 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 Ki-tae 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 Won-chang et al. conducted a real-time reefer container monitoring system using Interrogation Port. As a result, they 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 Young-sik 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 Hyun-sook 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 Sung-joon 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 Young-sik 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. As a result, they materialized a system for maintaining the internal temperature of the cargo loading room within a maximum of 0.5°C at the set temperature of 4.0°C and verified it [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 Ki-wook et al. conducted a study on the design of a reefer container monitoring system using a wireless sensor network. As a result of this, they 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 Sung-pil 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]. 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.

3. Calculation of Energy Required for Cargo Train Reefer Container and Analysis of Power Supplying Method

Reefer containers are used in railway logistic distribution for cold chains. However, power supply to reefer containers is possible at ports or container logistics center bases, but it is generally not possible on the train in operation. This results in a problem of the moving distance and moving time of the reefer container being limited. Therefore, there is a need for research on enabling power supply to the reefer container even during train operation. Firstly, we presented the power supply specifications of the reefer container and figured out the required capacity. Next, we compared the specifications for size and dimension when applying a tram line, battery, and generator as a reefer container power supply source and selected the most suitable power source among the three power supply sources and derived the specifications required when applied to freight trains. With the graph of the required energy and temperature change by time for the actual reefer container operation we could predict more reliable reefer container power consumption, so we referenced the temperature change and power consumption graph for 40ft reefer container presented in the previous research [10]. Table 1 shows the input power voltage, the maximum load energy, the continuous rated energy, and the required energy when we operate one reefer container and 33 reefer containers respectively. We applied the same values to the input power voltage and power factor for both since the input power is supplied from a three-phase inverter to each reefer container in parallel and in the same manner as the input power voltage for one reefer container. We calculated the energy required to operate one reaper container at a maximum load for 12 hours as 180kWh (15kW*12hour), and the energy required when 33 reefer containers operated at a maximum load for 12 hours as 5,940kWh (180kW*33). We applied mutatis mutandis the international standard for electrical equipment of the reefer container for the average active power consumption required for one reefer container.

Table 1. Power capacity calculation for 40ft reefer container

Item	For 1 container	For 33 containers
Voltage	(3Ø) 400 ~ 500Vrms(L-L) / 60Hz	
Power Factor	0.8	
Maximum rated load superficial power	18.75kVA	618.75kVA

Maximum active power consumption	15kW	495kW
Average active power consumption (based on 40ft reefer container)	7.5kW	247.5kW
Energy required for 12-hour operation	180kWh (15kW*12Hour)	5,940kWh (15kW*12Hour*33EA)

Figure 1 represents a reefer container power supply block diagram. The energy (electric energy) required to operate 33 reefer containers as on the right side of the figure for 12 hours is 5,940 kWh, and the maximum rated load superficial power is 618.75 kVA. In order to apply the corresponding power to the reefer container in parallel with a three-phase AC voltage of 440Vrms(L-L), a three-phase inverter, located in the center of the figure, converting Vdc (direct current voltage) into a three-phase AC voltage of 440Vrms(L-L) is required. And as shown on the left side of Figure 3, there are three ways to create a constant Vdc that becomes the input of a three-phase inverter. 1. A method of adding a power converter for converting a tram line voltage into Vdc through a transformer and a rectifier; 2. A method of adding a battery pack satisfying a required Vdc by stacking battery cells and modules in series and in parallel; 3. A method of converting mechanical energy into electric energy using a generator and a rectifier for creating the required Vdc. We calculated the volume and weight for each of the above three methods under the conditions of meeting the energy required for 33 reefer containers and the 760Vdc required by the three-phase inverter. Considering the volume and weight required to make 760Vdc the 3Ø inverter requires, and the advantages and disadvantages of the three methods, we tried to select the most suitable method.

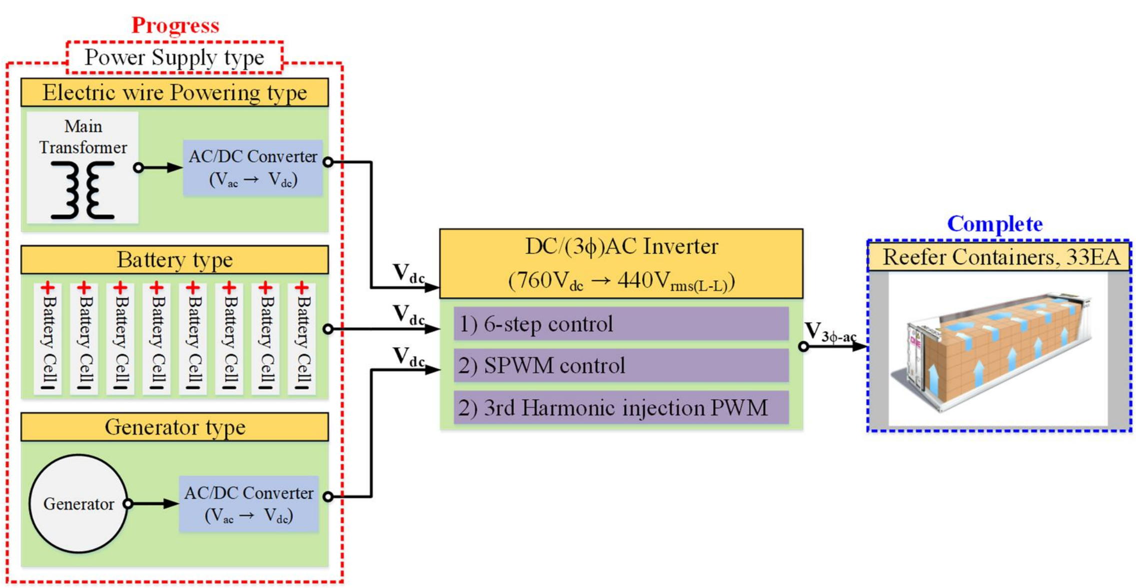

Figure 1. Reefer container power supply block diagram

First, we investigated the method of using tram lines. We expect that the method of supplying power by converting 25kV of a tram line into 760Vdc a three-phase inverter demands will inevitably reduce the volume and weight of facilities required to operate reefer containers compared to the method of mounting a battery and a generator together. However, we progressed the investigation because quantitatively knowing the difference in volume and weight for each method could be a big indicator when selecting a power supply device for reefer containers in the future. In general, in the case of a railroad vehicle using AC 25kV of a tram line, AC 25kV is applied to the primary winding of the main transformer and a voltage lowered to about 400V to a secondary winding to be used for the auxiliary power supply. When making a Vdc required for a three-phase inverter by additionally connecting an AC-DC converter to the relevant main transformer by a tertiary winding, we have to additionally consider only the AC-DC converter capable of actually maintaining power of 495 kW. When using a tram line, we have to consider the maximum active power of 100 kW and the output voltage range 620 to 1200 Vdc. A device satisfying this has a size of 0.465(W)*0.366(D)*0.24(H) and a weight of 27 kg. Since the power required for the 33 reefer containers is 495 kW, it can be assumed that about five of the corresponding AC-DC converters are used. Therefore, the volume added to apply the 760 Vdc voltage to the three-phase inverter is 0.204 m3 and the weight is 135 kg. Table 2 shows the specifications of AC-DC converters that meet the requirements.

Table 2. AC-DC Converter specifications

Item	Specifications
Max active power capacity	100kW
Output voltage range	620~1200Vdc (Vin=400Vac)
Size	0.465(W)*0.366(D)*0.24(H)[m]
Volume	0.0408m3 (1EA)/ 0.1224m3(5EA)
Weight	27kg(1EA) / 135kg(5EA)

Second, we investigated a method of using a battery pack. We intend to use Lithium-ion batteries, which have been widely used in the battery market, as power sources for reefer containers. Lithium-ion batteries used in EVs and railway vehicles may be divided into cells, modules, and packs, and cells are basic units of batteries and are mounted on vehicles in the form of modules and packs to safely and efficiently manage numerous battery cells. It means that battery cells collected become a battery module, and battery modules collected finally become a battery pack. For one reefer container, the battery capacity required for 12 hours of operation is 180 kWh, and for 33 containers, the battery capacity required for 12 hours of operation is 5,940 kWh. The rated voltage of the required battery pack is 388.8Vdc, the battery pack energy is 90.2 kWh, 36 modules are connected in series and the voltage per module is 10.8Vdc. One module consists of 12 cells, and as shown in Figure 2, four cells are connected in parallel and three bundles of corresponding parallel cells are connected in series. The size of the battery pack is 1.474(W)*2.28(D)*0.3(H)[m3] and its weight is 610kg.

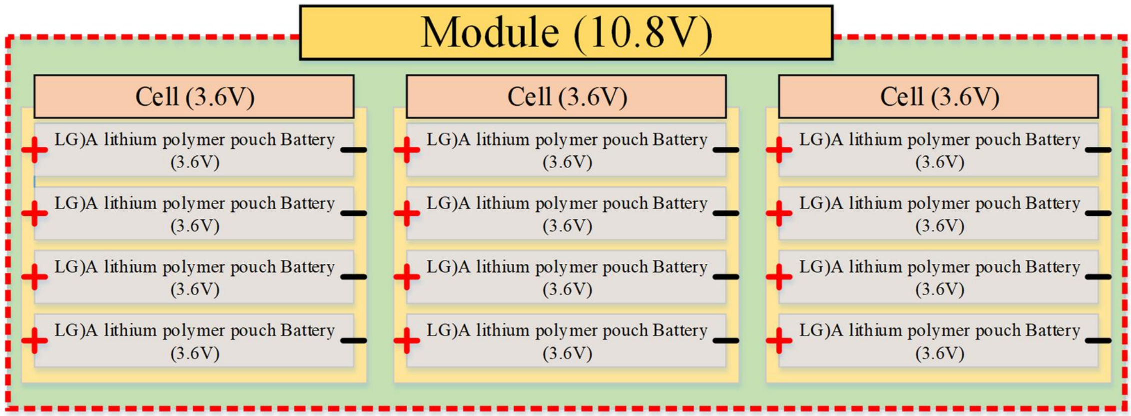

Figure 2. Battery module construction

When two battery packs are used in series, since the battery pack power capacity is 180.4kWh and the output power voltage is 777.6V (388.8V*2), we can see that the battery capacity required for 12 hours of operation and the output voltage of the battery required for the three-phase inverter are satisfied. When two battery packs in series are assumed to be one SET and 33 battery sets are connected in parallel to be used, the power capacity of the whole battery packs of 33 SETs is 5,953.2kWh and the output voltage is 777.6V (388.8V*2). So, we can see that satisfies the battery capacity required for operating 33 reefer containers for 12 hours, and the output voltage of the battery required for the three-phase inverter. In conclusion, the volume and weight of the battery pack put in one reefer container will be the same as the volume and weight of two battery packs, and the volume and weight of the battery pack put in 33 reefer containers will be the same as those of 66 battery packs. Figure 3 shows the sizes of the battery pack, the battery packs for one reefer container, and the battery packs for 33 reefer containers. Table 3 shows the specifications of the required battery pack.

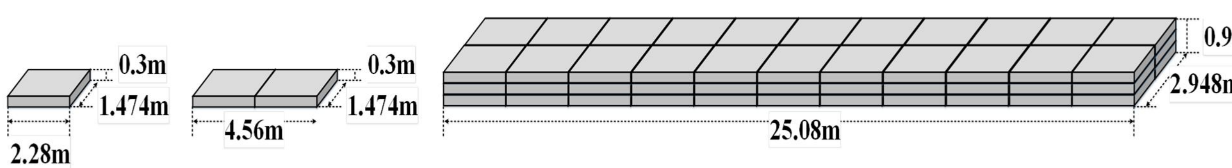

Figure 3. Calculation of Number of Battery Packs Require

Table 3. Specifications of Battery Pack

Item	Battery Pack (BP)	BP for one Reefer Container	BP for 33 Reefer Containers
BP Voltage [V]	388.8V	777.6V	777.6V
BP Energy [kWh]	90.2kWh	180.4kWh (90.2kWh*2EA)	5,953.2kWh (90.2kWh*66EA)
Number of Modules [EA]	36EA	72EA	2,376EA
Voltage per Module [V]	10.8V	10.8V	10.8[V]

Module to Module Connection	1P36S (1-parallel, 36-series)	1P72S (1-parallel, 72-series)	33P72S (33-parallel,72-series)
Cell to Module Connection	4P3S (4-parallel, 3-series)	4P3S (4-parallel, 3-series)	4P3S (4-parallel, 3-series)
Parallel Connections of Li-polymer Pouch per Cell	4EA	4EA	4EA
BP Width[m]	2.28m	4.48m	25.08m
BP Depth[m]	1.474m	1.474m	2.948m
BP Height[m]	0.3m	0.3m	0.9m
BP Volume [m3]	1m3	1.98m3	66.54m3
Weight [kg]	610kg	1,220kg	40,260kg

Third, we investigated the case of using a generator. For 30 reefer containers, we need a generator having a capacity with the max rated load superficial power of 618.75kVA and the max rated active power of 495kW. Therefore, we checked the size and volume added when using a generator as an energy source of the reefer container by referring to the size and weight of the diesel generator. The detailed specifications are as shown in Table 4, with a final volume of 24.47 m3 = 5.791(W)1.803(D)2.344(H) and a final weight of 6,162 kg.

Table 4. Generator Specifications

Item	Specifications
Number of Poles	4 poles
Number of phases	3 phases
Type of cooling	Forced-blast type
Continuous rating	450kW 480Vac (3-phase max RMS line voltage) 676.6A(max current) 1,800rpm
Insulation class	Class H
Connection type	Y-connection
Excitation type	Separate excitation
Excitation voltage	DC24V
Size	5.791(W)*1.803(D)*2.344(H)[m3]
Weight	6,162kg
Engine horsepower	755HP

4. Selection of optimal power supply method for reefer containers

To apply a 440Vrms (L-L) three-phase AC voltage to the reaper container we need a three-phase inverter and need a 760Vdc voltage as an input to the three-phase inverter. Before, we have investigated the volume and weight added when using three methods of making 760Vdc: method using tram lines, method using battery, and method using a generator. Table 5 and Figure 4 show the specifications for the cargo train reefer container. We see that when using a battery, the largest volume and weight are added to make a voltage of 760Vdc input to a three-phase inverter. Therefore, we conclude that it is appropriate to store the electric energy required for each reefer container in the corresponding battery by mounting a battery for each reefer container rather than storing the energy required for 33 reefer containers in one battery pack. The volume and weight when using a generator are relatively reasonable compared to when using a battery, and as a generator is often used to operate trains with reefer containers laden, it is deemed that the method would be sufficiently applicable. Finally, the volume and weight added are the smallest when using the tram line voltage. The advantage of using the tramline voltage is that the volume and weight added are significantly smaller as shown in the results of this investigation, enabling much simpler and more efficient reefer container operation systemwise. When operating on tracks without tram lines, diesel electric locomotives are usually used, so it is expected that a volume and weight similar to AC-DC converter's volume and weight will be added to diesel electric locomotives when using the tram line voltage.

Table 5 Comparison of using a tram line, using a battery and a generator

Item	Tram line voltage	Battery	Generator
Size	2.33(W)*0.366(D)*0.24(H)	11.4(W)*2.948(D)*1.8(H)	5.791(W)*1.803(D)*2.344(H)
Volume	0.204m313	66.54m3	24.47m3
Weight	135kg	40,260kg	6,162kg

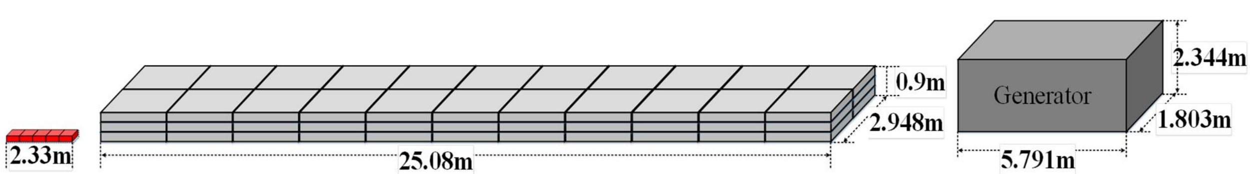

Figure 4 Concept graphic for comparing a tram line, a battery and a generator used

5. Conclusion

In this paper, we conducted a research on a power supply method of the reefer container as a basic research necessary for low-temperature distribution and cold chain construction based on the reefer container railroad. When the reefer container for railroad transportation is commercialized, fresh food such as a large amount of agricultural and marine products can be stably transported, and electricity supply and distribution of freight trains can be used not only for reefer containers but also various electric equipment. In this paper, we calculated the maximum energy required by the reefer container, and in investigating the power supply method we determined that the method of using the tram line voltage through the main transformer to be the most effective, and we carried out a power supply simulation by applying a three-phase inverter a three-phase inverter using the three harmonic wave injection SVPWM method. 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 addition, through a case study of Korean and foreign wiring plans in freight trains and investigation of technical standards thereof, we could find out the precautions when wiring the reefer containers. As a conclusion thereof, we calculated the maximum energy required to operate one reefer container and 33 reefer containers, and as for the power supply source for reefer containers we concluded that it is more practical to use the tram line voltage by adding a winding to the main transformer of the tractor vehicle than using batteries or generators. In addition, we conducted power supply simulation for one and 33 reefer containers through PSIM by selecting the three- harmonic wave injection SPWM among three control methods of the three-phase inverter. Based on freight electric locomotives operating in Korea, we derived the specifications required for supplying power to the reefer container, and we concluded that by adding three power converters with the same specifications as the auxiliary power system used in freight trains, we could meet the specifications required by 33 reefer containers. 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.

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