POWER SUPPLY SYSTEM FOR RAILWAY APPLICATIONS

D. Franković ¹, B. Rosanda ², A. Jakoplić ³, V. Kirinčić ⁴

¹ Faculty of Engineering, University of Rijeka, Vukovarska 58, Rijeka, Croatia
² Transagent d.o.o., Verdieva 6, Rijeka, Croatia
³ Faculty of Engineering, University of Rijeka, Vukovarska 58, Rijeka, Croatia
⁴ Faculty of Engineering, University of Rijeka, Vukovarska 58, Rijeka, Croatia

Keywords: railway, power supply, static converter, reefer container

Abstract. Modern era transport uses modern transport technologies. In fact, intermodal transport – means goods transportation in dedicated transport units by vehicles belonging to at least two different traffic branches, where in places that the different vehicles meet no manipulation with the goods takes place. Intermodal transport originated from the need to cut energy costs and reduce transport times in order to achieve a higher level of efficiency. The most common way of transport is road freight, with vehicles equipped with diesel-generator sets that are able to provide power supply to reefer containers, in order to maintain desired ambient parameters (temperature, humidity, number of air changes per hour, etc.) inside the containers. One of the key issues with road freight is under capacity, i.e. inability to transport a large number of containers in a short period of time.

On the other hand, reefer containers transported by rail are either left without power or powered by adding diesel gensets to the container housing. However, such transportation is not reliable nor acceptable to the cargo owners and as a rule most freight containers are transported by road.

In order to overcome afore stated problems an innovative technical solution which provides suitable power supply to reefer containers aboard wagons has been developed and tested in real-life conditions.

The basic idea is to draw power from the trains so called single-phase, head-end-power line (usually 1500 Vac, 1500 Vdc or 3000 Vdc), readily available at the locomotive, or on wagons with electric installation. Therefore, to supply the reefer containers it is necessary to perform the transformation of the single-phase voltage (AC or DC), into three-phase voltage, 400 Vac, 50 Hz. Since the permitted deviations from the nominal voltage, according to the relevant railway standard UIC 600, are considerable, a carefully designed static converter system had to be developed. Apart from the problem of output voltage stabilization a considerable number of additional requirements had to be met such as low weight, cooling, vibrations i.e. mechanical stress, EMC, suitable cable routing, remote control, etc.
Introduction

Transportation of refrigerated containers by rail is a natural extension of sea container transport and a link of multi-modal transport. Technical characteristics of modern refrigerated containers are such that they allow to maintain the temperature of goods in the range of -25 to +25 °C. This temperature range permits to transport virtually any goods requiring special temperature conditions. The main assortment of the so-called “cold goods” consists of food.

Transport by rail of refrigerated containers with a connection to a power source is not widely available within EU railway system. At least, for now. Power connection of containers at the departure terminal ensures reaching the desired transport temperature, therefore permitting the containers to travel only for a limited period of time to travel without power connection, thus in a non-controlled condition. At the arrival terminal the container is reconnected to the power supply.

On the other hand, on EU railways, a number of legal norms does not allow the use of any autonomous units to supply several containers with electricity at the same time. Despite the fact that there are self-contained diesel generator units, manufactured with dimensions of ISO-containers, for safety reasons, they are not allowed for use on EU railways.

The use of non-autonomous generators, i.e., diesel-generator units, serviced and maintained by people, is not less difficult. In the first place, the extremely high cost of labour in the EU makes such an approach inapt. Secondly, such transport requires specialized carriages both equipped with diesel generators, and passenger spaces to carry the maintaining stuff.

Another affordable way of railway transportation of refrigerated containers in Europe is the transport using gensets, i.e. mounted stand-alone diesel generators. Gensets are a universal tool that is commonly used on vehicles as well as on the railway. Generator’s capacity and fuel tank allow the units to supply one container with the power for a few days.

In fact, the afore mentioned mode i.e. using autonomous gen-sets is nowadays the most common mode of railway reefer container transport, providing controlled conditions. However, this solution is often compromised in the case of fuel theft, whole genset unit theft, fuel leakage, fuel lack, gen-set failure, etc. resulting in power loss.

The cutting-off of reefer container from electricity supply source, independent on its cause, should be considered a serious extraordinary situation which can quickly lead to loss of quality merits of refrigerated cargoes. In fact, when the container is cut-off from the electricity supply source the fans which have to ensure the above-mentioned uniformity, are also switched off, hence the temperature field inside the container becomes very non-uniform, especially in the case of rise of temperature of cargo. Heating the container from the top by sunshine makes natural convection of the air through the gaps between stocks of carton boxes placed on pallets difficult. Fig. 1.

As a result, the outer layers of carton boxes full of cargo (e.g. bananas), marked red and orange, have a higher temperature than those placed in the middle, and the calculated delay of heating the inner carton boxes as compared with the outer ones amounts from 4 h to 8 h, [1].

Fig. 1. Left - schematic diagram of arrangement of carton boxes filled with bananas in the reefer container; right – cargo’s (banana’s) temperature rate of rise in the upper layer of carton boxes (marked red in left figure) inside reefer container cut-off from electricity supply source, [1].

Following afore stated shortcomings of reefer containers genset powering during railway transport a research has been conducted that resulted with a solution that mitigates the highlighted problems. The solution that fulfilled all basic requirements for reefer container railway transport in controlled conditions without “fuel dependence” idea was to draw power from the trains so called single-phase, head-end-power line (usually 1500 Vac, 1500 Vdc or 3000 Vdc), readily available at the locomotive, or on wagons with electric installation.

Therefore, to supply the reefer containers it was necessary to perform the transformation of the single-phase voltage (AC or DC), into three-phase voltage, 400 Vac, 50 Hz. Since the permitted deviations from the nominal voltage, according to the relevant railway standards are considerable, a carefully designed static converter system had to be developed.

Power system layout of wagons for reefer container transport

As previously stated, the electrical energy for powering reefer containers is provided by the supply vehicle – the locomotive and is distributed to wagons through the train busbar. The electrical energy is supplied from the locomotive’s main power transformer. The voltage is single-phase AC, 1500 V RMS, 50 Hz. The distribution of electrical energy from the locomotive to the last wagon in the railway composition is performed with a single power line, which is in fact a high-voltage railway cable of appropriate cross-section. The cable is run through metallic conduit which protects the cable from mechanical stress. The conduit of appropriate diameter must be made of non-magnetic material and fixed to the metallic construction of the wagon, [2]. The return conductor of the head-end-power electrical circuit are the rails, composed of the wheelset contact assemblies with brushes (1 grounding circuit per axis), and protective resistors (1 resistor per axis), Fig. 2. The wagon’s grounding system has to comply with the standard DIN VDE 0123.
The interconnection of cable sections on the wagon and between individual wagons is performed with appropriate elements, in accordance with the railway standard UIC 552.

Given the significant permitted deviations from the rated voltage ($V_{\text{rated}} = 1500$ V, 50 Hz) and the sensitivity of electrical devices connected to the 400 V voltage level, this voltage must be stabilized. All the above stated requirements are realized through the power converter of appropriate configuration and size. The power converter itself is located and fixed in a metal housing, which is attached to the metal construction of the wagon.

The rated power of the converter was carefully selected to withstand the starting current of older generation reefer containers. Furthermore, the converter had to be equipped with an appropriate switch-disconnector for isolating the converter from the input high voltage and grounding for safe operation on the converter and to comply with stringent railway norms. Also, the converter is equipped with a device for emergency start and stop of operation in all conditions. The basic technical characteristics of the developed converter are listed in Table 1, while the multi-line diagram of the converter is given in Fig. 4. The proposed solution provides power supply for a single refrigerated container, i.e. one power converter per one reefer container.

### Table 1. Technical characteristics of developed power converter

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>$&gt;18.75$ kVA</td>
</tr>
<tr>
<td>Input voltage</td>
<td>1500 V, 50Hz</td>
</tr>
<tr>
<td>Output voltage</td>
<td>3x400 V, 50 Hz, 20 kVA, sinusoidal</td>
</tr>
<tr>
<td>Temperature range</td>
<td>-30 °C to +40 °C</td>
</tr>
<tr>
<td>Max. dimensions</td>
<td>2000x1500x600 mm</td>
</tr>
<tr>
<td>Standard compliance</td>
<td>UIC, IEC and RIC</td>
</tr>
</tbody>
</table>

Distribution of electrical energy on the 400 V, 50 Hz voltage level, from the power converter to the industrial sockets designated for power supply of the reefer containers is performed with low-voltage railway cables of appropriate cross-section and number of conductors. The cable is run through a metallic conduit of appropriate diameter, which protects the cable from mechanical stress and is made of non-magnetic material with. The conduit is fixed to the metal construction of the wagon. The industrial sockets are of the 3p+PE, 32A, 400V type, IP67 protection degree and located in a metal housing with lockable door.

In order to test the proposed solution two fully operational prototypes of "electrified" wagons were constructed on the basis of Sdkmms series wagons. In the following figure the result of the conversion is presented.
Upon completing the conversion (power converter assembly on the wagon, cable routing etc.) and obtaining necessary permits from the railway authorities, a series of tests were performed with great success in the final testing. In fact, problems met in the initial testing phase were solved by installing a LC smoothing filter on the power converter output.

Remote control and supervision of the power converter
Tracking the transport of goods in reefer containers along the supply chain is the means by which product quality can be guaranteed. [3]. The integration of emerging information technologies can now provide real-time status updates. In fact, in order to ensure real-time monitoring of reefer container’s power supply, a dedicated communication system has been developed using industrial grade communication equipment (GSM/GPRS modem). The application running on the GSM/GPRS modem has been developed and coded in LUA programming language. Testing and fine tuning of the developed software was performed on a scaled (laboratory) model of the power converter, Fig. 6.

Fig. 6. Remote control and supervision of the power converter (left-scaled model of power converter, right-LUA source code)

Conclusion
Transport by rail of refrigerated containers with a connection to a power source is not widely available for now within EU railway system. Power connection of containers at the departure terminal ensures reaching the desired transport temperature, therefore permitting the containers to travel only for a limited period of time to travel without power connection. In order to overcome such gap on the market a solution was developed that is based on power electronics technology. In fact, a power converter was developed that draws power from the train’s head-end-power line (usually 1500 Vac, 1500 Vdc or 3000 Vdc), readily available at the locomotive, or on wagons with electric installation. The proposed/developed solution is intended for single-voltage conversion i.e. 1ph, 1500 Vac to 3ph 400 Vac providing power for a single reefer container i.e. one power converter per reefer container. Alongside with power converter development a remote-control system was developed to provide real-time monitoring of reefer container’s power supply system.

Future research will be focused upon multi-voltage power converter development that will provide full compatibility with all railway standardised voltage ratings.

Acknowledgment and disclaimer
The project was partly financed by the European Union from the European regional development fund.

The authors share full responsibility for the contents of the manuscript.

References
[1] L. Filina, S. Filin, An analysis of influence of lack of the electricity supply to reefer containers serviced at sea ports on storing conditions of cargoes contained in them, Polish maritim research, Vol. 15, No. 4, pp. 96-102
[2] UIC code 552, Electrical power supply for trains - Standard technical characteristics of the train line