REEFER CONTAINER POWER SUPPLY AND SUPERVISION SYSTEM ONBOARD RAILWAY WAGONS

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Abstract: *Concerns about greenhouse gas emissions and environment protection in general, lead to application of new, eco-friendly solutions in almost all areas of human activities. Today, transportation is in the focus of many researchers since transport units generate substantial emissions locally as well as globally. Turning to electricity powered transportation units seems to be a logical step if global power production transitions to renewable energy sources (large hydro, wind, solar, biomass, etc). This paper demonstrates a technical solution applicable to reefer containers railway transport, as an alternative to road transport with conventional trucks or railway transport with diesel gen-sets. In fact, reefer containers are frequently used to transport sensitive goods. Therefore, containers must be almost constantly supplied with electric power to maintain desired ambient parameters (temperature, humidity, number of air changes per hour, etc.). An innovative technical solution which provides suitable power supply to reefer containers aboard wagons has been developed and tested in real-life conditions. Electrical power is drawn from the locomotive's single-phase, head-end-power line (usually 1500 Vac, 1500 Vdc or 3000 Vdc), available at the locomotive, or on wagons with electric installation. Throughout the paper, the developed static converter system suitable for transforming single-phase 1500 Vac, into three-phase 400 Vac, 50 Hz is presented. Furthermore, a dedicated communication system is developed which enables users to perform supervision of transported goods (temperature and relative humidity) and track the reefer container onboard railway wagons.*

Keywords: REEFER CONTAINER, STATIC CONVERTER, RAILWAY TRANSPORT, REMOTE SUPERVISION

1. Introduction

Intermodal (multimodal) transport of refrigerated goods demands continuous, stable power supply in order to preserve the quality of products inside reefer containers, transported from origin to destination. Modern refrigerated containers are such that they allow maintaining goods' temperature in the range of -25 to +25 °C. This in turn permits to transport virtually any goods requiring special temperature conditions. Reefer containers, while on ship, get power supply from ship's low voltage electric distribution system. When disembarked at port, reefer containers are powered from the land power distribution system. Land power connection provides reaching desired transport temperature, therefore permitting the containers to travel a limited period of time without power connection. At arrival terminal the container is reconnected to the power supply and hopefully the temperature inside the container hasn't raised above permitted level. If longer transport time is required, reefer containers must be powered. Naturally, for higher ambient temperatures and/or prolonged exposition to direct sunlight shortens allowed unpowered transport period, Fig. 1.

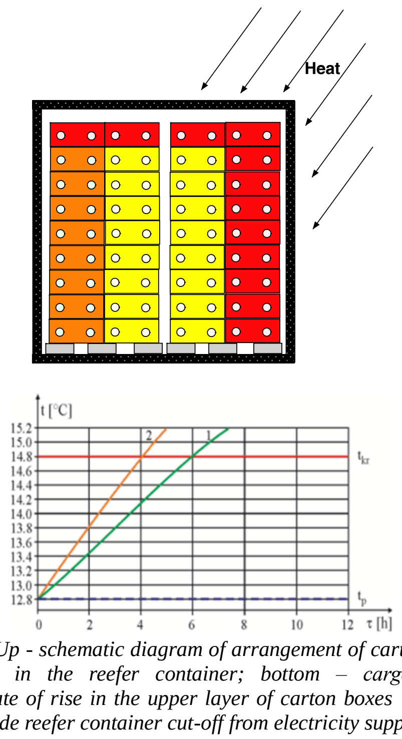

Fig. 1. *Up - schematic diagram of arrangement of carton boxes filled with bananas in the reefer container; bottom – cargo's (banana's) temperature rate of rise in the upper layer of carton boxes (marked red in left figure) inside reefer container cut-off from electricity supply source, [1]*

At present, railway transport of refrigerated containers with a connection to a power source is not common within EU railway system. On the other hand, a number of legal EU railway norms does not allow usage 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, serviced and maintained by service personnel, is not less difficult. Firstly, the extremely high labour cost 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 servicing staff.

Another way of refrigerated containers railway transport in Europe is transport using gensets. In fact, these stand-alone diesel generators 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 electric energy for a few days.

However, this solution is often compromised in the case of fuel theft, genset theft, fuel leakage, fuel lack, gen-set failure, etc. resulting in power loss and damage to transported goods.

If power supply is removed, independent on its cause, a serious extraordinary situation arises. In fact, when electric power supply is cut-off from the reefer container, the compressors of the cooling system stop as well as the fans which provide temperature uniformity of transported goods. Therefore, the temperature field inside the container becomes very non-uniform, especially in the case of cargo temperature rise. Container heating from above by direct sunlight 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 boxes amounts from 4 h to 8 h, [1].

Having in mind afore stated shortcomings of reefer containers railway transport relying on diesel generators, a research and development project has been conducted that resulted with a static power converter for railway application that mitigates highlighted problems.

2. Reefer container wagon power supply system

At the Faculty of Engineering in Rijeka, Croatia, in cooperation with the company Transagent also from Rijeka, supported by the European Union from the European regional development fund a research and development project has been conducted that resulted with a reefer container power supply for railway wagons. The developed power supply fulfilled all basic requirements for reliable reefer container railway transport in controlled conditions without “fuel dependence”. Electric power for the reefer container power supply is drawn from the train’s single-phase, head-end-power line (usually 1500 Vac, 1500 Vdc or 3000 Vdc), available at the locomotive, or on wagons with electric installation, connected to the locomotive. The constructed power supply includes a step-down, single-phase power transformer, an AC/DC rectifier, DC link, a DC/AC inverter and an output filter. Due to considerable permitted deviations from the nominal voltage, according to the relevant (e.g. UIC 552, IEC 60850, etc.) railway standards, a carefully designed control of the static converter system had to be developed.

Electric energy distribution from the locomotive’s main power transformer to the last wagon in the railway composition is performed with a single power line i.e. a high-voltage railway cable of appropriate cross-section. The cable runs through a non-magnetic metallic conduit which protects the cable from mechanical stress. The conduit of appropriate diameter is fixed to the metallic construction of the wagon, [2]. The return conductor of the high voltage head-end-power 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 earthing system is designed as to comply with the standard

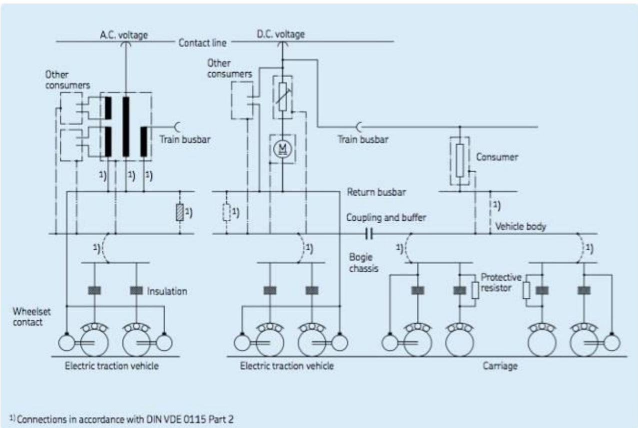

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Fig. 2. *Wagon’s grounding system, [2]*

Electrical interconnections of wagon’s electric power system are performed with appropriate standardized elements, in compliance with the railway standard UIC 552, Figure 3.

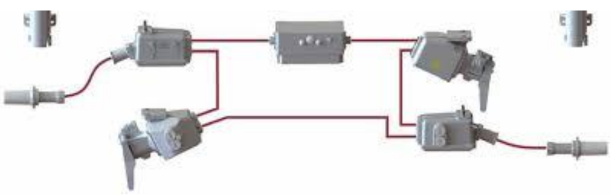

Fig. 3. *Connection elements according UIC 552, [3]*

The main component of the reefer wagon power system is the power converter that provides stabilized, sinusoidal, 3-phase output voltage 400 V, 50 Hz. As previously mentioned, the power converter consists of a 1-phase, step-down transformer, AC/DC rectifier, DC link capacitors, DC/AC inverter and a smoothing output LC filter. The reefer container wagon power supply is based on high power insulated-gate bipolar transistor (IGBT) switching technology. Before constructing the full-scale power converter, a prototype converter of same topology but with reduced power was constructed and tested in laboratory environment, Fig 3.

Fig. 3. *Small scale prototype model of the power converter*

The desired characteristics that the full-scale power converter for railway application should possess are listed in the following table.

Table 1: *Desired parameters of the power converter for railway application*

Power [kVA]	>18.75
Input voltage range [V]	1000-2000, 1ph
Frequency of input voltage [Hz]	50
Output voltage [V]	400, 3ph
Frequency of output voltage [Hz]	50
Output voltage waveform	sinus
Converter rated power [kVA]	> 20
Temperature range [°C]	-30 to +40
Max. dimensions [mm x mm x mm]	2000x1500x600
Standard compliance	UIC, IEC and RIC

The following two figures demonstrate the influence of the smoothing output filter (C=100 µF, L=200 µH) upon the voltage waveform.

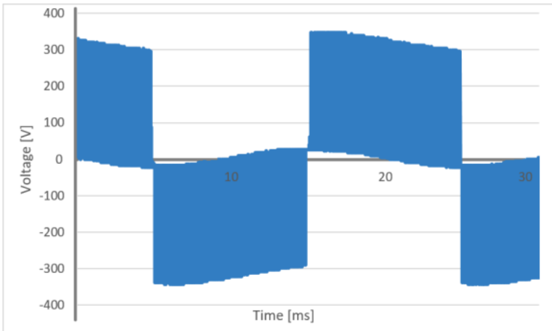

Fig. 4. *Voltage measured in front the smoothing filter of the power converter*

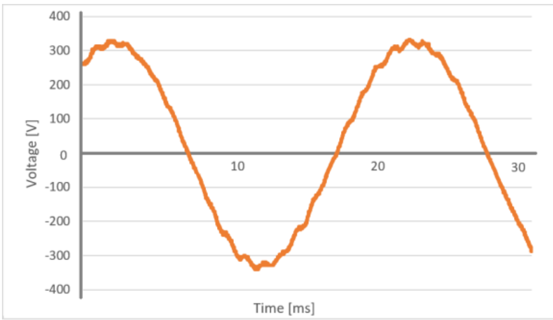

Fig. 5. *Voltage measured at smoothing filter terminals of the power converter*

Figure 6. demonstrates voltage waveform dynamics upon start-up and shut-down of the power converter.

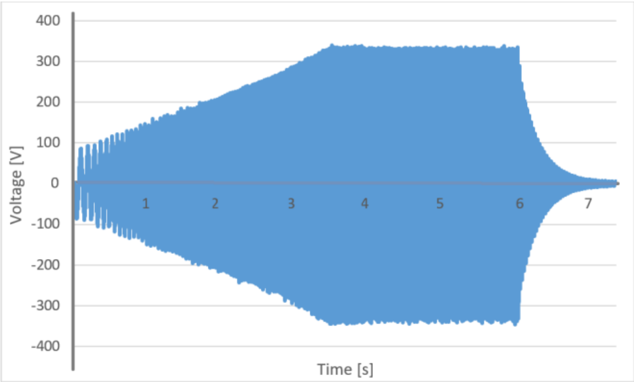

Fig. 6. *Voltage transient at power converter terminals upon start-up and shut-down*

After extensive testing in laboratory conditions on the small-scale prototype model, a full-scale model (Fig. 7) was constructed with constructive parameters as defined in Table 1.

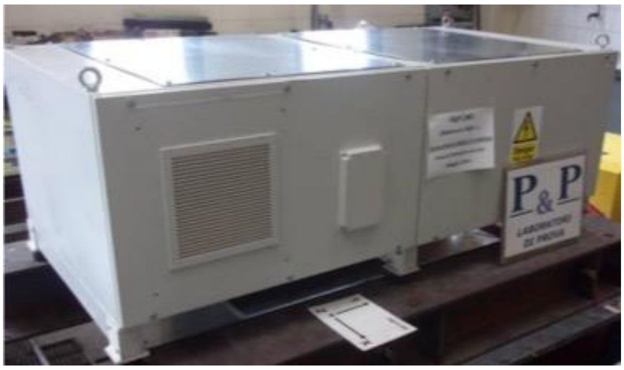

Fig. 7. *Full-scale power converter during vibration testing*

The nominal power of the converter was selected to be 30 kVA in order to withstand the starting current of older generation reefer containers, [4].

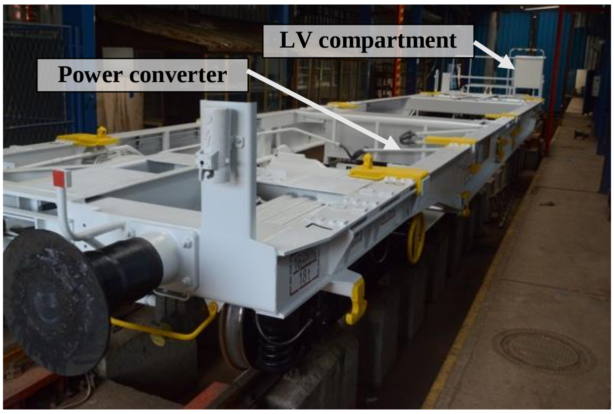

Fig. 8. *Wagon after installation of the reefer container power supply system components*

Furthermore, the converter had to be equipped with an appropriate switch-disconnector for isolating the converter from the input high voltage (1500 Vac) 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/stop in all conditions. The power converter itself is in a metal housing of appropriate size with adequate cooling openings providing IP67 protection degree. The metal housing is therefore attached to the metal construction of the wagon, as visible in the following figure.

Distribution of low voltage power (400 V, 50 Hz) 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. 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.

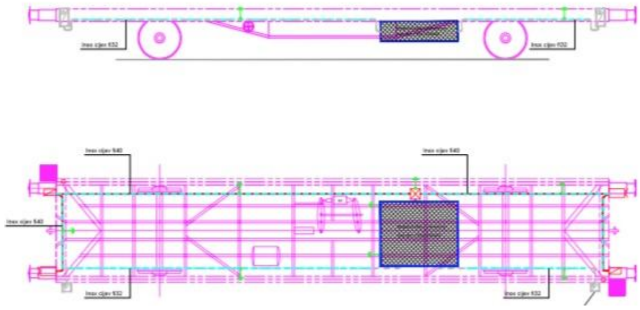

Fig. 8. *Reefer container wagon with power supply - layout*

3. Reefer container remote supervision system

Tracking transport of goods in reefer containers along the supply chain is the means by which product quality can be guaranteed, [5]. 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.

Reefer container's remote supervision system consist of several key elements:

- GSM/GPRS modem running the developed application for remote supervision for both the power converter and the reefer container powered from the converter,
- Server application that collects data from the GSM/GPRS modems,
- Mobile application for remote supervision of reefer containers installed on user's mobile phone.

Remote communication with the power converters installed on railway wagons and with reefer containers powered from these converters is done by Orbcomm's IDP 782 module for cellular fleet management, Fig. 9.

Fig. 9. *IDP 782 – GSM/GPRS module for remote communication, [6]*

The software application running on the IDP 782 module was written in LUA programming language and provides serial communication on Modbus protocol. Since there are two serial ports on the IDP module, one is used for communication with the power converter operating software while the other is selected for communication with the reefer container's control system.

Extensive testing by the principle of "trial and error" has been undertaken in order to establish communication with reefer container's logic i.e. microcontroller, Fig 10.

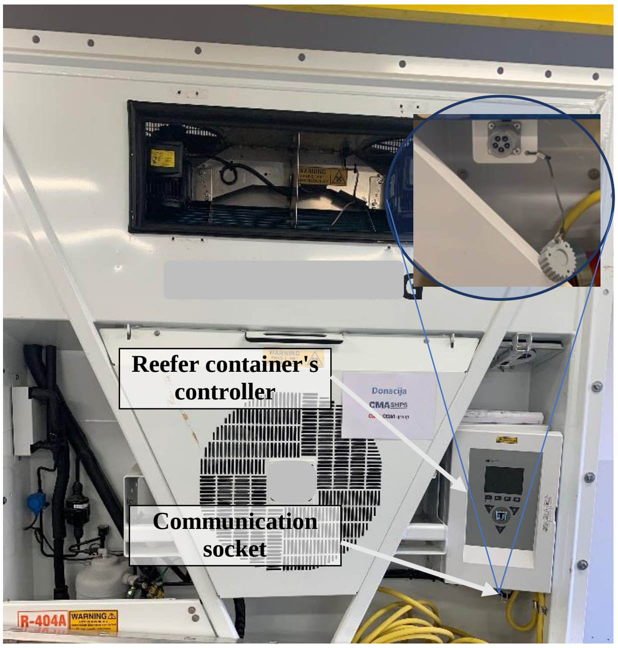

Fig. 10. Reefer container used for communication testing purposes

At the same time, a server application has been developed that collects data from the IDP 782 module. The data transmitted to the server application includes reefer container's parameters (container ID, temperatures, humidity, alarms, …) power converter data (status, power, energy, alarms, …) and actual GPS position.

Finally, a mobile application has been developed that permits registered users to remotely supervise reefer containers powered from developed converters during railway transport. The mobile application shows the user actual GPS position of the reefer container, ambient parameters inside the container and electric parameters reflecting power converter's operation, Fig 11.

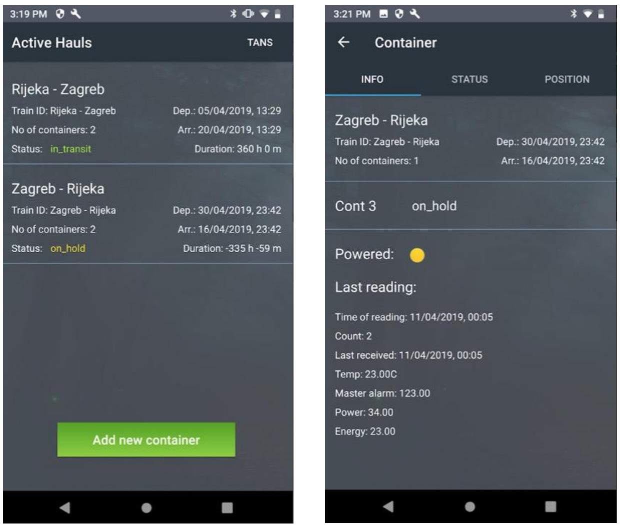

Fig. 11. Mobile application for reefer container remote supervision

4. Conclusion

Railway transport of refrigerated containers with a connection to a reliable power source is not common within the EU railway system. Today, it is common to power up containers at the departure terminal, thus ensuring desired transport temperature, and afterwards permitting the containers to travel for a limited period of time without power supply. In order to overcome the necessity for limited travel time and/or short travel distances a technical solution was developed that is based on power electronics technology. In fact, a high-power converter for railway application was developed. The power converter is powered from the train's head-end-power line (usually 1500 Vac, 1500 Vdc or 3000 Vdc), available at the locomotive, or on wagons with electric installation. The developed converter is resilient in terms of substantial input voltage fluctuations permitted by the railway regulations, due to large capacitance of converter's DC link.

A dedicated communication system has been developed using industrial grade communication equipment that permits the users to remotely supervise reefer containers while on railway wagons. The communication system consists of a GSM/GPRS modem running an application that continuously communicates both with the power converter logic and with reefer container logic circuits. The serial communication is based on the Modbus industrial protocol. Apart from the software application running on the GSM/GPRS modem, a server application has been developed that collects data from the modem. The data transmitted to the server application includes reefer container's parameters (container ID, temperatures, humidity, alarms, …) power converter data (status, power, energy, alarms, …) and actual GPS position. Also, a mobile application has been developed that allows registered users to access server data containing information regarding their reefer containers while on railway wagons during transport.

Future research and development will be focused on a multi-voltage power converter that will provide full compatibility with all railway standard voltage ratings. In fact, a multi-voltage power converter is already undergoing testing procedures.

5. Acknowledgment and disclaimer

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

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