Implementation of charger current sharing method in railway application using CAN bus.

Martin Šuňal
Research and development
EVPU, j.s.c.
Nová Dubnica, Slovakia
sunal@evpu.sk

Zdeno Biel
Research and development
EVPU, j.s.c.
Nová Dubnica, Slovakia
biel@evpu.sk

Marcel Pčola
Research and development
EVPU, j.s.c.
Nová Dubnica, Slovakia
pcola@evpu.sk

2022 International Conference on Applied Electronics (AE) | 978-1-6654-9482-3/22/$31.00 ©2022 IEEE | DOI: 10.1109/AE54730.2022.9920088

***Abstract*— This paper presents the application of parallel cooperation of chargers in auxiliary converters of rolling stock. A control strategy based on CAN serial bus communication has been proposed to achieve even load power sharing by the individual chargers of the parallel system without affecting the accuracy of the output voltage regulation. The paper describes the principle of the proposed control strategy and presents the regulation structure block diagram. The properties of the created control software for parallel cooperation of chargers were experimentally verified on a parallel system of two converters. The measured currents in static and dynamic modes are presented.**

Keywords*— *charger, current sharing, CAN bus

I. INTRODUCTION

The battery charger is very important part of auxiliary converters of railways vehicles. The power of the chargers is usually 6-15 kW. There are electrical devices and batteries on the rolling stock that need to be powered and charged. For this reason, they are equipped with chargers. In a presented application, two chargers were used on one vehicle. Each of the chargers is able to provide the full required power for the entire vehicle. Both chargers are connected in parallel to a common DC bus. This solution ensures 100% redundancy. An uninterrupted supply of voltage for appliances and battery charging is ensured even in the event of a failure of one of the chargers. Higher system availability and reliability will also be achieved. It is also possible to easily configure such a system. Changing the number of inverters connected in parallel makes it possible to achieve different values of the total supplied electrical power.

Due to the tolerances of used components the parallel connected chargers of the same type in constant voltage mode will supply different currents to a common bus. This causes unbalanced currents in the individual chargers of the parallel system. The charger with a higher output current will be more thermally and power stressed. This will negatively affect the service life and reliability of the device. The solution is to implement a control algorithm in the charger module, which will ensure even load current sharing by individual parallel operated chargers.

The proposed control method for parallel cooperation of chargers belongs to the group of active current sharing methods. The CAN serial bus is used to share information about the output currents of the individual chargers. In rolling stock, the CAN bus is often used to connect individual devices to a master control system to ensure their monitoring and control.

II. AUXILIARY CONVERTER AND CHARGER SYSTEM

Fig. 1 shows a block diagram of an auxiliary converter and charger system for powering AC and DC loads in electric train units. The converter is supplied by catenary voltage 1500V DC in accordance to UIC 550 standard and EN50163. Converter has AC output, used to supply three phase loads 3x400V AC 50Hz and single-phase loads 230V AC 50Hz of the coach. The converter contains a step-down DC/DC converter with maximum power 10kW, which provides output voltage 40Vdc. Its purpose is supplying of electromagnetic braking system. Battery charger with maximum power 10kW is installed in small separate cabinet and provides voltage for 24V DC loads and charging of 24V battery.

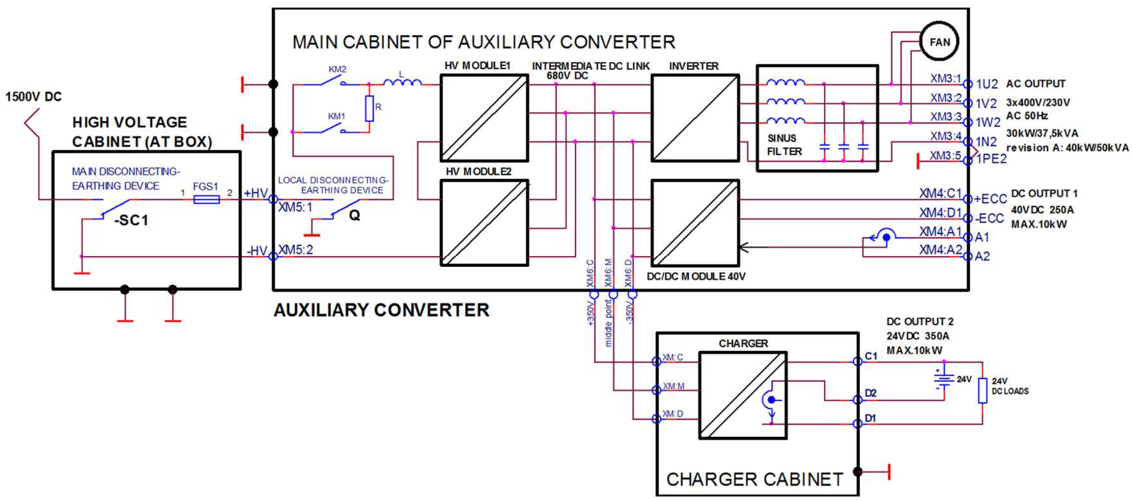

Fig. 1. Auxiliary converter block diagram

The charger is a static converter powered by DC link voltage designed for converting an DC input voltage to a DC output voltage with galvanic isolation. The main function of the charger is to transfer voltage and current to a level suitable for battery charging and powering DC loads. High switching frequency of power semiconductor devices allows to minimize the weight and dimensions of the power transformer, which ensures galvanic separation of the input and output of the charger. The secondary voltage from transformer is rectified and filtered by output LC filter.

The charger has splitted positive or negative pole of output in railway applications. One output is for connecting the battery and the other to connect 24V loads. Two separate regulators and output current sensors are also used. One for the total current supplied by the charger and the other one for the battery charging current. In this way optimum battery charging mode is ensured and the impact of loads on the charging process is excluded.

The block diagram of the charger control structure is shown in fig. 2. The control structure of the chargers is designed as a parallel combination of current and voltage controllers. The lower value from the controller outputs is always selected as the PWM modulator input.

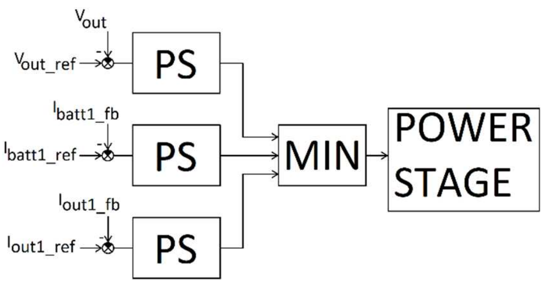

Fig. 2. Control structure of charger.

If the total output or charging current limit is reached, the appropriate controller starts to limit the output voltage so that the maximum required value of the charging current I_{batt_ref} or the total output current of the charger I_{out_ref} is not exceeded. In this operating mode the output of the current regulator is used as reference for the PWM modulator. The charger work in the constant current mode. The charging or total output current value will be kept constant. It depends on which reaches the limit value first. If no current limit value is reached, the voltage regulator keep the output voltage at the required value V_{out_ref} corresponding to a fully charged battery. In this mode the output of the voltage regulator is used as reference for the PWM modulator. The charger operate in the constant voltage mode.

III. PARALLEL OPERATION

In parallel operation, the outputs of two or more chargers are connected to a common bus. All parallel system chargers simultaneously supply power to the common bus. At the same time, loads are connected to this bus, which consume power from it. In case one of any charger fails the other chargers can keep the system functional.

Each charger has the ability to limit the charging current to the desired value. However, the maximum charging current of the battery should not be exceeded, even if two or more chargers supply one battery. Otherwise, battery life may be negatively affected or the battery may be damaged. One solution for parallel cooperation of two chargers is to set each of the chargers to charging current at half of maximum charging current of the battery. This scenario has the disadvantage that if one of the chargers fails, the charging current to the battery will be decreased to one half of maximum agreed value ($I_{batt}=I_{battmax}/2$) and time necessary for full charging of battery will be significantly prolonged.

In proposed parallel system both converters are interconnected via CAN interface, which ensures the exchange of operation data and output currents information between chargers. If the charger works independently, it is able to supply maximum current 350A what means power up to 10kW. If any charger detects via CAN interface that other charger is working, then its current limit will be decreased from 350A to 175A. As consequence each charger will be always loaded with maximum power no more than 5kW. If any difference between load sharing exist, regulators of chargers will minimize this deviation so in static load condition will be ensured equal current sharing 50% + 50%. In range of total load from 175A up to 350A the maximum deviation between chargers currents will be below 5%.

To ensure reliable battery charging, special asymmetrical connection of two chargers was used as shown in fig. 2. Each charger has own current sensor for battery output (Ibatt1, Ibatt2) so charging current of any charger will be always limited to the required value. Even if two chargers are active the summary charging current is well controlled because charging current into battery is always monitored by sensor Ibatt1. In case that charger 2 already provides some charging current, the charger 1 will provide rest of current. In extreme case if charger 2 provides maximum value of charging current then charger 1 will provide zero current for charging. Solution is safe because agreed charging value will be not overstepped even if two chargers feed common battery. This connection was used in applications where measurements and testing were performed.

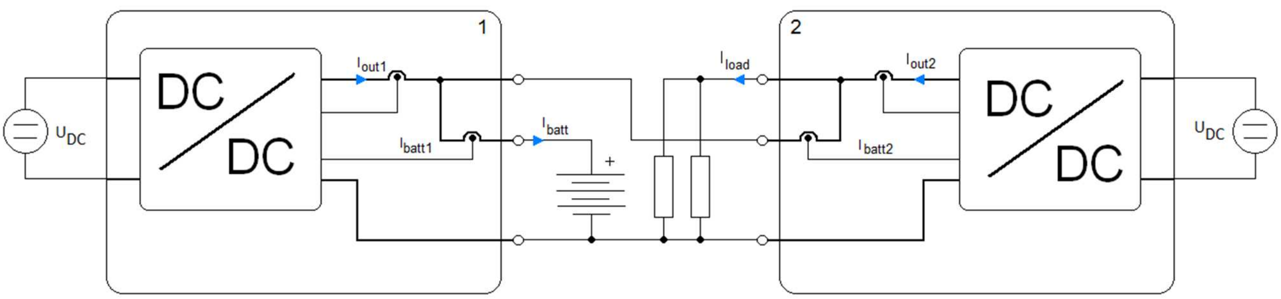

Fig. 3. Circuit diagram of safe battery and load connection.

$$I_{batt}=I_{batt1} \tag{1}$$

$$I_{batt}=I_{out1}+I_{batt2} \tag{2}$$

If the charger 1 is blocked or broken, the output current of charger 1 is equal to 0A.

$$I_{batt}=I_{batt2} \tag{3}$$

The battery current is calculated according to equations 1 and 3. Each of the chargers has information about the value of the current to the battery.

IV. Current Sharing Control Strategy

There are several methods of current sharing. They are divided into three main categories. Passive, active and combination of both methods.

The passive current sharing method has no signal connection between the power converters and is not affected by each other. It is an open loop current sharing method based on voltage drop. Output voltage will intentionally fall down with increasing of load. Disadvantage of this method is that voltage drop may prevent to reach requested charging voltage.

The active current sharing method is based on data exchange between power modules. In this method, currents values are collected from all modules and published to shared data bus. The power modules adjust the output voltage through the result of output current compare with the data provided by bus signal, and make the equal output currents.

In most of modern systems the chargers are controlled and monitored by the vehicle's superior system and are therefore equipped with a communication line. The CAN bus is popular for vehicles. It is advantageous to use this communication line in the algorithm for chargers current sharing. [4]

A. *CAN bus, feedback via CAN*

The advantage of CAN is the ability to connect a large number of devices to one line. The message is sent to the bus and depends on the individual devices whether they process it, it is not bound to a single device. This bus is suitable for real-time communication. Communication speed in proposed algorithm was 500kbps. The charger current value message is periodically sent in the interval from 200 ms to 800 ms. This period, data format, ID were given by an already established application and had to be adapted to the system used on the vehicle. The wide range of period values is given by the services performed over the CAN line, which have a higher priority. Each of the chargers publishes to the CAN line the value of the output current measured by the current sensor.

B. *Control Structure for Current Sharing*

The control structure described in fig. 2 cannot ensure even power sharing in parallel operation of two or more chargers connected to a common power bus. For this reason, it is necessary to supplement this control structure with an algorithm ensuring optimal sharing of the load current by individual chargers.

The proposed method of current sharing is based on the evaluation of differences between the currents of individual chargers. As the method belongs to a group of active current sharing techniques, it requires the existence of a common communication bus. In this case a CAN line is used. All chargers send to this communication line information about the value of their output current in the prescribed time cycle. A current difference regulator is added to the control structure of the both parallel operated chargers. The input of this controller is the difference between the value of the current of the other charger obtained from the CAN bus (I_{out2_CAN}) and the measured output current I_{out1_fb}. Based on this, the controller generates the corresponding output correction signal of the reference value I_{out1_ref} so that the current difference between the two chargers operating in parallel is zero. This allows even load current sharing to be achieved. The control structure ensuring the even current sharing of the two chargers operating in parallel is shown in fig. 4.

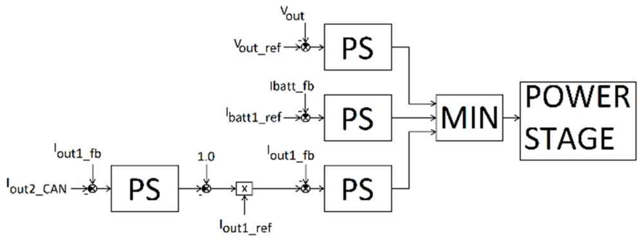

Fig. 4. Modified control structure of charger.

V. Experimental Measurements

The described current sharing algorithm has been implemented in the control systems of charger modules. Experimental measurements were performed on a system of two auxiliary converters and chargers to verify the properties of the proposed control algorithm. Inputs of converters were supplied by nominal voltage 1500VDC. Outputs of chargers were connected according to the schematic in fig. 5. A resistive load was connected to the common bus. Both of converters were interconnected via CAN interface, which purpose is exchanging information about operation and output currents between chargers. The output current sharing of the two chargers was verified at several different resistive loads.

Measurements were carried out, one near maximum total load about 350A and other with half value of total load about 175A, some measurements were done near total load 190A. Currents probes (YOKOGAWA power analyser) were installed in wires connected on terminals XM2:C1 on each charger. Criterion of test was equal current sharing in steady-state (static) conditions with maximum difference 5% between output currents of chargers.

Additional tests were carried out to see behaviour of chargers. When both chargers were running the load was splitted evenly between both chargers and each of them provide one half of total power up to 175A. If one charger has been intentionally deactivated (fault simulation), then the other charger takes over the entire load and provides full current up to 350 A.

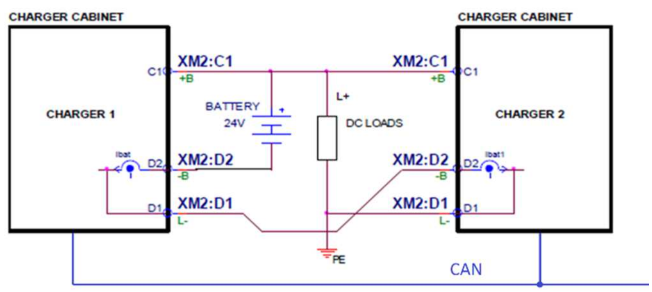

Fig. 5. Parallel connection of chargers during the measurement.

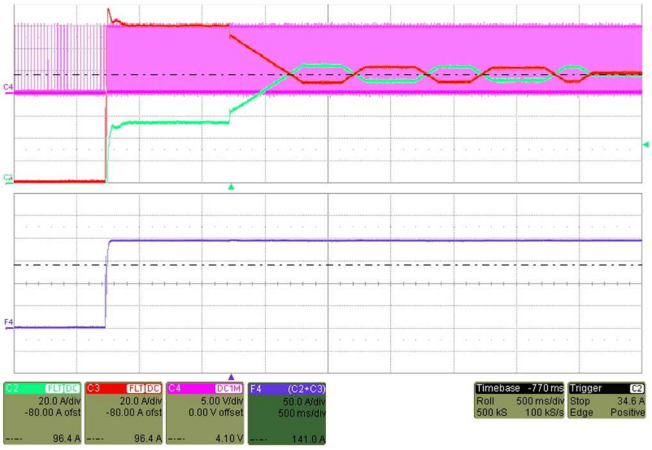

Fig. 6. Current balancing process. (*green-Ichar1, red-Ichar2, blue- Itotal*)

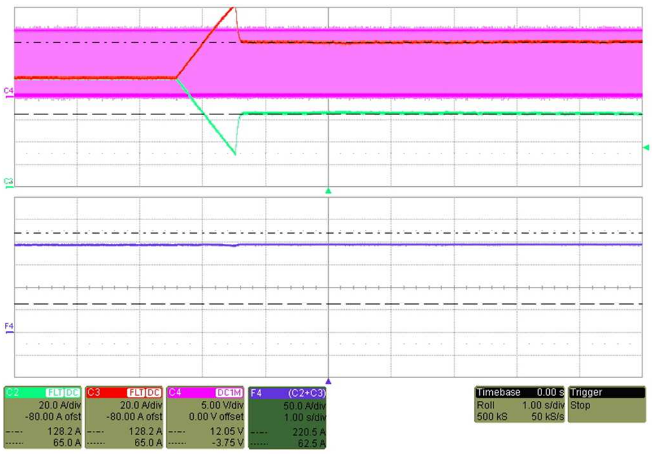

Fig. 7. Interruption of feedback via CAN. Natural current sharing. (*green-Ichar1, red-Ichar2, blue- Itotal*)

Fig. 6 shows the measured current waveforms during the current balancing process. The currents of both chargers are fully balanced within 3s. This time is acceptable for this application. Time of current balancing in dynamic processes is not critical for charger. In fig. 7 are output currents with disabled active current sharing control. The currents of chargers have unequal values 128,2A and 65A. The graph in fig. 8 shows the effect of changing the total load on the current sharing. The percentage deviation is then plotted in fig 9.

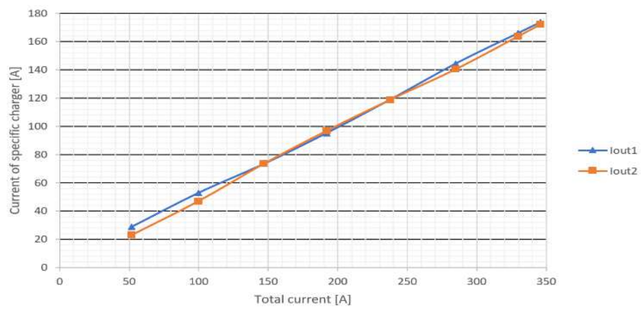

Fig. 8. Graphical representation of the relationship between total load current and charger currents in amperes. (*blue – Iout1, orange – Iout2*)

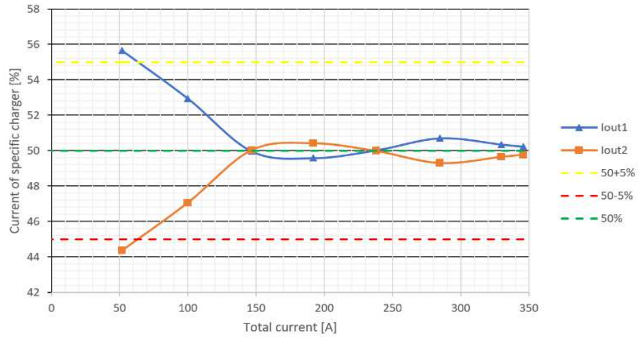

Fig. 9. Graphical representation of the relationship between total load current and charger currents in percent. (*blue- Iout1, orange – Iout2*)

VI. Conclusion

The proposed strategy for ensuring current sharing in parallel cooperation has been implemented in the control systems of charger modules. The chargers were applied in a parallel system of two railway auxiliary converters. Subsequently, experimental measurements were performed on this system to debug and verify the achieved properties of the system. The achieved current difference is less than 5% for a total current greater than 75A. A failure of one of the chargers was simulated and the CAN bus fault condition was tested. Battery charging current in any mode never oversteps maximal value and requested total power 10kW for loads was always available. The even current sharing provided by proposed control algorithm has improved the reliability and durability of the device, which is an important feature for railway devices. There was no need to make hardware modifications. Only the charger software was modified.

Acknowledgment

This work was supported by Slovak Research and Development Agency under the contract No. APVV-16-0574, and project HEES4T by Ministry of Education, Science, Research and Sport of the Slovak Republic .This publication was realized with support of Operational Program Integrated Infrastructure 2014 – 2020 of the project: Innovative Solutions for Propulsion, Power and Safety Components of Transport Vehicles, code ITMS 313011V334, co-financed by the European Regional Development Fund.

References

[1] J. Ilončiak, M. Šuňal and J. Bednár, "Charger of accumulator batteries for extreme operating conditions," 2015 International Conference on Electrical Drives and Power Electronics (EDPE), 2015, pp. 148-152, doi: 10.1109/EDPE.2015.7325285.

[2] S. Anand, B. G. Fernandes and J. Guerrero, "Distributed Control to Ensure Proportional Load Sharing and Improve Voltage Regulation in Low-Voltage DC Microgrids," in IEEE Transactions on Power Electronics, vol. 28, no. 4, pp. 1900-1913, April 2013, doi: 10.1109/TPEL.2012.2215055.

[3] Valčo M., Šuňal M.: "VS2017218 Multi-charger cooperation", EVPÚ, a. s.; 02/2018

[4] Valčo M., Biel Z.: "VS20171218 Review of cooperation of static converters", EVPÚ, a. s.; 02/2018

[5] M. Šuňal, J. Ilončiak and J. Bednár, "Smart converters implemented into auxiliary converter of public transport vehicles," 2015 International Conference on Electrical Drives and Power Electronics (EDPE), 2015, pp. 413-416, doi: 10.1109/EDPE.2015.7325330.