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Experimental Measurements of Four Parallel-Connected Three-Phase Inverters of Railway Auxiliary Converters

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Abstract In this paper, experimental measurements of four parallel-connected three-phase inverters of railway auxiliary converters were carried out. The purpose of this measurement was to verify the ability of parallel co-operation of four three-phase inverters connected to a common three-phase bus, verifying the starting sequence of the inverters and power sharing by individual converters. The converters were powered by a common high voltage AC source and the outputs were interconnected to form a common three-phase network. The ability to uniform power sharing was tested during 15 kW and 137 kW motor acceleration. The results showed that all inverters were able to synchronize and connect to the common bus and stable operate in parallel connection. Furthermore, the power sharing was uniform and stable under these conditions.

Keywords parallel connection, three-phase inverters, measurement

JEL L62, L92

1. Introduction

In railway auxiliary converters, parallel co-operation of multiple inverters is required to meet the increasing demand for high power and high reliability. Railway auxiliary inverters are one component of railway electrical systems, providing power to auxiliary equipment such as lighting, air conditioning, and signalling. They are powered by a high-voltage (HV) continuous train line. The auxiliary converter transforms this high voltage into a voltage with parameters suitable for supplying all the electrical appliances of the wagon. Parallel interconnection of the outputs of the auxiliary converters installed on the individual wagons of the train via a common line can bring some advantages. . One of the main advantages is to increase the reliability and availability of such a system through active redundancy. Another advantage is the better configurability and flexibility, which allows reduction the number of train converters. In case of sufficient power dimensioning of converters, they do not have to be installed on every wagon [1]. These advantages include improved efficiency, higher power density, and better reliability.

Parallel operation of three-phase inverters is a complex problem, requiring careful consideration of the starting sequence, synchronization, and power sharing of the individual inverters. In this paper, we present the results of an experimental measurement of four parallel-connected three-phase inverters of railway auxiliary converters, with a focus on verifying the starting sequence and power sharing of the inverters.

2. Experimental Setup

The experimental setup consisted of four separate railway auxiliary converters, each consisting of an input HV converter, a 3-phase inverter module with a 3-phase sine filter, and an output contactor connecting the converter output to the common bus. The converters were powered by a common high voltage AC source, and the outputs were interconnected by cables with a length of 30 meters to form a common three-phase network. Two asynchronous motors were used as loads, a 15 kW motor powering the fan and a 137 kW motor. The circuit connection for parallel co-operation is shown in Figure 1, and the converter parameters are listed in Table 1.

Table 1. Parameters of the experimental setup

Nominal input voltage	1000 V / 16,7 Hz, 22 Hz, 50 Hz 1500 V / 50 Hz 1500 V DC 3000 V DC
Nominal output power	55 kVA
Nominal output voltage	3x400 V AC
Nominal output frequency	50 Hz
DC bus voltage	680 V DC
Switching frequency	8 kHz

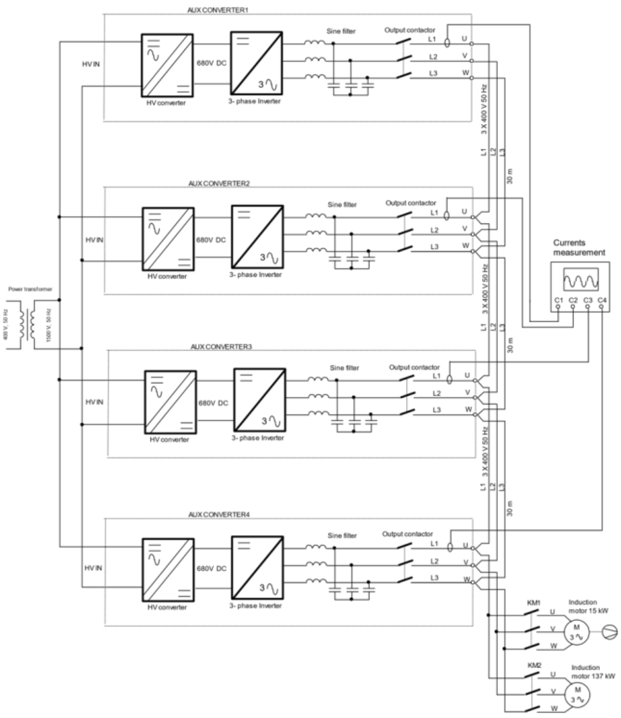
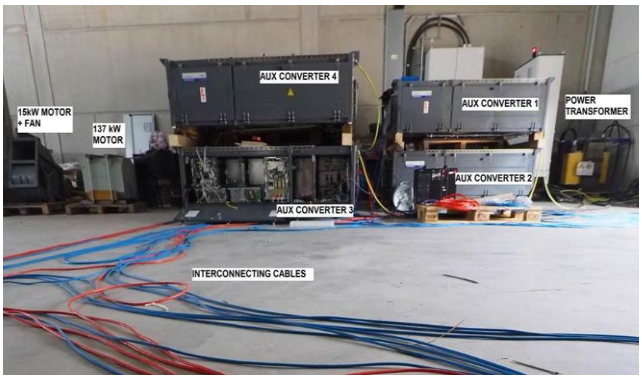


Figure 1. Hardware connection of the four parallel connected inverters to the input and output

The experimental setup is shown in Figure 2.



. **Figure 2.** Experimental setup of four parallel converter

3. Experimental measurements

The purpose of this measurement was to verify the ability of parallel co-operation of four three-phase inverters connected to common three phase bus, verifying the starting sequence of the inverters and power sharing by individual converters.

The converters are powered by 1500V 50Hz from a power transformer. After connection to the supply voltage, the input HV inverters begin to produce a 680V DC link voltage. In the inverters, the start sequence is activated and the random delay of the start of the inverter is generated by the software. One of the inverters is connected to the common bus as the first and the others are synchronized and sequentially connected to a common bus. Now all four inverters are connected in parallel and form a common three phase network. Measured line to line voltage waveform between U and V phases V_{U-V} of the common three phase grid is shown in Figure 3.

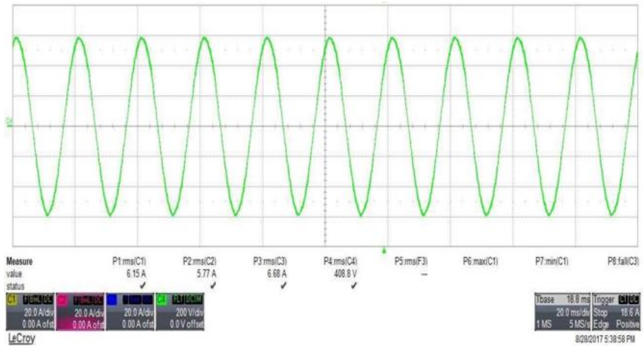


Figure 3. Line to line voltage V_{U-V} of the common three phase grid.

When a common network is formed, the load represented by 15 kW induction motor driving fan is added and the current sharing during motor acceleration and run is measured. Figure 4 shows the measured phase U currents of individual inverters (C1 – C4) and motor phase current (F3) during acceleration. The current waveforms during motor acceleration in detail are shown in Figure 5. The following RMS values of converter currents were measured during motor acceleration: Converter 1 phase U current I_{U1_RMS}=33.1 A, Converter 2 phase U current I_{U2_RMS}=35 A, Converter 3 phase U current I_{U3_RMS}=36.2 A, Converter 4 phase U current I_{U4_RMS}=36.9 A. The RMS value of the motor phase current was I_{M_RMS}=140.3 A.

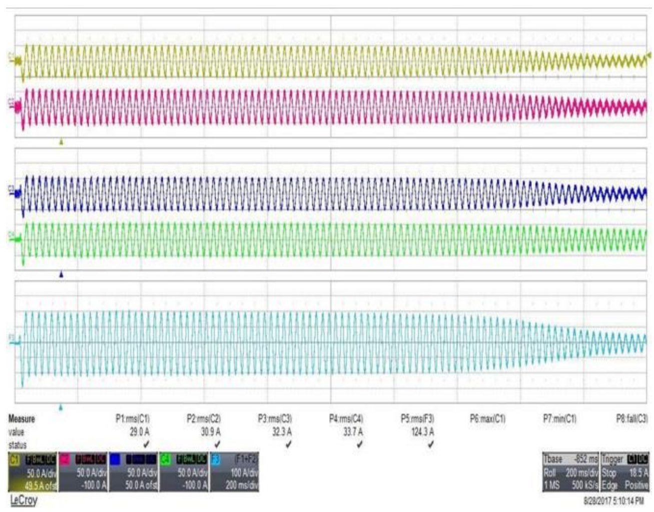


Figure 4. C1- converter 1 phase U current, C2- converter 2 phase U current, C3- converter 3 phase U current, C4- converter 4 phase U current, F3 – motor phase U current during 15 kW motor acceleration.

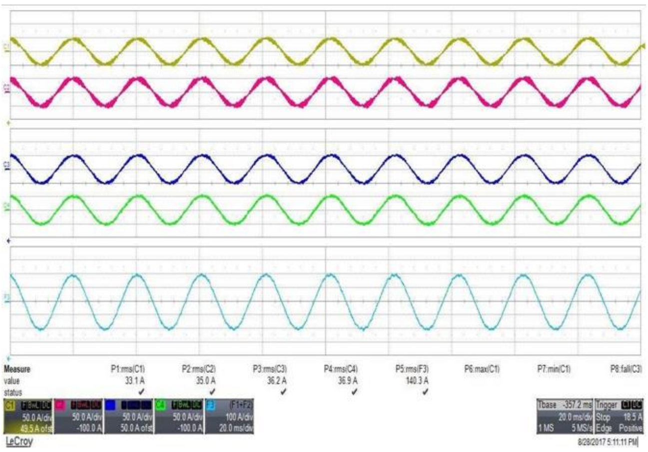


Figure 5. Detail of the current shown in Figure 4

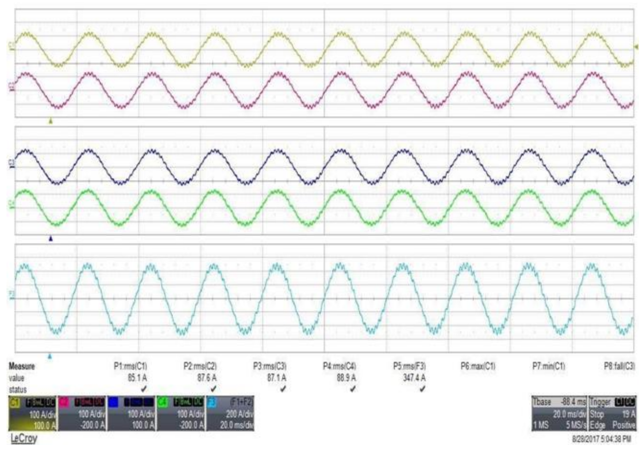


Figure 7. Detail of the current shown in Figure 6

Figure 6 shows converter currents and motor current during 137 kW no loaded motor acceleration. Motor is connected directly by the contactor to the common three phase bus created by four parallel connected converters. Currents in detail are shown in Figure 7. Measured converter currents were: Converter 1 phase U current I_{U1_RMS}=85.1 A, Converter 2 phase U current I_{U2_RMS}=87.6 A, Converter 3 phase U current I_{U3_RMS}=87.1 A, Converter 4 phase U current I_{U4_RMS}=88.9 A. The RMS value of the motor phase current was I_{M_RMS}=347.4 A.

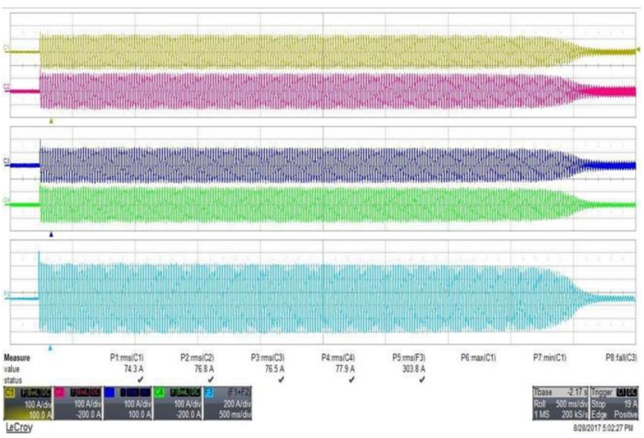


Figure 6. Currents during 137 kW motor acceleration. C1- converter 1 phase U current, C2- converter 2 phase U current, C3- converter 3 phase U current, C4- converter 4 phase U current, F3 – motor phase U current.

4. Conclusions

The purpose of this measurement was to verify the ability of parallel co-operation of four inverters installed in railway auxiliary converters. The converters were powered by 1500 V 50 Hz from transformer. After connection to the supply voltage, starting sequence of inverters was verified. All inverters were able to synchronize and connect to the common bus and stable operate in parallel connection. Furthermore, stable operation, dynamic response, and power sharing by inverters during 15 kW and 137 kW motor acceleration was tested. The constants of the control structure have been tuned to achieve good dynamic system responses, stability and good power sharing of the inverters under these conditions.

The ability to uniform power sharing can be seen from measured currents. The output currents of the inverters was divided in proportion Converter 1 – 23.6%, Converter 2 – 24.7%, Converter 3 – 25,6%, Converter 4 – 26.1% of the total load current during 15 kW motor acceleration. During 137 kW motor acceleration the current was divided in proportion: Converter 1 – 24.5%, Converter 2 – 25.1%, Converter 3 – 25%, Converter 4 – 25.4% of the total load current.

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REFERENCES

[1] Y. Han, H. Li, P. Shen, E. A. A. Coelho and J. M. Guerrero, "Review of Active and Reactive Power Sharing Strategies in Hierarchical Controlled Microgrids," in IEEE Transactions on Power Electronics, vol. 32, no. 3, pp. 2427-2451, March 2017, doi: 10.1109/TPEL.2016.2569597

[2] Shiguo Luo, Zhihong Ye, Ray-Lee Lin and F. C. Lee, "A classification and evaluation of paralleling methods for power supply modules," 30th Annual IEEE Power Electronics Specialists Conference. Record. (Cat. No.99CH36321), 1999, pp. 901-908 vol.2, doi: 10.1109/PESC.1999.785618.

[3] T. F. Wu, Y. H. Huang, Y. K. Chen and Z. R. Liu, "A 3C strategy for multi-module inverters in parallel operation to achieve an equal current distribution," PESC 98 Record. 29th Annual IEEE Power Electronics Specialists Conference (Cat. No.98CH36196), 1998, pp. 186-192 vol.1, doi: 10.1109/PESC.1998.701898.

[4] K. De Brabandere, B. Bolsens, J. Van den Keybus, A. Woyte, J. Driesen and R. Belmans, "A Voltage and Frequency Droop Control Method for Parallel Inverters," in IEEE Transactions on Power Electronics, vol. 22, no. 4, pp. 1107-1115, July 2007, doi: 10.1109/TPEL.2007.900456.

[5] M. Savaghebi, A. Jalilian, J. C. Vasquez and J. M. Guerrero, "Secondary Control Scheme for Voltage Unbalance Compensation in an Islanded Droop-Controlled Microgrid," in IEEE Transactions on Smart Grid, vol. 3, no. 2, pp. 797-807, June 2012, doi: 10.1109/TSG.2011.2181432.