AC / DC Converter for Traction Applications

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Abstract – **This contribution deals with new configuration of the traction converter with medium-frequency transformer intended for ac trolley wire fed locomotives. The main objective of this paper is the control of primary voltage source active rectifiers connected in series and operated on the primary side of medium-frequency transformer. This paper present simulation and experimental results of designed low-voltage laboratory prototype of rated power of 12 kW.**

INTRODUCTION

This project has been made in cooperation with our industrial partner Škoda Plzeň company. The objective of this project has been the research into the prospective configurations of the ac trolley wire fed traction converter for the new generation of the locomotives and especially suburban units. The presented converter configuration with medium-frequency transformer is one of the selected promising solutions. The explored converter consists of indirect frequency converters at its input. The input parts of the indirect converters are composed of voltage source active rectifiers, which are directly connected to the ac trolley wire. Therefore, they are connected in series – see Fig. 1 and Fig. 2. The medium-frequency transformer is fed by voltage source inverters operated in the six-step mode with the output frequency of 400 Hz. The voltage-source active rectifier (VSAR) at the secondary side of the medium-frequency transformer is fed by square wave voltage with frequency of 400 Hz and the control of this part was present in [1]. In the literature, there are published very interesting papers dealing with this new configuration of the traction converter for locomotive applications – e.g. [2] – [5].

This paper describes the control of the primary active rectifiers, presents simulation results as well as experimental evidence of designed laboratory prototype of loco converter of rated power of 12kW.

PROPOSED CONTROL STRATEGY OF PRIMARY SINGLE-PHASE VOLTAGE SOURCE ACTIVE RECTIFIERS

The proposed control strategy of the primary voltage-source active rectifiers is shown in the Fig. 3. We control the total dc-link voltage U_{cw} (it means the sum of dc-link voltages from all rectifiers). The dc-link voltage controller (solved as conventional PS controller) commands the angle ε between the trolley wire voltage and voltage at the rectifier ac side terminals (u_v). The magnitude of u_v is calculated from the information about the trolley wire voltage magnitude (U_m) and commanded angle ε. Thus, we employ the conventional model-based control of input rectifiers. The PWM with shifted carriers is used for the control of primary voltage-source active rectifiers.

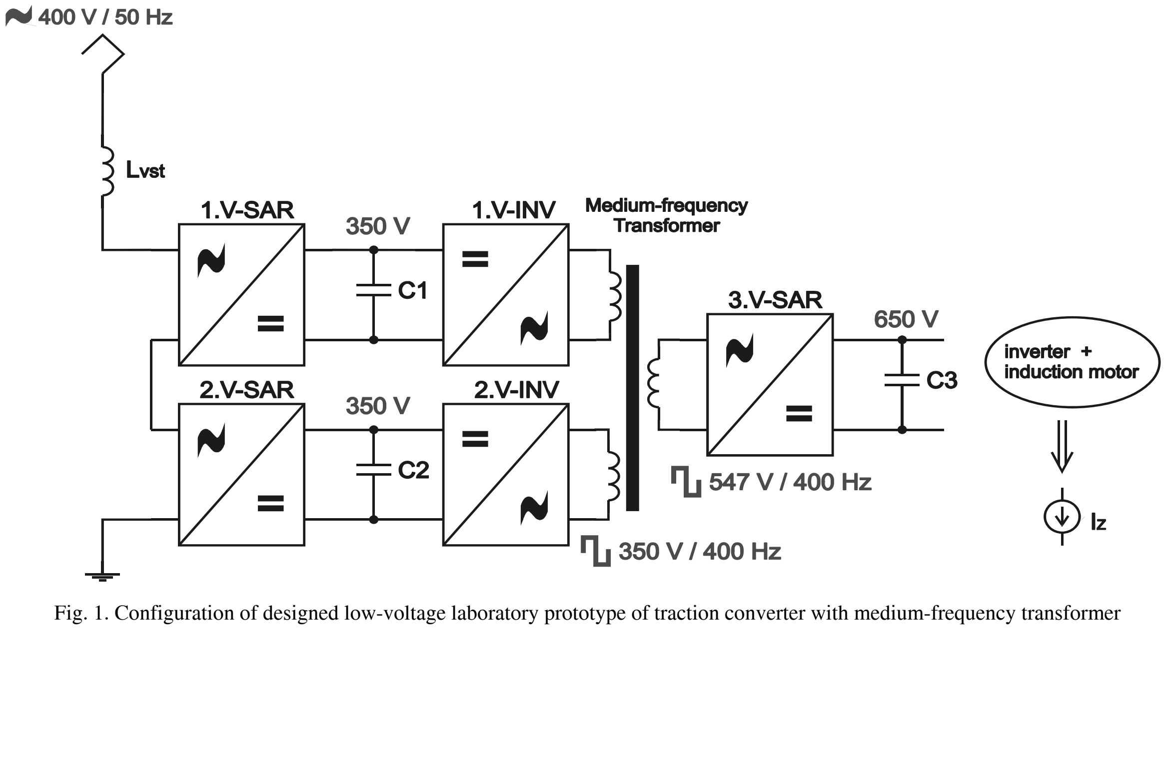

Fig. 1. Configuration of designed low-voltage laboratory prototype of traction converter with medium-frequency transformer

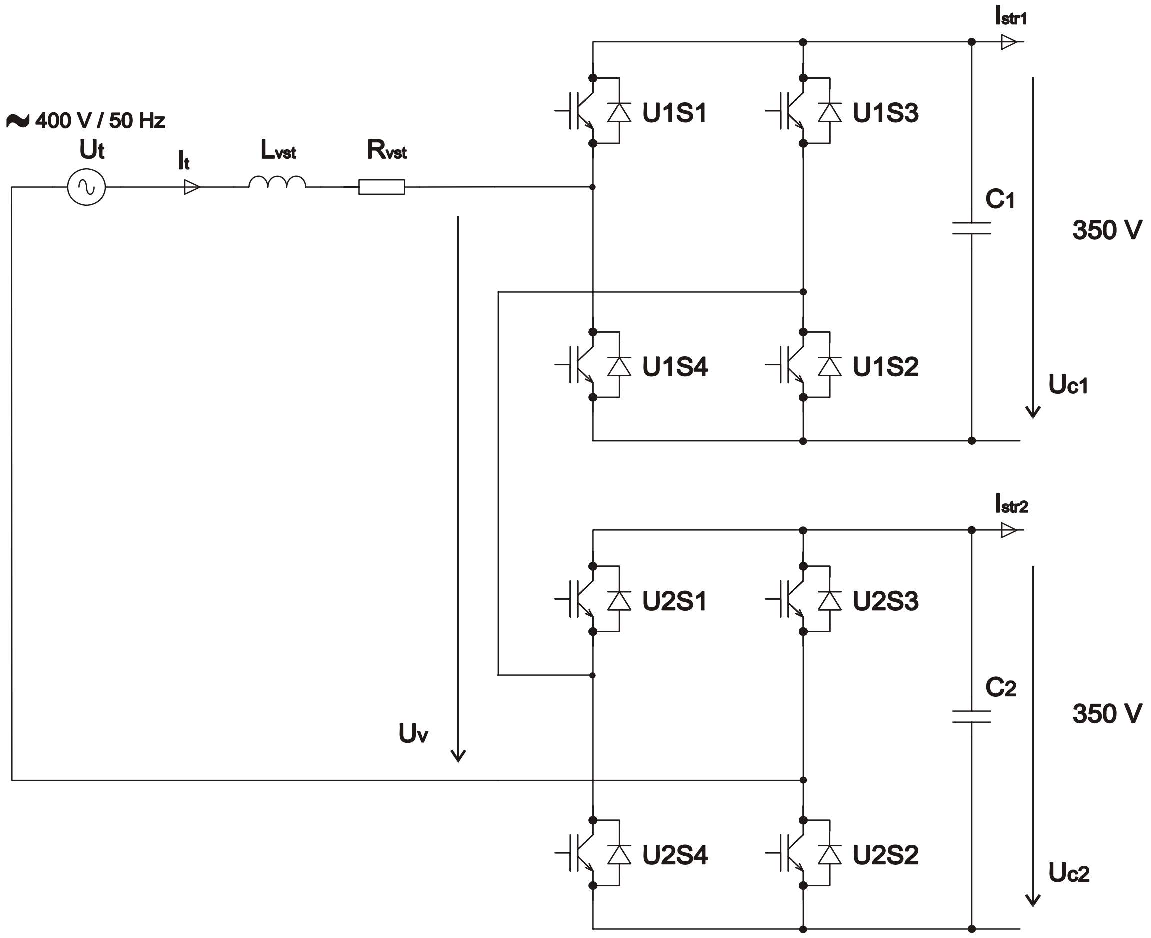

Fig. 2. . Power circuit of primary voltage-source active rectifiers

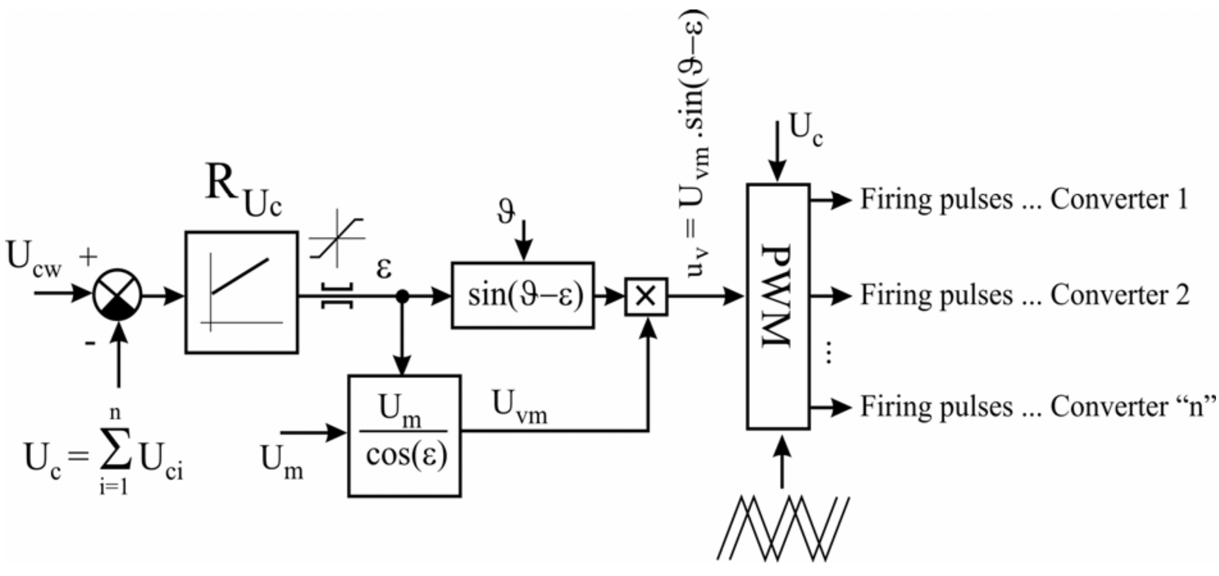

Fig. 3. Proposed control of primary voltage-source active rectifiers

SIMULATION AND EXPERIMENTAL RESULTS OF DESIGNED LABORATORY PROTOTYPE OF PRIMARY SINGLE-PHASE VOLTAGE SOURCE ACTIVE RECTIFIERS

The proposed converter control has been implemented in the fixed-point digital signal processor Texas Instruments TMS320LF2812. The designed converter prototype has rated power of 12kW. The prototype consists of two converter cells at the primary side (in the laboratory, we employ the transformer with two primary windings). Fig. 4 – Fig. 9 present simulation and experimental results of the primary voltage-source active rectifiers in rectifier mode and in inverter mode respectively under steady-state conditions. The converter behaviour under transient conditions is documented in Fig. 10 - Fig. 13.

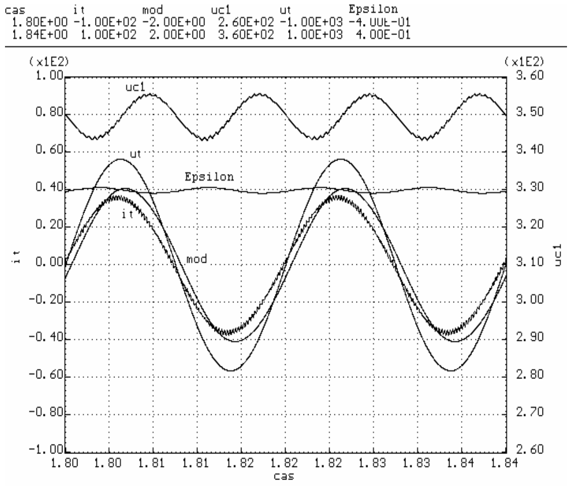

Fig. 4. Simulation-Behaviour of primary voltage-source active rectifiers under steady-state conditions in rectifier mode (load … P = 10 kW)

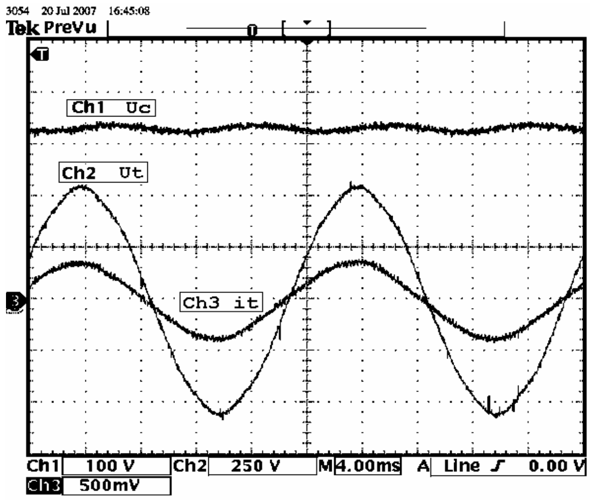

Fig. 5. Steady-state – rectifier mode (load … P = 6.5kW): ch1: Voltage U_{c1}, ch2: Trolley voltage U_t, ch3: Trolley current I_t (10mV/A)

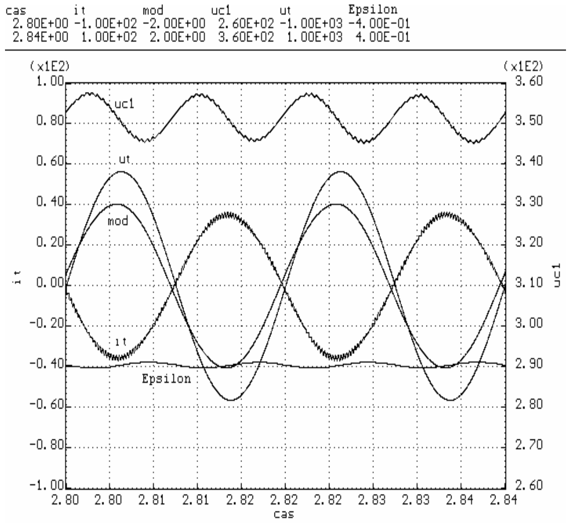

Fig. 6. Simulation-Behaviour of primary voltage-source active rectifiers under steady-state conditions in inverter mode (load … P = -10 kW)

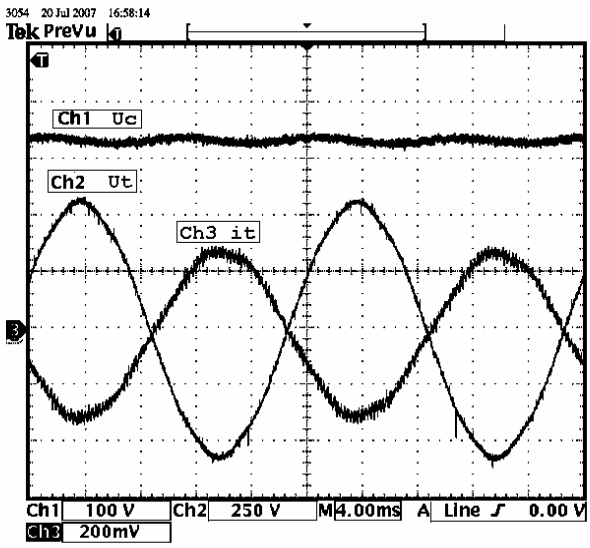

Fig. 7. Steady-state – inverter mode (load … P = -5.6 kW): ch1: DC-link voltage U_{c1}, ch2: Trolley voltage U_t, ch3: Trolley current I_t (10mV/A)

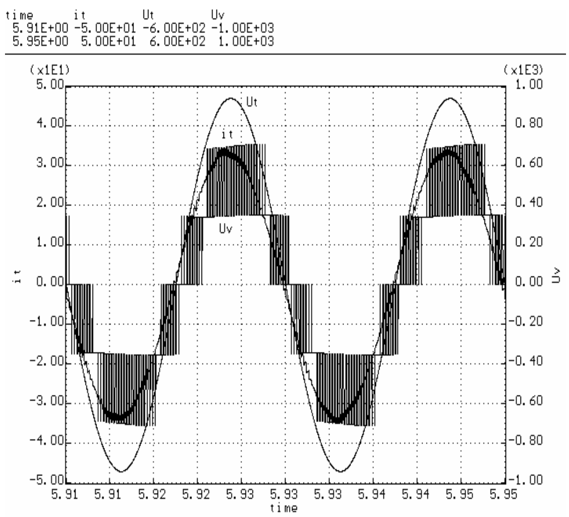

Fig. 8 Simulation-Behaviour of primary voltage-source active rectifiers under steady-state conditions in rectifier mode (load … P = 9.3 kW)

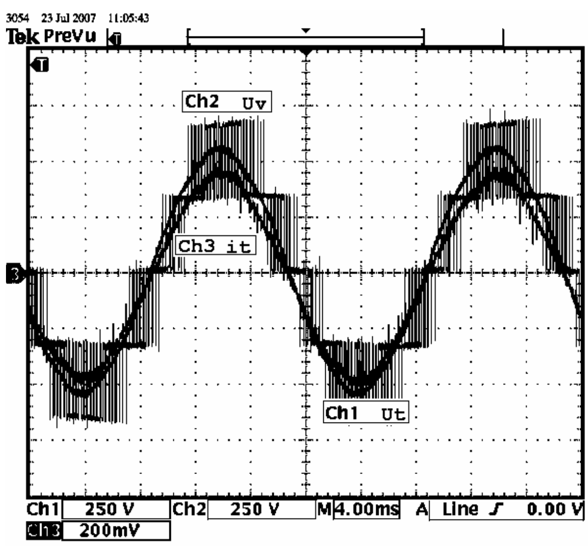

Fig. 9 Steady-state – rectifier mode (load … P = 9.3kW): Ch1: Trolley voltage U_t, Ch2: Sum of voltages at converters ac terminals u_v, Ch3: Trolley current i_t (10mV/A)

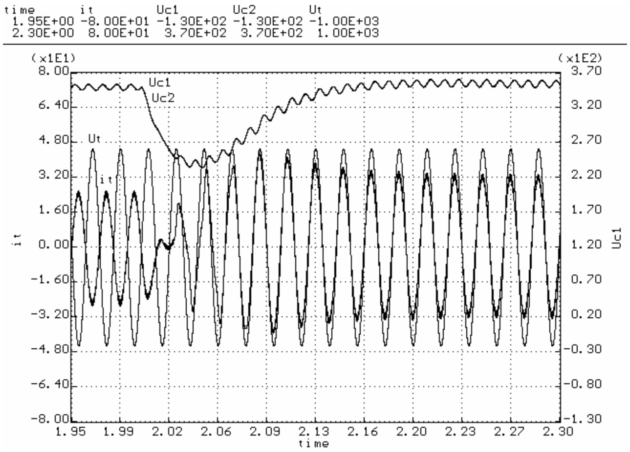

Fig. 10. Simulation-Transition from inverter to rectifier mode: Step change of the load … P = - 7.2 kW → 8.8 kW

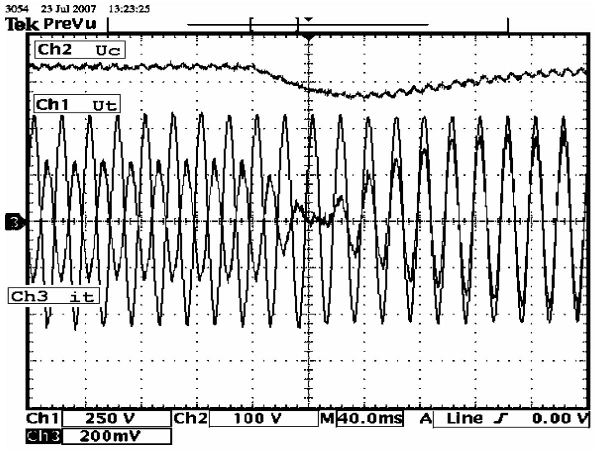

Fig. 11. Transition from inverter to rectifier mode: Step change of the load … P = - 7.2 kW → 8.8 kW
Ch1: Trolley voltage U_t, Ch2: DC-link voltage U_{c1}, Ch3: Trolley current i_t (10mV/A)

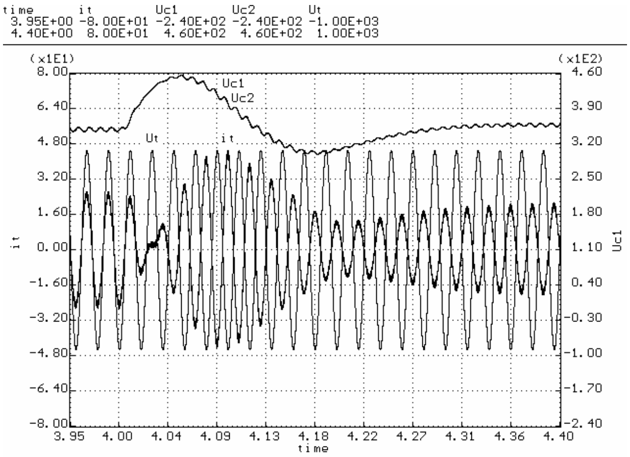

Fig. 12. Simulation-Transition from rectifier to inverter mode: Change of the load … P = 7 kW → -5.4 kW

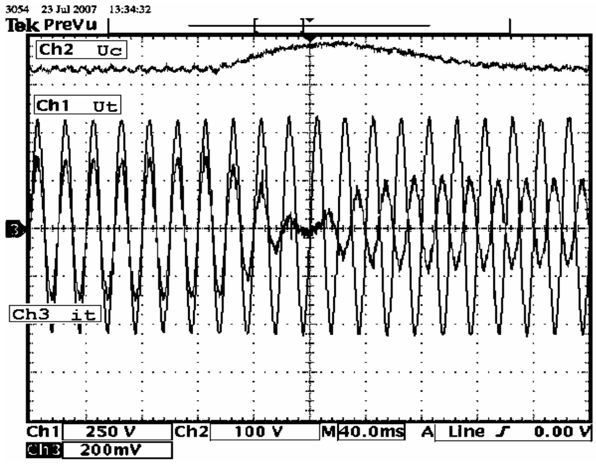

Fig. 13. Transition from rectifier to inverter mode: Change of the load … P = 7 kW → -5.4 kW
Ch1: Trolley voltage U_t, Ch2: DC-link voltage U_{c1}, Ch3: Trolley current i_t (10mV/A)

CONCLUSIONS

The presented configuration of the traction converter with medium-frequency transformer is one of the promising solutions for the new generation of the locomotives and especially suburban units. This contribution gives the main emphasis on the control of the primary voltage source active rectifiers, which are directly connected to the ac trolley wire. This paper describes proposed model-based control of primary rectifiers, simulation results under both steady-state and transient conditions and experimental evidence of the designed low-voltage laboratory prototype of the locomotive converter with rated power of 12kW. The employed PWM uses shifted carriers, thus, the converter behaviour is comparable to multilevel converter. The operated control as well as PWM are simple for implementation and sufficiently robust.

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