Control of Multilevel Converter for AC Traction Substation with Power Symmetrization Unit

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***Abstract* – This paper describes the control of multilevel converter for substation balancer. The topology of substation with electronic balancer is described. The principle of power symmetrization and reactive power compensation is introduced in paper. Designed control algorithm for independent current control is main goal of this paper. This control is based on the calculation of required current by Steinmetz's method. The paper presents simulation results of designed prototype of substation with rated power of 12.5 MVA for 25 kV / 50 Hz traction catenary.**

Keywords- multilevel converter; CHB control; railway substation; power symmetrization

I. INTRODUCTION

The advanced electric distribution power grid must cooperate with the controlled power sources, intelligent measurement system (for control load) and fast energy storage systems. That is important part for smart grids and for industry and transport 4.0. The important part of electric power consumption are electric railway locomotives. Where the most promising traction system is single-phase AC traction system. The objective of this research is AC traction substation with electronic balancer. The traction substation provides connection between power grid and catenary (in case decentralized system as a described in [1] - [3]). Electronic balancer is STATic COMpensation (STATCOM) device with additional function for power symmetrization.

The solution introduced in this paper is shown in simplified block diagram in Figure 1. This topology is promising industrial solution, that can be tracked in [4] and [5] (ABB and Siemens company). These solutions are industrially suitable against to the novel configurations described in papers [6] and [7]. The introduced solution have electronic balancer directly connected on secondary winding of substation transformer. The catenary and rail wires are directly connected to u_{g12} (phase to phase voltage 25 kV_{rms}), where disconnected is possible by reverse relay. The balancer is solved as three-phase multilevel converter, which can be disconnected in case of fault.

The advantages of this topology are full power symmetrization, harmonic compensation and reactive power compensation. However, in case of balancer defect, it is possible to operate catenary as uncompensated. That is the main advantage of described topology (this solution provide emergency operation, during balancer fault). The electronic balancer is solved as delta connection STATCOM device based on Cascaded H-bridge (CHB) topology. The CHB converter topology is well introduced in [8] - [11].

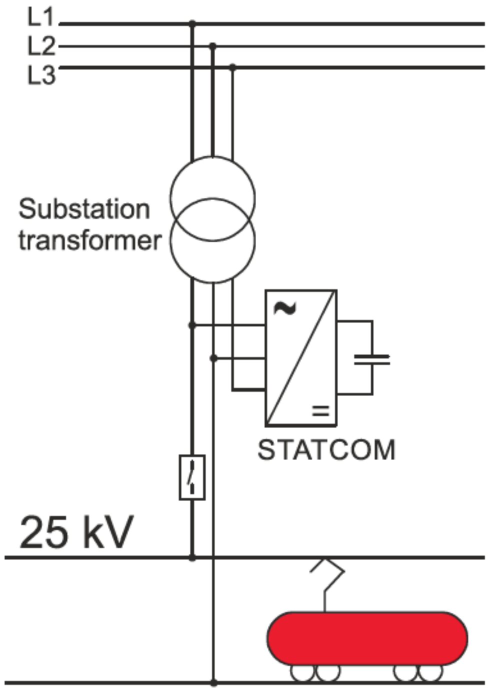

Figure 1. The substation for 25 kV /50 Hz railway traction system with electronic balancer for power symmetrization

II. DESCRIPTION OF BALANCER UNIT AND SYMMETRIZATION PRINCIP

The balancer power circuit is shown in Figure 2. The each phase of balancer is connected to phase to phase voltages (u_{g12}, u_{g23}, u_{g31}) and each phase is realized by CHB converter. This type of converter including modulation (PS-PWM in this case) is described in [11] - [14]. This type of modulation has the main advantage by regularly alternating of individual cells of converter. This converter has finally 25 levels for 12 HB cells. In paper [11] is possible found resulting harmonic spectrum of converter under PS-PWM and issue about balancing of HB cells.

The principle of power symmetrization is based on Steinmetz's method which is described in more detail in [15]. However, in this case the branches 2-3 and 3-1 are used for load symmetrization and branch 1-2 ensuring reactive power compensation. The following equations (1) – (3) were derived for the required currents of balancer.

$$i_{HB12\_w} = \left(I_{amp\_cat} . \sin(\varphi_{cat})\right) \sin\left(\vartheta - \frac{\pi}{2}\right) \tag{1}$$

$$i_{HB23\_w} = \left(I_{amp\_cat} . \cos(\varphi_{cat})\right) \sin(\vartheta) + \frac{1}{\sqrt{3}} \left(I_{amp\_cat} . \cos(\varphi_{cat})\right) \sin\left(\vartheta - \frac{5\pi}{6}\right) \tag{2}$$

$$i_{HB31\_w} = \left(I_{amp\_cat} . \cos(\varphi_{cat})\right) \sin(\vartheta) - \frac{1}{\sqrt{3}} \left(I_{amp\_cat} . \cos(\varphi_{cat})\right) \sin\left(\vartheta - \frac{\pi}{6}\right) \tag{3}$$

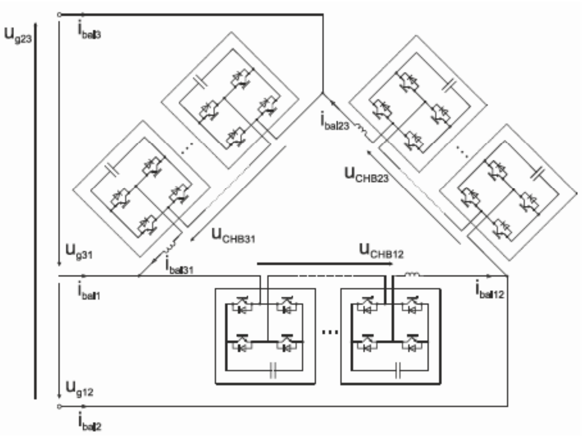

Figure 2. Power circuit of electronic balancer for AC traction substation based on CHB multilevel technology

III. PROPOSED CONTROL OF MULTILEVEL CONVERTER

The presented control algorithm operates with three different autonomous phase control. This allows proper converter function in single-phase short circuit condition or under other single-phase grid faults. The balancer designed control is shown in Figure 3. There is a common part voltage synchronization and load evaluation with computation of important value. Then follows independent control loops for each balancer phase. There is three input values: feedforward voltage (u_{ff}), sum of dc-links voltages (ΣU_{dc}) and required currents (i_{HB_w}). The computation of feedforward voltages (u_{ff}) is simplified to used grid voltages (u_{g12}, u_{g23}, u_{g31}). The summation of dc voltage (ΣU_{dc}) is used for controller, which provides constant voltage at dc-links (electrical losses on semiconductros are covered by active part of current). The required currents i_{HB_w} is calculate as a sum of balancing and compensating currents ($i_{HB\_w\_bal}$ described in equation (1) – (3)) and output from PI controller ($\Delta i_{HB\_w\_PI}$). The direct current control is provide by PR controller and resonant controllers are used for harmonic compensation (for dead-time effect minimization). This method is well described in [16]. The voltage balancing is important during fast transient and is possible used some of these method [11], [17], [18].

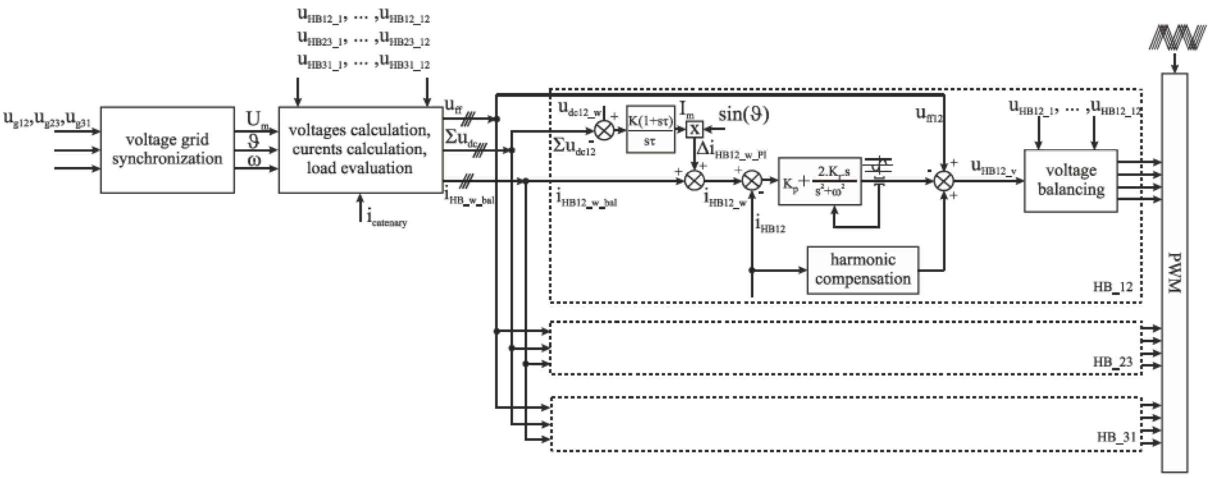

Figure 3. Proposed control for theree-phase traction balancer based on CHB multilevel converters

IV. SIMULATION RESULTS

The control of electronic balancer is tested for pure active catenary current (P = 12.5 MW, Q = 0 MVA, Figure 4. – Figure 6.) and for active and reactive current (P = 10.8 MW, Q = 6.25 MVA) Figure 7. - Figure 10.

The catenary current (i_{cat}) is in phase with voltage (u_{cat}) as a shown in Figure 4. This condition occurs when the locomotives have converter topology with full currents control loop (modern locomotive with PWM rectifier). Electronic balancer provides the power symmetrization and grid currents are symmetrical, shown in Figure 5. During this load is symmetrization provided by branches 2-3 and 3-1 as a documented in Figure 6. The reactive power compensation is necessary during reactive load shown in Figure 7. The grid currents (i_{g1}, i_{g2}, i_{g3}) are lower, because the active power is lower (10.8 MW), shown in Figure 8. The balancer current i_{bal12} compensate reactive power, shown in Figure 9. The multilevel voltages behavior of CHB converter is in Figure 10.

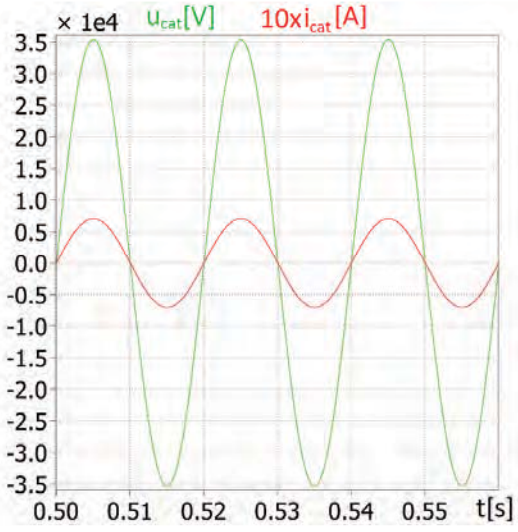

Figure 4. Catenary voltage and catenary current during active power load (P = 12.5 MW, Q = 0 MVA)

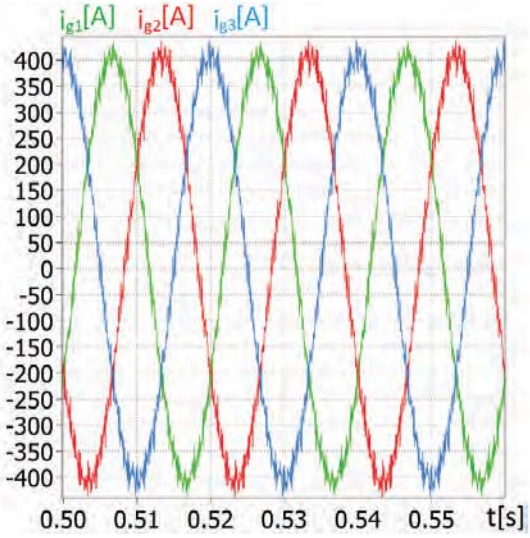

Figure 5. Currents at secondary windings of traction transformer symmetrized by balancer unit during active power load (P = 12.5 MW, Q = 0 MVA)

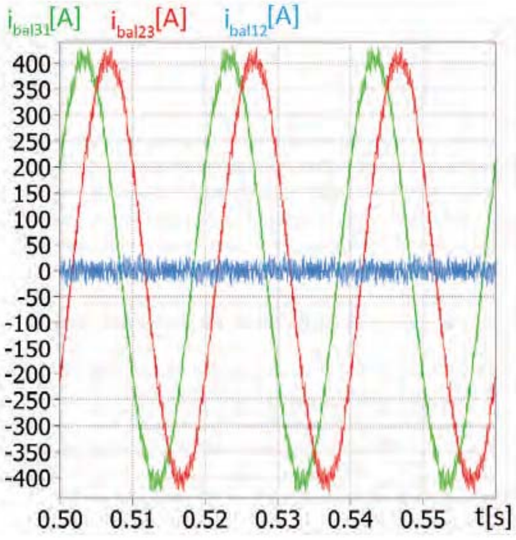

Figure 6. Currents of electronic balancer during active power load (P = 12.5 MW, Q = 0 MVA)

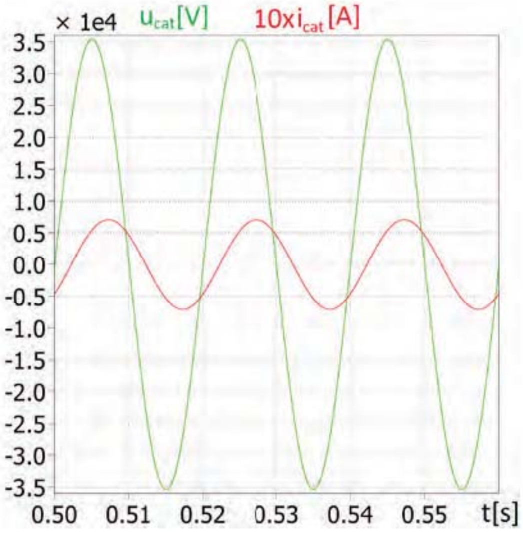

Figure 7. Catenary voltage and catenary current during active and reactive power load (P = 10.8 MW, Q = 6.25 MVA)

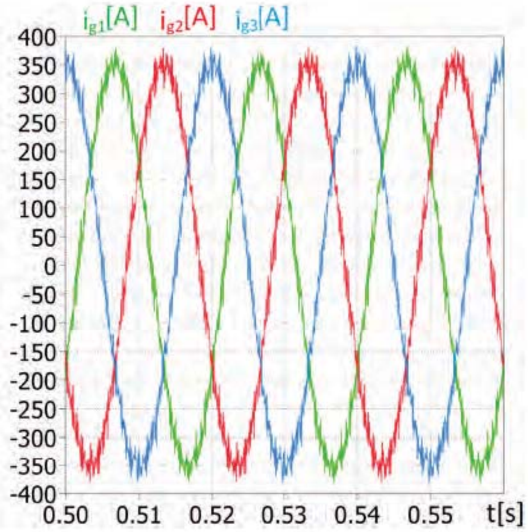

Figure 8. Currents at secondary windings of traction transformer symmetrized by balancer unit during active and reactive power load (P = 10.8 MW, Q = 6.25 MVA)

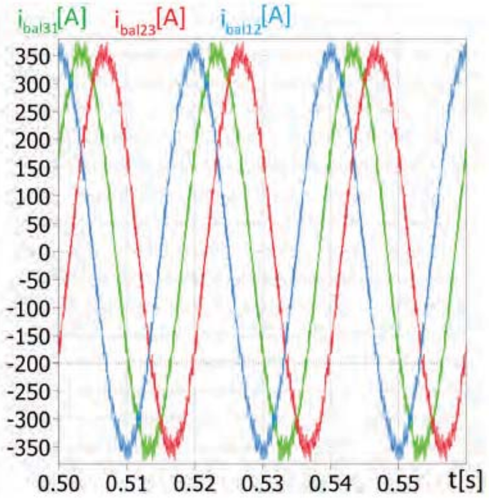

Figure 9. Currents of electronic balancer during active and reactive power load (P = 10.8 MW, Q = 6.25 MVA)

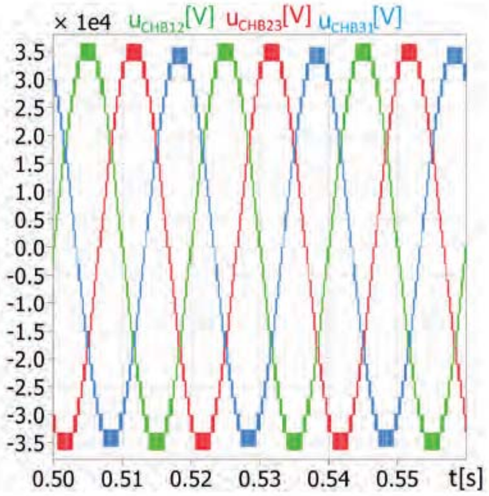

Figure 10. Voltages of multilevel converter during active and reactive power load (P = 10.8 MW, Q = 6.25 MVA)

V. CONCLUSION

The presented topology of AC traction substation with electronic balancer is one of the promising solutions. The power symmetrization and reactive power compensation is realized by multilevel CHB converter. This converter is controlled as a single phase converters with superior loop. Where is analyzed load and computed required currents. The proposed control was successfully tested by simulations model under steady-state conditions.

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