

Compensation of Power Quality Problems in Traction Power System Using Direct Power Compensator

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ABSTRACT— A power quality problems in power systems have been increased due to nonlinear loads. To compensate these problems Direct Power Compensator was proposed in this paper. A Direct Power Compensator (DPC) is proposed in this paper to eliminate the harmonic currents, compensate power factor and voltage unbalance problems created by the nonlinear loads present in three phase systems. A DPC contains back to back converter by sharing the same dc link power and v/v transformer to provide a voltage balance in transmission line. Hysteresis harmonic current controller is used to produce pulse for back to back converter. A controller maintains the dc-link voltage and compensates the power factor, harmonic currents. A comparative analysis for traction system with and without DPC was performed using MATLAB-Simulink. Simulation results are provided to eliminate power quality problems effectively.

KEYWORDS— DPC, Traction power, Harmonic Elimination, Power Factor Correction, Non-linear Loads, Co-phase System.

I. INTRODUCTION

Electrified transportation systems are non-linear systems representing a reality in continuous evolution. Innovation in information and component technology results in new opportunities of integration and standardization for railway systems. Furthermore the advent of the deregulated energy market requires reinvestigating the planning and operating criteria for railway companies. In this context the massive introduction of power electronics, automation and control techniques has to be properly taken into account [2], allowing handling these complex problems in a proper

way according to the modern point of view of an DPC integrated approach.

Electrified Railway Systems are very complex systems in which a variety of components (or subsystems) cooperate to realize the transport service for which the system has been designed.

A railway system is perhaps one of the most critical real systems, from the safety and reliability viewpoint, because it must satisfy numerous requirements and presents complex architectural links among its various subsystems [3]. In fact, a lot of safety requirements are strongly dependent on correct interaction operation.

The performance of this kind of systems strictly depends on the capability of the system to be correctly integrated. A correct approach to the analysis of traction systems is the fundamental starting point for the right design and functionality of this complex reality.

The amount of negative-sequence currents depends on the topology of the traction power system, in particular, the type of traction transformers used [14]. Typical transformers used include Scott transformers, Woodbridge transformers, three-phase V/V transformers, impedance-matching balance transformers, etc., [15]. Scott transformers, Woodbridge transformers are balanced transformers but three-phase V/V transformers are unbalanced. When balanced transformers are used, no negative-sequence current is injected into the public grid when two feeder sections consume the same power. However, for the traction systems with three-phase V/V transformers, the negative-sequence current injected into the public grid is half of the positive-sequence current even when two feeder

sections consume the same power. The problem with this topology is that a strategy to effectively compensate the negative-sequence and harmonic currents needs to be developed.

In this paper, a hybrid device combining active and passive compensators, named as the Direct Power Compensator (DPC), is proposed for compensation in co-phase traction power supply. The parameter design procedure for minimum DPC voltage operation as well as the minimum voltage rating achievable is discussed.

II. V/V TRANSFORMER

The structure of DPC with three-phase V/V transformers is depicted in Fig. 2. The 220-kV three-phase high-voltage source is converted into two 27.5-kV single-phase voltage sources, which are connected to the two feeder sections, via a three-phase V/V traction transformer. The turns ratio of the V/V traction transformer is K_V [7]. The DPC consist of back to back converter through a common dc capacitor with a stable dc-link voltage, is connected to the two feeder sections via two step- down transformers with a turns ratio of K_D . The two converters are connected to the single-phase step-down transformers via two output inductor L_a and L_b respectively. The two converters can be controlled as current sources to shift a certain amount of active power from one feeder section.

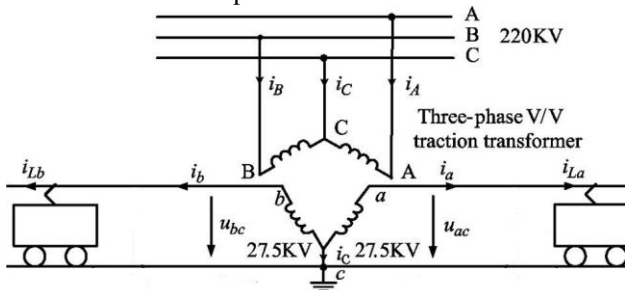


Fig. 1 Construction diagram of V/V Transformer

These two converters can also provide harmonic suppression and reactive power compensation [9]. Hence, the system can achieve integrated compensation of negative sequence currents, harmonic currents and reactive power.

III. CONTROLLER

The control block of the system is

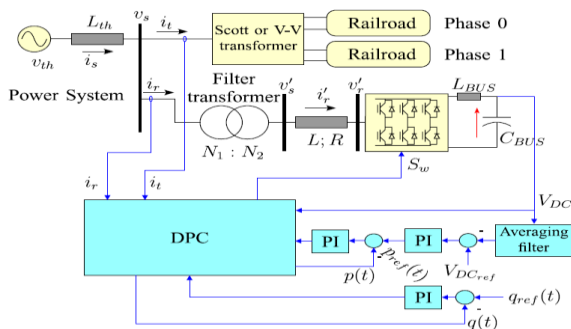


Fig. 2 Instantaneous Real and Reactive Power Compensator Controller
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The instantaneous load active and reactive power is computed using the modified instantaneous pq theory .The mathematical expression, in which v_{ac} and i_L are the load voltage and current rms, while v_{acd} and i_{Ld} are 90°delay of load voltage and current, respectively. P_L and Q_L refer to the instantaneous load active (real) and reactive (imaginary)power

$$\begin{bmatrix} P_L \\ Q_L \end{bmatrix} = \begin{bmatrix} v_{ac} \cdot i_L + v_{acd} \cdot i_{Ld} \\ v_{acd} \cdot i_L - v_{ac} \cdot i_{Ld} \end{bmatrix} \quad (3.1)$$

The active power part P_L can be split into dc part P_{dc} which corresponds to the fundamental average active load power; [12] and oscillating part P_{ac} which corresponds to the oscillating active power between system source and load and contributes as part of harmonics and reactive power (which need to be compensated). The mathematical expression is shown in

$$P_L = P_{dc} + P_{ac} \quad (3.2)$$

The required compensation power is then computed according to the power quality requirement, where P_{ca} and Q_{ca} are the required active and reactive compensation power.

$$\begin{bmatrix} P_{ca} \\ Q_{ca} \\ P_{cb} \\ Q_{cb} \end{bmatrix} = \begin{bmatrix} \frac{1}{2} P_{dc} + P_{ac} \\ \frac{1}{2\sqrt{2}} P_{dc} + q \\ -\frac{1}{2} P_{dc} \\ -\frac{1}{2\sqrt{2}} P_{dc} \end{bmatrix} \quad (3.3)$$

The reference of V_{ac} and V_{bc} phase compensation current, i_{ca} and i_{cb} , can then be computed ,where V_{bc} and V_{bcd} are the V_{bc} phase voltage and its 90° delay value

$$i_{ca}^* = \frac{1}{\sqrt{v_{ac}^2 + v_{acd}^2}} [v_{ac} \quad v_{acd}] \begin{bmatrix} P_{ca} \\ Q_{ca} \end{bmatrix} \quad (3.4)$$

$$i_{cb}^* = \frac{1}{\sqrt{v_{bc}^2 + v_{bcd}^2}} [v_{bc} \quad v_{bcd}] \begin{bmatrix} P_{cb} \\ Q_{cb} \end{bmatrix} \quad (3.5)$$

The computed reference current signal is then sent to the hysteresis current controller, which pulse width modulated signals are generated for the electronic switches of V_{ac} and V_{bc} phase converters.

The DPC balances the grid-side current by transferring active power from the V_{ac} phase to the V_{bc} phase .Concerning the design of the LC filter parameter, it is selected so as to reduce the harmonics compensation capacity of the compensator [14]. Although the highest load harmonic contents are located at the third harmonic frequency, the LC filter is tuned at the second highest load harmonics (fifth harmonic) for smaller physical size of the components.

IV. SIMULATION RESULTS

Simulations using MATLAB done to verify the before mentioned theoretical studies. The circuit schematic of the system used in simulations is provided in Fig. 12. The parameters are selected as close to practical applications as possible [16], [19]. The substation V/V transformer is composed of two 20 MVA

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single-phase transformers, with turning ratios of 110 kV/27.5 kV and 110 kV/13.75 kV. Traction loads are simulated using rectifier RL load, with linear capacity of 15 MVA. The compensation device is then connected across the two single-phase outputs of V/V transformer to provide power quality compensation of the system. [19] Notice that the LCL filter is included here to filter the ripples introduced by the compensator.

A. Co-phase Traction Power Without Compensation

The system performance without compensation is investigated first. Shown in Fig. 4 is the three-phase source, secondary voltage, and current waveforms for co-phase traction power without compensation [6]. It could be observed that the system suffers from unbalance, reactive power and harmonics problem. A traction load of 25MVA is connected to 110 KVA grid through step down transformer (110/25KV).

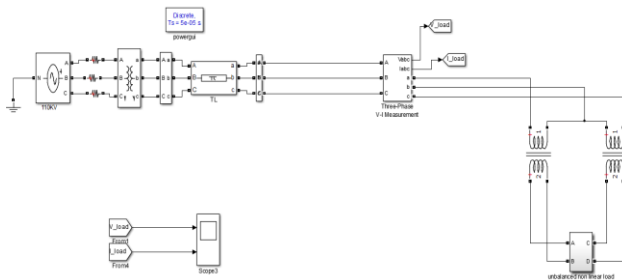


Fig. 3 Co-phase Traction Power Without Compensation

Traction load is a time varying load which is represented by rectified with RL-load (non-linear load). In general the non-linear load generates harmonics, voltage unbalance, power factor variation and other power quality problems. The load we used on the test system generated a THD of 33.8% and power factor of the system was decreased to 0.77.

Rectifier with RL load will be the best example of traction load. Traction loads are changes with time [14]. Traction power system connected to secondary side of three phase v/v transformer. It will cause voltage unbalance among other phases.

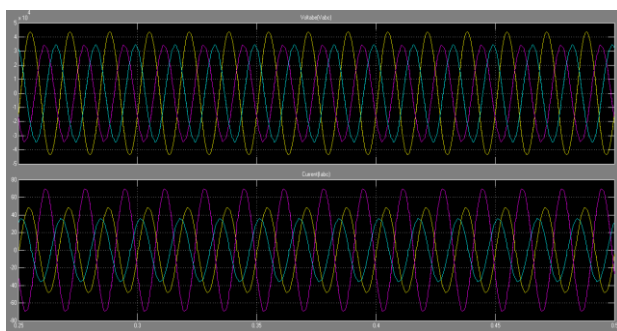


Fig. 5 Unbalanced voltage and current in transmission line

The Three phase back to-back converter is adopted in the power conditioner, which could balance the active currents in Transmission line. Two single phases at the secondary side of the traction transformer directly supplies the traction loads.

B. Co-phase Traction Power With DPC Compensation

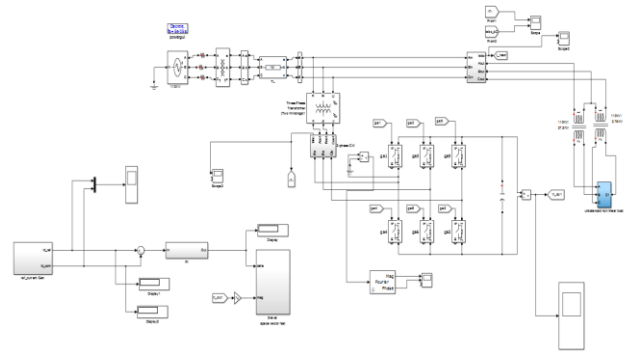


Fig. 6 Cophase Traction Power With DPC Compensation

DPC is connected with a traction load of 25MVA which is connected to 110 KVA grid through step down transformer (110/25KV), to mitigate the THD and to increase the power factor. Traction load is a time varying load which is represented by rectified with RL-load (non-linear load).

V_{ac} and V_{bc} phase side traction load is connected and three phase line side DPC is connected. V_{ac} and V_{bc} side traction loads are cause voltage unbalance and it will reduced by compensating voltage by using side transformer. Rectifier with RL load will be the best example of traction load [19]. Traction loads are changes with time. Traction power system connected to any one of the phase of three phase supply with Direct Power Compensator.

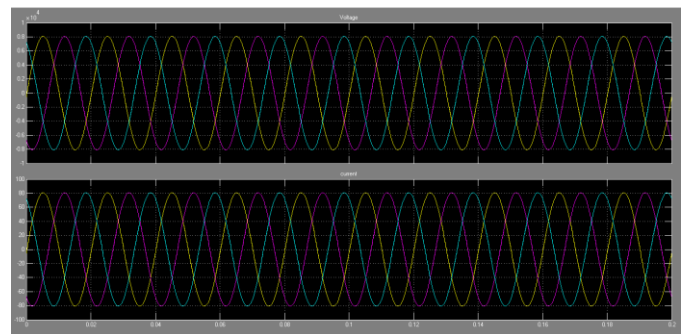


Fig. 8 balanced voltage and current in transmission line with DPC

V. CONCLUSION

A strategy to improve the power factor and eliminate harmonic currents in high-speed traction systems using co-phase Direct Power Compensator (DPC) was designed. The current references for the DPC converters are generated according to the load currents on both sections of the traction power supply system and current controllers are designed to track the current references. A comparative analysis for traction system with and without DPC was performed using MATLAB-Simulink.

TABLE I. OUTPUT COMPARISON

Without compensation		DPC compensation	
TABLE I. <i>Po</i> <i>wer factor</i>	TABLE II. <i>armonics (%)</i>	TABLE III. <i>ower factor</i>	TABLE IV. <i>armonics (%)</i>
0.77	33.8	0.90	12.54

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