Analysis of Hybrid Power Compensator for Non-linear Traction Loads

Natesan P, Madhusudanan G

***Abstract*— A power quality problems in power systems have been increased due to nonlinear loads. To compensate these problems hybrid power compensator was proposed in this paper. A hybrid power compensator (HPC) 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 HPC 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 HPC was performed using MATLAB-Simulink. Simulation results are provided to eliminate power quality problems effectively.**

***Index Terms*—HPC, traction power, harmonic elimination, power factor correction, non-linear loads, cophase system**

I. *INTRODUCTION*

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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 trans- formers, 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 hybrid power compensator (HPC), is proposed for compensation in cophase traction power supply. The parameter design procedure for minimum HPC voltage operation as well as the minimum voltage rating achievable is discussed.

II. V/V TRANSFORMER

The structure of RPC 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 HPC consist of back to back coverter 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.

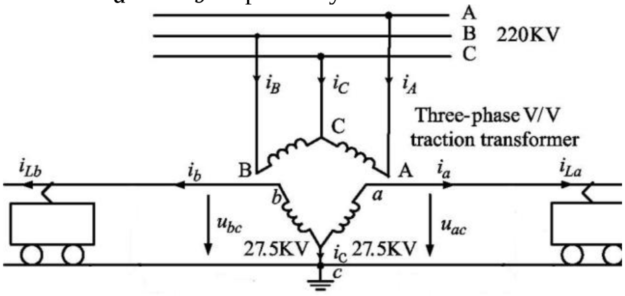

Fig. 1 Construction diagram of V/V Transformer

The two converters can be controlled as current sources to shift a certain amount of active power from one feeder section to the other. These two converters can also provide harmonic suppression and reactive power

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compensation [9]. Hence, the system can achieve integrated compensation of negative sequence currents, harmonic currents and reactive power.

III. CONTROLLER

The The control block of the system is

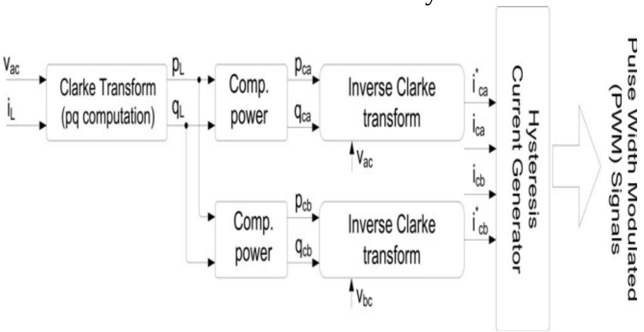

Fig. 2 Hysteresis Controller

The instantaneous load active and reactive power is computed using the modified instantaneous pq theory .The mathematical expression, in which vac and i_L are the load voltage and current rms, while vacd and iLd 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

$$\begin{bmatrix} p_L \\ q_L \end{bmatrix} = \begin{bmatrix} v_{ac} \cdot i_L + v_{acd} \cdot i_{Ld} \\ v_{acd} \cdot i_L - v_{ac} \cdot i_{Ld} \end{bmatrix} \qquad (3.1)$$

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

$$p_L = p_{dc} + p_{ac} \qquad (3.2)$$

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.

$$\begin{bmatrix} p_{ca} \\ q_{ca} \\ p_{cb} \\ q_{cb} \end{bmatrix} = \begin{bmatrix} \frac{1}{2} p_{dc} + p_{ac} \\ \frac{1}{2\sqrt{3}} p_{dc} + q \\ -\frac{1}{2} p_{dc} \\ -\frac{1}{2\sqrt{3}} p_{dc} \end{bmatrix} \qquad (3.3)$$

The reference of Vac 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

$$i^*_{ca} = \frac{1}{v_{ac}^2 + v_{acd}^2} \begin{bmatrix} v_{ac} & v_{acd} \end{bmatrix} \begin{bmatrix} p_{ca} \\ q_{ca} \end{bmatrix} \qquad (3.4)$$

$$i^*_{cb} = \frac{1}{v_{bc}^2 + v_{bcd}^2} \begin{bmatrix} v_{bc} & v_{bcd} \end{bmatrix} \begin{bmatrix} p_{cb} \\ q_{cb} \end{bmatrix} \qquad (3.5)$$

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 HPC 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 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. Cophase 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 cophase 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).

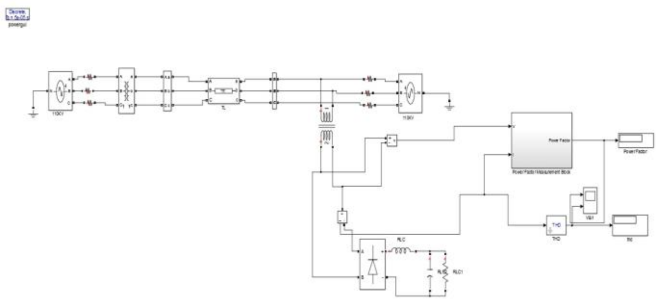

Fig. 3 Cophase Traction Power Without Compensation

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.

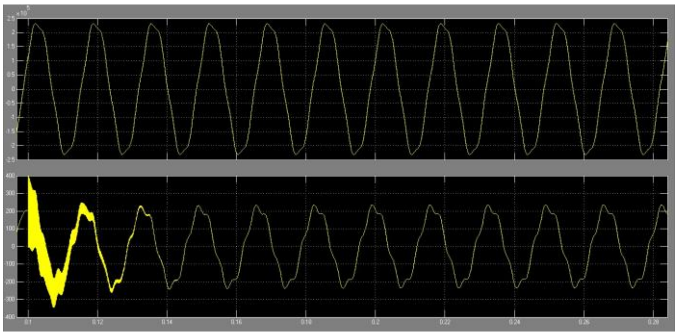

Fig. 4 Vac side voltage and current without compensation

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

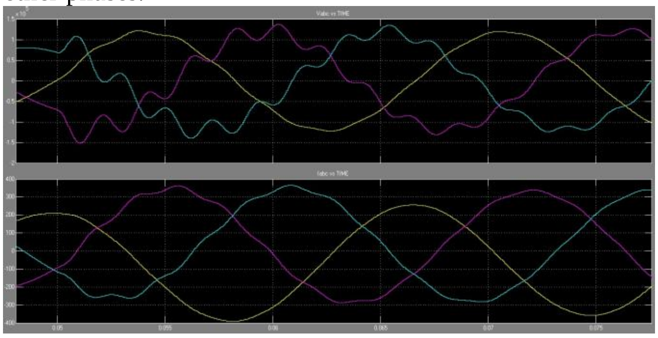

Fig. 5 Unbalanced voltage and current in transmission line

The single-phase back to-back converter is adopted in the power conditioner, which could balance the active currents between the transformer's two secondary windings. One phase at the secondary side of the traction transformer directly supplies the traction loads. The other phase supplies the loads indirectly via a power conditioner.

B. Cophase Traction Power With HPC Compensation

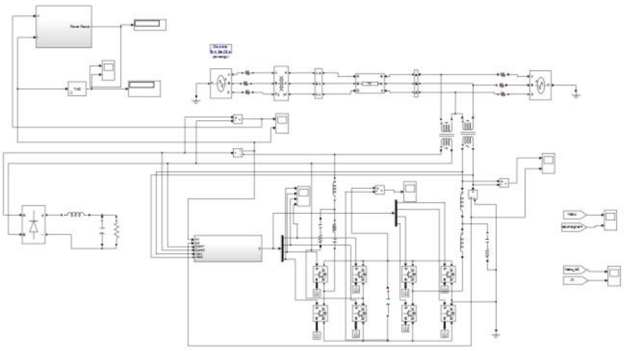

Fig. 6 Cophase Traction Power With HPC Compensation

HPQC 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).

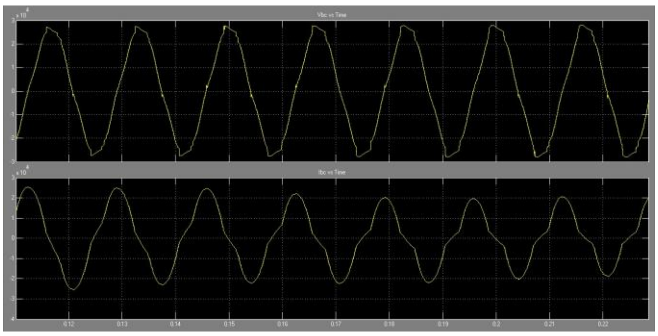

Fig. 7 Vac side voltage and current with HPC

V_{ac} phase side traction load and V_{bc} side HPC is is connected. V_{ac} side traction loads are cause voltage unbalance and it will reduced by compensating voltage by using V_{bc} 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 Hybrid Power Quality Compensator.

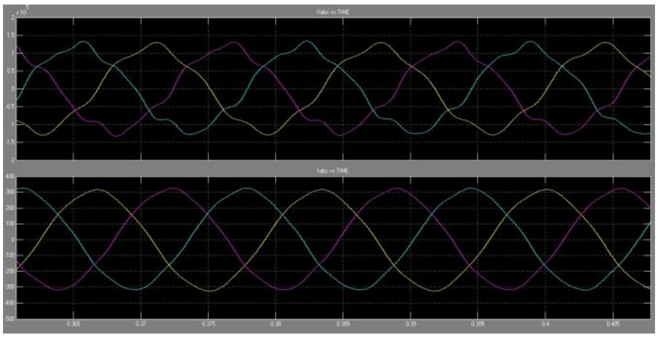

Fig. 8 balanced voltage and current in transmission line with HPC

V. Conclusion

A strategy to improve the power factor and eliminate harmonic currents in high-speed traction systems using co-phase hybrid power quality compensator (HPQC) was designed. The current references for the RPC 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 HPQC was performed using MATLAB-Simulink.

TABLE I. Output comparison

Without compensation		HPC compensation	
Power factor	***Harmonics (%)***	***Power factor***	***Harmonics (%)***
0.77	33.8	0.90	12.54

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