A Review on Power Conditioning for High-Speed Railway Systems

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***Abstract*— With the rapid development of high-speed railway, power quality has become a major issue for traction supply system .As compared with normal electrification railway locomotive load, high-speed locomotive load has some characteristics, such as large instantaneous power, high power factor, low harmonic components and high negative sequence component. A large amount of negative current is injected into grid, which causes serious adverse impact on power system, such as increasing motor vibration and additional loss, reducing output ability of transformers and causing relay protection misoperation. These adverse impacts threaten the safety of high-speed railway traction supply system and power system. Therefore, it is necessary to take measures to suppress negative sequence current & Harmonic current. Many methods and power quality compensators are studied in order to solve the issue of power quality**

Keywords—Negative Sequence Current(NSC), Half-bridge-converter-based railway static power conditioner(HBRPC)

I. INTRODUCTION

Recent years, high-voltage, large-capacity Static Var Compensator, Active Power Filter and Static Compensator (STATCOM) have become focus on power quality compensation of electrified railway. However, these methods all need high-voltage transformers which increase cost. Active Power Filter is effective in suppressing harmonic currents in electrified railway but rarely used in negative sequence compensation. An active power quality compensator (APQC) with a impedance-matching balance transformer or a Scott transformer is this in to compensate negative-sequence current, harmonics and reactive current.

Reference and put forward a proposal of Railway Power Conditioner (RPC), RPC can make comprehensive compensation of negative sequence components, harmonics and reactive power. Reference carries a dual-loop control strategy in order to improve the control effect and performance of RPC. Taken into account the disturbance and variation of electrified railway environment, a recursive PI control based on fuzzy algorithm is adopted to realize a fast and smooth tracking to reference current. Reference raises a method of setting up two groups of thyristor control reactors (TCR) and two groups of thyristor control 3rd harmonic wave filter besides RPC. The RPC is used to transfer active power; the reactive power is supplied by the TCR and the filter. These works prove that RPC is a effective way to solve the power quality problems in railway system.

Half-bridge-converter-based (RPC) (HBRPC) which consists of two half-bridge converters connected by two capacitors connected series. As compared with the traditional railway power conditioners (RPC), the HBRPC requires only a pair of power switch legs and two capacitors. The same function of RPC, this conditioner can reduce half of the power switches, which can make it with lower hardware complexity at lower cost. A double-loop control is this for HBRPC to keep the dc-link voltage stable and achieve the dynamic tracking of the current reference signals, while a balanced voltage control is this to eliminate the error of two capacitor voltages and maintain the normal operation of HBRPC.

II. NEED OF POWER CONDITIONING IN HIGH SPEED RAILWAY SYSTEM

With the rapid development of high-speed and high power railway system, power quality such as the negative sequence current and harmonic current caused by electric locomotives becomes more and more critical. High-speed locomotives which have a high power factor; however, they will generate a lot of harmonic currents in a broad spectral range. These NSC and harmonic currents would have much impact on the stable and economic operation of the grid, which can increase power losses of the traction system, reduce the life and reliability of the traction transformer, and lead to malfunctions of sensitive equipment. These adverse impacts threaten the safety of high-speed railway traction supply system. Therefore, it’s necessary to take measures to suppress negative current & Harmonic current

The amount of negative-sequence currents depends on the topology of the traction power system, in particular, the type of traction transformers used. Typical transformers used include Scott transformers, Woodbridge transformers, three-phase V/V transformers, impedance matching transformers, etc. Scott transformers, Woodbridge transformers are balanced transformers but three-phase v/v transformers are unbalanced. When balanced transformers are used, so 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.

Since most electric locomotives are single-phase rectifier load, random unwanted fluctuations are frequent, large amounts of harmonic & negative sequence current produced by the electric traction power supply system are injected into the power grid. As a result, grid voltage and current are asymmetrical and the harmonic content is increased, which

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lead problems including the overheat of motor rotor in power plant, the service life of transformer is reduce, the misoperation of relay protection device and, these issues have a great influence on the safe and stable operation of power system.

III. NEGATIVE SEQUENCE & HARMONIC CURRENT IN RAILWAY SYSTEM

In a perfectly balanced system, no negative phase sequence currents would exist. However, it is virtually impossible to achieve this perfectly balanced system in practice and so these negative phase currents need to be assumed. Line voltage imbalances caused by electrical system faults or imbalanced loads lead to current imbalances in each conductor. Therefore, magnetic coupling between windings becomes uneven. A counter rotating field (in respect to the main field) will now exist and the resultant field will cause undesirable eddy currents to flow. The consequences of this for generators will be a loss of torque or depending on the load, will increase the current for same slip speed and hence raise the temperature of the alternator.

In a rotating machine, the negative sequence current vector rotates in the same direction of rotor. It is the magnetic flux produced by the negative sequence current that rotates in the reverse direction of the rotor. Thus, rotor cuts through the flux at twice of the synchronous speed, & the induced current in the rotor is twice the line frequency. For measurement of negative sequence, it measured by the negative sequence filters within the relays. The net torque is reduced and if full load is still demanded, so the motor will be forced to operate at a higher slip, thus increasing the rotor losses & heat dissipation.

Harmonics-use of power electronics devices and nonlinear load in traction system generates large amount of unwanted frequency component these component are called harmonics, these are integral multiple of fundamental frequency. Convertor used in traction system and switched mode power supply are main source of harmonics even harmonics present in system are easily reduced because of their symmetrical nature but odd harmonics of low order cause distortion and poor performance. Flow of higher order harmonic current result in false or enormous tripping of relay and reduction in efficiency of traction transformer due to enormous amount of iron and core losses. Harmonics in traction system are measured with harmonics analyzer

IV. COMPENSATION METHODS FOR HARMONIC & NEGATIVE SEQUENCE CURRENT IN RAILWAY SYSTEM

A. Compensation Based on active filters
B. Compensation Based on SuperSMES
C. Compensation Based on Direct Power Control
D. Compensation Based on Railway static power conditioner
E. Compensation Based on Half-Bridge-Convertor based Railway Static power Conditioner

A) Compensation based on active filters

Active filters for power conditioning which provide the following multifunction reactive power compensation, harmonic compensation, flicker unbalance compensation, and or voltage regulation. Active filters intended for harmonic solutions are expanding their functions from harmonic compensation of nonlinear loads into harmonic isolation between utilities and consumers, and harmonic damping oscillations throughout power distribution systems. The main purpose of the active filters installed by individual consumers is to compensate for current harmonics and or current imbalance of their own harmonic-producing loads. On the other hand, the primary purpose of active filters installed by utilities in the near future is to compensate for voltage harmonics and/or voltage imbalance, or to provide “harmonic damping” throughout power distribution systems. In addition, active filters have the function of harmonic isolation at the utility-consumer point of common coupling in power distribution systems. [1]

B) Compensation Based on SuperSMES

A SuperSMES is composed of inverters connected in series to a power system and another inverter in parallel and superconducting magnet for energy storage. It is an universal power quality controller because of its multi-purpose ability. The application presented here aims a general filtering system in large industrial power consumers. The SuperSMES can provide a sinusoidal and balanced voltage to loads which are sensitive for voltage distortion and unbalancing it also eliminates current harmonics and unbalance in three phase lines of the distribution system, which flow upstream of connecting point.

Here are two types of applications for SMES, in which SMES has unmatched advantage among existing other devices. One is applications in power transmission system for transmission grid control and stability enhancement. Another type of applications of SMES is with large industrial power consumers connected to a relatively weak grid. Among the second type applications, much attention has been paid on voltage dip compensation for voltage sensitive load by a Micro Superconducting Magnetic Energy Storage (Micro-SMES). One of purposes of the system is supplying sinusoidal and balanced voltage to loads which are sensitive for voltage distortions. There are voltage harmonics and unbalancing to some extent in distribution system, and some loads are affected from the distortion and unbalancing. Another purpose, of the system is compensating harmonic and unbalanced current caused by non-linear loads and single phase loads. The system aims at such a general filtering system. The filtering system requires some small energy storage device to compensate above mentioned distortions and unbalancing of voltage and current. Conventional active power filters use capacitors for the energy storage device, but larger capacity is required to compensate not only harmonics but also unbalanced voltage and current, which are negative sequence components in three phase system. As a superconducting magnet has higher energy density than a capacitor, it is preferable to use a superconducting magnet for compensation of negative sequence voltage and current. [2]

C) Compensation Based on Direct Power Control

Power quality problems in power systems have been increased due to nonlinear loads. To compensate these problems Direct Power Compensator discussed. A Direct Power Compensator (DPC) is proposed to eliminate harmonic currents, compensate the power factor and voltage unbalance problems created by the nonlinear loads present in three phase

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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. The 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

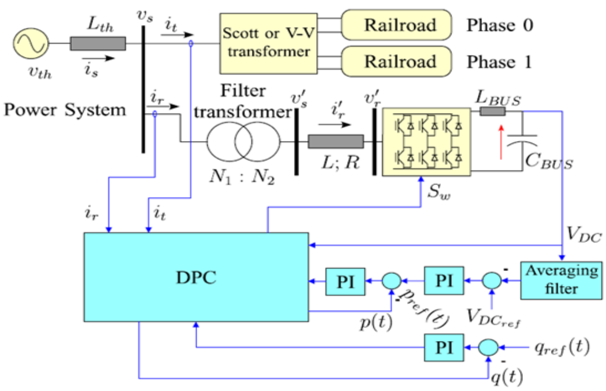

Fig.1 compensation scheme of DPC

This DPC-based compensation scheme reduces negative sequence currents injected by an uncompensated electric traction system using any power transformer connection. This technique can be used to reduce the current THD to values complying with international regulations, and additionally regulates power factor observed in the common coupling point between the traction substation and the grid. [3]

D) *Compensation Based on Railway static power conditioner (RPC)*

This power quality compensator is constituted by railway static power conditioner (RPC), two thyristor-controlled reactors and two thyristor-controlled 3^{rd} filters. The RPC contains two converters which are connected back-to back by sharing the DC link and is only used to transfer active power and suppress harmonics. The thyristor controlled3rd filters are used to suppress 3rd harmonic current and change he phase angle of power supply current. The Thyristor-controlled reactors are as the same used to change the phase angle of power supply current. This power quality compensator has small capacity and low cost. Furthermore, based on the working principle of this power quality compensator, its equivalent electrical models are established in fundamental and harmonic domain respectively

The structure of this power quality compensator which suitable for high-speed electrified railway system is shown in Fig.2 The compensator is constituted by the three parts: railway power regulator consisting of two single phase H bridge inverter which is linked by the capacitor CR1 and CR2; two sets of thyristor-controlled reactor constituting by the inductors L3 and L4; two sets of thyristor-Controlled 3rd single tuned filter constituting by the inductors L1, L2 and capacitor C1, C2. The transformer is a single-phase three-winding step down transformer.

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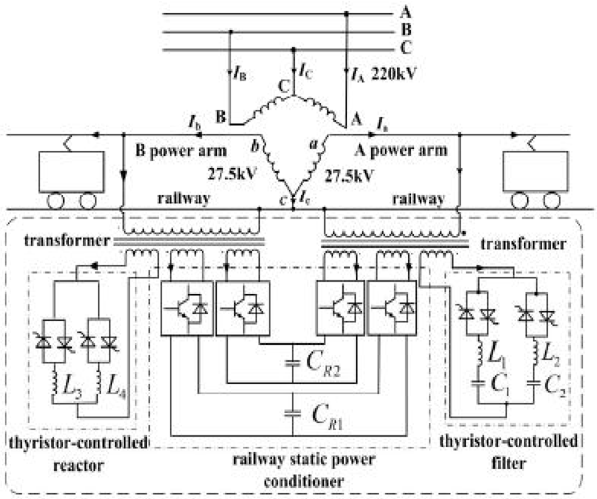

Fig.2 Compensation System based on RPC

The railway power regulator makes a connection with two power supply arms of the V/V traction transformer's second side by step-down transformer. Thyristor-controlled 3rd single-tuned filter is installed under a phase-leading power arm. Thyristor-controlled Reactor is installed under b phase-lagging power arm. When the locomotive load is under A power arm, the 3rd filters composed of L1, C1 and inductor L3 are switching on respectively. When the locomotive load is under B power arm, then 3rd filters composed of L2, C2 and inductor L4 are switching on respectively. In this new structure, in order to reduce the capacity of active part of RPC and improve the stability of entire compensation system, RPC is only used to transfer active power.

The thyristor-controlled reactor and 3rd filters provide reactive power. And here thyristors only play the role of switch, so they do not generate additional harmonics. Because the 3rd filter is capacitive in fundamental wave, thyristor-controlled 3rd filters and thyristor-controlled reactor are equivalent to the function of SVC, which can provide capacitive and inductive reactive power for power supply system. In Fig.2, *IA, IB, IC* means the three-phase current of the original edge of the traction transformer V/V; *Ia, Ib, Ic* means the three-phase current of the Vice-edge. [5]

E) *Compensation Based on Half-Bridge-Convertor based Railway Static power Conditioner*

Half-bridge-converter-based railway static power conditioner (RPC) (HBRPC) which consists of two half-bridge converters connected by two capacitors in series. Compared with the traditional RPC, the HBRPC requires only a pair of power switch legs and two capacitors. Under the premise of accomplishing the same function of RPC, this conditioner can reduce half of the power switches, which can make it with lower cost and hardware complexity. A double-loop control is proposed for HBRPC to keep the dc-link voltage stable and achieve the dynamic tracking of the current reference signals, while a balanced voltage control is this to eliminate the error of two capacitor voltages and maintain the normal operation of HBRPC.

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HBRPC is made of two power switch legs and two dc link capacitors, and two switch legs are connected to each other by two capacitors in series. So, this power conditioner is essentially two back-to-back half-bridge converters, and one converter can be dealt with rectification to absorb energy and charge the dc-link capacitors while the other can be treated with inversion to release energy and discharge the dc-link capacitors; then, a dynamical energy balance can be achieved. So, HBRPC has the ability of transferring active power to the traction power arms. If HBRPC can adopt a reasonable control strategy to adjust the output voltage and current of two half bridge converters, it would achieve the purpose of transferring active power from one power arm to the other, compensating NSC and suppressing harmonic currents. Compared with RPC, this topology of HBRPC can reduce a pair of switch legs which has four power switches. Under the premise of completing the same function of RPC, HBRPC can reduce the cost, hardware complexity, and power losses. However, the switch voltage stress of HBRPC would double, and the equivalent switching frequency would reduce by 50%, which can increase harmonic content

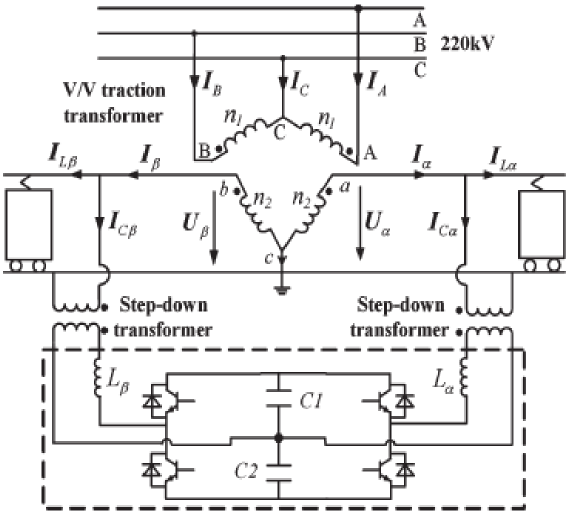

Fig 3 Compensation System based on half bridge converter

A comprehensive compensation system HBRPC has been presented for power quality of the high-speed railway, which is based on two half-bridge converters. Compared to RPC, the number of power switches is reduced, so the cost, hardware complexity, and power losses are reduced correspondingly. A real-time reference detection method for NSC and harmonic currents under *V/V* traction system has been presented, and the hysteresis control is adopted to achieve fast tracking of the current reference and improve the dynamical compensation performance. Considering the dc-link voltage balance of two capacitors, a BV control has been proposed to eliminate the voltage imbalance and reduce the unbalanced influence on system performance. Finally, simulation and experiment results have confirmed that this system has a good effect on NSC compensation and harmonic current suppression, this HBRPC provides a new attempt for managing the power quality of railway system.

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CONCLUSION

After the referring above method of compensation, Half-Bridge Converter method is efficient than other methods of compensation due to advantages like the number of power switches is reduced, so the cost, hardware complexity, and power losses are reduced, a real-time reference detection method for NSC and harmonic currents under V/V traction system has been presented, and the hysteresis control is adopted to achieve fast tracking of the current reference and improve the dynamical compensation performance

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