Power conditioning based on Half-Bridge Converter for Train Traction Power Supply Systems

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***Abstract*—With the rapid development of Traction supply systems in India, power quality has become a major concern for traction supply system. Locomotive load has some characteristics, such as large instantaneous power, high power factor, low harmonic components etc. The four quadrant pulse width modulation (PWM) is adopted by high speed locomotive which have high power factor; however they generate lot of harmonic currents in broad spectral range. Since most electric locomotives single phase rectified load, random fluctuations are frequent, large amounts of harmonic current produced by the electric traction power supply system are injected into power grid. As a result, the grid voltage and current are asymmetrical and harmonic content is increased, which lead to series of problems including the overheating, service life of transformer is shorten, the mis-operation of relay protection device, these issues have great influence on the safe and stable operation of power system.**

After reviewing various methods of harmonic compensation in traction system, we found that a half-bridge converter based railway static power conditioner (HBRPC) is more advantageous than other methods. A Half bridge converter based railway static power conditioner which consists of two half-bridge converters connected by two capacitors in series. Compare with traditional railway static power converters, the HBRPC needs only a pair of power switch legs and two capacitors. So 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 used to eliminate the error of two capacitor voltages and maintain the normal operation of HBRPC. Finally, simulation and experiment result have verified the proposed structure and its control method effectively

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

I. INTRODUCTION

With the rapid development of high-speed railway power quality has become a major concern for traction supply system. Compared with normal electrification railway locomotive load, high-speed locomotive load has some characteristics, such as big instantaneous power, high power factor, low harmonic components and high negative sequence component. A large amount of negative sequence 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 mis-operation. These adverse impacts threaten the safety of high-speed railway traction supply system and power system. Therefore, it's necessary to take measures to suppress harmonic & negative sequence current.

The characteristic of the electric traction system which converts a three-phase symmetrical source to two independent single-phase sources can bring in a lot of negative Sequence current (NSC) into a three phase power grid. The four-quadrant pulse width modulation is adopted by 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,

Half-bridge-converter-based (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, the proposed 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 proposed to eliminate the error of two capacitor voltages and maintain the normal operation of HBRPC.

II. 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

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of two capacitor voltages and maintain the normal operation of HBRPC.

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

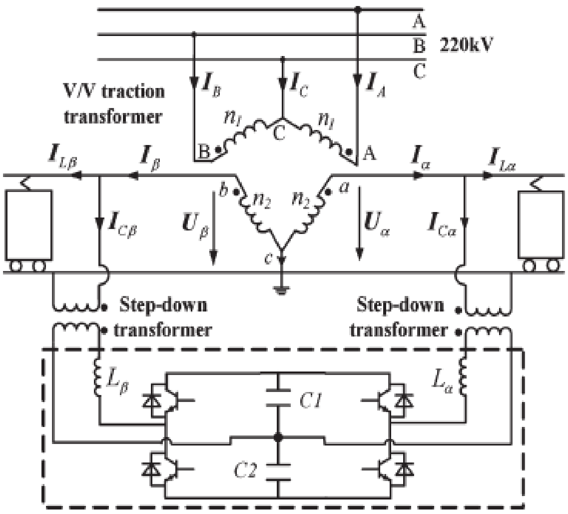

Fig.1Compensation System based on half bridge converter

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 fuzzy 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.

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. [7]

III. MATLAB SIMULATION

In order to validate the project this is based on half-bridge converter and its control method, the simulation diagram of HBRPC by using MATLAB 10 software is built. Assume that the power loads of a-and b-phase traction power arms of different wattage energies by single phase supply, respectively. Here, a load model is linear resistors.

Ia and Ib represents a and b phase traction power currents for compensated and uncompensated circuit. Vdc and Vdc1 are the voltages of two dc-link capacitors. Before compensation two traction power currents are unequal which contains a lot of harmonic currents. However, after switching into HBRPC at 0.3 s, it can transfer a certain amount of active power from b-phase traction power arm to the other and compensate the specific reactive power and harmonic current for two traction power arms respectively. After compensation, two traction power currents are balanced. The harmonic currents are significantly reduced. Before the compensation of HBRPC at 0.3s, two capacitor voltages are unbalanced. After putting the HBRPC, the balanced voltage controller can internally enhance the conduction or shutdown time of some power switch in order to discharge capacitor C1 and capacitor C2 with more energy. After a period of adjustment, two capacitor voltages keep stable. So the dc link voltage balance is achieved

The load power currents of two traction power arms before compensation shows in fig.3 and traction power currents of two traction power arms after compensation shows in fig.5 The harmonic components in traction power currents of two power arms with HBRPC’s compensation are smaller than one of two load currents. According to the specific harmonic current comparison of two traction power currents before and after compensation, the harmonic currents of two traction power currents are greatly reduced.

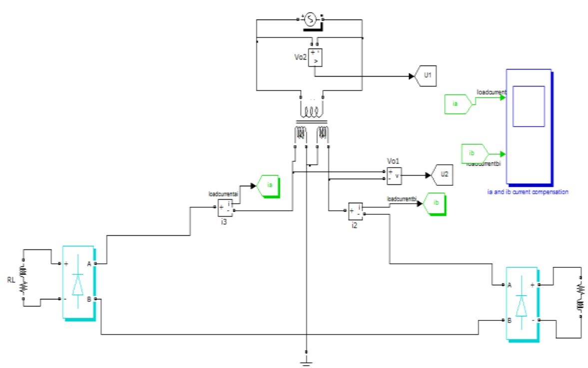

Fig.2 Simulation diagram of before compensation

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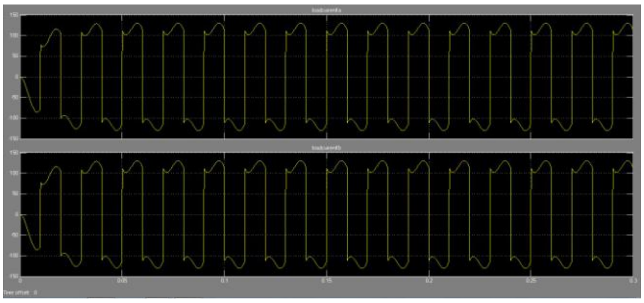

Fig.3 Traction Currents waveform before compensation

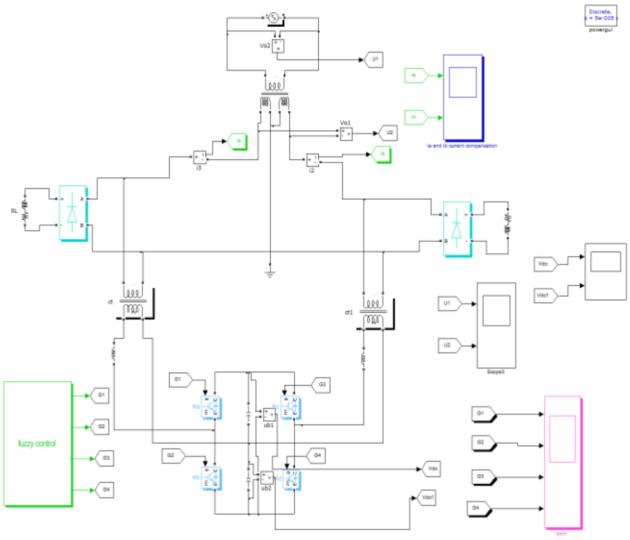

Fig.4 Simulation diagram of after compensation

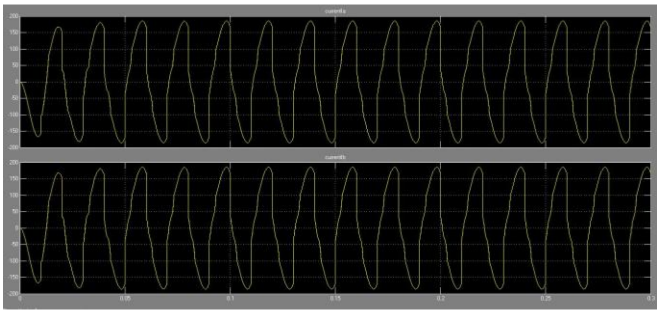

Fig.5 Traction Currents waveforms after compensation

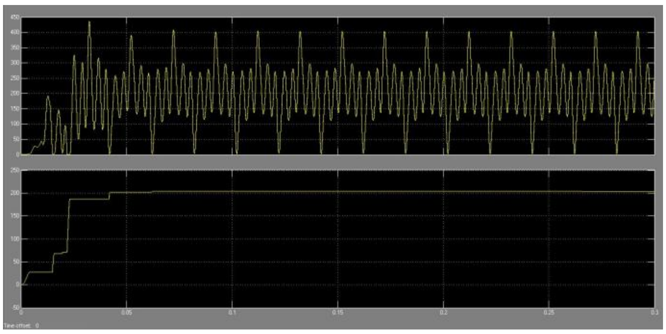

Fig.6 Waveforms of two dc-link capacitors

After this we calculate Total Harmonic Distortion (THD) of both compensated and uncompensated circuit. The total harmonic distortion is reduced from 40.25 % 24.39 % respectively i.e. nearly 16%. So the harmonic currents are effectively suppressed. For calculation of THD we use FFT analysis tool. FFT analysis also provides 3^{rd}, 5th, 7^{th}, 9^{th}harmonics data of both circuits. So we observed that the harmonics level is effectively reduced

Harmonic Current	I-3^{rd} %	I-5^{th} %	I-7^{th} %	I-9^{th} %
Percentage	28	16	12	9

Table 1 Average value of the significant current harmonics before compensation

Harmonic Current	I-3^{rd} %	I-5^{th} %	I-7^{th} %	I-9^{th} %
Percentage	11	7	6	4

Table 2 Average values of the significant current harmonics after compensation

IV. FUZZY LOGIC CONTROLLER

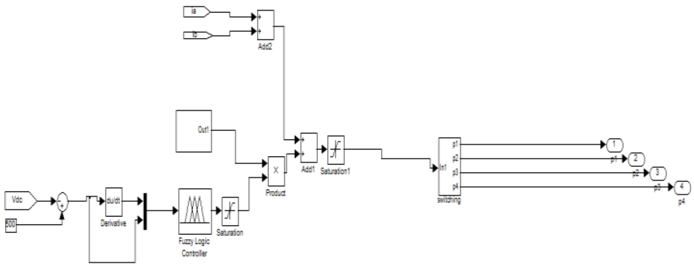

Fig.7 HBRPC switching signal Generation

The basic fuzzy logic control system is composed of a set of input membership functions, a rule-based controller, and a defuzzificationprocess. The fuzzy logic input uses member functions to determine the fuzzy value of the input. There can be any number of inputs to a fuzzy system and each one of these inputs can have several membership functions. The set of membership functions for each input can be manipulated to add weight to different inputs. The output also has a set of membership functions. These membership functions definethe possible responses and outputs of the system. The fuzzy inference engine is the heart of the fuzzy logic control system. It is a rule based controller that uses If-Then statements to relate the input to the desired output. The fuzzy inputs are combined based on these rules and the degree of membership in each function set. The output membership functions are then manipulated based on the controller for each rule. Several different rules will usually be used since the inputs will usually be in more than one membership function. All of the output member functions are then combined into one aggregate topology. The defuzzification process then chooses the desired finite output from this aggregate fuzzy set. Thereare several ways to do this such as weighted averages, centroids, or bisectors. This produces the desired result for the output. (8)

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The fuzzy model for the harmonic distortion diagnostic was implemented in MATLAB using the fuzzy logic toolbox. This toolbox allows for the creation of input membership functions, fuzzy control rules, and output membership functions. To implement this system in Simulink the system will need tohave two different inputs: the harmonic currents and the DC link voltage. A simple (two-variable example) diagnostic system was created as shown in fig.7. These two inputs will then be processed by a fuzzy logic controller that will output gives to four mosfets & also provides PWM signal for switching

V. PROTOTYPE OF HBRPC POWER CONDITIONER

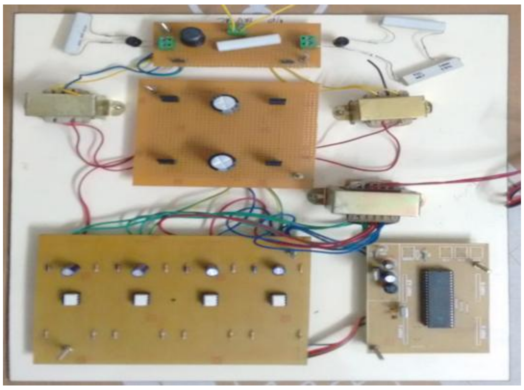

Fig.8 Prototype of HBRPC power conditioner

In order to validate the proposed HBRPC, a prototype of HBRPC under single phase traction transformer at a rank 230V has been built. The transformer and uncontrollable rectified load is used to simulate high speed locomotive. Assume that the load power values of a-and b-phase traction power arms. A PIC16F877A is used to carry out the project control algorithm. The 4 current signals are sampled and they can process by PIC16F877A to obtain PWM signals for MOSFET according to control strategy. The Switch frequency is 5 kHz. Without compensation, the different power loads of two traction arms can make the load currents of both arms unbalanced so they generates lots of harmonic currents. As HBRPC is switched into the system, it can compensate the specific fundamental and harmonic currents suppression. After putting into HBRPC, the BV controller is adopted to control the voltages of two dc-link capacitors. After a period of adjustment time, finally, two capacitor voltages are stable. This control method can realize the voltage balance of two capacitors and can maintain the normal and reliable operation of the compensator. Fig. 9 and Fig. 10 is specific current comparison of two traction power currents before and after the compensation; the specific harmonic currents are greatly reduced by the compensation of HBRPC.

As shown Fig.8 prototype of project. In order to validate the HBRPC, a prototype of HBRPC is under single phase transformer at a rank of 230V has been built. The single phase step-down transformer is connected to single phase supply and his secondary is connected to unbalanced and uncontrollable rectifier which is 12V. RL is used to equivalent on single phase power line. We apply the voltage to both side of load. We check the load current on CRO without any compensation circuit i.e. without HBRPC we got harmonics on both side of load shows in Fig.10

To minimize the harmonics we use the arrangement of HBRPC. By Keeping ON a single phase power line connect second single phase transformer that is tap changed transformer which is connect to Microcontroller Kit used. Second transformer supply 12V PIC Microcontroller which generates PWM signals. This PWM signals going to driver circuit. Driver circuit will amplify the PWM signals, and then amplified PWM signals goes to Gate terminal of mosfet switch. After this HBRPC will start working then it will compensate power quality problems occurred in single phase.

Second transformer stepping down 230V AC to 12V AC, which is given to bridge rectifier & filter (470µF) of microcontroller kit. Amplify and convert it into 12V DC. By use of 7805 regulator reduce it to 5V DC output. This 5V DC goes to PIC16F877A microcontroller. PIC microcontroller has 5 ports A, B, C, D & E. Out of these 5 ports Port C will be given four PWM signals. These four PWM signals are going to driver unit. The purpose of driver unit is to pulse amplification. IC-TLP250 gate is the gate driver which is used to amplify 5V pulse to 12V pulse. This driver unit needs 12V DC power supply to amplify 5V pulse to 12V pulse.ie. PIC needs 5V DC power to generate 5V magnitude pulse & driver unit needs 12V DC power supply to amplify 5V pulse to 12V pulse. The power supply circuit consist four driver units present in project because we need four PWM signals for four MOSFET switches. To obtain 12V DC IN4001 rectifier is used which is going to IC-TLP250 driver unit. The switches will triggered in X pattern. H Bridge starts working compensation. Two transformers are present right and left side of H Bridge. They provide balanced voltage to both sides of traction arms. After this when we check waveforms on CRO we get compensated waveforms shows in Fig.10

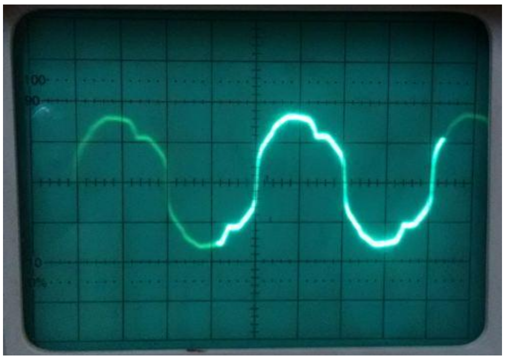

Fig.9 Output waveforms of load currents before compensation

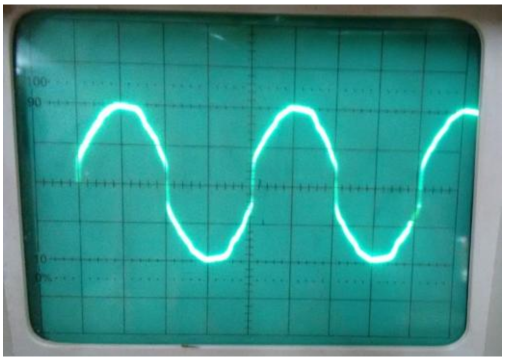

Fig.10 Output waveforms of load currents after compensation

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VI. CONTROL STRATEGY OF HBRPC

In order to analyze the switching control principle of half bridge converter, the circuit model of half-bridge converter is established. T1 and T2 are the power Switches and VC1 and VC2 are the voltages of the capacitors C1 and C2, respectively. For the easy analysis, a variable M is introduced. When M =1, T1 is turned on, i.e.T1 is conducted, as shown inwhen M = 0, T2 is turned on, i.e.T2 is conducted. According to the circuit, the voltage and current equation of the converter can be achieved

$$di/dt = [u - MVC1 - (1 - M)VC2] / L \quad (1)$$

When the supply current i >0, the circuit has two operating modes: 1) T1 is conducted, and M = 1 this is called the charging mode of the dc-link capacitor and 2) T2 is conducted, and M = 0this is called the discharging mode of the dc-link capacitor Assume that the amplitude of supply voltage u is less than the dc-link capacitor voltage, i.e., max |u| <(VC1 or VC2). During the charging process of the dc-link capacitor when i >0, the supply current i changed from i0 to i1 in a small period of time Δt. Assuming that Δi = i1 − i0, the following equation can be obtained from(1)

$$\Delta i = \Delta t \frac{[u - MVc_1 - (1-M)Vc_2]}{L} \quad (2)$$

When i >0 and M = 1, can be converted to Δi = Δt(u − VC1)/L; then, whether u ≥ 0 or u <0, there are u −VC1 <0 and Δi <0. In this case, i1 < i0 is always established, i.e., when T1 is conducted, the capacitor C1 is charging, and |i| starts to decrease.

When i>0 and M = 0, (2) is changed into Δi = Δt(u + VC2)/L; then, whether u ≥ 0 or u <0, there are u + VC2 >0 and Δi >0. In this case, i1 > i0 is established, i.e., when T2 is conducted, the capacitor C2 is discharging, and |i| starts to increase.

Similarly, when the supply current i <0, the circuit has two operating modes: 1) T1 is conducted (this is called the discharging mode of the dc-link capacitor), the capacitor C1 is discharging, and |i| starts to increase and 2) T2 is conducted (this is called the charging mode of the dc-link capacitor), the capacitor C2 is charging, and |i| starts to decrease.

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 harmonic currents under single phasetraction system has been presented, and the fuzzy logic control is adopted to achieve fast tracking of the current reference and improve the dynamical compensation performance. The current references for the HBRPC converters are generated according to the load currents on both sections of the traction power supply system. . Even though the half bridge converter has some drawbacks, further improvements can be done by increasing the level of converter and controlling its switching using PWM controller so that harmonics can be minimized. The project HBRPC provides a new attempt for managing the power quality of train traction power supply system.

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