International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 6, No. 4, December 2015, pp. 772~780
ISSN: 2088-8694

A Novel Power Factor Correction Rectifier for Enhancing Power Quality

Bindu KV, B. Justus Rabi
Department of Electrical and Electronics Engineering, Anna University, India

Article Info

Article history:

Received Jul 15, 2015
Revised Nov 10, 2015
Accepted Nov 27, 2015

Keyword:

Active filters
Current injection technique
frontend rectifier
Power quality
Total harmonic distortion

ABSTRACT

In this paper, the disturbances in power system due to low quality of power are discussed and a current injection method to maintain the sinusoidal input current which will reduce the total current harmonic distortion (THD) as well as improve the power factor nearer to unity is proposed. The proposed method makes use of a novel controlled diode rectifier which involves the use of bidirectional switches across the front-end rectifier and the operation of the converter is fully analyzed. The main feature of the topology is low cost, small size, high efficiency and simplicity, and is excellent for retrofitting front-end rectifier of existing ac drives, UPS etc. A novel strategy implementing reference compensation current depending on the load harmonics and a control algorithm for three-phase three-level unity PF rectifier which draws high quality sinusoidal supply currents and maintains good dc link- voltage regulation under wide load variation. The proposed technique can be applied as a retrofit to a variety of existing thyristor converters which uses three bidirectional switches operating at low frequency and a half-bridge inverter operating at high frequency .The total power delivered to the load is processed by the injection network, the proposed converter offers high efficiency and not only high power factor but also the Total Harmonic Distortion is reduced. Theoretical analysis is verified by digital simulation and a hardware proto type module is implemented in order to confirm the feasibility of the proposed system. This scheme in general is suitable for the common variable medium-to high-power level DC load applications.

Corresponding Author:

Bindu K V,
Research Scholar, Departement of Electrical and Electronics Engineering,
Anna University, India.
Email: kvbindu2014@gmail.com

1. INTRODUCTION

In the recent years, the power quality (PQ) problems have been increased reasonably because of increased use of power electronic equipments, and motor drives in household, commercial and industrial applications. The non-linear loads generate harmonics in AC mains current like diode rectifiers with smoothening DC capacitor or thyristor converters with smoothening inductors. Therefore any of these types of drives create a number of problems for power utilities [1]. These problems, usually referred as PQ problems, have been of main concern to the international community and addressed by various PQ standards, practices and norms In view of these PQ problems, some suitable measures are required for the compensation of these current harmonics. The most popular method is the usage of LC filter and the current source non-linear loads and voltage source nonlinear loads have dual relations to each other in circuits and properties and need parallel and series compensation respectively, for controlling the harmonics [2]. Synchronous motors (SMs) with speed control are very popular in high-power and/or high-speed applications as they are economic alternative at high power levels. For the speed control of SMs, the load commutated inverter (LCI) is used, as it can be naturally commutated by the load voltage with a leading power factor (PF) [3]. Most of the applications of LCI-fed SM drives are using six-pulse controlled converter. However, the six-pulse converter topology has higher current harmonic distortion at AC mains which reduces the Power Factor tremendously. This paper deals with various solutions for mitigation of PQ problems, and provides a suitable power quality solution for any non-linear application [4]. A conventional inverter for three phase induction motor drives uses a diode bridge rectifier to provide the dc link voltage which pollutes ac mains by injecting current harmonics [5]. The characteristics of recently used three-phase PWM rectifiers have nearly sinusoidal input current waveform with unity displacement power factor and regeneration capability [6]. The PWM rectifier cannot be used for high power conversion due to the high switching losses and need of filters are still required to suppress high switching frequency harmonics. The new approach overcomes the complicated gating circuit with a novel control strategy, which takes into account actual load level on the rectifier and also reduces its cost [7],[8]. The topology to be had is controlling the conduction period of bidirectional switches and which eliminates the input current harmonics considerably and the input power factor can be well improved. A prototype with a rated output power of 1.5 kW was set up in the laboratory for the experimental study and the results obtained are coinciding with simulation studies. From the literature review of three-phase rectifier topologies, three phase star-connected switch three-level rectifier is a choice because of its reduced voltage stress [9],[10]. Thus, the input current waveform is well shaped and approximately sinusoidal and the bidirectional switches conduct at twice of the line frequency, therefore, the switching losses are negligible [11]. However, this technique was proposed for the rectifier operating with a fixed load and fixed optimal input inductor. So that the dc link voltage is sensitive to the load variation, and high performance is achieved within a very limited output power range.

2. FRONT END RECTIFIER ANALYSIS AND PRINCIPLES OF OPERATION

A control strategy with conventional voltage-source current-controlled (VSCC) pulse width modulation (PWM) rectifiers is to work simultaneously as active power filters [12]-[14]. The active front-end rectifier acts directly on the mains line currents, forcing them to be sinusoidal and in phase with the mains voltage. For shaping the line current to be sinusoidal and in phase with the respective phase voltage, the active front end converter operates as a rectifier [15]. There are only two conducting diodes in the stages 1, 4, and 7 and three conducting diodes in the stags 2, 5, and 8. In the stages 3, 6, and 9, only two phases are conducting and the third phase current is discontinuous. When the output power is higher than the rated output power, the conduction angle is adjusted to maintain the output voltage constant around the value V_O. In this case, as expected the conduction angle will be larger than 30 degree.

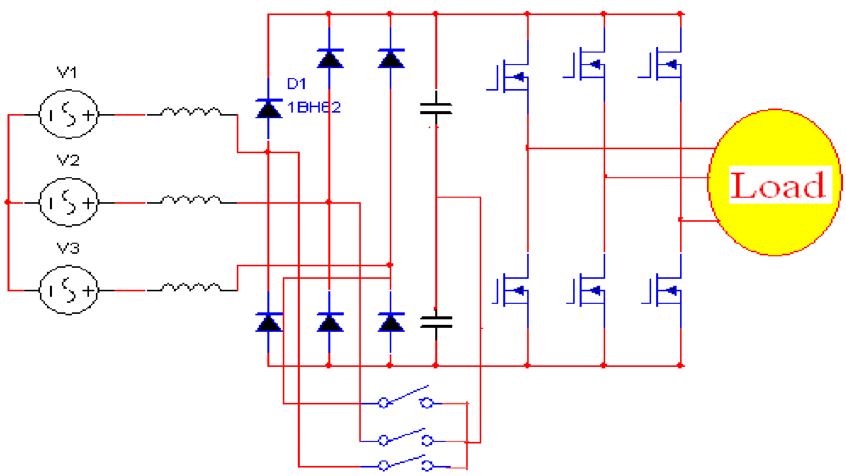

Figure 1. Implementation of Bidirectional Switch

When the output power is lower than the rated output power, bidirectional switch conduction angle is adjusted to make the output voltage constant and to the rated value and the phase current is continuous and equals to zero. Therefore there are six well-known conduction stages and two-phase conduction stages 3, 6, and 9 do not exist here.

3. FRONT-END RECTIFIER CONTROLLER DESIGN

As the input phase voltage crosses zero-volt axes, the corresponding switch will be triggered and the bidirectional switches (sa, sb and sc) conducts twice in every line voltage cycle [16]. The drive pulse width for the bidirectional switches is determined by the dc link current i_{dc} to control the conduction angle α (thus pulse width). The proposed control circuit diagram is shown as the dc link voltage is compared with reference voltage to provide the compensation [17]. Due to the uncontrolled switches from upper and lower halves of the input phases remains non-conducting, resulting in bridge characteristic of diode rectifier, a tiny compensation can achieve optimum performance. After performing a number of analysis and simulation to find the most suitable value, 0.5 was chosen to be used in the voltage compensation block. The ideal rectifier bridge with six diodes has six well known conduction sequences, when the load current is continuous. In each of these sequences, the dc-side load is connected to two of the input phases through two diodes one each from the upper and lower halves of the input phases remains non-conducting, resulting in bridge. Hence, during each of these sequences, heavy harmonic distortions occur. With a capacitive load, the situation gets aggravated. The topological modifications are only remedy to this situation and make it possible to have currents in all the input phases at all times, as in the case of a linear balanced load on the 3-phase mains. The modulation strategy proposed in this paper is a refinement which is aimed to improve the current shaping so as to yield a better harmonic and power-factor performance, under varying load conditions. The input line inductor and the switches lead to additional operating modes involving the normally idle input phase. When the switch connected to the idle phase is closed the current begins to build up.

4. SIMULATION OF THE PROPOSED RECTIFIER

A PSIM model for the proposed three phases three level high power factor rectifier is developed to perform the digital simulation and control signals are generated for the proposed front end rectifier. To verify the performance of the proposed control strategy, a prototype of the rectifier is developed. A system with two active networks was suggested, with the first one for generating the third-harmonic current and the second one for injecting the current to the ac mains. The injection networks of the proposed converter do not process all the power delivered to the load, resulting in a very efficient alternative. As the converter is active, it can be adapted to different operating points. The system uses two controllers, with the first one being in open loop for the injection network and the second one for the shaping network in closed loop. The system exhibits a fast dynamic response, high efficiency, high power factor, and low harmonic content. The average real power consumed by load is supplied by the source, and the active compensation circuit does not provide or consume any average real power. Then the reference compensational current can be obtained. The conduction period of bidirectional switches (Sa, Sb and Sc) is controlled by using the hysteresis current control. The idea lies in the high switching frequency, resulting in the input inductor size being effectively reduced.

Figure 2 shows the PSIM simulation circuit for the proposed three phase active current injection rectifier. Figure 3and Figure 4 shows the converter input source current waveform and its source voltage at rated output power operation. The simulation is performed for three phase high power rectifier is done with both resistive and inductive load. Figure 5 & 6 shows the source current and current waveforms for R load, without and with active current injection circuit. Figure 7 shows the source waveform of proposed high power factor rectifier (RL-Load) and simulation result of output voltage is shown in Figure 8.

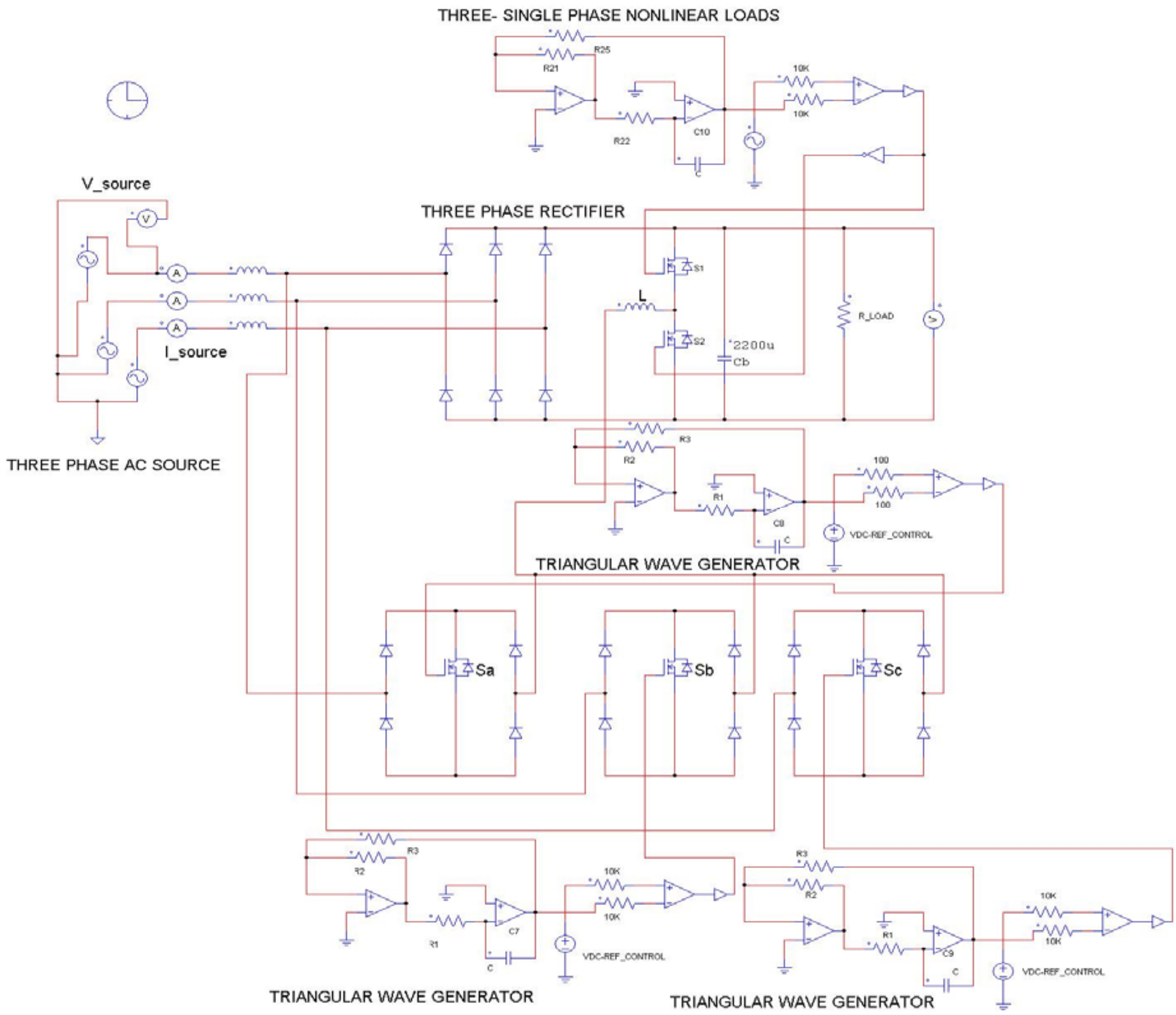

Figure 2. Proposed three phase active current injection rectifier

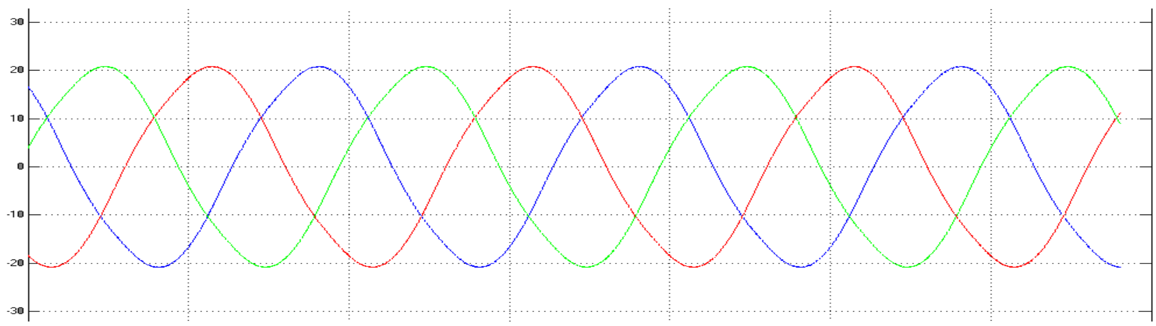

Figure 3. Simulation results of source current waveform in three phase rectifier

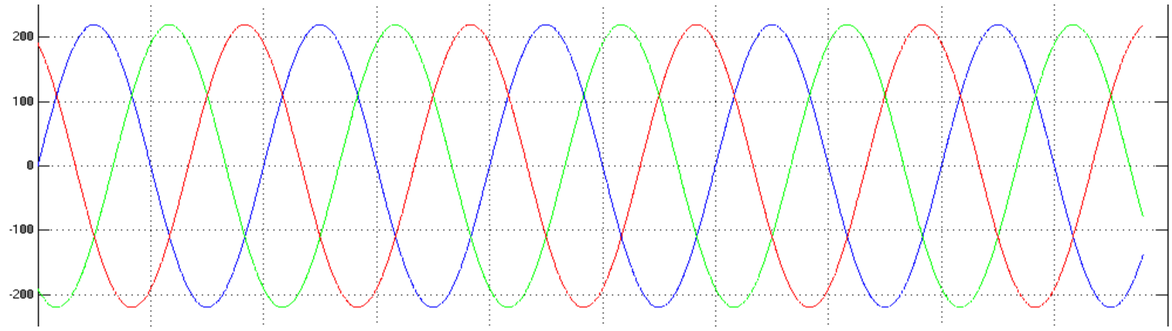

Figure 4. Source voltage waveform of proposed high power factor rectifier (R-Load)

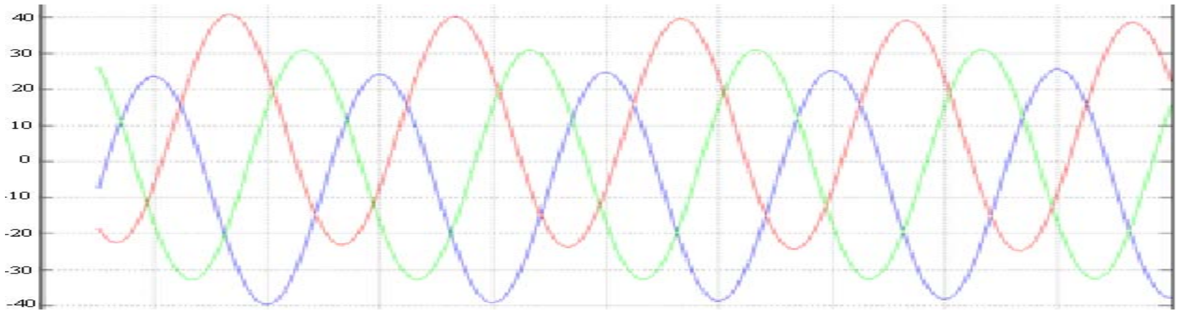

Figure 5. Source current waveform of high power factor rectifier without injection circuit.(R-Load)

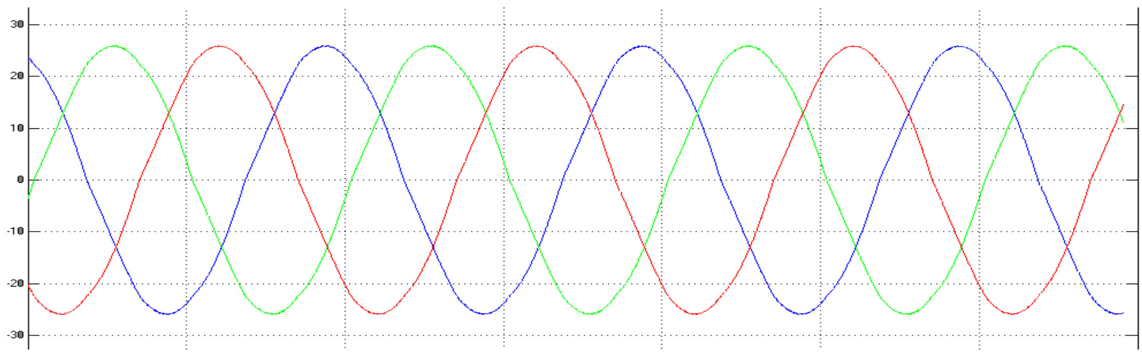

Figure 6. Source current waveform of proposed high power factor rectifier with current injection circuit (R-Load)

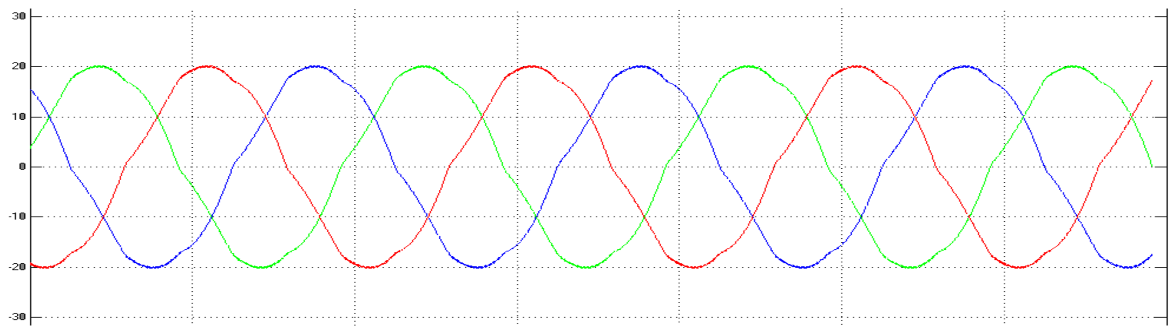

Figure 7. Source current waveform of proposed high power factor rectifier (RL-Load)

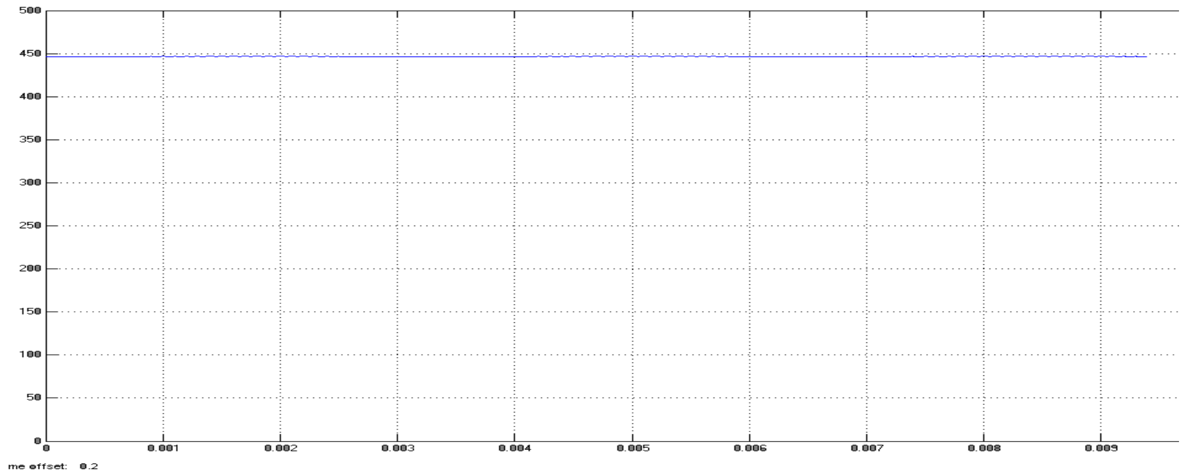

Figure 8. Simulation result of output voltage

5. HARDWARE DESCRIPTION

A laboratory prototype of the proposed three phase high power rectifier circuit is designed as shown in Figure 9 and the experimental waveforms for the three phase input current waveforms are depicted in Figure 10 and Figure 11.

Design Values:
Vin=220V
La=Lb=Lc=25mH
To illustrate the design feasibility of the proposed
converter, a prototype with the following specifications is chosen.
Load feeding inductance = 2mH
C1=C2=2200 microF
Ro=100 Ohms
Duty Cycle=50%.
Switching Frequency = 25 KHz
Output voltage = 340 Volts

Figure 9. Hardware Setup

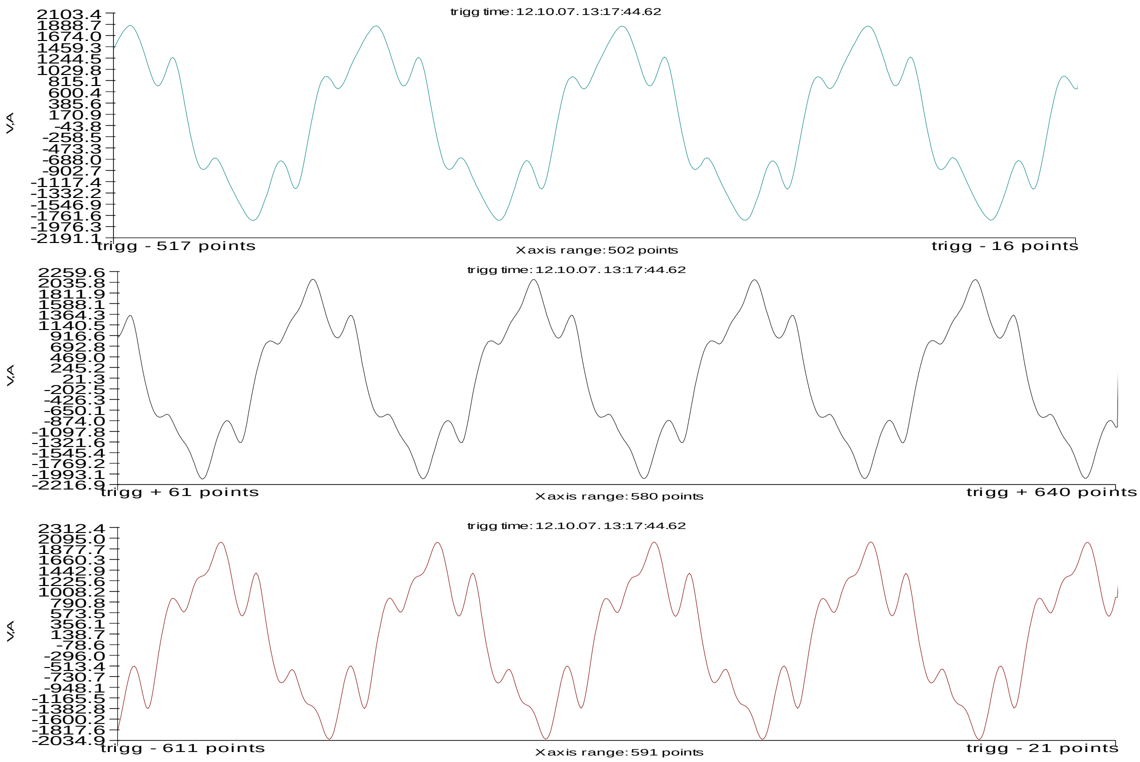

Figure 10. Current Waveforms of R, Y & B Phases without Current Compensation

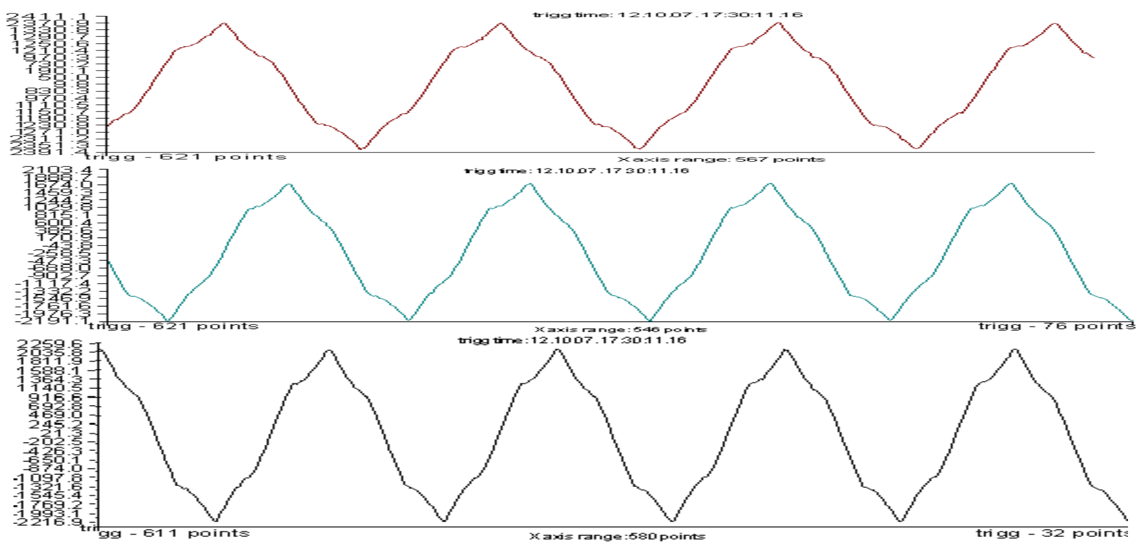

Figure 11. Current Waveforms of R, Y & B Phases with Current Compensation

Table 1. Measured PQ Parameters

Parameters	Without Injection Circuit			With Injection Circuit		
Phase	R	Y	B	R	Y	B
Crest Factor	1.4	1.58	1.61	1.58	1.62	1.624
Total % I_{THD}	27.5	24.2	33	8.7	8.7	9.8
5^{th} Harmonic	25.2	22.3	27.2	8.1	8.2	9.1
7^{th} Harmonic	10.2	8.0	18.3	2.8	2.8	3.1
PFs		0.87			0.98	

6. CONCLUSION

In this paper, a three-phase active current injection rectifier is used to achieve high power factor operation of heavily distorted and unbalanced load currents at the point of common coupling (PCC). The linear control regulator used to control the converter was designed with the help of suitable hardware circuitry. The proposed strategy reduces the harmonic content of a three-phase rectifier. Simulations and experimental results were found to be in good agreement. The system exhibits a fast dynamic response, high efficiency, high power factor, and low harmonic content. The harmonics injected by conventional rectifier can be compensated by the active compensation circuit, thus the input power factor can be increased. The average real power consumed by load is supplied by the source, and the active compensation circuit does not provide or consume any average real power. The simulation results show that the input power factor can be well improved and input current harmonics can be effectively eliminated under wide load variation. The proposed control strategy also exhibits a sufficient adaptability to load variations. The design of high performance UPF operation of front end rectifier has been presented in this work. It is good alternative for current harmonics compensation and displacement power factor correction. Another technical disadvantage of passive filters is related to the small design tolerances acceptable in the values of inductor and capacitor. And also individual harmonic current only compensated. In order to overcome these problems UPF operation of front end rectifier is designed, which is based on the sinusoidal bidirectional switching topology to compensate simultaneously all the order of harmonics. Hardware is implemented with unbalanced system, it is possible to redistribute and equilibrate the mains phase currents, providing that the total amount of power coming from the mains same as the amount required for the load.

REFERENCES

[1] Montero MIM, et.al., "Comparison of Control Strategies for Shunt Active Power Filters in Three-Phase Four-Wire Systems", *IEEE Transactions on Power Electronics*, vol. 2, pp 229-236, 2007.

[2] Pengju Kong, "A novel high-frequency digital PFC controller with second harmonic compensation", IEEE Region 10 Conference, vol. 4, pp 53-56, 2004.

[3] Zhong Chen, Dehong Xu, "Control and design issues of a DSP-based shunt active power filter for utility interface of diode rectifiers", IEEE Applied Power Electronics Conference and Exposition, vol. 1, pp 197 – 203, 2004.

[4] Pini, SH, Barbi I., "A Single-Phase High-Power-Factor Rectifier, Based on a Two-Quadrant Shunt Active Filter", *IEEE Transactions on Power Electronics*, vol. 26, pp. 3131 - 3143, 2011.

[5] Fukui K., Koizumi H., Class E., "Rectifier with Controlled Shunt Capacitor", *IEEE Transactions on Power Electronics*, vol. 27, pp. 3704 – 3713, 2012.

[6] Meral ME., "Using active power factor correction (PFC) boost rectifiers for an improved topology of static series compensators with no energy storage", *IET Power Electronics,* vol/issue: 5(8), pp. 1438 – 1445, 2012.

[7] Po-Tai Cheng, et. al., "Design of an Auxiliary Converter for the Diode Rectifier and the Analysis of the Circulating Current", *IEEE Transactions on Power Electronics*, vol/issue: 23(4), pp. 1658 – 1667, 2008.

[8] Cichowlas M., et. al, "Active filtering function of three-phase PWM boost rectifier under different line voltage conditions", *IEEE Transactions on Industrial Electronics*, vol/issue: 52(2), pp. 410 – 419, 2005.

[9] Wiroj Tangtheerajaroonwong, et. al., "Design and Performance of a Transformerless Shunt Hybrid Filter Integrated Into a Three-Phase Diode Rectifier", *IEEE Transactions on Power Electronics*, vol. 22, pp. 1882 – 1889, 2007.

[10] Xiong Du, et. al., "DC Link Active Power Filter for Three-Phase Diode Rectifier", *IEEE Transactions on Industrial Electronics*, vol. 59, pp. 1430 – 1442, 2012.

[11] Terciyanli A, et. al., "A Selective Harmonic Amplification Method for Reduction of kVA Rating of Current Source Converters in Shunt Active Power Filters", *IEEE Transactions on Power Delivery*, vol. 26, pp. 65-78, 2011.

[12] Rahmani, B., "Reciprocal effects of the distorted wind turbine source and the shunt active power filter: full compensation of unbalance and harmonics under 'capacitive non-linear load' condition", *IET Power Electronics*, vol. 6, pp. 1668 – 1682, 2013.

[13] Beak J, et. al., "Re-using & re-rating older rectifiers with new DC/DC choppers", *IEEE Transactions on Industrial Applications*, vol/issue: 37(4), pp. 1160–1166, 2001.

[14] Scaini V., "High-current DC choppers in the metals industry", *IEEE Transaction on Industrial Applications Magazine*, vol/issue: 8(2), pp. 26–33, 2002.

[15] AI. Maswood, F. Liu, "A novel unity power factor input stage for AC drive application," *IEEE Transactions on Power Electronics*, vol/issue: 20(4), pp. 839-846, 2005.

[16] Darly SS., et. al., "Fault Tolerant Control in Z-Source Inverter Fed Induction Motor", *International Journal of Power Electronics and Drive System,* vol/issue: 1(1), pp. 29~35, 2011.

[17] C. Qiao, KM. Smedley, "Three-phase unity-power-factor star connected switch rectifier with unified constant-frequency integration control", *IEEE Transactions on Power Electronics*, vol/issue: 18(4), pp. 952-957, 2003.

BIOGRAPHIES OF AUTHORS

She is pursuing her PhD in Electrical Engineering in Anna University. She received her M.E Degree from Anna University in the year 2005. Her areas of interest include Power Electronics, Active current injection and power quality.

He received his PhD in Electrical Engineering from Anna University. He has published 41 research articles in peer-reviewed national and international journals. He is an Advisory Board Member in various International Conferences and an active Editor and reviewer of various reputed Journals. His span in research is across the areas of power quality solutions, Intelligent Controllers, data mining, energy conservation, adjustable speed drives and technology management.

\