Hybrid Rectifier with Low Total Harmonic Distortion and Unity Power Factor

Shilpa R., A. Sreedevi
Department of Electrical and ElectronicsEngineering
RV college of Engineering
Banglore, India

Abstract

Line commutated rectifier are being used in many industrial applications. This draws non sinusoidal current from the supply which has harmonics in the line current. Hence, to reduce these harmonics and to adopt this circuit operation in high power application another circuit called unidirectional two level pulse width modulation (PWM) rectifier is connected with line commutated rectifier in parallel. The power is shared between these two rectifiers. The main objective of this proposed circuit is to obtain the sinusoidal line current and output voltage regulation. The passive rectifier operates at low frequency and high power rating. PWM rectifier is designed to operate at high frequency and low power rating. Lesser the power given to the passive rectifier lesser will be the harmonics. PI controller is used to regulate the output voltage. Closed loop control for both current and voltage are implemented. The simulation is done using MATLAB for 24.5KW output power. The input current of sinusoidal in nature is obtained having unity power factor. The load voltage is regulated at 700V.

Index terms- Active rectifier; boost converter; Hybrid rectifier; passive rectifier; power factor correction; voltage regulation.

1. Introduction

Traditionally, AC to DC power conversion is performed by diode or phase controlled rectifiers. These are called "line commutated" rectifiers as commutation takes place at the zero crossing of the current. These are robust and less cost. These rectifiers by themselves cannot be used for the controlling of the output voltage. Hence in many industries these are rarely used. Another disadvantage is high total harmonic distortion (THD) which is observed in the input current, which deteriorates the power quality. In order to compensate this, passive linear filters or power factor correction circuits may be used.

In multipulse, three phase rectifier, harmonic cancellation can be achieved by phase shift with the help of special three phase transformer [1], [2]. It is simple and reliable but is heavy, bulky and expensive. This weight and volume can be reduced by using autotransformer with differential connection instead of 2 winding transformer. Six secondary windings and four inter phase reactors for 12 pulse structure and twelve secondary windings and six inter phase reactors for 18 pulse structure are required and the rating of autotransformer is only 20% of the output power. Even though it improves the quality of the input current, control of output voltage cannot be achieved.

Three phase PWM rectifiers are employed in low and medium power applications. These structures are the most promising rectifiers for high power quality point of view as they can present low harmonic distortion and unity power factor [3]–[6]. The standards IEEE519 and IEC 61000-3-4 have been framed regarding the restrictions in the harmonic content generated by the power converter. This has become an aim in many recent studies. However obtaining of low THD in high power converter is a complex task.

The recent advances have introduced a solution for the high power converters called 'Hybrid Rectifier' [6], [7] which have series or parallel connection of line commutated rectifiers and self commutated converter. Self commutated converters consist of three active switches. Even though it has reduced THD and output voltage control, the power shared by self commutated converter is 45% of the total output power and THD obtained is between 0 to 32%. Lesser the power given to the self commutated converter lower is the THD [8].

All the above factors motivated an envisioning the design concept with several intended benefits like improved power sharing, output voltage control, high efficiency, high reliability and simple control scheme. This paper presents a scheme which contains voltage and current controllers in the feedback loop of Hybrid rectifier to achieve constant DC voltage and unity power factor on the AC side to maintain power quality.

IJERT

2. Hybrid rectifier

It is well known that undesirable harmonic line currents may be generated during rectification. These non-linear loads cause severe current harmonics that may not be tolerated by either a shutdown of the device or unacceptable powering of the devices. Thus, a significant opportunity exists to facilitate power electronics applications by using AC to DC rectifiers that produce low harmonic current in the ac source. The proposed Hybrid rectifier is a parallel connection of line commutated rectifier and self commutated converter as shown in Fig. 1. This line commutated rectifier or passive rectifier operates with low frequency and high rated power. The self commutated converter, unidirectional PWM rectifier or active rectifier is designed to operate at high frequency and low power rating. This active rectifier cannot be classified as active filter because this rectifier processes active power where as active filters have the characteristic to process only reactive power. Each rectifier shares around 50% of the output power thereby increases the efficiency and improves robustness.

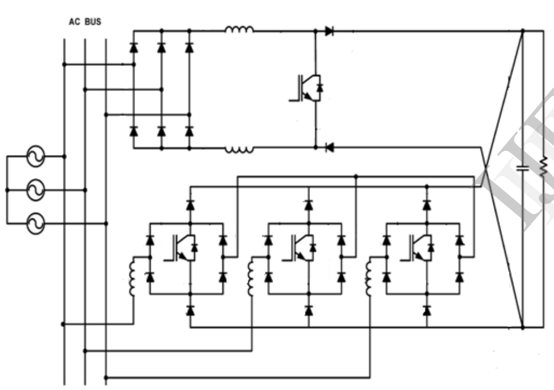

Fig. 1. Three phase Hybrid rectifier

2.1 Passive rectifier

The passive rectifier consists of both Diode Bridge and the boost converter as shown in Fig. 2. The diode bridge circuit draws non sinusoidal current from the input and do not meet with the IEEE519 and IEC61000-3-4, hence it effectively reduces the power quality. Boost regulator can also be used as power factor correction circuit and can reduce the harmonics in the input current. The output from diode rectifier is given to the boost converter. Inductor is used as an energy storing element and maintains the current constant. The modification has been done in the circuit such as splitting of boost inductor as (Lp1 and Lp2) and boost diode to avoid inappropriate current paths. This variation does not affect the operation of the circuit. The capacitor is used as a filter to obtain constant DC voltage.

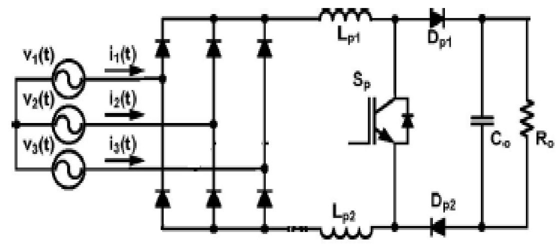

Fig. 2. Three phase diode rectifier fed boost converter

2.2 Active rectifier

IJERT

Unidirectional PWM rectifier is the self commutated converter. In the view of obtaining high power factor and low THD for high power applications, the active rectifier is connected in parallel to provide compensation current (or active current) to compensate passive current of passive rectifier. This technique maintains the input current to be sinusoidal. The three phase AC to DC converters without neutral wires are used in many applications such as power supply for telecommunication, UPS's and electric drives. Many PWM topologies have been developed to obtain input current with low THD which belongs to the family of three level converters called Vienna rectifiers, require complex strategy to obtain steady output voltage across the capacitors. In case of two level PWM rectifiers, shown in Fig. 3, the split capacitors method is not required. Therefore the design and control is simple when compared to three level PWM rectifier.

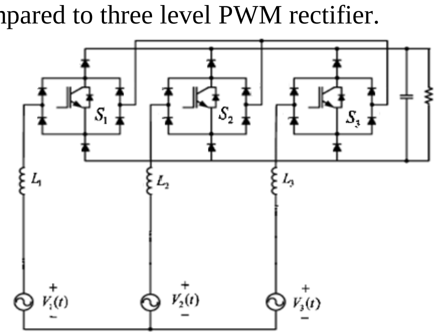

Fig. 3. Three phase three switch two level PWM rectifier

3. Controlling Technique

Figure 4 shows the overall controlling scheme of the hybrid rectifier. It consists of two current controllers. A voltage controller which is common for both active and passive rectifier is designed. Voltage controller will regulate the output voltage to a desired value. Current controller of passive rectifier is used to control the boost inductor current and current controller of active rectifier is used to control the supply current to meet the requirement. K1 and K2 are the gains for signals fed to current controllers, used to adjust the current sharing of each circuit.

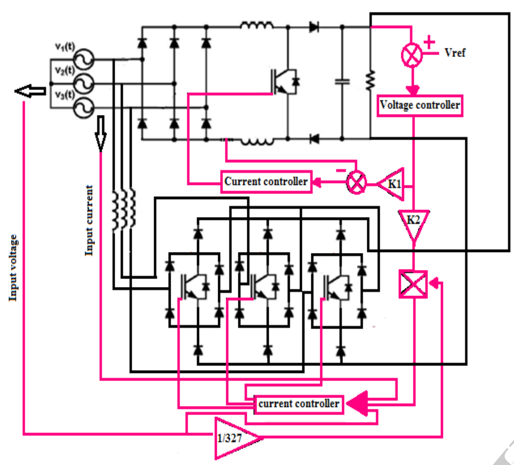

Fig. 4. Control scheme for Hybrid rectifier

IJERT

3.1 Passive rectifier control

The passive rectifier controlling consists of voltage control loop and current control loop as shown in Fig. 5. The output voltage is sensed and compared with the reference voltage V_{ref}. This error is given to the PI controller. The PI controller is tuned by using Ziegler and Nichols second method. The output of PI controller is used to adjust the current reference if the load or input voltages change. In the current controller, the boost inductor current is sampled and compared with the current reference and the error is used to generate the gate signal to the switch directly without any logic block.

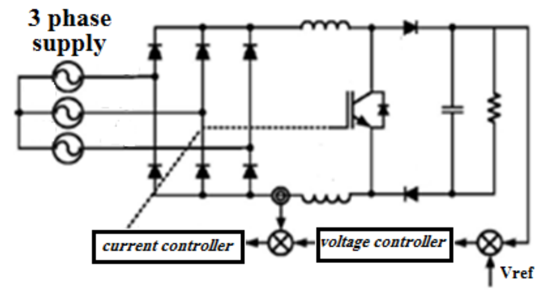

Fig. 5. Passive rectifier control

3.2 Active rectifier control

Figure 6 shows the simulation of unidirectional PWM rectifier (active rectifier).

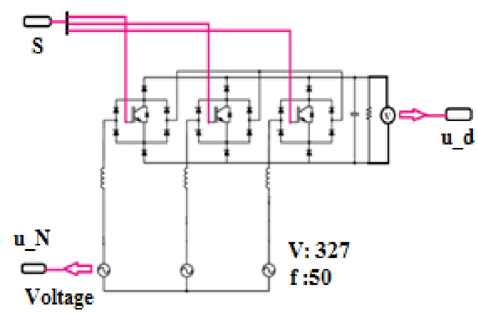

Fig. 6. Active rectifier

The controlling circuit consists of two subsystem block loops as shown in Fig. 7. This consists of an inner current loop and outer voltage loop. The voltage loop regulates the voltage using PI controller. The output of PI controller is the reference for the main current amplitude I_N*. This is multiplied with the three phase sinusoidal signal which is synchronized with the supply voltages to obtain the three phase supply current reference i_N*. Finally, this reference current is given to the current controller.

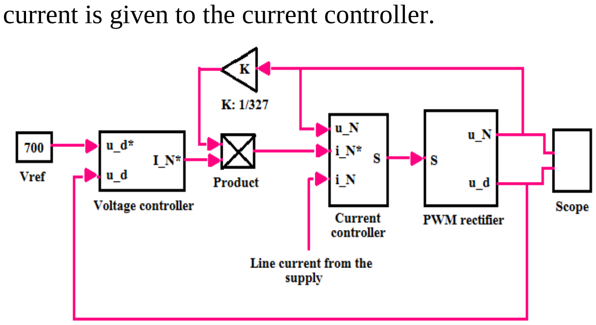

Fig. 7. Controlling loops for PWM rectifier

The current controller to limit the switching frequency is shown in Fig. 8. The main reference current is compared with the line current. The error is determined and tested to lie within the limits ±h. The relay block switches between two specified values. When ON (Si´=1), it remains on until the input drops below the value -h. When OFF (Si´=0), it remains off until it exceeds the value +h. This is given to the logic controller.

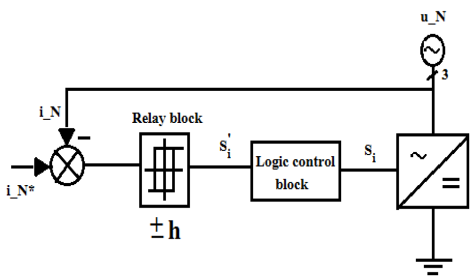

Fig. 8. Current control

4. Simulation

The MATLAB simulation of the open loop passive rectifier is as shown in Fig. 9.

Specifications used in simulation are:

Output power	24.5KW
Phase-phase RMS input voltage	400 V
Supply frequency	50Hz
Output voltage	700 V
Boost inductor of passive rectifier	2mH
Inductor of active rectifier	2.5mH
Output capacitor	4400µF
Output resistance	20 ohms
Gains K1=0.25, K2=0.4	

The duty cycle of the switch should be 23.3% to get the output voltage of 700V.

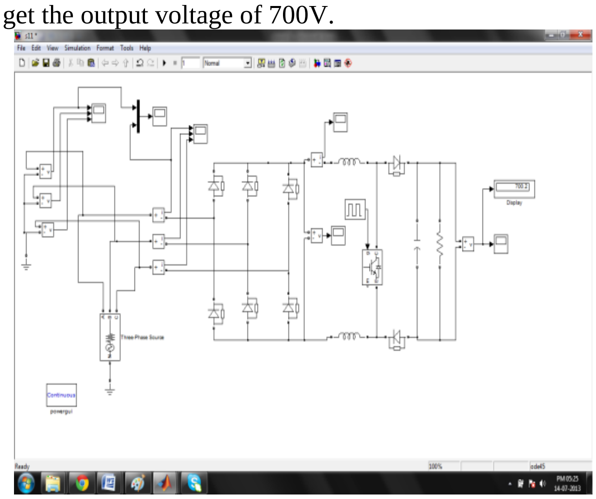

Fig. 9. Open loop passive rectifier

The open loop simulation for PWM rectifier is as shown in Fig. 10. The duty cycle of the three switches should be 29% to get the output voltage of 700V . All the three switches are switched ON simultaneously.

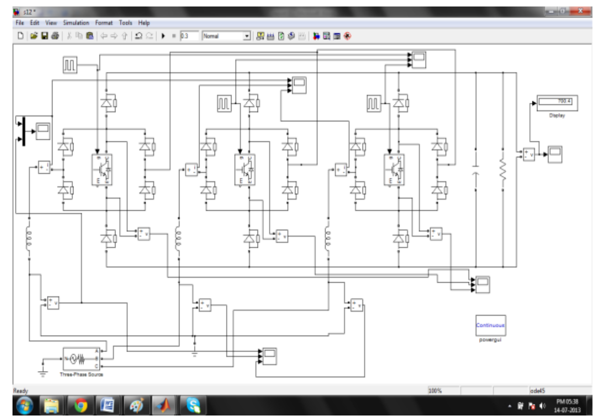

Fig. 10. PWM rectifier with open loop

The hybrid rectifier simulation circuit is shown in Fig. 11. The highlighted blocks are the controlling subsystem blocks.

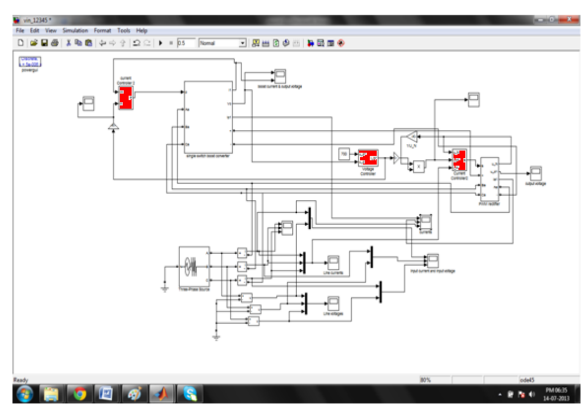

Fig. 11. Hybrid rectifier

Figure 12 shows the voltage controller which is common for both the rectifier circuits. The saturation will impose upper and lower bounds for the signal obtained by the PI controller. When the output of the PI controller is within the specified limits, it passes through nonlinear block (saturation block) without any variation. But if it is outside the limits of the saturation block, the block clips the signal to the upper or lower limit. This PI controller is designed to limit the

IJERT

maximum allowable voltage to 800. The parameters are manually tuned.

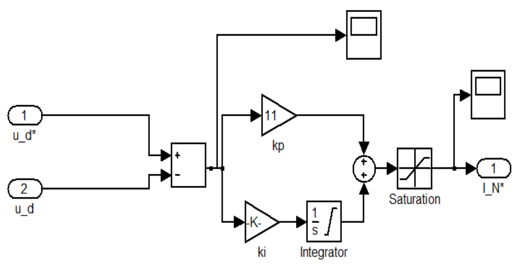

Fig. 12. Common voltage controller block

Figure 13 shows the current controller block of the passive rectifier. The inductor current is compared with the reference current obtained from the voltage controller. The error is fed to the relay block. The relay block has switch ON point and switch OFF point as +0.1 and -0.1 respectively.

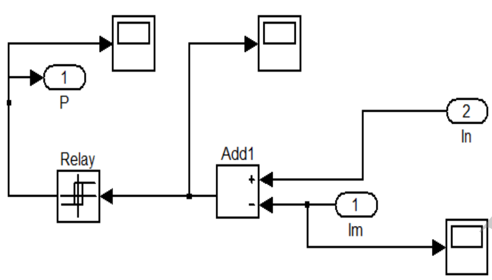

Fig. 13. Current control of passive rectifier

The reference current obtained from PI controller is compared with the line current of the supply by the current controller of the active rectifier as shown in Fig. 14 and the error is given to relay having switch ON and OFF point of +0.001 and -0.001 error respectively. This output is given to the logic control block.

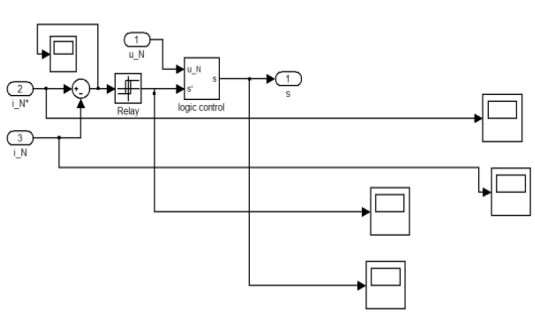

Fig. 14. Current control of active rectifier

The logic control block along with the control is shown in Fig. 15. The output of the logic controller is described below.

S = S´ if u_N ≥ 0

S = NOT S´ if u_N < 0

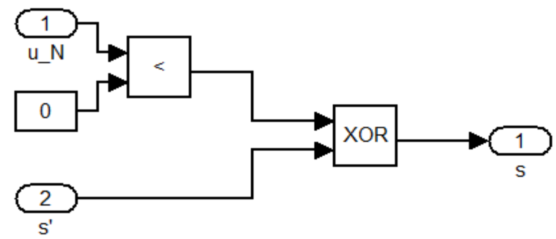

Fig. 15. Logic control block

5. Results

The input voltage of phase to phase RMS voltage of 400V is shown in Fig. 16.

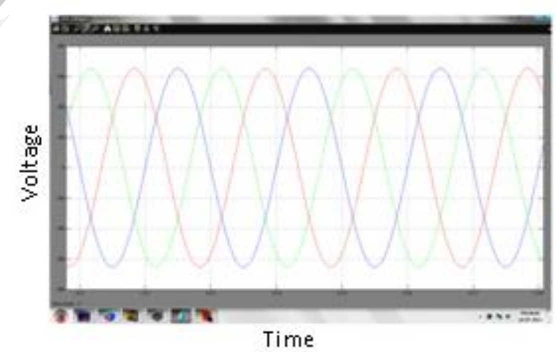

Fig. 16. Input voltages

The output voltage waveform of open loop passive rectifier is as shown in Fig. 17. As this waveform is the under damped oscillatory in nature, the controlling is required to reduce this oscillation.

IJERT

ISSN: 2278-0181
Vol. 2 Issue 8, August - 2013

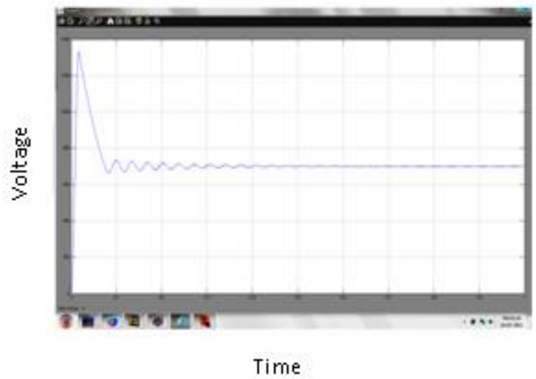

Fig. 17. Output voltage of passive rectifier with open loop

Input current drawn from the supply is as in Fig. 18. From this waveform it is clear that, the input current draws non sinusoidal current from the supply.

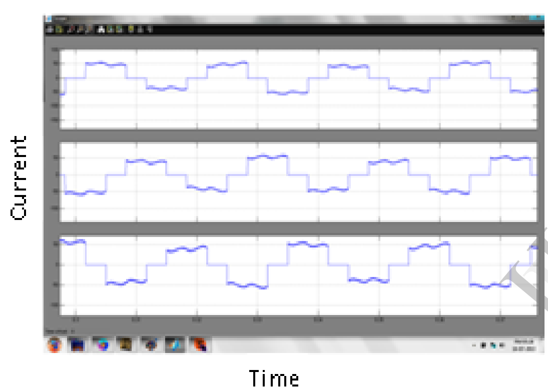

Fig. 18. Input current of passive rectifier in open loop

The input voltage and current drawn from the supply when only passive rectifier is considered, is as shown in Fig. 19. It is seen that both current and voltages are in phase when the resistive load is applied.

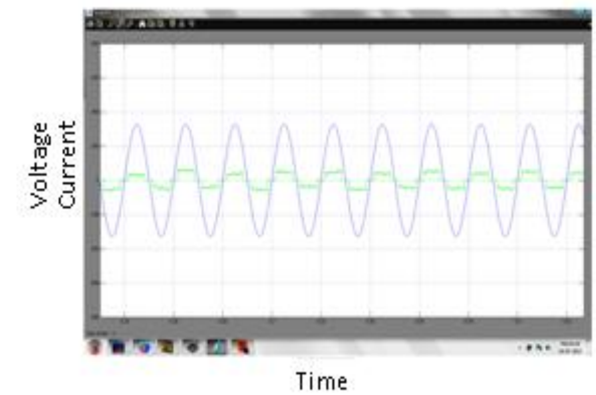

Fig. 19. Input voltage and current of open loop passive rectifier

The output voltage of open loop active rectifier is shown in Fig. 20. As there exist a peak overshoot for both passive and active rectifier output voltages, Ziegler Nichols second method is used in the design of PI controller.

IJERT

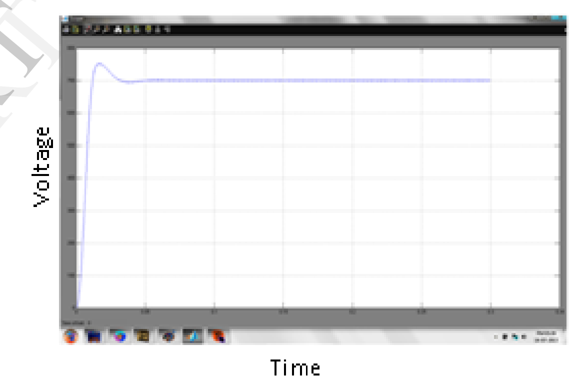

Fig. 20. Output voltage of PWM rectifier

It is observed from Fig. 21 that input voltage and the input current drawn from the open loop PWM rectifier circuit are not in phase. By using the controller, the power factor is improved.

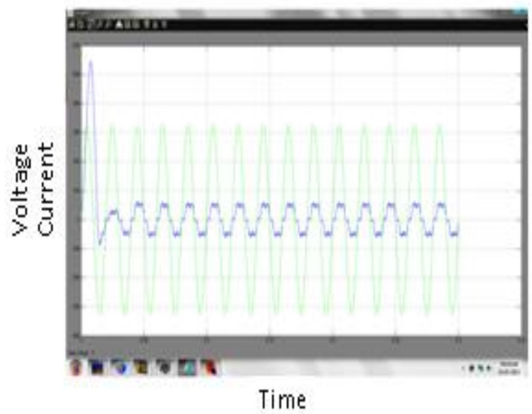

Fig. 21. Input voltage and current of open loop active rectifier

The current drawn by the three phase passive rectifier, active rectifier and the total current are shown in Fig. 22. This shows that passive rectifier is drawing around 30A from the supply current. The compensation current drawn by the active rectifier gives the rest of the part of the required source current to take care of the load. This leads to realize sinusoidal supply current. Hence from the results it is seen that active current is 20A. The total input current from the supply is 50A. So, around 60% of the power is given to passive rectifier.

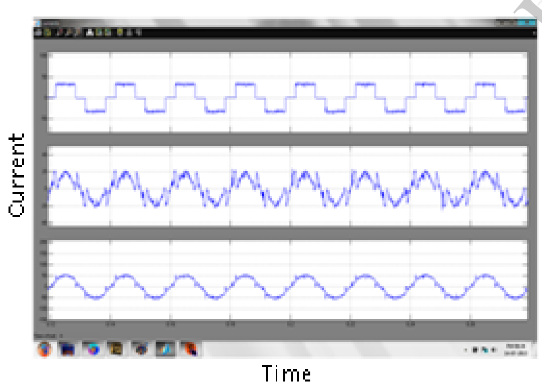

Fig. 22. Phase a currents

The power factor for the closed loop Hybrid rectifier system is shown in Fig. 23. This shows that both current and voltage are in phase.

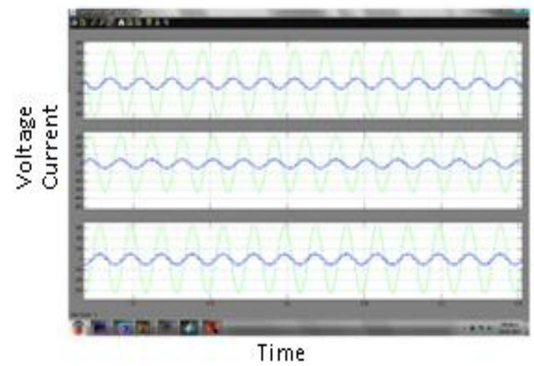

Fig. 23. Input current and input voltage

The output voltage of 700V obtained is shown in Fig. 24 with the elimination of oscillations.

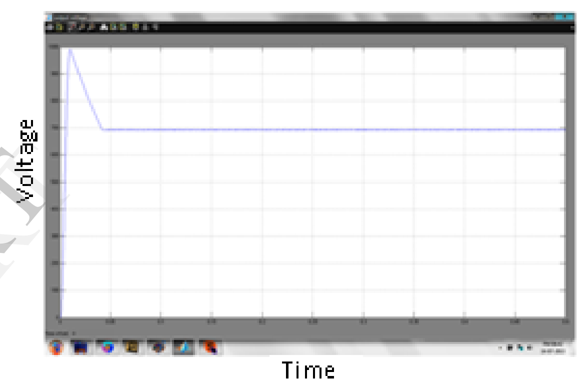

Fig. 24. Output voltage

The load drawing current of 35A is shown in Fig. 25.

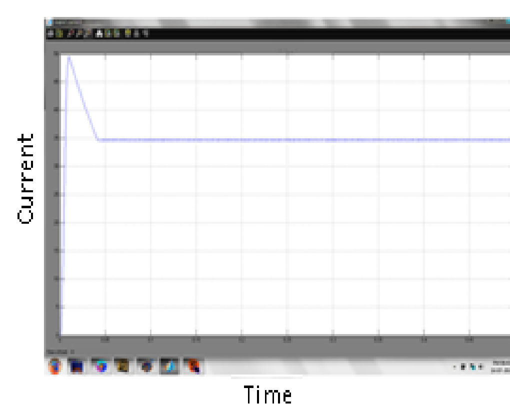

Fig. 25. Output current

The current and voltage across a single switch of passive rectifier is shown in Fig. 26. It is seen that the

IJERT

maximum current and the voltage across the switch is approximately 40A and 700V. From these values, the voltage and current rating of the switch to be used in hardware are determined.

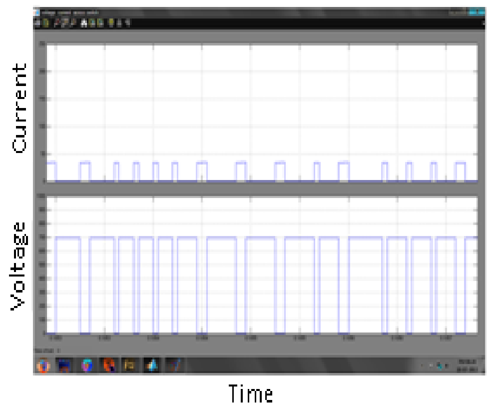

Fig. 26. Voltage and current of a passive rectifier switch

Figure 27 and 28 shows the voltage and current across the three switches of the active rectifier. It is observed that peak voltage across the switch is 700V and maximum current through it is 20A approximately.

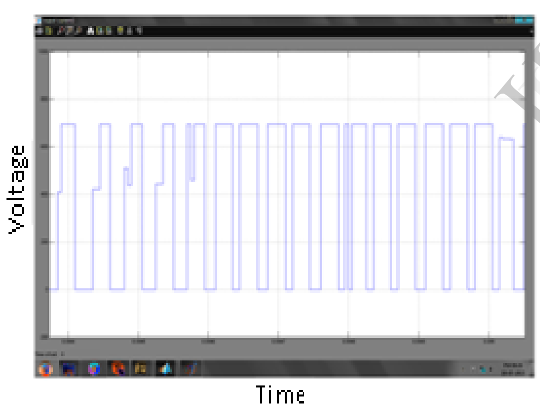

Fig. 27. Voltage across the switch of active rectifier

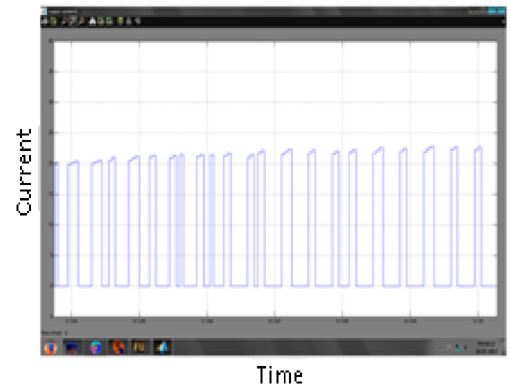

Fig. 28. Current through the switch of active rectifier

6. Conclusion

The adopted control technique regulates the output voltage and maintains it constant. The AC input current has low harmonics and high power factor. The passive rectifier operates at high power and low switching frequency and active rectifier is designed to posses' low power and high frequency. The power shared by the passive rectifier is 60% and active rectifier is 40%.

The simulation results show that the power factor achieved is unity and the input current is sinusoidal. The main advantage of this is that it can be operated for the high power since power is shared between the two circuits. It is observed that on increasing the load resistance the settling time increases. The voltage rating of the active and passive rectifier switches is 700V. The current rating of active rectifier switches is 40A and for passive rectifier switch is 20A. The THD obtained for the open loop passive rectifier is 31.83% where as in the proposed circuit, the THD obtained is 13.19%.

7. Reference

[1] M. E. Villablanca, J. I. Nadal and M. A. Bravo, "A 12-pulse AC–DC rectifier with high-quality input/output waveforms," *IEEE Trans. Power Electron.*, vol. 22, no. 5, Sep. 2007, pp. 1875–1881.

[2] B. Singh, S. Gairola, B. N. Singh, A. Chandra and K. Al-Haddad, "Multipulse AC–DC converters for improving power quality: A review," *IEEE Trans. Power Electron.*, vol. 23, no. 1, Jan. 2008, pp. 260–281.

[3] R. Ghosh and G. Narayanan, "Control of three-phase, four-wire PWM rectifier," *IEEE Trans. Power Electron.*, vol. 23, no. 1, Jan .2008, pp. 96–106.

IJERT

[4] F. A. B. Batista and I. Barbi, “Space vector modulation applied to three-phase three-switch two-level unidirectional PWM rectifier,” *IEEE Trans. Power Electron.*, vol. 22, no. 6, Nov. 2007, pp. 2245–2252.

[5] Deivis Borgonovo, Yales Romulo de Novaes and Ivo Barbi, “A Three Phase Three switch Two level PWM Rectifier,” *Power Electronics Specialist Conference, 2003. PESC ’03. IEEE 34th Annual*, vol. 3, 2003, pp. 1075-1079.

[6] H. Yoo, J. Kim and S. Sul, “Sensorless operation of a PWM rectifier for a distributed generation,” *IEEE Trans. Power Electron.*, vol. 22, no. 3, May 2007, pp. 1014–1018.

[7] Sunt Srianthumrong and Hirofumi Akagi, “A Medium-Voltage Transformerless AC/DC Power Conversion System consisting of a Diode Rectifier and a Shunt Hybrid Filter,” *IEEE Transactions on Industry Applications*, vol. 39, no. 3, May/June 2003, pp. 874-882.

[8] L. C. G. de Freitas, M. G. Sim˜oes, C. A. Canesin and L. C de Freitas, “Programmable PFC based hybrid multipulse power rectifier for ultraclean power application,” *IEEE Trans. Power Electron.*, vol. 21, no. 4, Jul. 2006, pp. 959–966.

[9] Ricardo Luiz Alves and Ivo Barbi, “Analysis and implementation of a Hybrid High Power Factor Three Phase Unidirectional Rectifier,” *IEEE Trans. on Power Electron.*, vol. 24, no. 3, March 2009, pp. 632-640.

[10] Ankusha. Biradar and Nagabhushan. Patil, “Implementation of a Hybrid High Power Factor Three-Phase Unidirectional Rectifier,” *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, vol. 2, no. 4, March 2013, pp. 203-206.

[11] Yun Wei Li, Bin Wu, Navid R. Zargari, Jason C. Wiseman and David Xu“ Damping of PWM Current-Source Rectifier Using a Hybrid Combination Approach,” *IEEE Trans. on Power Electron.*, vol. 22, no. 4, July 2007, pp. 1383-1393.

[12] Ruma and Mohammad Ali Choudhury, “Power Factor Improvement of a Three Phase Rectifier by Boost Regulator,” *Journal of Electrical engineering*, vol. EE 36, no. 2, Dec. 2009, pp. 22-27.

[13] S.M. Bashi, N. Mariun, S.B. Noor and H.S. Athab, “Three-phase Single Switch Power Factor Correction Circuit with Harmonic Reduction,” *Journal of Applied Sciences*, vol. 5, no. 1, 2005, pp. 80-84.

[14] Mubktiar Ahmed Mahar, Muhammad aslam Uqaili and Abdul Sattar Larik, “Harmonic Analysis of AC-DC Topologies and their Impacts on Power Systems,” *Mehran University Research Journal of Engineering and Technology*, vol. 30, no. 1, Jan. 2011, pp. 173-178.

[15] Juing-Huei Su, Chien-Ming Wang and Chao-Liang Chien, “Learning the Design of Power Factor Correction Circuits Via Matlab/Simulink,” *Journal of Technology*, Vol. 19, no. 3, 2004, pp. 269-276.

[16] Sanjay L Kurkute, Pradeep M Patil and K.C. Mohite, “A Digital Power Factor Correction using Floating Point Processor for Pulse Width Modulation Control in Boost Converters,” *International Journal of Electronic Engineering Research*, Vol. 1, no. 2, 2009, pp. 135–146.

[17] Grzegorz Radomski, “Analysis of Vienna Rectifier,” *Electrical Power Quality and Utilisation Journal*, vol. XI, no. 1, 2005, pp. 49-56.

[18] Vimla Patel and Shivendar Singh Thakur, “Simulation of Vienna Rectifier to Enchance Power Quality by Reduce THD,” *International Journal of Engineering and Innovative Technology (IJEIT)*, vol. 2, no. 9, March 2013, pp. 238-235.

[19] Katsuhiko Ogata, *Modern Control Engineering*, Pearson, 5th Edition, 2009.

[20] Muhammad H.Rashid, *Power Electronics Ciruits, Devices and Applications*, Pearson Education Inc., Third Edition, 2004.

[21] Ned Mohan, Tore M.Underland and William P.Robbons, *Power Eletronics Converters, Applications and Design*, John Wiley and Sons Inc., Third Edition, 2007.

IJERT