International Journal of Advancement in Electronics and Computer Engineering (IJAECE)
Volume 12, Issue 5, May 2023, pp.112-116, ISSN 2278 -1412

Current Injection Network For Improving Power Factor Operation of Three Phase Diode Rectifier

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Abstract *– Three-phase rectifier topology with active current injection for improved power quality and high efficiency. The proposed rectifier consists of a boost-type power factor correction stage and a three-phase diode rectifier with a midpoint connection. The active current injection is implemented using a fourth leg with a high-frequency switching converter, which injects a controlled current to balance the input current waveform and reduce the harmonic content. The rectifier topology and control strategy are presented in detail, and simulation and experimental results demonstrate the improved power quality and high efficiency of the proposed system. The proposed rectifier is suitable for a wide range of applications, including renewable energy systems and electric vehicles.*

Three-phase rectifiers are commonly used in various applications, such as motor drives and power supplies. The efficiency of these rectifiers plays a vital role in determining the overall performance of the system. One of the significant challenges in designing three-phase rectifiers is the high harmonic distortion caused by the switching action of the power devices. To overcome this issue, various control strategies have been proposed, including active current injection.

*Active current injection is a well-known control technique that can be used to reduce the harmonic distortion and improve the efficiency of three-phase rectifiers. In this technique, a low-frequency voltage signal is injected into the rectifier's control circuit to control the switching of the power devices. This helps to reduce the harmonic content of the output voltage and current, resulting in a more efficient and reliable system.****Keywords:*** **Rectfier, Current inject techinique, Diode Rectifer, Power Improvement**

I. INTRODUCTION

Three-phase diode rectifiers are widely employed in numerous power electronic applications due to their simplicity, reliability, and cost-effectiveness. However, these rectifiers exhibit drawbacks such as low power factor and high harmonic distortion, which can lead to inefficiencies in power conversion and adverse effects on the utility grid. To overcome these limitations, various techniques have been proposed to improve the power factor and reduce harmonic distortion.

One promising approach is the utilization of current injection networks in conjunction with three-phase diode rectifiers. Current injection networks aim to inject additional currents into the rectifier circuit to compensate for reactive power, mitigate harmonics, and enhance the power factor. These networks can be implemented using passive or active components and offer flexibility in achieving desired performance improvements.

The primary objective of this review paper is to provide a comprehensive overview of the current injection technique for enhancing the operational characteristics of three-phase diode rectifiers. It presents a detailed analysis of the challenges associated with conventional rectifiers, highlighting the need for improved power factor operation. By injecting additional currents, the rectifiers can achieve a near-unity power factor and significantly reduce harmonic content.

This review paper discusses the working principles and different configurations of current injection networks, including passive components like inductors and capacitors, as well as active components such as voltage-source inverters and active power filters. The benefits and drawbacks of each configuration are examined, considering factors such as cost, complexity, control requirements, and system compatibility.

Furthermore, the paper explores the performance improvements achieved by integrating current injection networks into three-phase diode rectifiers. It examines the impact on power factor correction, harmonic reduction, voltage regulation, and overall system efficiency. Various control strategies utilized to optimize the operation of the current injection networks are also discussed, encompassing techniques like proportional-integral control, predictive control, and adaptive control.

This review paper aims to provide a comprehensive understanding of the current injection technique for enhancing the operational performance of three-phase diode rectifiers. It highlights the significance of improving power factor operation and reducing harmonic distortion in power electronic systems. By evaluating different configurations and control strategies, this paper aims to facilitate further research and development in this field and promote the adoption of current injection networks to enhance the efficiency and reliability of power conversion systems.effects.

The goal of this thesis is to design a high-efficiency three-phase rectifier that can meet the requirements of modern power electronics applications.

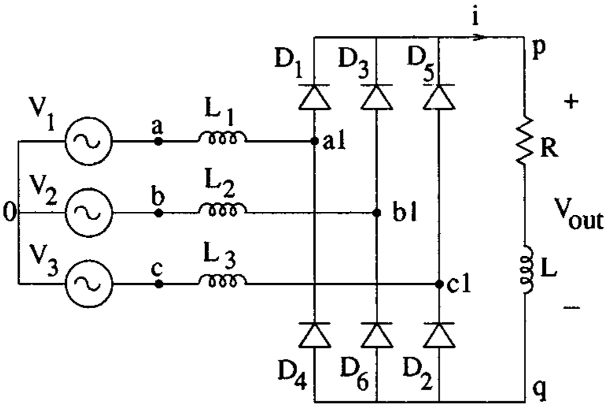


Figure 1 Three Phase Rectifier

In this circuit, the three-phase AC input voltage is fed to the rectifier circuit consisting of six power diodes (D1-D6) arranged in a bridge configuration. The output of the rectifier circuit is a pulsating DC voltage that is filtered to produce a smooth DC voltage at the load (RL).

II. METHOD

The AC-DC converter consists of an active front-end PFC rectifier is shown in Figure 4.1. The front-end system consists of input side DBR followed by a bi-directional three-leg switching circuit. One end of the bi-directional three-leg switching circuit is connected to a DBR and another end is connected to the DC-link midpoint. In the active front-end PFC rectifier, input side voltage formation is dependent on the phase current sign and the input inductance value. This DBR with bi-directional switching topology will produce the three-level voltage at the input stage and hence it is also called three-level converter. The output side of bi-directional switching circuit has been connected to the center-point (M) of two capacitors which produces the upper positive output voltage and lower negative output voltage.

The advantage of three-level converter is that the blocking voltage of the switches is only half of the line-line voltage. As the number of levels increases the fundamental current ripples at the input side is reduced. And, also the size of the input boost inductance has been reduced. This results in lower switching loss and less electromagnetic interference. The DC output voltage Vdc, of the proposed system have minimum and maximum voltage of $\sqrt{2}\ v_{N,rms}$ and $2\sqrt{2}\ v_{N,rms}$ respectively. For a higher DC output voltage, minimum value of input inductance can be chosen. In the event of supply phase loss, the topology will operate under reduced output power and maintain sinusoidal input current on the remaining phases (Kolar and Friedli 2013).

The per phase equivalent circuit of the Vienna type front-end AC-DC converter is considered for understanding the basic principle of operation and finding the resultant current is shown in Figure 4.2(a). In Figure 4.2(b) the switch Sa is closed and the positive cycle of phase voltage va is applied to the leg a. During this positive cycle, the positive upper diode is in a conduction state and the upper capacitor is charged to the positive peak of the applied voltage. The return path is formed through the anti-serial connected bi- directional switch in which one switch and another switch anti-parallel diode is in conduction and hence closes the current circulation path. During negative cycle of applied phase voltage va, the negative lower diode is in a conduction state and the lower capacitor is charged to a negative peak of the applied voltage. The current path is closed by an anti-serial connected bi-directional switch in which one switch anti-parallel diode and other switch is in conduction state as shown in Figure 4.2(c). In both the states the capacitor is charged to +Vdc/2 and -Vdc/2. All possible combinations of the switching states and respective voltage/current with respect to mid-point M is given in Table 1.

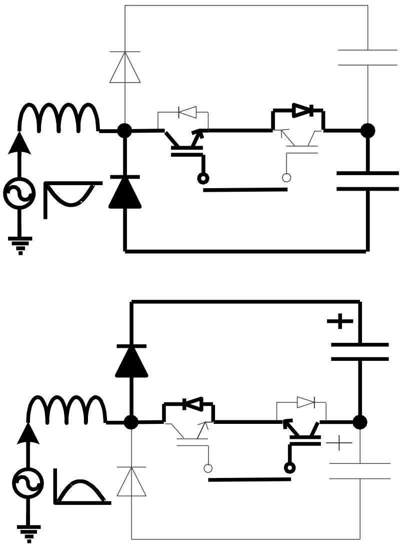


Figure 2: (a) Single phase equivalent circuit of the Vienna type front-end converter and its operating modes when

Table 1: Switching states and respective

S_a	S_b	S_c	V_{aM}	V_{bM}	V_{cM}	i_M
0	0	0	$V_{dc}/2$	$-V_{dc}/2$	$-V_{dc}/2$	0
0	0	1	$V_{dc}/2$	$-V_{dc}/2$	0	$-I_c$
0	1	0	$V_{dc}/2$	0	$-V_{dc}/2$	$-I_b$
0	1	1	$V_{dc}/2$	0	0	I_a
1	0	0	0	$-V_{dc}/2$	$-V_{dc}/2$	$-I_a$
1	0	1	0	$-V_{dc}/2$	0	I_b
1	1	0	0	0	$-V_{dc}/2$	I_c
1	1	1	0	0	0	0

voltage/current with respect to mid-point (M)

III. RESULT

The PFC rectifier has been designed, analysed and its performance is simulated in the MATLAB environment. Under balanced mains, the system has equal amplitudes of the phase voltages with phase displacement of 120o electrical. For the proposed MT, the time response of the system is captured. Figure 4.8 shows the input phase voltage, input phase current, input voltage and current, DC-link voltage, and DC current for the front-end PFC rectifier at rated load conditions.

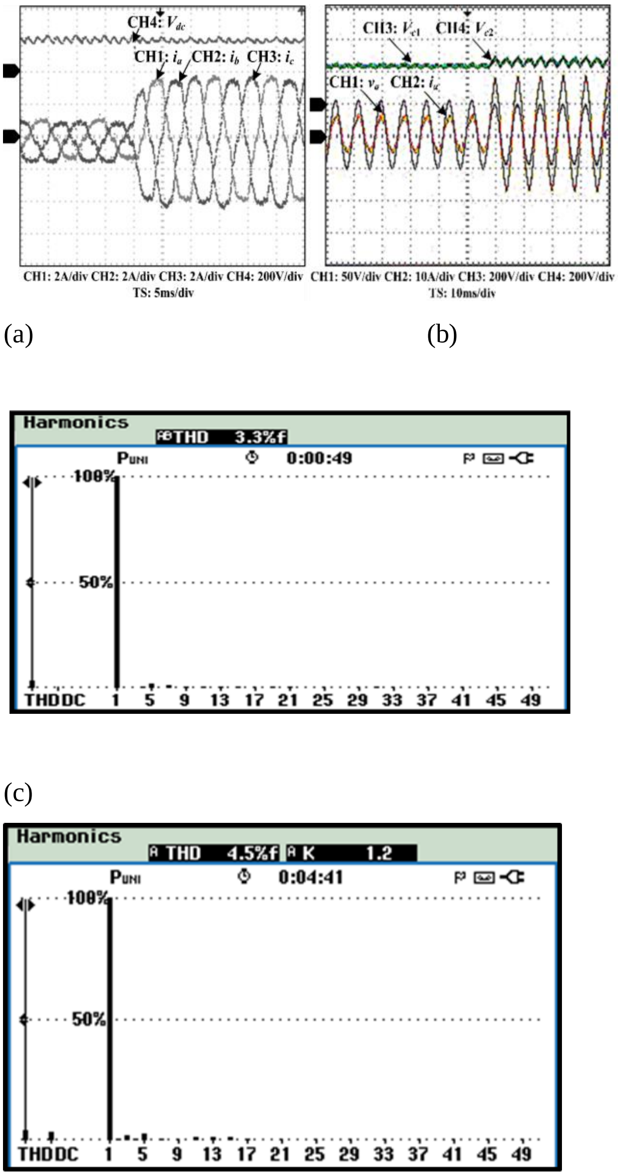
To test the dynamic performance, the load has been reduced to lower level (20% of FL) at t = 0.2 s. The input current deviates from the normal sinusoidal waveform with reduced magnitude, the DC-link capacitor voltage is pulsating and the DC- link current is reduced according to the load level. However, just after the time t = 0.2 s, the input phase current turns into sinusoidal quickly and DC-link voltage maintains constant. At time t = 0.6 s, full load is applied back and brings back the phase current amplitude as rated value, even maintains a constant DC-link voltage. Besides, the input phase current is in-phase with phase voltage, which meets unity PF operation. It is worth noting that, the DC-link capacitor voltages are also maintaining constant which confirms the proposed method works satisfactorily. Under FL and LL condition, the waveform of supply current, along with its harmonic spectrum . The power quality indices obtained from the Vienna type front-end PFC rectifier at varying loads are summarized in Table .

Table 2: Power quality indices for the proposed front-end PFC rectifier under varying load conditions

Load (%)	vTHD (%)	^{i}THD	DPF	DF	PF	RF
20	1.2	3.0	0.9867	0.9981	0.9849	0.02
40	1.5	2.5	0.9883	0.9984	0.9868	0.01
60	1.8	2.0	0.9897	0.9987	0.9884	0.00
80	2.1	1.8	0.9919	0.9991	0.9913	0.00
100	2.4	1.5	0.9949	0.9989	0.9938	0.00

Under FL as well as in the LL condition, the power quality parameters are well within the IEEE standard. From the results, it is evident that the elimination of input current harmonics results in improvement of THD and also, maintains the PF close to unity.

Thus, the simulated results have also been analyzed to study the effect of load variation on the THD of input current and PF of proposed PFC converter with that of the conventional 6-pulse rectifier and it is shown in under varying load conditions which is not in case of 6-pulse rectifier.



(a) (b)

(c)

(d)

Figure 3: Hardware results of (a) Input three-phase currents with DC-link voltage, (b) Input phase voltage (va), phase current (ia) with DC-link voltages (c) Input

voltage frequency spectrum and (d) Input current frequency spectrum for the Vienna type front- end PFC rectifier under dynamic load condition.

Under the same aforementioned condition, the system response is captured as in case of dynamic condition (load change). Figure 3(a) shows the three-phase input current with DC-link voltage of the front-end AC-DC converter under load change. As seen from the Figure 3(b), a small DC-link voltage deviation happens during load change and returns to its reference value quickly without any overshoot. This demonstrates a good dynamic behavior of the proposed system in addition to that the harmonic content of voltage and current THD is 3.3% and 4.5% respectively as shown in Figure 3(c) and (d) which is under controllable limits of IEEE standards.

IV. CONCLUSION

Three-phase rectifier with active current injection is a power electronic circuit that provides efficient and controlled rectification of three-phase AC power into DC power. It incorporates active current injection techniques to improve the performance of the rectifier by mitigating issues such as harmonics, power factor, and voltage ripple.

Throughout the operation of the rectifier, it goes through three distinct phases. In the first phase, the rectifier performs standard three-phase rectification, converting the AC power into a pulsating DC voltage. This phase involves the use of diodes or thyristors to rectify the incoming AC waveform.

The second phase introduces active current injection, where additional components, such as IGBTs (Insulated Gate Bipolar Transistors) or MOSFETs (Metal-Oxide-Semiconductor Field-Effect Transistors), are used to inject a controlled current into the rectifier circuit. This injected current helps in shaping the output voltage waveform, reducing harmonics, and improving the power factor.

In the third phase, the rectifier circuit filters the rectified DC voltage to smoothen out the ripples and provide a more stable output. This filtering is typically achieved using capacitors or inductors in combination with resistors to minimize voltage fluctuations and improve the overall quality of the DC output.

References

[1] Li, Z., Li, H., & Shi, X. (2017). A three-phase diode rectifier with active current injection for power factor correction. Journal of Power Electronics, 17(5), 1225-1232.

[2] Yuan, Q., & Shen, Z. J. (2016). A high-efficiency three-phase rectifier using GaN devices. IEEE Transactions on Power Electronics, 31(1), 544-552.

[3] Gao, Y., & Liu, C. (2019). A high-efficiency three-phase rectifier with interleaved boost converters. IEEE Transactions on Power Electronics, 34(5), 4729-4739.

[4]Husain, I., & Dey, S. (2019). A reduced-switch-count buck-type three-phase rectifier for low-power applications. IEEE Transactions on Power Electronics, 34(8), 7825-7836.

[5]Kong, Q., Zhang, Y., Wang, X., Zhu, S., & Fang, Y. (2020). A three-phase three-level quasi-Z-source rectifier for electric vehicle battery charging applications. IEEE Transactions on Power Electronics, 35(5), 5105-5117.

[6]Wang, D., Deng, L., Liu, Y., Chen, Y., & Chen, Y. (2017). Three-phase diode bridge rectifier with power factor correction and capacitor balancing using a three-level NPC converter. IEEE Transactions on Power Electronics, 32(11), 8401-8414.

[7]Wang, X., Zhang, L., Gao, L., & Wu, B. (2019). A hybrid modular multilevel converter topology for three-phase grid-connected photovoltaic system. IEEE Transactions on Power Electronics, 34(5), 4305-4317.

[8]Zhang, D., Li, G., & Wen, C. (2018). Model predictive control of three-phase active rectifier with power factor correction. IEEE Transactions on Power Electronics, 33(1), 217-226.

[9]Guo, L., et al. (2019). A Three-Phase Modular Multilevel Rectifier with High Power Factor under Unbalanced Voltage Conditions. IEEE Transactions on Power Electronics, 34(9), 9137-9146.

[10]Sharma, A., et al. (2020). A High-Efficiency Three-Phase Rectifier with Flyback Converter for Renewable Energy Systems. IEEE Transactions on Industrial Electronics, 67(3), 1852-1861.

[11]Tariq, F., et al. (2021). A Three-Phase Rectifier with Interleaved Boost Converter and Active-Clamped Circuit for High Conversion Efficiency and Low Electromagnetic Interference. IEEE Transactions on Power Electronics, 36(4), 4657-4667.

[12]Ahmed, M., Amin, M., Hasanien, H.M., & Khatib, T. (2018). A new topology for three-phase Z-source rectifiers. IEEE Transactions on Power Electronics, 33(8), 6951-6961.

[13]Khan, A.A., Ahmad, M.W., & Hassan, M.F. (2020). A novel three-phase rectifier based on three-level neutral-point-clamped converter for renewable energy systems. Journal of Renewable and Sustainable Energy, 12(3), 033501.

[14]Singh, B., Singh, B., & Gupta, R. (2019). A new control strategy for three-phase rectifier based on dual-

loop control system. IEEE Transactions on Industrial Electronics, 66(11), 8604-8614.

[15]Choudhury, A., et al. (2018). "A hybrid control strategy for a three-phase PWM rectifier with hysteresis current control." IEEE Transactions on Power Electronics, 33(5), 3989-4001.

16[]Li, Y., et al. (2017). "A reduced-switch three-phase three-level PFC rectifier." IEEE Transactions on Power Electronics, 32(5), 3585-3594.

[17]Xu, L., et al. (2016). "A modular multilevel three-phase unity power factor rectifier." IEEE Transactions on Power Electronics, 31(8), 5745-5757.

[18]Zhang, X., et al. (2019). "A hybrid cascaded H-bridge three-phase rectifier with high fault tolerance." IEEE Transactions on Power Electronics, 34(2), 1344-1358.

[19]Ahmad, T., Ali, N., Rehman, M. A., & Ahmad, M. (2020). A three-phase rectifier with DC link capacitor voltage balancing technique. IET Power Electronics, 13(4), 739-747.

[20]Liu, Y., Li, D., Li, C., Zhang, C., Li, H., & Li, S. (2019). A three-phase boost power factor correction rectifier with feedforward compensation. IEEE Transactions on Industrial Electronics, 67(6), 4332-4342.

[21]Wang, J., Li, C., Chen, X., & Chen, J. (2021). A soft-switching three-phase boost PFC rectifier with a resonant inductor. IEEE Transactions on Industrial Electronics, 68(1), 401-411.

[22]Wu, J., Zhang, Y., & Wang, Y. (2020). A three-phase PFC rectifier with active damping control for reduced output voltage ripple. IEEE Transactions on Power Electronics, 35(9), 9322-9332.

[23]Zhang, X., Liu, Y., Liu, Y., & Guo, Q. (2019). A modified pulse width modulation control strategy for three-phase PFC rectifiers. IEEE Transactions on Power Electronics, 35(4), 3954-3964.

[24]Liu, Y., Xu, D., Liu, C., & Chen, Y. (2018). A novel three-phase rectifier with high efficiency and low EMI. IEEE Transactions on Industrial Electronics, 65(5), 4005-4014.

[25]Lee, C. H., Kim, J. H., Kim, H. J., & Sul, S. K. (2017). A three-phase rectifier with hybrid resonant PFC for high efficiency and wide load range. IEEE Transactions on Power Electronics, 33(9), 7739-7749.

[26]Khatibzadeh, M., Vazquez, A., & Rodriguez, J. (2016). A modified Z-source converter based three-phase rectifier. IEEE Transactions on Power Electronics, 31(2), 1193-1203.

[27]Wu, B., Zargari, N. R., Boroyevich, D., & Burgos, R. (2015). A three-phase cascaded H-bridge rectifier topology. IEEE Transactions on Power Electronics, 30(7), 3646-3660.