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Power Quality Research On Three-Phase Pfc Rectifier (Minnesota Rectifier)

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Abstract—The Minnesota rectifier is a well established topology, however, no serious attempts have been made to explicitly investigate the improvement in power quality by the use of this rectifier. This paper discusses the harmonic reduction in the line currents of a three-phase diode bridge rectifier by third harmonic current injection technique. The improved performance of the current injection technique is validated by comparing the simulation results of a rectifier unit with and without current injection technique.

Keywords—THD, third harmonic, zig-zag transformer, ZCS Quasi-Resonant Converter.

I. INTRODUCTION

Power electronics component plays a vital role to energy conversion with improved efficiency and improved operating characteristics. Most of the converter systems are affected by the non linear characteristics. Harmonic distortion caused by these nonlinear loads leads to degradation in the power quality. IEEE 519-1992 [1] and the IEC-555 are the recommended standards for the limitation of harmonic currents at ac side to meet the power quality standards. To achieve those standards, it is essential to obtain the nearly sinusoidal current with low distortion and desired power factor at the ac mains to meet the high power quality standards. Use of six-switch PWM rectifier [2] reduces the harmonics, but the problems of PWM technique are EMI and switching losses. In comparison to this approach, dc link current is modified by 3rd harmonic injected current component , fed through the rectifier input side requires only two controllable switches on the dc link side as shown in the Fig. 1.

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Zero-current switching or zero-voltage switching [3]-[8] of these switches overcomes the problems of PWM technique. Zig-zag transformer can be used as a third harmonic current injector [7] or a simple LC circuit [8]. Apart from the current injection network, the presence of source inductance is the added advantage to obtain the sinusoidal line currents with lower value of harmonic [8].

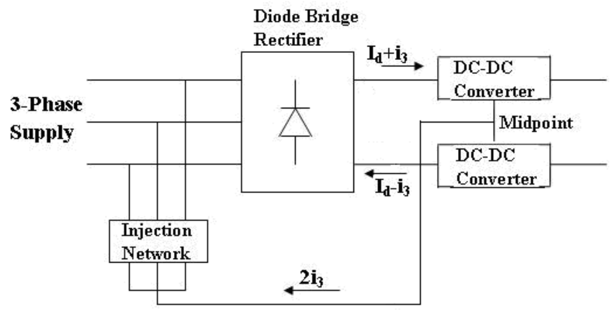

Fig. 1.Rectifier with Injection network

II. OPERATION OF THE RECTIFIER TOPOLOGY

A. Current injection device

Zig-zag transformer is used to give the 3rd harmonic current as a feedback to the utility interface from dc link interface to reduce harmonics. Three phase wye transformer is the basic model to obtain the zig-zag transformer. Three phase wye transformer has three windings with neutral point; each winding has cut in the middle so that it splits into two windings namely outer winding and inner winding in each leg. The outer winding of each leg are turned around and rejoined to the inner coil of adjacent leg. In the connection sequence, the outer coil of A phase is coupled to inner coil of B, outer coil of B is coupled to inner coil of phase C then outer coil of C is coupled to inner coil of phase A as shown in Fig. 2.

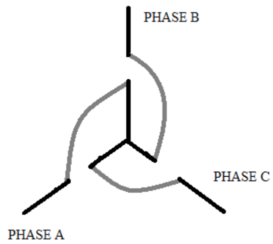

Fig.2. Zig-zag transformer connection.

In the minnesota rectifier topology, the main role of zig-zag transformer is to circulate 3rd harmonic current at supply side.

Due to very high magnetizing impedance, it can be operated as open-circuited for both positive and negative sequence voltage components. If

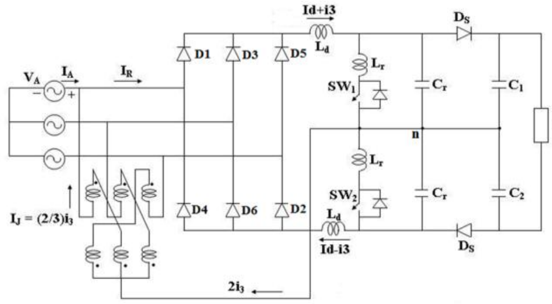

Fig. 3. Circuit diagram of the harmonic injected rectifier with back connection of zig-zag transformer.

distortion occurs at the utility side which results the appearance of zero sequence voltage component. Due to this zero sequence components, midpoint potential of n raises with respect to ac side. However, zero-sequence current is absent in the utility side due to raising of zero-sequence voltage at the midpoint terminal n, since the midpoint current in the zig-zag transformer is compelled to $2i_3$.

B. *Current injection network*

1) *Third harmonic modulated rectifier*

Fig. 3 shows the third harmonic injected rectifier with two quasi resonant zero current switching converters (QR-ZCS). The purpose of the two QR-ZCS converters are used to regulate the dc-link currents to be $(I_d + i_3)$ and $(I_d - i_3)$ where, Id is the average value of dc bus current and i_3 is the current component of 3rd harmonic flowing through the dc bus inductors. The two QR-ZCS in the dc output side act as harmonic current sources. Combination of dc link current and third harmonic current which is taking from the 3rd harmonic current sources are added at the midpoint n, and total current of $2i_3$ is fed to the rectifier input using zig-zag transformer. The total third-harmonic current $2i_3$ can be split equally in the three limbs of transformer. Thus the current in each limb I_J is one-third of the current flowing through the neutral. The ac utility line current I_A is the difference between current I_J and the rectifier input current I_R. The utility line current I_A is now devoid of third harmonic current component and hence has reduced harmonic content and improved wave shape.

2) *Quasi-Resonant Zero Current Switched Converter (QR-ZCS)*

QR-ZCS converter is shown in Fig. 4. Following assumptions are done to design the converter: (i) ideal components have chosen, (ii) $L_d >> L_r$; $C_o >> C_r$ and (iii) To keep the input current i_{in} and the output voltage V_o are approximately constant by designing the large value of Ld and the C_o during one full switching cycle. Initially switch SW_1 is assumed to be open and the diode D_s conducts such that the voltage V_{cr} and output voltage V_o are both equal. After some instant of time switch SW_1 is closed. At this instant current begins to commutate from diode D_s to switch SW_1. Current through the resonant inductor current linearly increases when the current through the diode current D_s decreases. Diode current D_s reach when switch SW1 current decreases. When the current through Ds is zero. Resonant condition occurs between resonant inductor and resonant capacitor such that switch diode D_s makes reverse biased. Current through the resonant inductor is varying sinusoidal nature with respect to switching cycle. When negative polarity current is flowing through the resonant inductor, it chooses the path of anti-parallel diode of switch SW_1 such that voltage across the resonant capacitor is linearly decreasing below the value of output voltage V_o. When the condition $(V_{cr} = V_o)$ is satisfied, the switch diode Ds entering into the forward biasing mode and increasing input current flows the switch diode.

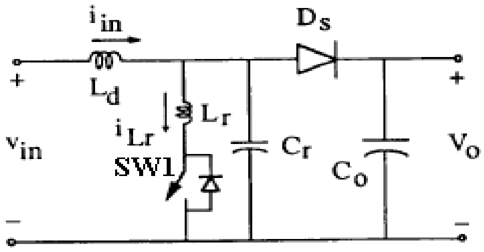

Fig. 4. ZCS-QR boost converter.

3) *Controller for switches SW_1 and SW_2*

The switches SW1 and SW2 are managed with separately each. The controller diagram for SW1 shown is in Fig 5.

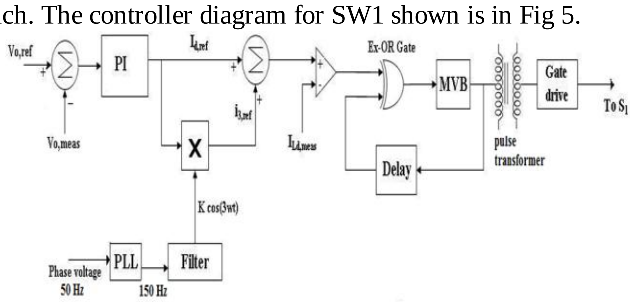

Fig. 5. Controller diagram for switch SW_1

TABLE I

PARAMETERS SELECTION FOR SIMULATION

Converter Topology	Ld (mH)	Lr (µH)	Cr (µF)	C1 &C2 (µF)	Load (Ω)	Zero-sequence resistance and reactance of zig-zag transformer (p.u.)	THD (%)
Rectifier without current injection network	-	-	-	-	20	_	30.91
Rectifier with current injection network	10	4.89	10e-3	5	20	0.035, 0.0005	8.17

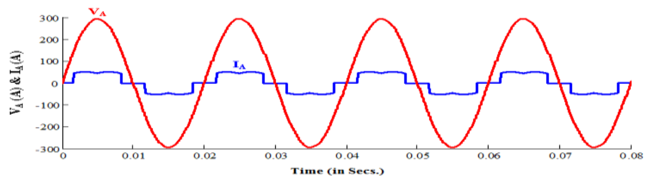

Fig. 6. Phase voltage and line current of an ac mains coupled to three-phase rectifier unit using resistive load.

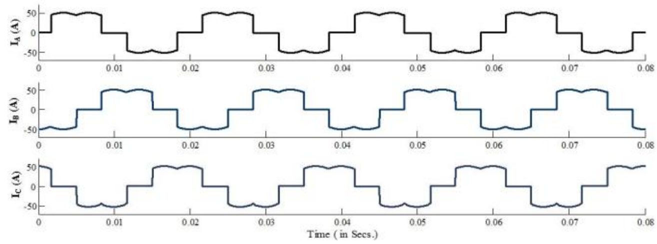

Fig. 7. Line currents of supply side directly coupled to a rectifier unit using resistive load.

The deviation of the output parameter is measured across the load (V_o,meas) from a constant reference output voltage (V_o,ref) is given as feedback variable to a P_I controller to give the I_d reference term. Phase Locked Loop (PLL) gives loop for third harmonic and utility voltage in which both are locked. It acts as a frequency multiplier ($f_0 = n\ f_s$, here n = 3) based on divide by n-counter logic. The filter circuit phase shifts the third harmonic component by 90 degrees and also scales up the magnitude by a gain constant K. The reference value for the third harmonic current (i_3) is related to average dc current as

$$i_{3,ref} = K\ I_d \cos(3\omega t - \varphi_3).$$

The sum of PI regulator output Id,ref and the current reference of 3 harmonic i3,ref is compared with the measured dc link inductor current using a comparator. The comparator output is fed as input to the Exclusive OR gate. Switch is keeping on for particular period of fixed time using monostable multi-vibrator such that ZCS is achieved for same fixed on time under rated loading conditions. Delay is given to multi-vibrator output to force the output to varying between upper and lower limits. Thus generate the control signals which are given to pulse transformer. The gate drive circuit provides the triggering pulses for switch SW_1. A similar controller is used for switch SW_2.

III. SIMULATION OF THREE-PHASE DIODE BRIDGE RECTIFIER TOPOLOGIES

The three-phase diode bridge rectifier topology where the it is coupled to the ac utility via 3rd harmonic current insertion network is simulated for a resistive load and harmonic distortion of ac utility input current is obtained. For the same resistive loading the improvement in power quality is justified by comparing the results obtained for a third-harmonic modulated rectifier with those of a conventional 3-phase bridge rectifier in which diode bridge unit is directly coupled to ac line side.

A. Premises

The three-phase ac system is assumed to undistorted symmetric with zero impedance with a 50 Hz fundamental frequency. The phase order of ac line is supposed to be ABC. Power diodes of diode bridge unit are ideal. The inductive and capacitive elements present in the current insertion network have zero resistance and hence lossless.

B. Simulation Parameters

A rectifier unit is functioning from 208 V (L-L), 50 Hz ac line feeding a resistive load is considered. The simulation parameters selection for harmonic injected rectifier topology is shown in Table I. Simulation parameters are described below:

L_d – dc-link inductor
C_1 & C_2 – dc- link capacitors
L_r – inductor in the resonant circuit
C_r – capacitor in the resonant circuit

For a resonant frequency of f_r = 720 kHz, the value of L_r and C_r is calculated from

$$f_r = \frac{1}{2\pi\sqrt{L_r C_r}}$$

Zig-zag transformer of 1 KVA rating is connected at the utility interface.

IV. RESULTS AND DISCUSSIONS

A. Conventional Rectifier unit without current injection network

Input line current and phase voltage at ac line side are shown in Fig. 6 and Fig. 7. These two figure shows that three line current which is measured at mains is straight away connected to the diode bridge unit using resistive load. Fast fourier transform method is applied to line current to analyse the harmonic presence as shown in Fig. 8. 20 cycles have been considered for FFT analysis. Usually triplen harmonics are described as odd multiple of 3 harmonics. From the FFT analysis, harmonics are not exhibit in line current. However sequence harmonics are present in the ac line current. Due to this sequence harmonics, source current THD are measured with 30.91% which is comparatively higher value with IEEE 519-1992 standard limits of below 5%. This higher THD will limit the application of the rectifier.

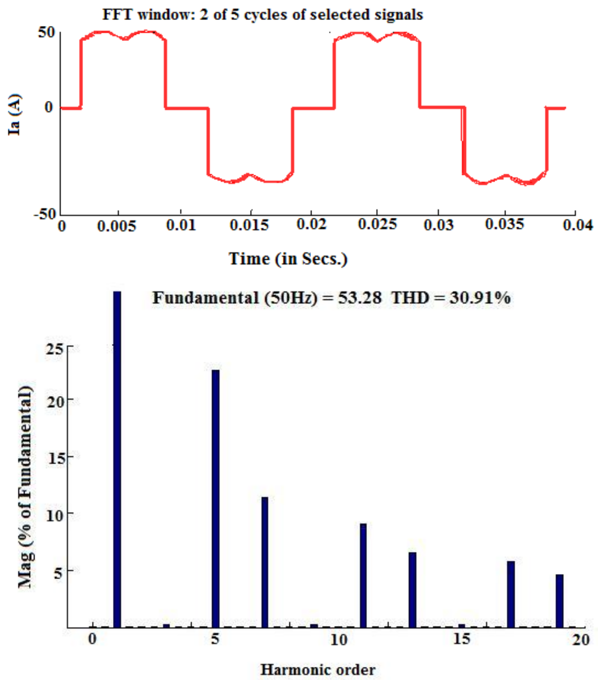

Fig. 8. FFT analysis of line current IA, at the supply side for rectifier unit using resistive load without 3rd harmonic current injection network.

B. Rectifier unit with a current injection network

The ac utility line current IA of a conventional rectifier unit using R load is discontinuous as shown in Fig. 6 and Fig. 7. The line current is zero for a time period of 3.33ms during every half cycle of 10ms with respect to supply frequency of 50Hz at ac mains. To diminish the source current harmonics, the important criterion is that the gaps in the line current during assumed intervals when phase voltages are maximum or minimum which causing the both switch diodes are connected to be reverse biased to that corresponding phase.

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This gapping of line current with assumed time intervals is patched with third harmonic injected current.

Fig. 9 shows the supply voltage and the source current that are continuous and almost sinusoidal. Fig. 10 shows all the three source currents of an ac mains connected to a three-phase bride unit using resistive load with a third-harmonic current injection network. An important point to be noted is that the bridge unit is a uniform load supplied by a balanced three-wire system; thus triplen harmonics are absent with and without the current injection network.

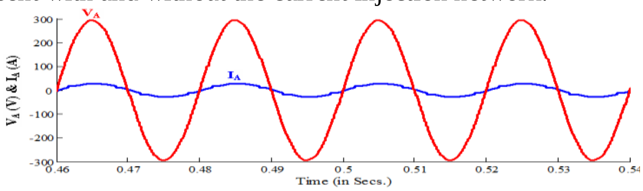

Fig. 9. Phase voltage and line current of an ac mains connected to a three-phase bridge rectifier unit using resistive load with a 3-harmonic current injection network at ac mains

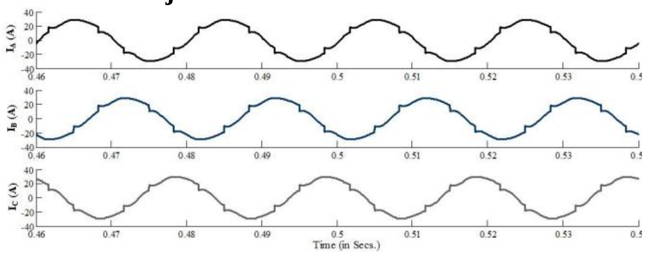

Fig. 10. Lline currents of supply side for rectifier unit using resistive load with a 3-harmonic current injection network at ac mains.

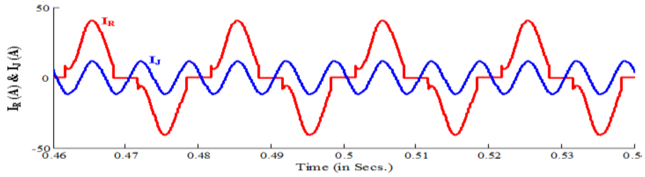

Fig. 11. Input current (I_R) of rectifier unit using resistive load with a 3-harmonic current injection and the third harmonic current (I_J) injected at the interface.

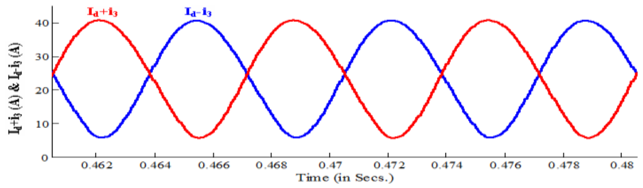

Fig. 12. Load currents (I_d+i_3) and (I_d-i_3) of a rectifier unit with a harmonic current injection network.

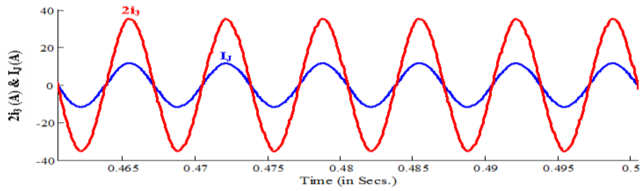

Fig. 13. Neutral current ($2i_3$) and the current in each leg (I_J) of a zig-zag transformer coupled at the interface between the ac mains and third harmonic modulated rectifier.

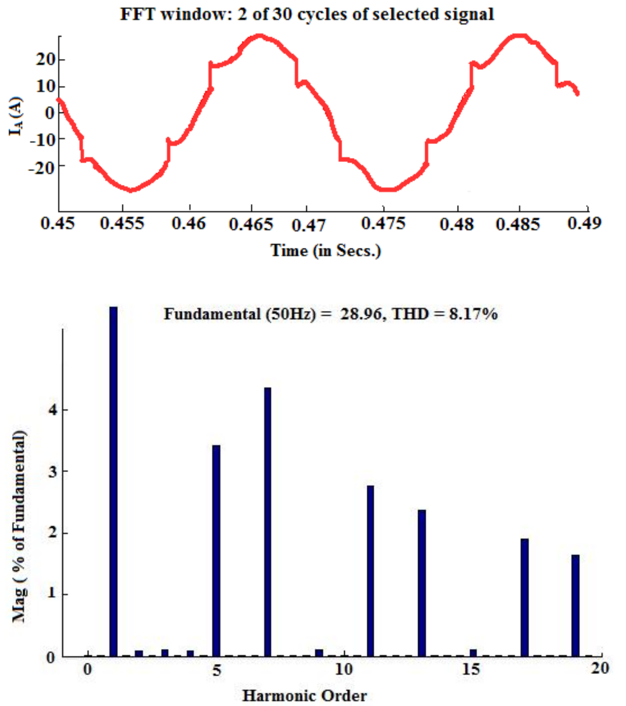

Fig. 14. FFT analysis of line current I_A, at ac mains for rectifier with a resistive load with a 3rd harmonic current injection network.

From Fig.11 it is identified that input currents of rectifier are discontinuous. During one time period at supply frequency of 50Hz, the current in phase A is positive when diode D_1conducts and it becomes negative when diode D_2 conducts. Similarly the current in the other two phases is the sum of the current through each device connected to that phase. Applying Kirchoff's current law at the utility interface, the input current to the rectifier is considered below,

$$I_R = I_A + I_J$$

One third of the line period i.e., 20ms is similar to the diode bridge load currents I_d+i_3 and I_d-i_3 as shown in Fig. 12.

For a balanced three phase system the zero sequence harmonics can flow through the neutral. Fig. 13 shows the neutral current $2i_3$ which has a frequency of 150Hz. From Fig. 13 it can be seen that the current in each leg (I_J) of the zigzag transformer which is the current feeding device in this case has a magnitude that is one third of the magnitude of the neutral current or the current supplied by the current injection network.The actual current is divided into three parts and fed back through the current injection network.

From the FFT analysis of the source current I_A shown in Fig. 14 it is evident that the triplen harmonics are absent as in previous topology. However the line currents are more nearly sinusoidal and hence the THD of this waveform is 8.17%.

V. CONCLUSION

The addition of a current injection network and a current injection device to a three-phase rectifier unit circuit shapes the input currents to be almost sinusoidal. Injection of third harmonic currents having equal magnitude and phase displacement relation same as that of the supply current and voltage at the ac mains provides in a THD reduction of the source current by about 22% as compared to values obtained for a conventional diode bridge rectifier.

REFERENCES

1. C. K. Duffey and R. P. Stratford, "Update of Harmonic Standard IEEE-519 IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems", IEEE/IAS Trans., vol. 25. no. 6, pp. 1025-1034, Nov/Dec 1989.
2. J. Rodriguez et al., "PWM regenerative rectifiers: State of the art," IEEE Trans. Ind. Electron., vol. 52, no. 1, pp. 790-797, Feb. 2005.
3. Rastogi M., Mohan N. and Henze C. P., "Three-phase sinusoidal current rectifier with zero-current switching", Proceedings of APEC, vol. 2, pp. 718 - 724, 1994.
4. K. H. Lui, "High Frequency Quasi-Resonant Converter Techniques", Ph.D. Dissertation, Electrical Engineering Department, Virginia Polytechnic Institute and State University, 1986.
5. J. Barbi and S. A. Oliviera da Silva, "Sinusoidal line current rectification at unity power factor with Boost Quasi-Resonant Converters", Proceedings of APEC, pp. 553-562.
6. K. H. Lui, R. Oruganti and F. C. LEE, "Resonant switches-Topologies and Characteristics", IEEE Tran., Power Electron., vol. 2, no. 1, pp. 62-74, Jan. 1987.
7. R. B. Ridely, W. A. Tabisz, F. C. Y. Lee and V. Vorperian, "Multi Loop Control for Quasi-Resonant Converters", IEEE Trans. Power Electronics, vol. 6, no. 1, pp.28-37, Jan. 1991.
8. R. Naik, M. Rastogi and N. Mohan, "Third Harmonic Modulated Power Electronics Interface with 3-Phase Utility to provide a regulated dc output and to minimize line current harmonics", IEEE/IAS Annual Meeting, pp. 689-694, Oct. 1992.
9. R. Naik, M. Rastogi and N. Mohan, "Optimization of a novel DC-link current modulated interface with 3-phase utility systems to minimize line current harmonics", Power Electronics Specialists Conference, PESC'92 Record, 23rd Annual IEEE, pp. 162-167, 1992.