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A New Approach to Improve Power Factor, Efficiency and Reduce Harmonics in a Three Phase Diode Rectifier

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Abstract

An active current injection network for a three-phase diode rectifier is proposed. Current injection is done by using two networks: injection network and injection device. The injection network composed by a half-bridge inverter operating at high frequency and injection device is composed by three bi directional switches operating at low frequency. It also uses one inductor in order to get the desired injected current .This proposed converter offers high efficiency, high power factor and also total harmonic distortion will be reduced. Operation, analysis, simulation results are shown in this paper.

Keywords— Current Injection, high power factor, three-phase rectifiers, THD

1. Introduction

The increase of nonlinear loads to the electric power distribution has motivated to research for finding different options in order to alleviate the difficulties associated with the power quality. Diode rectifiers are extensively used; this is because they are cheap and simple. Three phase current injection rectifiers are recently among the most attractive AC to DC energy conversion topologies required in medium and high power applications.

A three phase current injection rectifier is typically the association of three circuits: a classical diode bridge that is responsible for the energy rectifying operation, a modulation circuit that has the major role in the current shaping process, and a distribution circuit which has the property of injecting a zero sequence current into the source phases, avoiding thus the current discontinuities at the input of the diode bridge. The modulation and distribution circuits can be either passive or active. The use of a passive modulation circuit yields a high power factor at the expense of a low efficiency.

Based on current injection technique, this topology uses two active networks: an injection device composed by three bidirectional switches operating at low frequency and a current injection network consisting of two high frequency switches and only one inductance. The current injection device selects the part of the inductor current to be injected into the respective phase, where as the current injection network generates the third harmonic current needed to improve the input current waveform and injects it onto the respective phases through the current injection device.

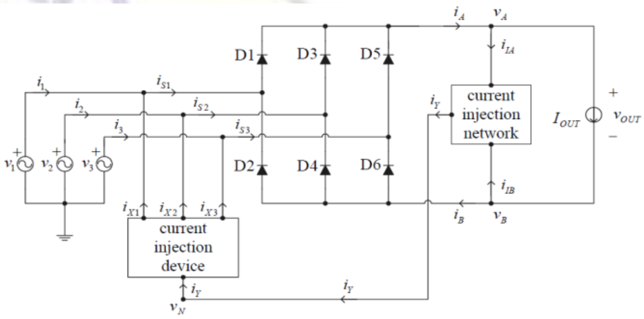

Fig.1 Proposed rectifier block diagram

The figure 1 shows a different topology of three phase rectifier with active current injection proposed. This circuit consists of an inductor that operates at high frequency.

This paper is organized as follows. The proposed three phase rectifier with active current modulation is explained in Section 2, the simulation and experimental results are discussed in Section 3, the power processing analysis of the topology is shown in Section 4, THD analysis is shown in section 5 and finally, conclusions are given in Section 6.

2. Proposed Three Phase Rectifier With Active Current Injection

The proposed circuit uses two active networks shown in fig: 1.

2.1 Current injection network: The network "almost" produces the third-harmonic current synchronized together with the ac mains. This is implemented with a half-bridge inverter. The three-phase system voltage is sensed.It consists of two switches and one inductor that operate at high frequency. This network main role is based on generating the desired current i_l and on making the circuit adaptable to any load variation.

2.2 Current injection device: The current injection device divides the current supplied by the current injection network into three equal parts and injects them back to the supply lines. It is based on three bidirectional switches connected to the three supply phases. The injection device selects the part of the inductor current to be injected into the respective phase. The related switches operate at low frequency equal to the double of the source supply frequency.

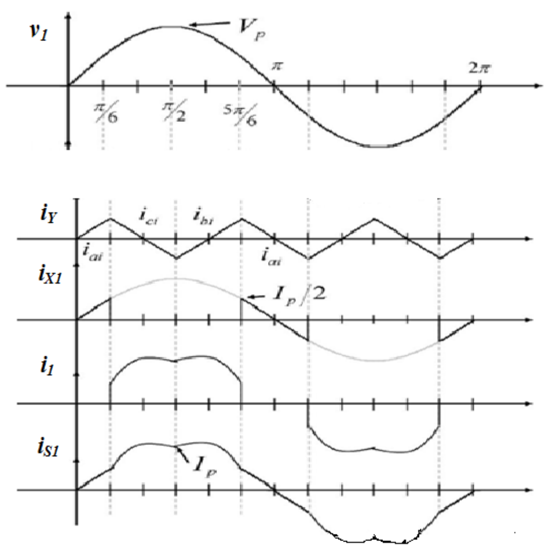

Fig 2: Waveforms of the proposed converter

Fig 2 shows the waveforms of proposed network for one phase. Just a single device is turned on at a time; however a small overlap between the control signals of the switches is needed in order to avoid over voltages due to the inductor topology.

Switches sequence command in the injection network indicated in given table 1 for intervals between 0^o and 180^o. Intervals between 180^o and 360^o could be deduced similar to the first demicycle.

Table 1. Sequence of command for S_1, S2, S3

Interval	i_y	State of S_1	State of S_2	State of S_3
[0^0 - 30^0]	$i_1=i_{1i}$	ON	OFF	OFF 2.3.2
[30^0 - 90^0]	$i_3=i_{3i}$	OFF	OFF	ON
[90^0 - 150^0]	$i_2=i_{2i}$	OFF	ON	OFF
[150^0 - 180^0]	$i_1=i_{1i}$	ON	OFF	OFF

2.3 **Control strategy**:

2.31 Current injection network:

Current injection network implemented with a half bridge inverter consisting of two IGBT's with the load of an inductor.

Figure 3 shows the circuit of half bridge inverter.

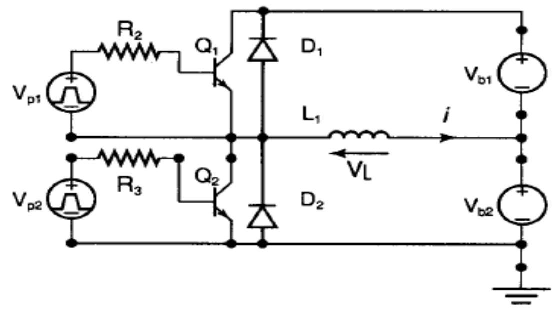

Figure 3 Half bridge inverter

When Q_1 switches off at maximum positive current, the inductive voltage v_L reverses its polarity, the voltage rises above V_{b2} and forward biases D_2, allowing the decay of current until load current zero, when Q_2 will start the flow of current in the negative direction. When the negative current reaches its maximum value, Q_2 switches off, v_L reverses, rising above V_{b1} and forward biasing diode D_1, until load current zero. Q_1 will then allow current to grow in the positive direction and the cycle is repeated. In figure 4, the current will ramp up and ramp down in response to switching.

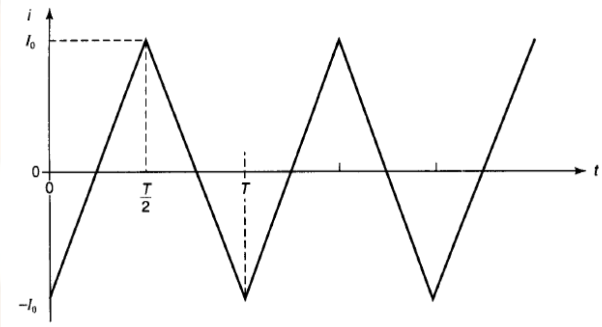

Fig 4 waveform of the half bridge inverter

Current injection device:

The switching current injection device is represented in figure 5. It consists of three switches commanded by a logic control. Every switch is turned on when the specified phase are unconnected to the diode bridge; therefore the current in each phase doesn't present a discontinuity after injection.

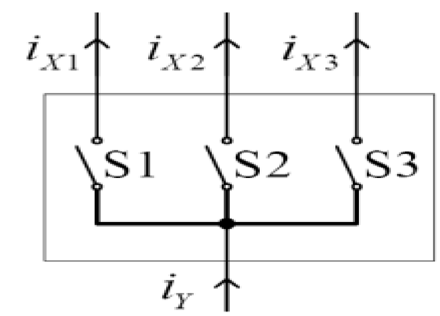

Fig.5. Switching current injection device

The control signals for the switches in the current injection device shown in figure 6.

2.4 **Control signals for injection device**:

2.4.1 During 0 − π/6 Radians: The current required by the injection device for phase “a” is proportional to the respective phase input voltage. This current is the same with that of the current injection network during this time. The other two phase voltages have zero current demanded by the injection network. The rectifier current during this time is zero. Then, the required current from the voltage source is the same with the current demanded by the injection device.

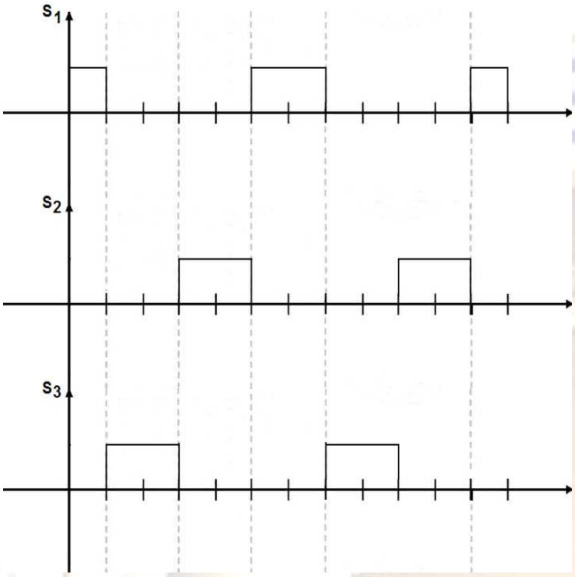

Fig.6. control signals for the switches in the current injection device

2.4.2 During π/6 − π/2 Radians: The current demanded from the injection device by phase “a” is zero during this time. The current of the injection network *il* is now injected to phase “c.” The rectifier current during this time is different to zero. The current demanded from the phase “a” voltage source is the same with that required by the rectifier

2.4.3 During π/2 − 5π/6 Radians: The required current by the injection device for phase “a” is zero during this time. The current of the injection network *il* is now injected to phase “b.” The rectifier current during this time is different to zero for phase “a.” Then, the required current from the voltage source is the same with that demanded by the rectifier.

2.4.4 During 5π/6 − π Radians: The required current by the injection device from phase “a” is proportional to the respective-phase input voltage. This current is, again, the current injection network during this time. The rectifier current during this time is zero. Furthermore, again, the required current to the voltage source is the same with that demanded by the injection device.

2.4.5 During the Following π Radians: The converter operation during the negative semicycle of phase “a” is similar to the positive semicycle.

The circuit of current injection device is shown below.

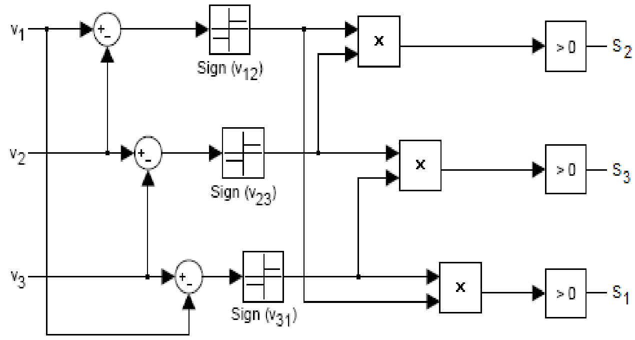

Fig. 7 control signals for injection device

3. Simulation Results

The system was mathematically simulated on Simpower System Matlab. The phase-to-neutral RMS-voltage is 127 V, the mains frequency is 60 Hz, the resistive load has a value of 61 Ω, the adopted switching frequency is 100 kHz, and the inductor’s value is 6.22 mH.

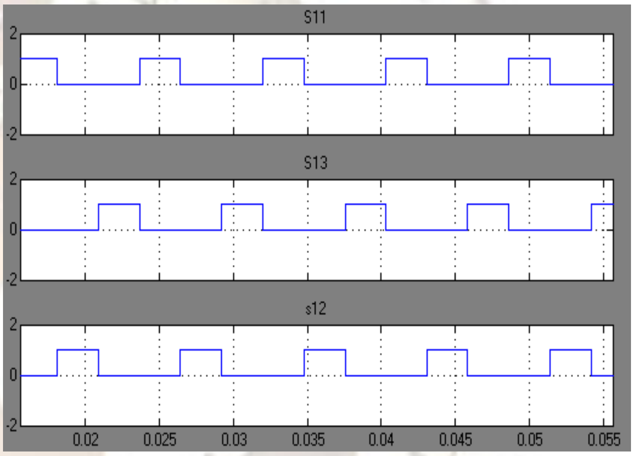

Fig. 8 Simulation results of pulse sequence.

In the given fig.9 represents the simulink diagram for the proposed converter and fig.10 represents the output waveforms with current injection for phase ‘a’.

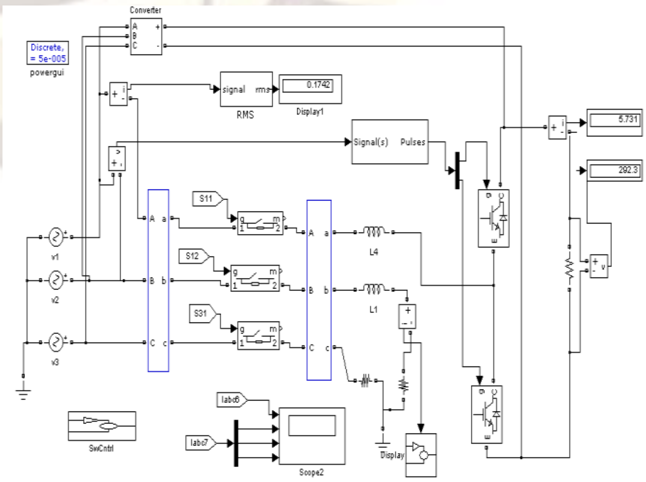

Fig. 9 Simulink diagram for proposed converter

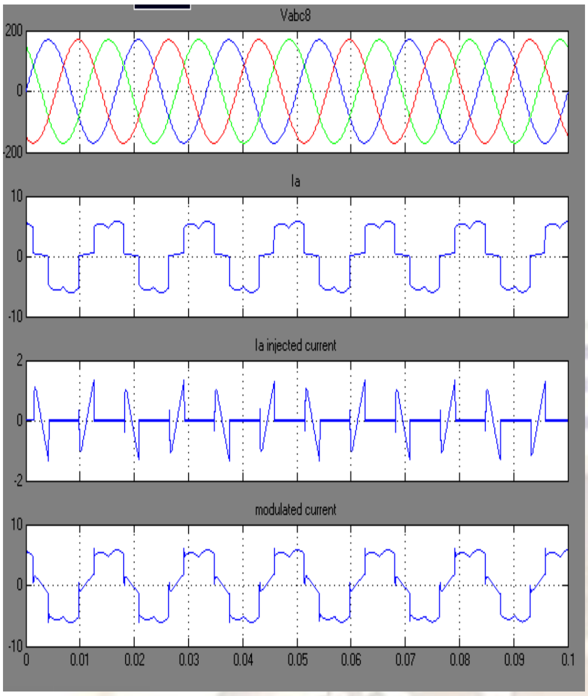

Fig 10 output waveforms with current injection for phase ‘a’

In fig10 Vabc is the 3phase input waveform having the magnitude of 120* $\sqrt{2}$ v. The plot of ***Ia*** is the current flowing through the phase “a” in the diode rectifier. The injected current which is injected in to the phase current is also shown in fig10. After injecting the resultant current is modulated current is also shown in fig10.

4. Power Processing Of The Converter

Power flow representation of the converter is shown in given figure

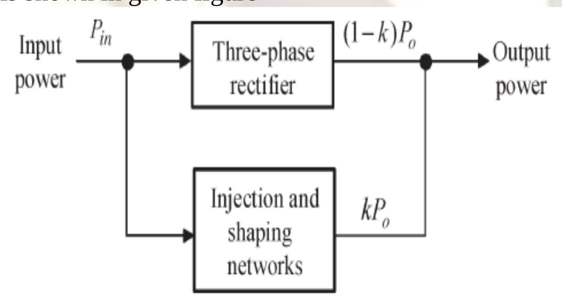

Fig. 11 power flow diagram of converter.

The converter has the important feature that only part of the power released to the load is processed by the injection and shaping networks. Part of the energy is processed by the three-phase rectifier; type another part (k) is processed by the networks.

The three-phase rectifier losses are negligible, *Pin* is obtained as

$$P_{in} = (1-K)Po + \frac{kP_o}{\eta_n}$$

(1)

By solving the above equation the efficiency is

$$\eta = \frac{P_o}{P_{in}} = \frac{1}{1-k\left(1-\dfrac{1}{\eta}\right)}$$

(2)

The rate k is around 3.7%, and considering the network efficiency of 80%, the efficiency obtained for the complete system is 99%.

The processed power by the injection and shaping networks can be estimated with

$$\frac{kp_o}{\eta_n} = 3\frac{1}{T}\int_{-T/2}^{T/2} v_a i_a dt.$$

(3)

Where T is the period of the input voltage and i_a is the current demanded by the network. By solving the above equation.

$$\frac{kp_0}{\eta} = 3V_P I_P\left(\frac{1}{6} - \sqrt{3}\frac{1}{4\prod}\right)$$

(4)

Where $Ip = 3Vp/2R$.

The output power of a three-phase rectifier is

$$P_0 = \frac{(1.6554V_P)^2}{R}$$

(5)

Using (4) and (5) obtains the rate of the processed energy

$$K = \eta_n \frac{3}{1.8269}\left(\frac{1}{6} - \sqrt{3}\frac{1}{4\prod}\right) = 0.0473\eta_n$$

(6)

When the efficiency η takes a value of 80%, the percentage k is 3.7%.

From equations (2) and (6), the efficiency of the system is obtained as a function of injection and shaping network efficiency

$$\eta = \frac{P_0}{P_{in}} = \frac{1}{1-0.0473(\eta_n - 1)} \quad (7)$$

If η_n is reduced, the system efficiency is even quite acceptable because the rate of the processed energy is minimum. For example, if we consider ηn equal to 60%, the efficiency of the system is 98%; this becomes a high efficiency for the whole converter. If we draw the graph between converter efficiency and complete system efficiency we can observe the high efficiency. The power factor is improved to 0.99.

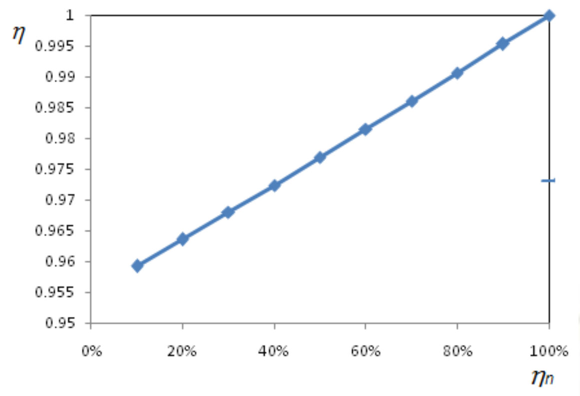

Fig12: improvement of complete system efficiency

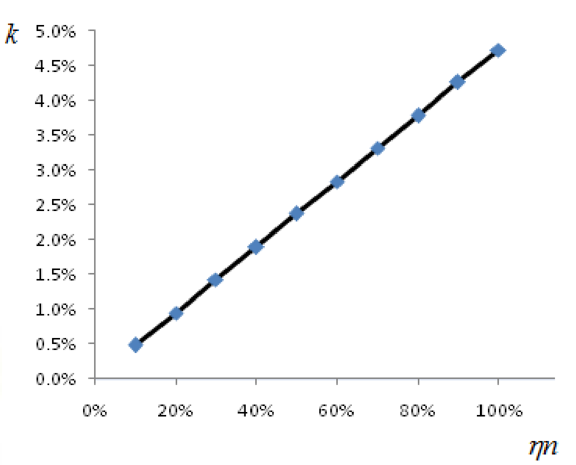

Fig 13: graph between k and η_n

5. THD Analysis

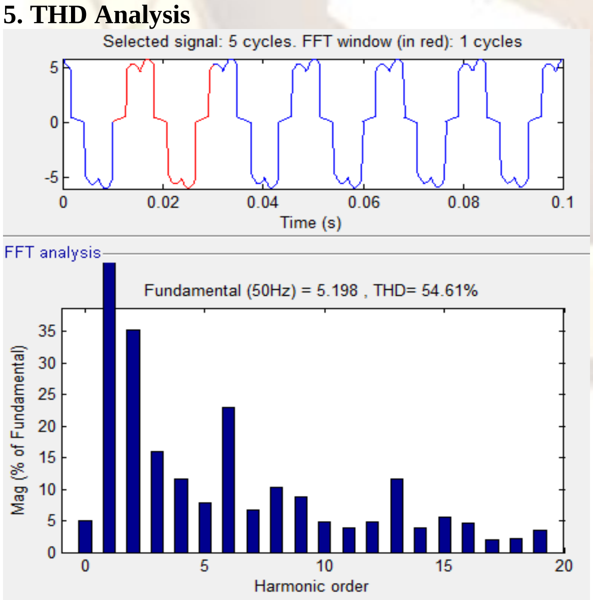

Fig 14. FFT analysis before current injection

The fig 12 shows that the harmonic order before current injection in the diode rectifier. The THD value is 54.6% . However ,this THD can be reduced to 22.44% by current injection in to the diode rectifier.this is shown in the fig13.

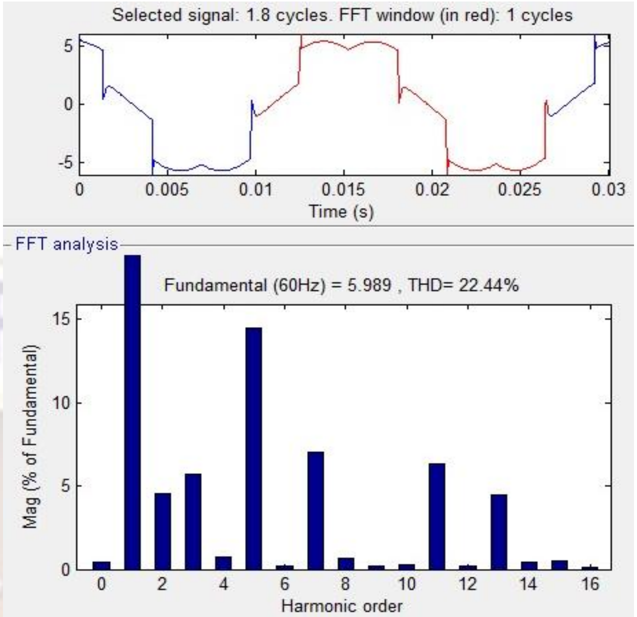

Fig15. . FFT analysis after current injection

6. Conclusion

This project has offered a different method to alleviate the harmonic content of a three-phase diode rectifier. A system with two active networks was suggested, with the first one for generating the modulated injecting 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. By introducing this active topology the system efficiency is improved to 99%, the power factor is increased to 0.99 and THD is reduced from 54.6% to 22%.As the converter is active, it can be adapted to different operating points. These results were verified through simulation experiments using the Simpower tool of Matlab/Simulink.

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