A Comparative Evaluation and Design of Input Current Waveshaping Methods for Rectifier

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Abstract

This paper presents a comparative evaluation of passive current waveshaping methods for single-phase rectifier. The simulation results show that the new method can further lower the input current components and THD_i of a single-phase diode rectifier as compared with the three passive current waveshaping methods by P. D. Ziogas [5], Ji Yanchao [4] and H. A. Kazem [6]. The relevant input current and voltage waveforms, the input current total harmonic distortion and the input power factor value are derived from the computer simulation or theoretical analysis. A design example is provided and simulation results have been verified on 500 mW experimental models.

Keywords: Current Waveshaping, Rectifier, Power Factor Corrections, Harmonics.

1. INTRODUCTION

The major polluters of power system harmonics are the rectifier circuits. The economic advantages that these rectifiers presently enjoy in the marketplace can change overnight by the imposition of stricter harmonic standards. With this threat in mind, many researchers have started to probe into the possibilities of passive and active waveshaping methods. Single-phase rectifiers (Fig. 1) have the problems of poor power quality in terms of injected current harmonics, resultant voltage distortion and poor power factor at input ac mains and slowly varying rippled dc output at load end, low efficiency, and large size of ac and dc filters, [1]-[2].

A growing number of current waveshaping methods applied to single-phase rectifier are now available including active, passive and hybrid methods, [3]. Among the proposed passive waveshaping methods, the Ziogas method in [4] is superior to the others in reducing the input current harmonic components and improving the input power factor. On the bases of the Ziogas method, Ji Yanchao [5] proposed an improved method, which can further improve the input current waveform and therefore has a better input power factor. On the bases of the two methods Hussein [6] proposed anther improvement to reduce THD_i. This paper presents a comparative evaluation of the three previews method.

2. CONVENTIONAL SINGLE-PHASE RECTIFIER

The nature of rectifiers either it is conventional (Fig. 1) or switch mode types, all of them contribute to high THD_i and low efficiency to the power system. However, this method has the disadvantage of generating pulsed as line currents drawn from the ac distribution network. Under the condition that the input peak voltage is 1 pu (12 volt) and fundamental frequency is 1 pu (50 Hz), the relevant input voltage and current waveforms of the conventional rectifier and its input current Fourier analysis results are obtained as shown in Fig. 2, which makes it clear that the input current contains a very large quantity of harmonics.

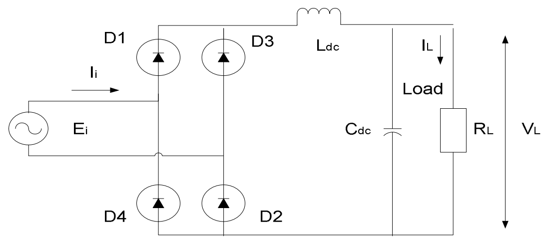
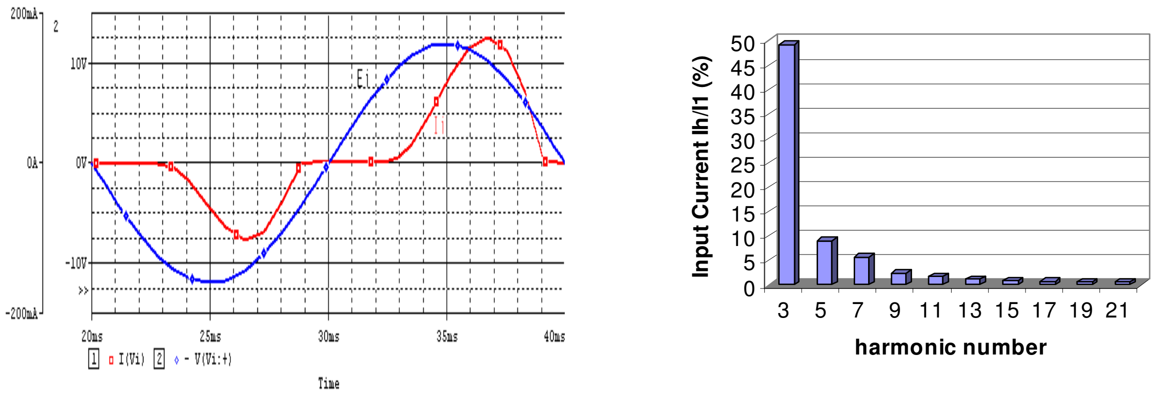


FIGURE 1: Conventional single-phase diode rectifier topology.



(a) (b)

FIGURE 2: a. simulated waveform of input current and voltage with conventional rectifier topology, b. Harmonic spectrum of input current with conventional rectifier.

Due to the presence of the considerable distortion power, the power factor of the conventional topology is very low. It is found that the power factor to deliver 1.0 pu power P_r is only about 0.698. This conventional method has many disadvantages, including:

1) High input current harmonic component and THD_i is 55.16% also 3^{rd} harmonic is 49.3%;
2) Low input power factor, the maximum value of which to deliver 1.0 pu P_r is only about 0.698;
3) Low conversion efficiency.

3. PASSIVE WAVESHAPING FOR SINGLE-PHASE RECTIFIER

In 1990 passive waveshaping method proposed by P.D. Ziogas (Fig. 3), which uses an input L_r-C_r parallel resonant tank to remove the third harmonic component from the input current. The input power factor increases because the third harmonic component is the main reason of the low input power factor. The relevant input current and voltage waveforms of the novel diode rectifier and Fourier analysis result of the input current waveform are illustrated in Fig. 4. It is shows that the parallel resonant tank can effectively eliminate the third harmonic component and reduce the rectifier input THD_i. The advantages of the novel method over the conventional method include:

1) Lower the input current THD_i, which is about 30.26% also 3^{rd} harmonic is 11.51%.
2) Higher input power factor, the maximum value of which to deliver 1.0 pu P_r is only about 0.931.
3) Increase efficiency of the rectifier.

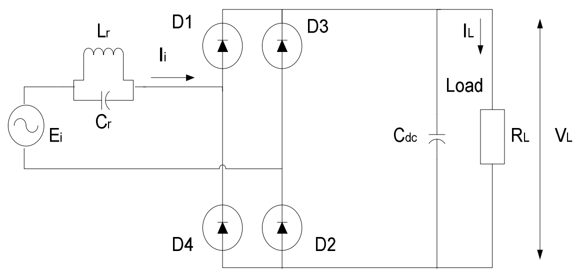
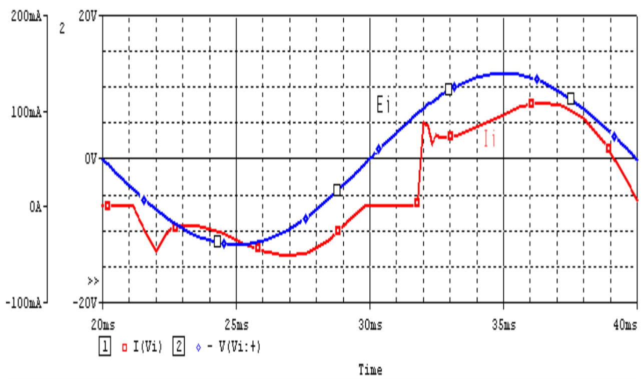
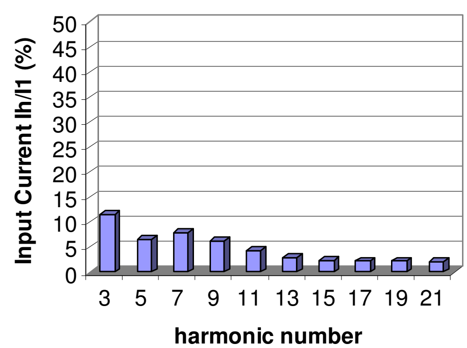


FIGURE 3: Ziogas single-phase diode rectifier topology.





(a) (b)

FIGURE 4: a. simulated waveform of input current and voltage with Ziogas rectifier topology, b. Harmonic spectrum of input current with Ziogas rectifier.

4. IMPROVED METHOD-1 FOR SINGLE-PHASE RECTIFIER

To further lower the input current THD_i of the novel diode rectifier, Ji Yanchoa [4] proposed improved method (Fig. 5) by place a capacitor C_b in parallel between the parallel resonant tank and the rectifier bridge. When C_r has a value of 7.93μF or 0.39 pu and L_r is 141mH or 0.31 pu, the value of C_b is selected such that the input power factor at the rated output power reaches its peak value. The input current and voltage waveforms and variation of the input power factor with the value of C_b at the rated output power is shown in Figs. 6 & 7 respectively. It is clear from Fig. 7 that for the rated output power, the value of C_b should be selected to be 2.5μF or 0.11 pu. Under this condition, the relevant input power factor approaches its maximum value of 0.967.

The advantages of the improved method-1 over the novel and conventional methods include:

1) Lower the input current THD_i, which is about 27.80% also 3^{rd} harmonic is 9.59%.
2) Higher input power factor, the maximum value of which to deliver 1.0 pu P_r is only about 0.935.
3) Increase efficiency of the rectifier.

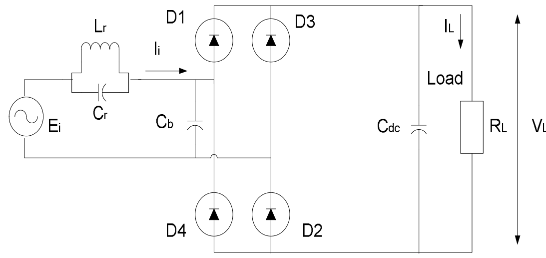
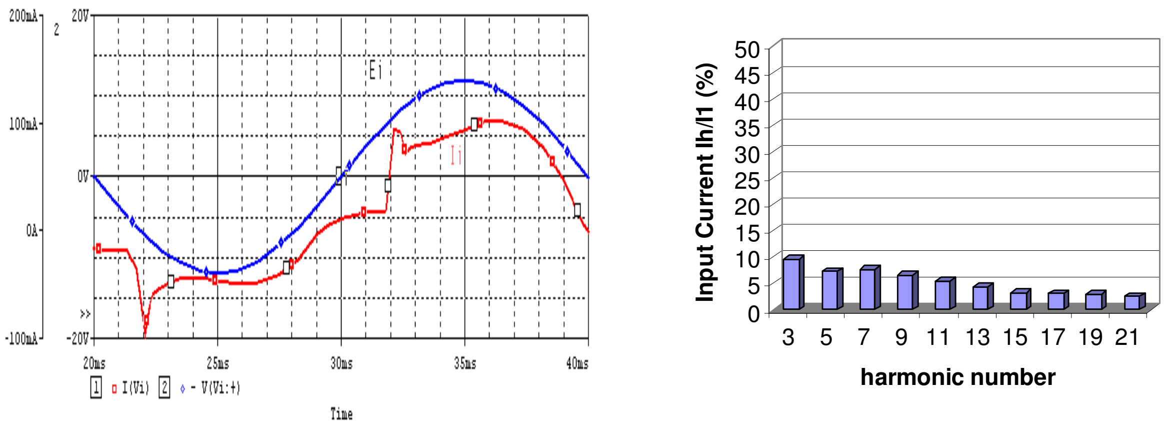


FIGURE 5: Improved-1 single-phase diode rectifier topology.



(a) (b)

FIGURE 6: a. simulated waveform of input current and voltage with improved-1 rectifier topology, b. Harmonic spectrum of input current with improved-1 rectifier.

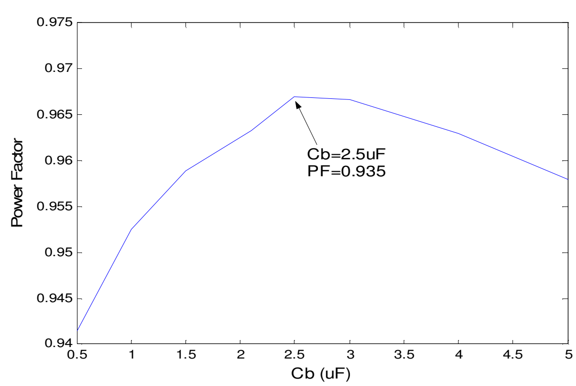


FIGURE 7: Variation of PF with C_b at rated load

5. IMPROVED METHOD-2 FOR SINGLE-PHASE RECTIFIER

To further lower the input current THD_i of the novel and improved method-1 diode rectifier, an improved method-2 is proposed by place inductance L_o in series with the output of the rectifier (Fig. 8). When C_r has a value of 7.93μF or 0.39 pu, L_r is 141mH or 0.31 pu, and C_b 2.5μF or 0.11 pu, L_o is selected such that the input power factor at the rated output power reaches its peak value.

The input current & voltage waveforms and harmonic spectrum and variation of the input power factor with the value of L_o at the rated output power are shown in Figs. 9 & 10 respectively. It is clear from Fig. 10 that for the rated output power; the value of L_o should be selected to be 0.35 mH or 0.76×10^{-3} pu. Under this condition, the relevant input power factor approaches its maximum value of 0.969.

The advantages of the improved method-2 over improved method-1, novel and conventional methods include:

1) Lower the input current THD_i, which is about 25.03% also 3rd harmonic is 8.40%.
2) Higher input power factor, the maximum value of which to deliver 1.0 pu P_r is only about 0.969.
3) Increase efficiency of the rectifier.

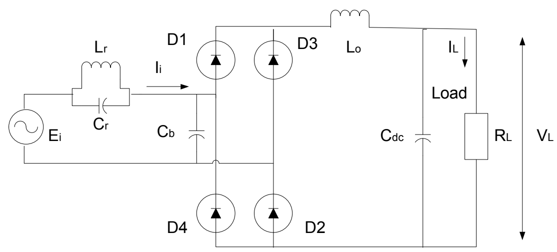
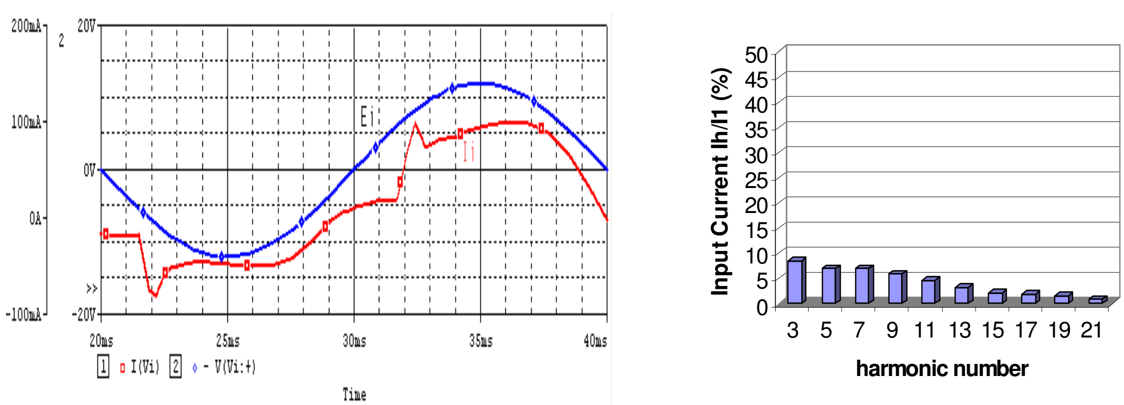


FIGURE 8: Improved-2 single-phase diode rectifier topology.



(a) (b)

FIGURE 9: a. simulated waveform of input current and voltage with improved-2 rectifier topology, b. Harmonic spectrum of input current with improved-2 rectifier.

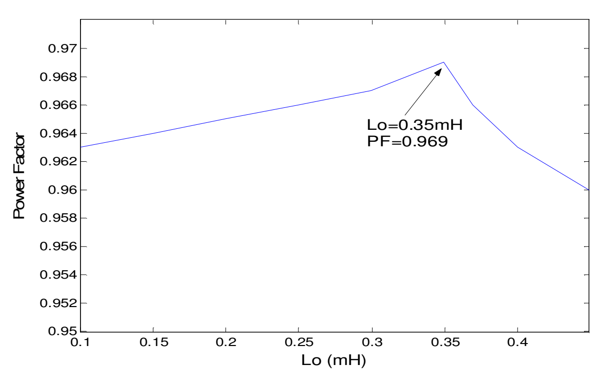


FIGURE 10: Variation of PF with L_o at rated load.

Table 1 illustrates a comparison between the four cases. It is clear seen that improved method-2 have better power factor and less THD_i.

	conventional	novel	Improved-1	Improved-1
PF	0.698	0.931	0.935	0.969
THDi	55.16%	30.26%	27.80%	25.03%
3^{rd}	49.3%	11.51%	9.59%	8.40%

TABLE 1: PF and THDi for the four cases.

6. DESIGN EXAMPLE AND EXPERIMENTAL RESULTS

A. Design example

To illustrate the validly of the simulation analysis in the previous sections, the following design example is presented. The rectifier has the following specifications:
V_s = 8.5 rms ≡ 1.0 pu;
P_r = 500 mW ≡ 1.0 pu;
Output voltage V_L ripple = 5%.
From these values
1 pu angular frequency = 2 πf = 314 rad/sec;
1 pu current = 0.5/8.5 = 59 mA
1 pu impedance = 8.5/0.059 = 143.8Ω
1 pu inductance = 143.8/314 =457.8mH
1 pu capacitance = 1/(143.8×314) = 22.13µF

The value of DC Filter Capacitor C_o
The value of C_o for 5% harmonic on the capacitor voltage at the optimum operating from [3] is given by

$$C_O = \frac{100 \times I_{o,2}}{2\omega V_{L,o} \times 5\%} \tag{1}$$

Where

$V_{L,o}$: The dc average value of the output voltage.

$I_{o,2}$: The rms value of the 2^{nd} harmonic output current.

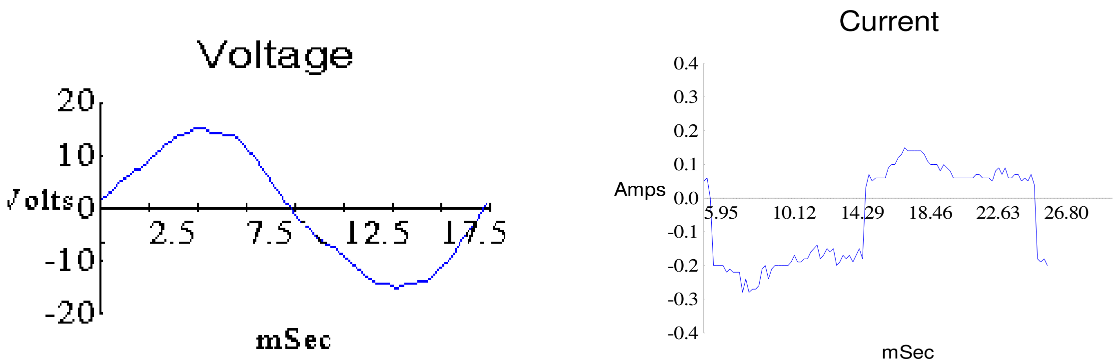
The value of C_o (assuming 5%) can be calculated by using (1). Its value is 102.8µF or 4.61 pu.

The value of ac Compensation Capacitor C_b
From section-IV: C_b = 0.11×22.13=2.5µF.

The value of dc Filter Inductor L_o
From the previews section-V: L_o = 0.00076×457.8= 0.35 mH.

B. Experimental Results

To verify the predicted results obtained in the previews sections, a 500 mW experimental diode rectifier was implemented with the following circuit parameters: C_r= 8µF, L_r=150mH, C_b=2.2µF, L_o=0.3mH, C_o=100µF, R_L=150Ω. The experimental waveforms of the input voltage and current are shown in Figs. 11, which are obtained under the condition that the output power is 1.0 pu, the input rms voltage is 8.5V and its frequency is 50Hz. Evaluation of Figs. 11 and 9a shows that the simulation results are in close agreement with the experimental results.



(a) (b)

FIGURE 11: an Experimental input voltage waveform of the improved method-2 rectifier, b. Experimental input current waveform of the improved method-2 rectifier

7. CONSLUSION & FUTURE WORK

A novel passive input current waveshaping method for single-phase rectifiers has been proposed and the relevant waveforms of the input current and voltage obtained from computer simulation and the spectrum of the input current obtained from Fourier analysis have been shown in this paper. Also, an improved method-1 to reduce THD_i and increase power factor was developed by installing a parallel capacitor C_b between the parallel resonant tank and the rectifier bridge. For further reduction in the input current THD_i and increase power factor achieved by install a series inductor with the output of the rectifier. The validity of the simulation results and the feasibility of the improved method have been verified on a 500 mW laboratory prototype unit.

8. REFERENCES

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