

Harmonic Correction in Power Supplies Feeding Non-Linear Loads

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Abstract – This paper focuses on the design of an electronic circuit which can be used in conjunction with the power supplies used at the input of non-linear loads (computers, TV sets, etc.) in order to filter out the input current harmonics in such loads. The electronic circuit will fill the gaps of the distorted current waveform so that it becomes sinusoidal and also in phase with the mains supply. In this paper different configurations of the proposed electronic circuit are covered (depending on the location with respect to the non-linear load). An optimization algorithm is carried out in order to find the best location, minimum device rating for different type of loads. The proposed circuit monitors the input current, output voltage and power rating of the power supply. The circuit will then decide whether to filter the input current harmonics or the output voltage harmonics. The circuit will also optimize the best switching frequency for the required load so that the power supply operates at the maximum possible efficiency.

Index Terms – Power electronics, the event of Current distortion in AC – CD power supply systems, Harmonic analysis and Harmonic Distortion, suggested methods for current correction.

I. INTRODUCTION

In AC/DC power supplies, the use of smoothing capacitor causes a much distorted input current waveform. This is mainly due to the fact that the input current at the AC side is a reflection of the charging and discharging current of the capacitor at the DC side. A typical Total Harmonic Distortion (THD) of the input current in such power supplies is greater than 100%, depending on the value of the filtering capacitance. Although a single computer may cause very little distortion, however in a buildings with more than 500 or 1000 computers, the distortion can be sever causes voltage distortion at the feeder and this may cause problems to other loads including linear loads [1-2]. Some of these problem many include [3, 10]

- Heating of induction motors.
- Heating of transformers.
- Heating of capacitors.
- Overloading of neutrals.
- Telephone transmission interference.

The harmonic distortion caused by an electronic circuit, according to IEEE standards, must not exceed a total of 5% [12-13], with a maximum of 4% due to any one even

harmonic (i.e., second, fourth, etc) and 2% to any one odd harmonic (i.e., third, fifth, etc) [12].

II. CURRENT DISTORTION CAUSED BY THE SINGLE PHASE TWO-PULSE BRIDGE RECTIFIER

The circuit shown in Fig. 1 is a typical bridge rectifier circuit which could be used in the power supplies of several applications (TV's, computers, printers, UPS systems, etc.)

A smoothing capacitor is usually used to filter out the output voltage, however this causes the input current to be discontinuous and full of odd order harmonics. The input and output current and voltage waveforms are shown in Fig. 2.

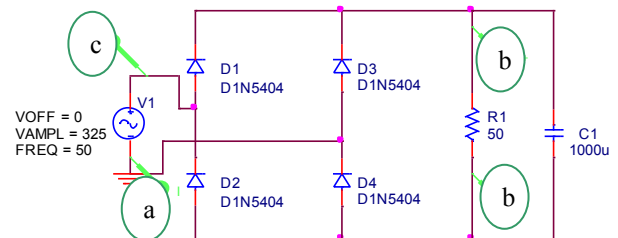


Figure 1. A single phase full wave diode bridge rectifier.

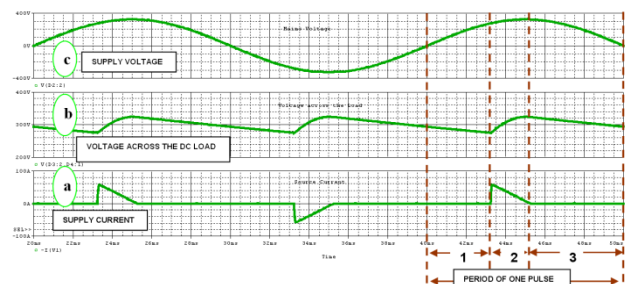


Figure 2. The mains AC voltage supply (c), the distorted current source (a), and the output voltage (b) of the circuit shown in Fig. 1

Small distributed loads, such as computer loads and TV sets with switched-mode power supplies at their inputs, add up to a large increase in the amount of harmonic current injected in power distribution systems [14]. Fig. 3

illustrates the input current and voltage waveforms of a television receiver, with a diode rectifier,

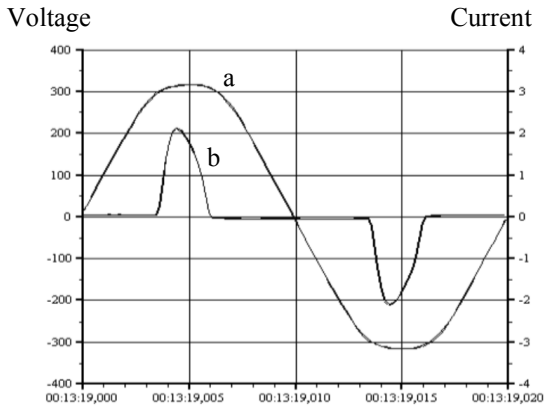


Figure 3. Phase voltage (continuous) (a) and phase current (pulsed) (b) to a television receiver [6].

III. CURRENT CORRECTION

A simulation of the input current waveforms shows that the Total Harmonic Distortion (THD) could be as high as 200% [6]. The FFT analysis of the simulated current wave form of Fig. 4-a is shown in Fig. 4-b.

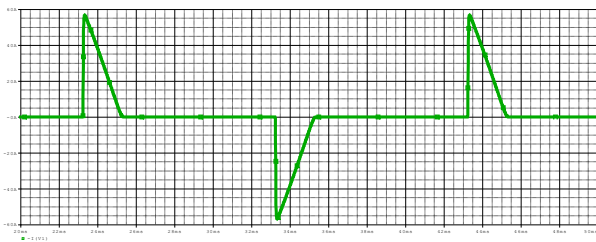


Figure 4-a. Distorted power supply input current

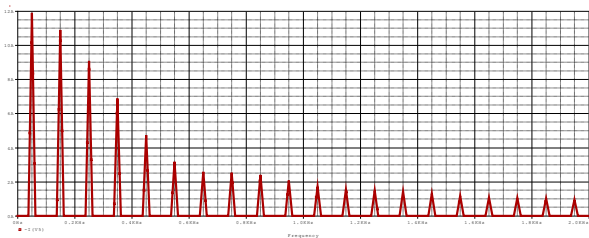


Figure 4-b. The FFT analysis of the current waveform shown in Fig. 4-a.

The Total Harmonic Distortion of the current, according to the simulation on the circuit of Fig.1, is:

$$THD = \frac{\sqrt{I_{TOTAL(RMS)}^2 - I_{1(RMS)}^2}}{I_{1(RMS)}} = \frac{\sqrt{15.558^2 - 8.418^2}}{8.418} = 1.554$$

$$THD_{(\%)} = 155.4\%$$

In order to reduce the upper THD (155.4%) to the limits of 5%, according to the EEE519 standard, the waveform of the distorted supply current must be transformed to a

sinusoidal form. This paper covers – investigates different configurations of the proposed electronic circuit (depending on the location with respect to the non-linear load), in order to transform the distorted supply current to a sinusoidal waveform.

Two possible positions for the compensating circuit are investigated:

- One is to locate the compensator at the dc side of the load, as shown in Fig. 5.

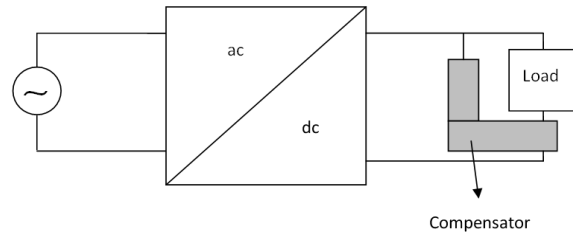


Figure 5. Compensating circuit located at the dc side of the load.

- The other option is to locate the compensator at the ac side of the ac/dc converter like the one shown in Fig 6.

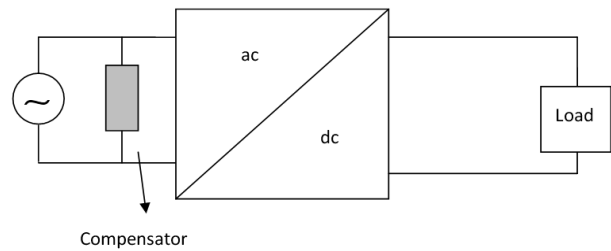


Figure 6. Compensating circuit located at the ac side of the ac/dc converter.

IV. COMPENSATOR LOCATED AT THE DC SIDE OF THE LOAD

A. Use of Pulse Width Modulation (PWM) technique

A systematic switching sequence is implemented with the PWM technique where the distorted supply current (Fig.7-a) is added with an amount of complementary supply current (Fig.7-b). The idea is that the compensator current waveform fills the gap or the difference between the distorted current and the desired sinusoidal waveforms as shown in Fig.7.

The procedure is as follow: in order to gain a sinusoidal shape of the current waveform, a sample of the sinusoidal input voltage is detected (reference signal) and it is compared to the current waveform (actual signal). The amplitude of the reference signal must be estimated according to the ratings of the shape (in voltage) of the distorted current, having the same frequency and phase difference of $\Delta\Phi = 180^\circ$. Also, there must be: $v = V_{max}\sin(\pi-\omega t)$, where v is the maximum value of the

voltage and $\omega t \approx 1/3\pi (\approx 58.5^\circ)$, according to the setup of Fig. 1.



Figure 7. The distorted supply current (a), the complementary supply current (b), the product sinusoidal source current (c) of the addition of (a) and (b), and the mains supply voltage (d).

After that, the shape of the curve of the complementary supply current (in voltage), is modulated (Fig.8-a) in pulses (Fig.8-b) and their complementary (Fig.8-c). These pulses control a power switching transistor Z1 (Fig.8.c), in order to pass the complementary supply current, which is being added with the distorted one, passing through the Z2 transistor, which is controlled by the complement pulses (Fig.8-c and Fig.9-b).

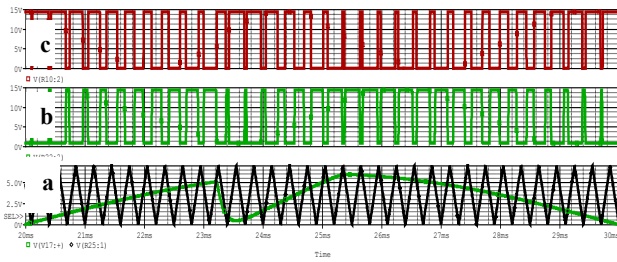


Figure 8. (a) A half period of the mains pulse, where the complementary supply current is being modulated. (b) Modulated complementary pulses. (c) Complementary pulses.

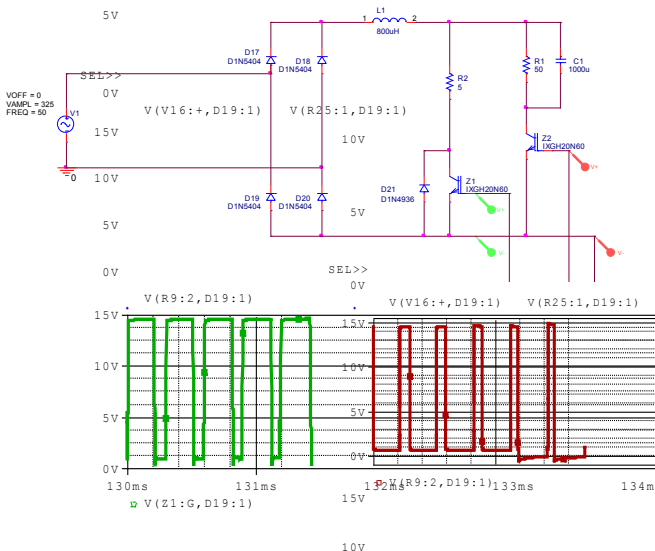


Figure 9. The PWM compensator located at the dc side of the load and the switching pulses for Z1 and Z2.

The Figure 9 shows how the complementary supply current is added with the distorted supply current, through the PWM and boost (L1) technique, by the activation of the switching devices Z1 and Z2 respectively. R2 acts as a current control in order to pass the proper amount of the complementary current. According to $i = I_{max}\sin(\omega t)$, where the i is the peak value of the distorted current and I_{max} is the maximum value of the mains sinusoidal current. Also remember that $\omega t \approx 1/3\pi (\approx 58.5^\circ)$.

Fig 10 illustrates the mains voltage and the compensated input current waveform.

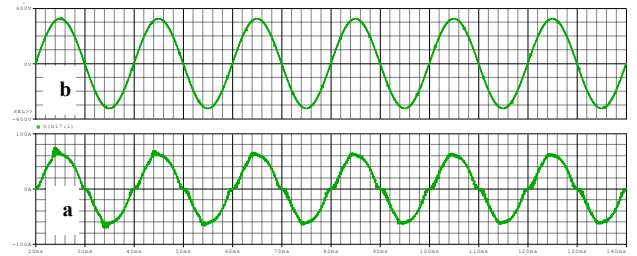


Figure 10. The input voltage and the compensated current waveforms

The Fig. 11 shows the FFT analysis of the compensated current waveform. It can be seen the dramatic reduction in the THD.

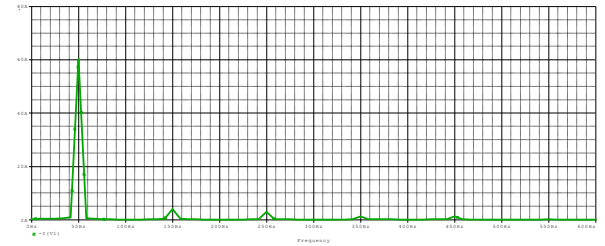


Figure 11. The FFT analysis of the corrected source current.

Through the above method of current correction at the dc side of the load, the resulted Total Harmonic Distortion can be decreased to about 10%:

$$THD = \frac{\sqrt{I_{TOTAL(RMS)}^2 - I_{1(RMS)}^2}}{I_{1(RMS)}} = \frac{\sqrt{42.889^2 - 42.671^2}}{42.671} = 0.101$$

$$THD_{(0\%)} = 10.1\%$$

By adjusting the complementary supply current's switching pulses and controlling the value of 'L' the THD can be decreased to less than 5%.

B. Use of Complementary Constant Square Pulse switching technique

An alternative less expensive and easy method of current correction at the DC side of the load can be applied by the

use of Complementary Constant Square Pulse Switching technique. In this technique, the inductor 'L' and the switch Z2 are used to boost the energy in the inductor. The switching transistor Z2 is operated by square pulses at 10 kHz and duty cycle 75%. When Z2 is off, switch Z1 is operated 'complementary', passing the distorted supply current of the load as shown in the circuit diagram of Fig. 12.

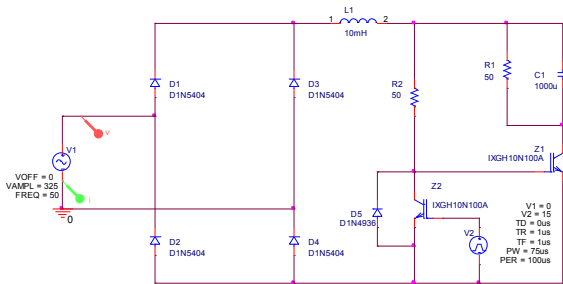


Fig.12. The Complementary Square Pulse Switching compensator located at the dc side of the load.

And here also, the control current R2 can be replaced by a current mirror, which acts as a switched mode (Constant Square Pulse Switching) current source.

The Fig. 13 show the resulting corrected source current and the mains voltage.

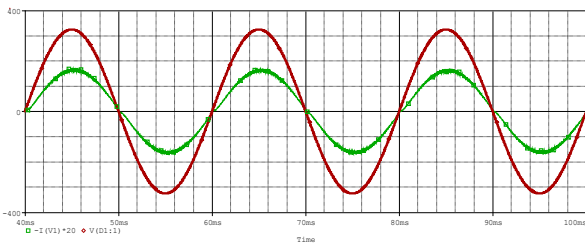


Figure 13. The resulting corrected source current and supply voltage.

The Fig. 14 shows the FFT analysis of the compensated source current, where here also, can be seen the high decrease of the harmonics in order and amplitude.

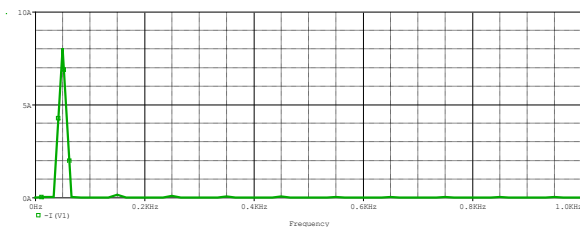


Figure 14. The FFT analysis of the compensated source current.

Through the above method the resulted Total Harmonic reaches to:

$$THD(\%) = 4.6\%$$

V. COMPENSATOR LOCATED AT THE OTHER SIDE OF THE AC/DC CONVERTER

A. Use of Pulse Width Modulation (PWM) technique

The method of the use of PWM technique, which has been applied at the dc side of the load, is the same being applied at the other side of the ac/dc converter too.

The Fig. 15 shows a bidirectional switching system, consisted by a diode bridge rectifier D5, D6, D7, D8 and transistor Z2, which is being controlled by the complementary supply current's switching pulses by the use of PWM technique; the R17 acts as a current control. The Fig. 15 also shows the bidirectional switching system which consists of a diode bridge rectifier D13, D14, D15, D16 and transistor Z3, which passes the distorted load current each time just when Z2 is in off position.

The control current R17 can be replaced by a current mirror, which acts as a switched mode (Constant Square Pulse Switching) current source.

IV. CONCLUSIONS

The application of the semiconductors in the switching mode power manipulation, like diode rectifier power supply with filtering capacitance, results to the distortion of the supply-source current. The distorted source current is not sinusoidal any more, with an amount of a Total Harmonic Distortion (THD) rising up to 150%, as it has been noticed from the simulation. Considering that the established value of the THD is 5%, according to IEEE standards, by switching methods has been achieved firstly the current correction successfully, where an amount of source current (complementary to the distorted) is injected to the dc side of the load, or at the other side of the ac/dc converter through a compensator circuit. The current injection either it happens through PWM or through constant square pulses, by the activation of transistor switching components (here IGBTs), results to the correction of the distorted supply current, decreasing the THD to 10.1% and down to 4.6%. Also the Power Factor (PF) is not lower than 0.93. In the case where there is high power distribution systems like buildings with many non-linear loads, as TV's, Computers, Printers, UPS's etc. one compensator circuit located between mains supply and input of the ac/dc converter is enough, after controlling - adjusting the complementary source current related to the final distorted one. For unique cases, compensator circuit can be located at the side of the load.

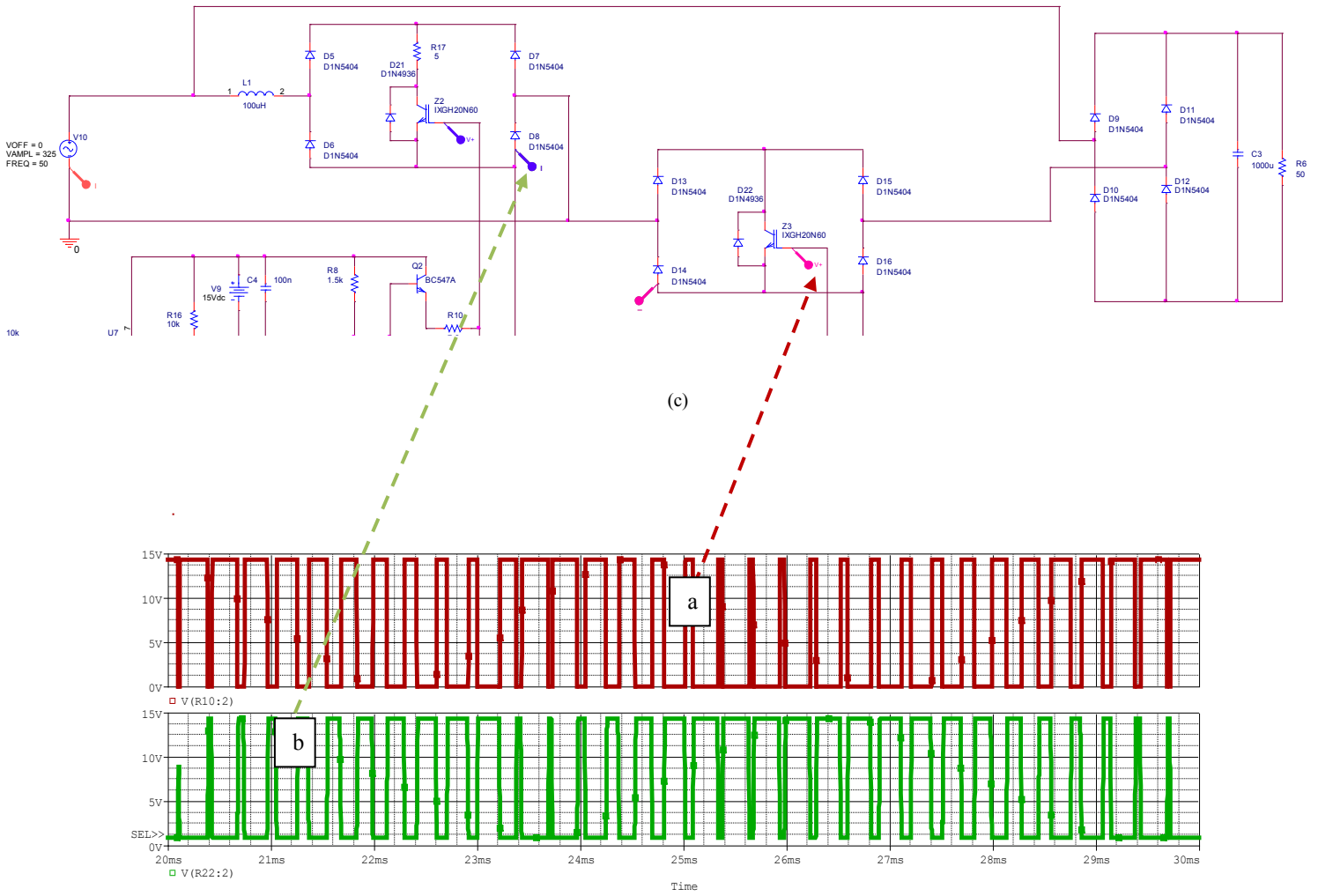


Figure 15. The PWM compensator (D5, D6, D7, D8, Z2, D13, D14, D15, D16, Z3, L1, and R17) located at the other side of the ac/dc converter (c) and the switching pulses: the PWM modulation of the shape (in volts) of the complementary supply current (a) and the complement of them (b).

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