Proceedings of the
Conference on Engineering Research, Innovation and Education 2011
CERIE 2011, 11-13 January, Sylhet, Bangladesh

PERFORMANCE ANALYSIS OF A SIMPLE POWER QUALITY CONDITIONER FOR MITIGATION OF HARMONICS

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Power quality issues are gaining significant attention due to the increase in use of equipment that are sensitive to distortions or dips in supply voltages. At the same time, the usage of static power converters has been growing tremendously to provide controlled electric power in various applications such as arc furnaces, computer power supplies and adjustable speed drives. The nonlinear characteristics of these power converters create poor power factor, low system efficiency, interference in nearby communication networks and disturbance to other consumers due to increased harmonics, negative sequence and reactive power components of current from AC mains. To curb this, regulations apply in many places that limit the distortion and unbalance that a customer can inject to a distribution system. These regulations may require the installation of active filter on customer premises to reduce harmonics. In this paper behavior of a simple converter circuit has been analyzed experimentally to find its effectiveness for cost effective solution as power conditioner. The circuit consists of four diodes and one MOSFET has been used at the input of a resistive loaded single phase rectifier circuit to mitigate harmonics. It is found that the total harmonic distortion (THD) is reduced; power factor and efficiency are improved. The work has also been simulated by ORCAD simulation software and it is found that simulation results matched closely with those of experimental results.

Key words: Power Quality, Unified Power Quality, Harmonic Mitigation, Power Quality Conditioner, Reactive Power

1. INTRODUCTION

The advances in the power semiconductor devices have led to the increase in the use of power-electronic converters in various applications such as heating, lighting, ventilating and air conditioning applications, large rated dc and ac drives, adjustable speed drives (ASDs), HVDC systems, in process technology such as electroplating, welding units etc., battery charging for electric vehicles, power supplies for telecommunication systems etc [1-4]. And many of these use ac to dc conversion by various rectifiers. Rectifiers are non-linear circuit elements and generate harmonic currents. The non-sinusoidal harmonic currents drawn by the rectifiers are injected into the ac power lines /transformers /source causing a number of problems for the power distribution network and for other electrical systems in the vicinity of the rectifier deteriorating the power quality at the point of common coupling (PCC), thereby affecting the nearby consumers [5-7]. Consequently, design and development of rectifiers with improved waveforms has gained importance for stringent power quality regulation and strict limit on total harmonic distortion (THD) of input current placed by standards such as IEC 1000-3-2 and IEEE 519-1992 [8-10].

Several methods have been employed for improving the input current wave shape and power factor of rectifiers which include both active and passive means. Among the passive wave shaping methods, the novel method, using an input L-C parallel resonant tank proposed by P. D. Ziogas [11] in 1990, is worth mentioning. However, further improvement of the input power factor is difficult to achieve, and the input current's total harmonic distortion is still high, which is the main disadvantage of the novel topology. To overcome the weakness, Yanchao in 1996 [12] proposed an improved passive wave shaping method where a capacitor is placed in parallel between the parallel resonant tank and the rectifier bridge, which could compensate the reactive power and absorb the

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ISBN: 978-984-33-2140-4

distortion power. As a result the improved method has a better filter feature and the higher input power factor than the novel method. Though the passive methods are attractive for their simplicity, reduced cost and reliability [9, 13-14] but they are bulky and fail to provide satisfactory results. On the other hand, the active methods using high frequency switching technique to shape the input current with small size filter are much preferred [10, 15]. Although due to design complexity and cost of the additional circuitry often found them to be unacceptable in low power applications. In 1991, a novel active power factor correction method for power supplies with three phase front end diode rectifiers is proposed and analyzed by A. R. Prasad and P. D. Ziogas [16]. The implementation of this method requires the use of an additional single switch boost chopper. This method does not deal with total harmonic distortion but the power factor is near unity. Based on the analysis of the novel active power factor correction of three phase diode rectifiers by A. R. Prasad and P. D. Ziogas [16], M.A. Khan et al. in 2007 [17] designed a single phase rectifier with switching on AC side for high power factor and low total harmonic distortion. This method uses a single MOSFET switch on the ac side to provide alternative path for input current to flow and hence make it continuous. The rectifier is connected to the ac mains through a series combination of inductor and capacitor, which keeps the input current smooth and in phase with the supply voltage. The simulated results revealed that the total harmonic distortion is reduced and overall efficiency is improved significantly.

2. OBJECTIVE

In this paper behavior of a simple converter circuit has been analyzed experimentally to find its effectiveness for cost effective solution as power conditioner. The circuit consists of four diodes and one MOSFET has been used at the input of a resistive loaded single phase rectifier circuit to mitigate harmonics. The work has been simulated by ORCAD simulation software and the simulation outcomes have been verified with those of experimental results.

3. CIRCUIT DESCRIPTION

Fig. 1 shows the schematic diagram of the circuit present here for making the current continuous. When the switch (M1) is ON or closed, it provides an alternative path when all the diodes (D1 to D4) are reverse biased. Since input current flows naturally when the supply voltage approaches its maximum value (positive or negative), the switch should be triggered off during that period. For the rest of the period, the switch should be turned ON and OFF with continuously varying duty cycle. The duty cycle should be smoothly varying, starting with maximum ON period and reaching to minimum ON period as the supply voltage sweeps through its zero to maximum values. The ON time initially should be high to ensure the increase of input current to a reasonable value, so that during smaller OFF periods current does not fall appreciably and thus remains smooth. As the supply voltage increases, the ON period should decrease accordingly to prevent the input current from rising indefinitely and also to allow input current sufficient time to fall accordingly during the OFF period. This concept reveals that the duty cycle of the switching should be varied like a rectified cosine function with a frequency twice that of the supply.

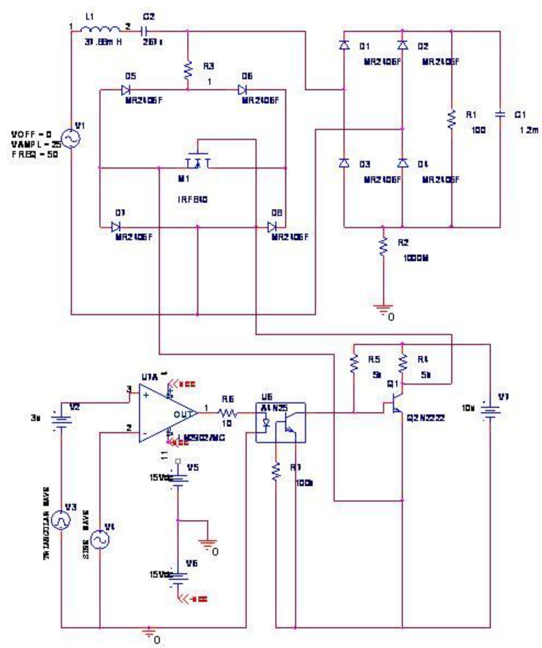


Fig. 1: Single phase diode rectifier with switching on input side

The inductor (L1) connected in series with the supply makes the current smoother by eliminating any sharp variation that might exist. However, the inductance value required for this purpose may become large, causing a significant portion of supply voltage to be dropped across it. This would result in unacceptably low output voltage. Moreover, the phase difference between input current and supply voltage in this case would be also unacceptable. Therefore a capacitor (C2) has been connected in series with L1 to keep the current in phase with the supply voltage.

3.1 The Switching Scheme

The objective of the switching scheme is to enhance the continuity of the input current by providing it an alternative path through closing an electronic switch. A MOSFET (IRF 840) is used as the switch because of its high switching speed compared to other semiconductor switches. The gate pulses have been generated by a PWM module which mainly consists of an opamp, an opto-coupler and BJT. A 4 KHz triangular wave is compared with a 50 Hz sinusoidal signal to generate the gate pulses in order that the duty cycle can be smoothly varying, starting with maximum ON period and reaching to minimum ON period as the supply voltage sweeps through its zero to maximum values, so as to make the input current sinusoidal and in phase with input voltage. The opto-coupler is used to provide necessary ground isolation between the PWM module and the switch while producing the pulses. The BJT amplifier is connected for increasing the voltage level at about 10 volts to drive the switch.

3.2 Input Filter Design

The values of L1 and C2 forming the input filter are chosen in such a way that its resonant frequency equals that of the supply frequency which is 50 Hz. This produces a selectivity due to which only the fundamental frequency component of the input current can flow unimpeded and causes negligible voltage drop across the LC combination. For a given supply frequency the value LC constant can be found as-

$$X_L = X_C$$

$$\Rightarrow 2\pi f L = \frac{1}{2\pi f C}$$

$$\Rightarrow LC = \frac{1}{4\pi^2 f^2} = 10.132 \times 10^{-6}$$

The values of the series L-C filter are adjusted to produce a series resonance at supply frequency with the intention to keep the input current in phase with the supply voltage and to improve the overall system efficiency.

3.3 Output Filter Design

A simple capacitive input dc filter is used to reduce the ripple content of the output voltage of the single phase rectifier. The ripple factor RF can be found from

$$RF = \frac{1}{\sqrt{2}(2 f_r RC - 1)}$$

Where f_r is the ripple frequency = 100 Hz. Considering the ripple voltage to be reduced to 1% after filtering, the value of RC constant can be found as 0.12855. Again, for the *n*th harmonic ripple current to pass through the filter capacitor, the capacitance value should be so chosen that the load impedance must be much greater than that of the capacitor. That is, $R >> \frac{1}{2\pi f_r C}$. Allowing for a dc load of 100Ω the value of the output filter capacitor C1 is taken 1.2 mF.

4. RESULTS AND DISCUSSION

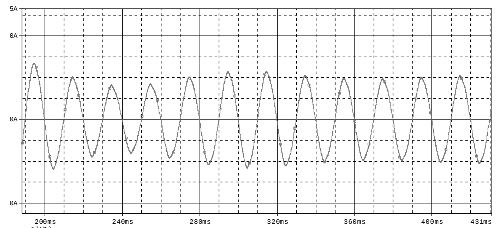
The converter circuit was simulated by ORCAD simulation software with various combinations of input filter L, C values and was verified with practical examination to find its effectiveness for cost effective solution as power conditioner.

Initially the total harmonic distortion of the input current of a single phase rectifier has been studied as a power quality problem. Fig. 1 shows the non-sinusoidal input current wave shape of the supply mains due to rectification action. The high current peaks cause harmonic distortion of the supply current and low power factor.

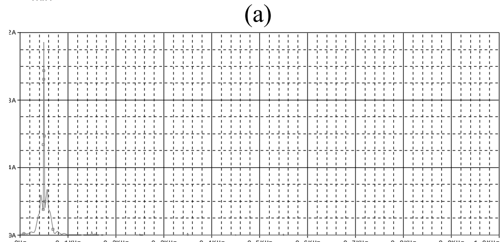
Fig.2: The non-sinusoidal input current wave shape of the supply mains due to rectification action

This results in a poor power quality, voltage distortion, poor power factor at input ac mains, slowly varying rippled dc output at load end and low efficiency. Thus the switching scheme has been developed exploiting a single MOSFET switch driven by rectangular gate pulses whose duty cycle is continuously varied over the period of supply voltage. The switch provides an alternative path for the input current makes it sinusoidal during the periods when due to the reverse biasing of rectifier diodes input current causes to flow otherwise.

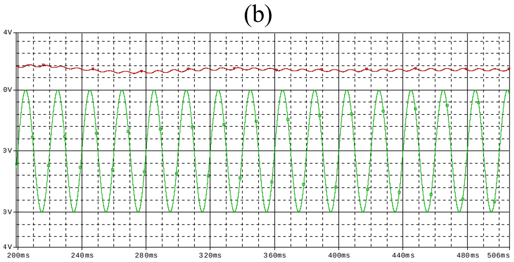
Simulating the circuit using ORCAD for various combination of LC filter, we get the wave shapes of input current and its frequency spectrum, output voltage waveforms, samples of which are presented in Fig. 3 and the summary of the simulation results is given in Table 1.



(a)



(b)



(c)

Fig. 3: wave shapes of (a) input current, and (b) its frequency transform, (c) output voltage along with supply voltage for L=37.88mH and C=267.5µF

Table 1. Summary of the simulation results

Input filter		THD	Vin	Iin	Vout	Iout	H	P.f.
L (mH)	C (µF)	(%)	(V)	(A)	(V)	(A)	(%)	
160	64	2.46	11.3	1.24	12.5	0.82	73.15	0.95
37.88	267.5	3.55	11.3	0.6	14.3	0.42	89.21	1
44.8	226.16	4.02	4.11	0.22	4.26	0.19	86.53	0.99

The simulation output shows that the THD of the input current has been improved significantly, power factor has been close to unity and the overall efficiency has also been enhanced.

Additionally using simulation the total harmonic distortion (THD) and the efficiencies of the prototype are calculated for various switching frequencies and the efficiency vs. switching frequency curve is plotted as shown in Fig. 4. From the curve it is clear that the efficiency is more for a switching frequency of 4 KHz. Thus we employed the switching frequency of 4 KHz in practical implementation of the circuit.

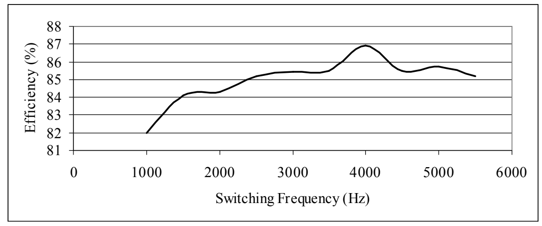


Fig. 4: Circuit efficiency for various values of switching frequency

Finally, the simulation results have been verified with practical results obtained from a laboratory setup as shown in Fig.5. The converter circuit has been implemented practically keeping the switching frequency of gate pulse at 4 KHZ. The input side LC filter has been adjusted to give the desired series resonance by varying inductor and capacitor bank. When the gate pulses were applied to the MOSFET and the input resonant filter was tuned, a dramatic change was observed in the input current wave shape like the simulation outcome.

It was one of the significant parts of our practical work to measure the THD and keep it in allowable range. We used Virtual Instrument Kit (VIK) to measure THD. VIK is a special instrument which measure THD with a probe connected to the node where THD is to be measured, and is interfaced with computer through parallel port. From the computer we can view frequency spectrum graphically and measure THD directly using VIK.

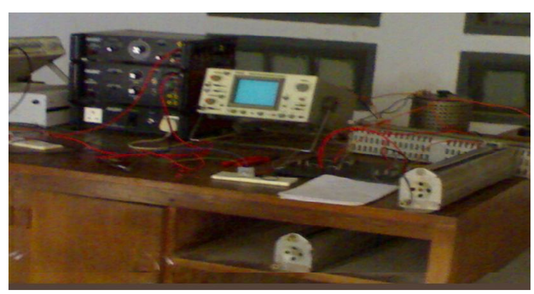
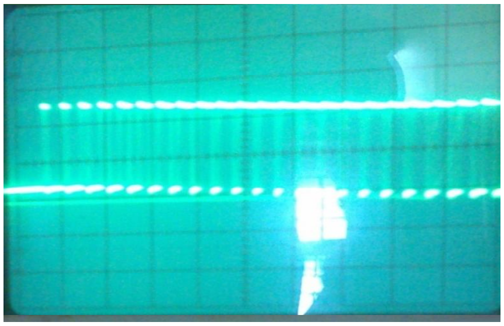
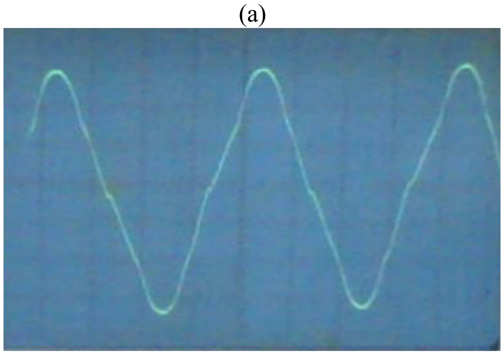


Fig. 5: Laboratory setup of the simple power quality conditioner

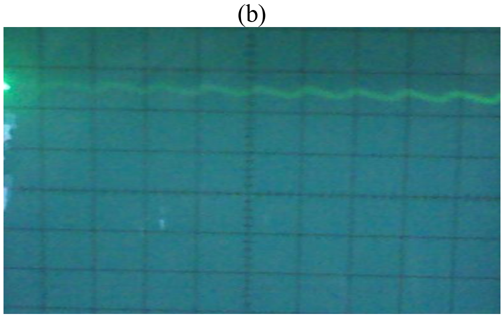
A sample of wave forms of the gating signals, the input current and the output voltage obtained from practical realization of the circuit for various filter combinations is shown in Fig. 6. Also the summary of results of the practical implementation is illustrated in Table 2.



(a)



(b)



(c)

Fig. 6: sample experimental wave forms of (a) gating signals, (b) input current and (c) output voltage for L=37mH and C=267.5µF

Table 2. Summary of the experimental results

Input filter		THD	Vin	Iin	Vout	Iout	η	P.f.
L(mH)	C(µF)	(%)	(V)	(A)	(V)	(A)	(%)	
37	267.5	4.92	11.3	0.89	12.83	.628	86.74	0.969
44.8	226.1	4.29	4.11	0.542	4.72	0.39	82.65	0.92
63	160.1	7.26	4.82	0.625	4.96	.435	71.47	0.83

The experimental outcome demonstrates close resembles to the simulation output. The THD of the input current has been considerably improved compare to that without conditioner and, power factor has been close to unity and the overall efficiency has also been better. A comparative study on simulation and practical data is demonstrated by bar charts as shown in Fig. 7 & 8.

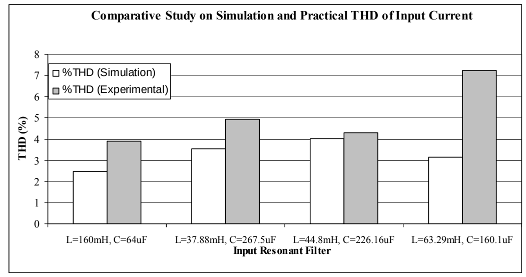


Fig. 7: %THD of input current for different LC combination (simulation & experimental)

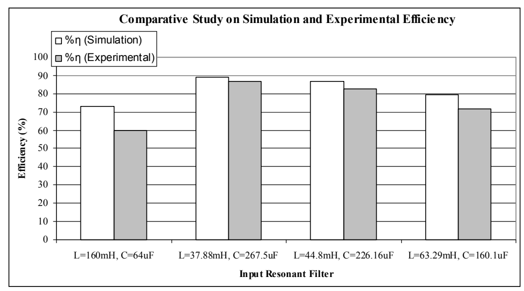


Fig. 8: Efficiency of the system for different LC combination (simulation & experimental)

With the deployment of the power conditioner circuit the performance of the single phase rectifier has been improved appreciably as demonstrated by simulation and practical implementation. The total harmonic distortion (THD) is reduced; power factor and efficiency are improved and simulation results matched closely with those of experimental results. The best result of efficiency is obtained for input filter parameter L=37mH, C=267.5uF and switching frequency of 4 KHz. In this case THD of the input current is about 4%, efficiency more than 86% and power factor is close to unity. Also the output voltage is found to be greater than the input voltage amplitude. This is important because as the output voltage becomes higher than the supply voltage amplitude, the rectifier diodes are reverse biased and the current can flow naturally only when the switch is turned on.

5. CONCLUSION

In this paper a scheme for improving the input current wave shape and power factor of a single phase rectifier has been successfully analyzed experimentally and also by simulation to find its effectiveness for cost effective solution as power conditioner. The simulation outcomes matched closely with those of experimental results. However, the experiment has been conducted in low power levels and low voltages. If power levels would be high it would offer more desirable results as switching power would be minimized to enhance the overall system efficiency. Moreover, the effects of different types of loads on required switching frequency, duty cycle variation and efficiency should also be studied. The use of IGBTs instead of MOSFET may have significant effect in reducing the THD and the efficiency may still go up. For that the input and the output filter circuits should be designed accordingly.

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