ISSN 2229-5518

Improvement of Input-Side Current of a Single Phase Rectifier with Variable Output Voltage Range using Boost Converter and Investigation of Harmonic Minimization

Ahmed Al Mansur, Abdullah Al Bashit, A.S.M. Mahfuzur Rahman, Md. Shahinur Alam,Hasina Begum

Abstract— In order to reduce the Total Harmonic Distortion (THD) in a single phase boost rectifier, active switching & passive filters are incorporated in this work. A constant frequency switching is used for active filtering & pulse width modulation is used to regulate the output voltage. A passive LC filter is used in the input side to suppress the unwanted high frequency harmonic components generated by the active switching and output filtering. Using passive filtering the THD could be made less than one percentage, which is a great improvement over the earlier rectifiers that have only Electro-Magnetic Interference (EMI) filter. In the earlier types of rectifiers, the THD value was as high as three percentages. The efficiency of the module is also studied. As the output voltage has the nonlinear relation with duty cycle, the efficiency is also nonlinear with output voltage variation. But up to certain range of duty cycle it could be made linear in nature with output voltage. The efficiency versus duty cycle and THD versus duty cycle curve for the proposed rectifier circuit is given for a clear understanding of the model. The conventional Power Factor Correction (PFC) circuit has a fixed output voltage. However, in some applications, a PFC circuit with a wide output voltage range is needed. A single phase power factor correction Boost rectifier circuit with wide output voltage range (150V to 300V) and efficiency more than 95% is developed in this work using passive filter and boost rectifier.

Index Terms— Active Switching, Electro Magnetic Interference, Power Factor Correction, Single Phase Rectifier, Total Harmonic Distortion

1 INTRODUCTION

THE input stage of any AC-DC converter comprises of a full-bridge rectifier followed by a large filter capacitor. The input current of such a rectifier circuit comprises of large discontinuous peak current pulses that result in high input current harmonic distortion. The high distortion of the input current occurs due to the fact that the diode rectifiers conduct only for a short period. This period corresponds to the time when the mains instantaneous voltage is greater than the capacitor voltage. Since the instantaneous mains voltage is greater than the capacitor voltage only for very short periods of time, when the capacitor is fully charged, large current pulses are drawn from the line during this short period of time. Fig. 1 shows the schematic of a typical single phase diode rectifier filter circuit while Fig. 2 shows the typical simulated line voltage and current waveforms. The typical input current harmonic distortion for this kind of rectification is usually in the range of 55% to 65% and the power factor is about 0.6 [1]. The actual current wave shape and the resulting harmonics depend on the line impedance. Conventional AC rectification is thus a very inefficient process, resulting in waveform distortion of the current drawn from the mains. A circuit similar to that shown in Fig. 1 is used in most mains-powered AC-DC converters. At higher power levels (200 to 500 watts and higher) severe interference with other electronic equipment may become apparent due to these harmonics sent into the power utility line. Another problem is that the power utility line cabling, the installation and the distribution transformer, must all be designed to withstand these peak current values resulting in higher electricity costs for any electricity utility company [2],[3].

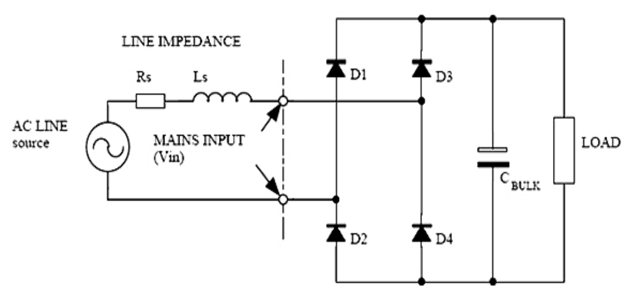

Fig. 1. Schematic diagram of a single phase diode rectifier with capacitor filter circuit [2],[3]

The power factor correction (PFC) technique has been gaining increasing attention in power electronics field in recent years. For the conventional single-phase diode rectifier, a large electrolytic capacitor filter is used to reduce dc voltage ripple. This capacitor draws pulsating current only when the input ac voltage is greater than the capacitor voltage, thus the THD is high

- Ahmed Al Mansur is currently pursuing PhD degree in Electrical and Electronic Engineering (EEE) in Islamic University of Technology, Bangladesh, E-mail: mansur.iut@gmail.com
- Abdullah Al Bashit is working as a lecturer in the Dept. of EEE, Prime University, Bangladesh, E-mail: eeebashit@gmail.com
- A.S.M. Mahfuzur Rahman is with the dept. of EEE in Prime University, Bangladesh, Email: mahfuz.pbtl@gmail.com
- Md. Shahinur Alam is with the dept. of EEE in Prime University, Bangladesh, Email: shahinur.alam9@gmail.com
- Mrs. Hasina Begum is with the dept. of EEE in Prime University, Bangladesh, Email: hasina.pu@gmail.com

and the power factor is poor. To reduce THD and improve power factor, passive filtering methods and active wave-shaping techniques have been explored [4],[5],[6],[7].

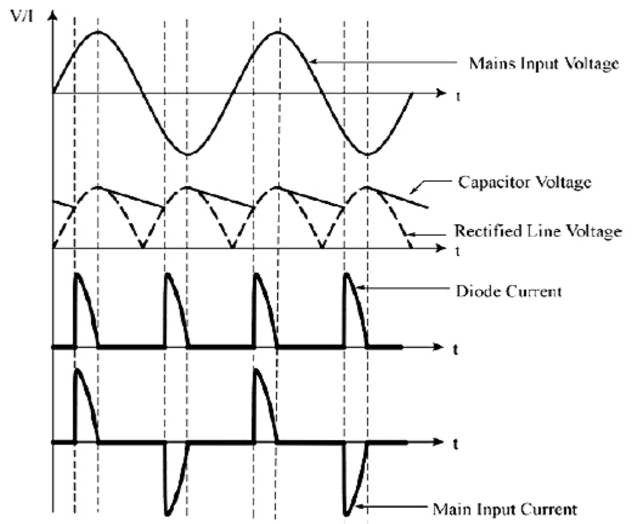

Fig. 2. Typical line current and voltage waveforms [2],[3]

2 Rectifiers THD Improvement

2.1 Rectifier with output filter Capacitor

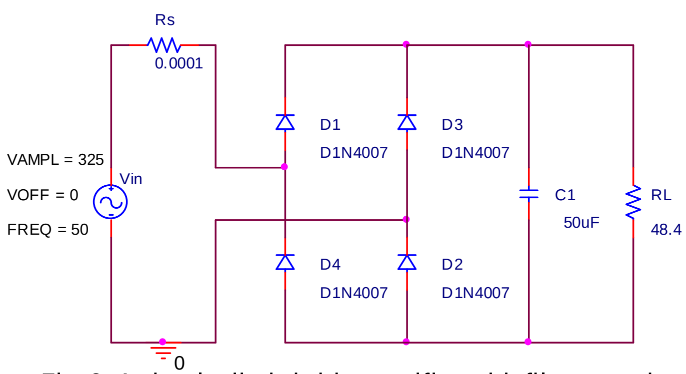

Fig. 3. A simple diode bridge rectifier with filter capacitor

TABLE 1
Effects of Filter Capacitor on Efficiency and THD

L_1	V_o (Volt)	I_{in} (Amp)	η (%)	THD (%)
10uF	338	6.5	98	3.24
20uF	330	7	98	9.10
30uF	325	7.9	98	15.48
40uF	320	8	99	21.77
50uF	315	8.5	99	27.70
60uF	320	9	99	33.17
70uF	320	9.5	99	38.14
80uF	320	10	99	42.27
90uF	322	11	99	46.88
100uF	225	12	99	51.70

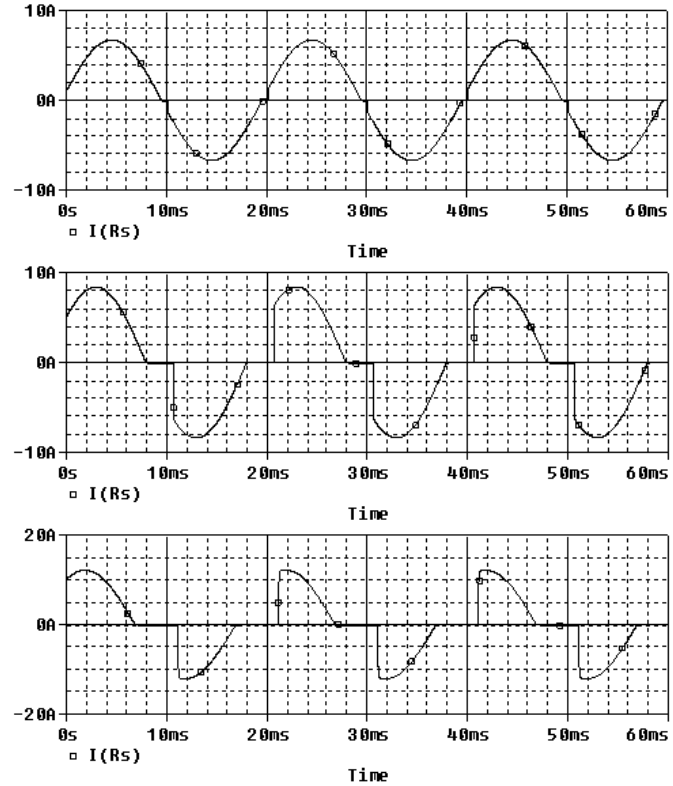

Fig. 4. Input current at capacitor C1=10uF, 50uF, 100uF

The effects of output filter capacitor on the THD and the input current and output voltage are analyses by changing the values of the output capacitor, C1 in Fig. 3. When the capacitor, C1 is increasing than the output voltages, Vo are becoming more pure dc but input currents are distorting due to harmonics generated by the filter capacitor, C1 [8],[9] shown in Fig. 4 and the summarized results are shown in the Table 1.

2.2 Rectifier with input inductive filter

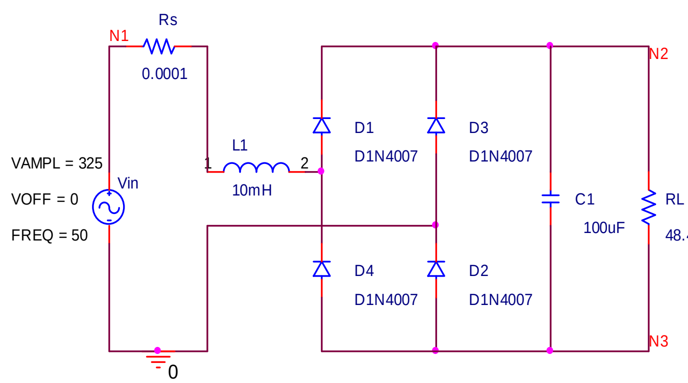

Fig. 5. Single-phase rectifier with input inductance

Input side filter is a must to reduce the harmonics contain in the input current. Passive filters are always very much cost effect than active filters [10],[11]. Because of that an inductive filter, L1 is used as a passive filter in the input side of the recti-

ISSN 2229-5518

fier shown in Fig. 5. The effects of the inductor, L1 on the output voltage, input current and THD has been analyzed and shown in Table 2. It is clear that THD are minimizing with increasing the values of input filter L1 but the output voltage level are decreasing which is a drawback of the inductive filter.

TABLE 2
EFFECTS OF INPUT FILTER L1 ON EFFICIENCY AND THD

L_1	Vo (Volt)	I_{in} (Amp)	η (%)	THD (%)
1mH	330	12.5	98	46.32
30mH	400	11	98	37.93
50mH	385	10	98	28.03
100mH	290	7.5	97.5	15.43
150mH	230	6	97	9.43
200mH	198	5	97	6.66
500mH	87	2	97	2.38

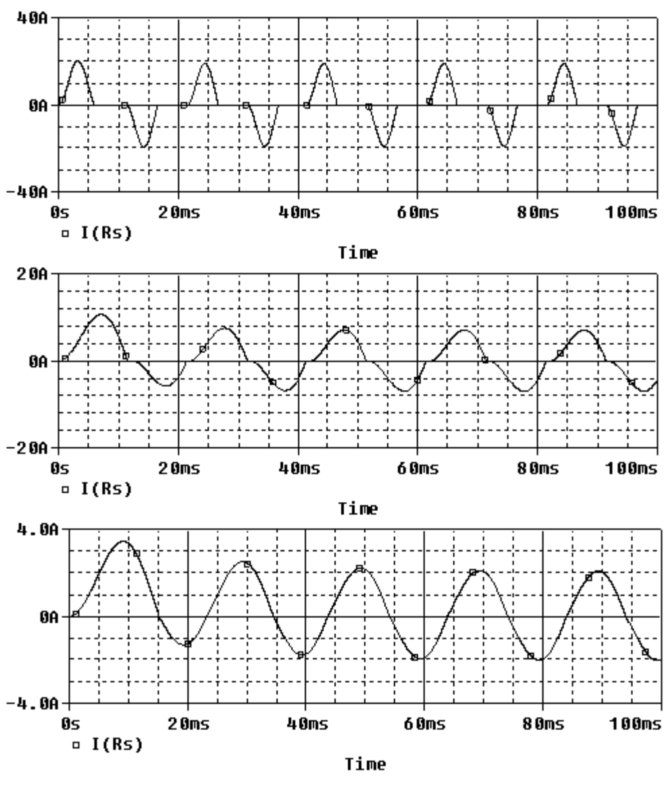

Fig. 6. Input current at L1= 10mH, 100mH, 500mH

From Fig. 6 it can be visualized that with increasing the value of the input side inductive filter, L1 from 10mH to 500mH, the current wave shapes are gradually improving means becoming more sinusoidal but the output voltage and the peak value of the input current both are decreases shown in Table 2.

2.3 Rectifier with input LC filter

The effects of input side inductive filter, L1 with capacitive filter, C2 on the output voltage, input current, efficiency and THD can determine from Table 3. From the Table it is clear that when inductive filter, L1 increases and capacitive filter, C2 decreases than output voltage, Vo decreases. The efficiency also decreases at this condition. But the THD values are not like that, it has different values at different L1, C1 combination. At L1=100mH, C1=100uF THD is less than 1% and Vo is 295Volt which is a great achievement.

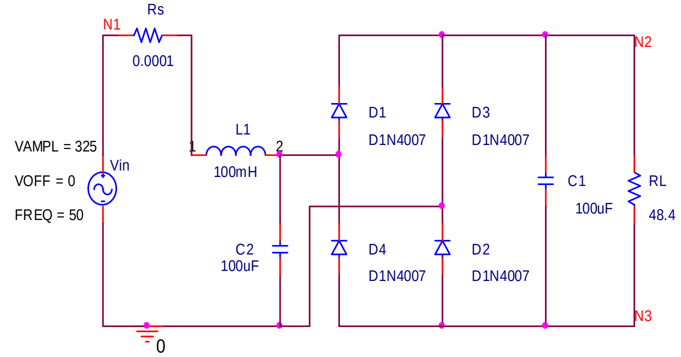

Fig. 7. Rectifier with input LC passive filter.

TABLE 3
EFFECTS OF L_1, C_2 FILTERS ON EFFICIENCY AND THD

L_1	C_2	V_o (Volt)	I_{in} (peak)	η (%)	THD (%)
50mH	220uF	515	64	98	0.54
70mH	150uF	405	37	99	0.79
100mH	100uF	295	20	97	0.969
170mH	60uF	176	9	98	1.05
215mH	47uF	140	6.5	98	1.06
340mH	30uF	90	4.5	97	0.96
1H	10uF	32	1	93	0.64

2.4 Proposed Boost Rectifier with LC filter

Boost rectifier is the combination of boost converter with a single phase rectifier [12]. An N-channel MOSFET IRF540 [13] is used in the boost converter and to drive this MOSFET with variable duty cycle a PWM [14] driver circuit is used also shown in Fig. 8. To make the rectifier with a variable output

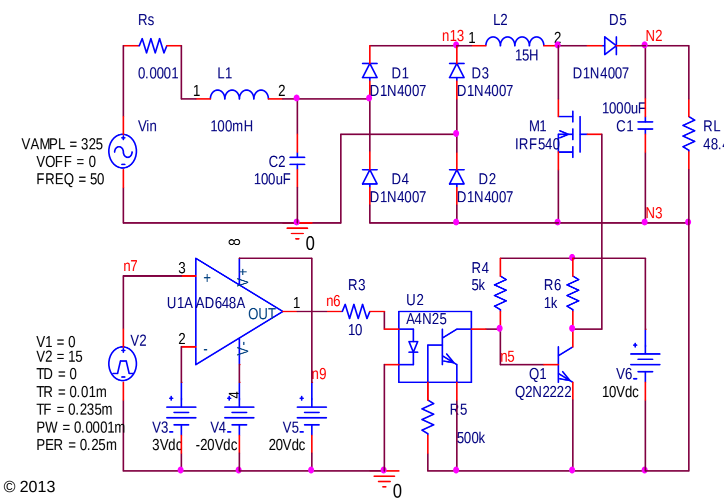

Fig. 8. Proposed model of the single phase boost rectifier

TABLE 4
INVESTIGATION OF THD AND EFFICIENCY AT DIFFERENT BOOST INDUCTOR, L_{BOOST} & CAPACITOR, C_{OUT}

L_{Boost}	C_{out}	V_o(peak)	I_{in}(peak) (Amp)	η (%)	I_{in}(peak) (Amp)
15mH	50uF	245	15	93	3.25
15mH	100uF	210	15	87	5.8
15mH	1000uF	200	10	84	7.6
25mH	1000uF	210	10	85	7.22
10mH	1000uF	200	12	84	7.81
25mH	100uF	210	12	88	5.72
100mH	100uF	318	17	89	4.2
100mH	50uF	300	15	89	3.9
50mH	50uF	230	11	89	3.19
25mH	50uF	220	14.5	89	4.02
15mH	60uF	240	15	89.5	4.04
15mH	70uF	240	15	89.5	4.86
10mH	50uF	238	15	89.5	1.94
5mH	50uF	245	16	90	1.49
2.5mH	50uF	248	16	91	1.25
1mH	50uF	250	16.5	93	1.21
0.5mH	50uF	252	15.5	96	0.998
0.5mH	100uF	247	15	95	4.39
1mH	100uF	245	10	92	11.47
0.25mH	50uF	220	13	94	23.75
0.1mH	50uF	163	11	92	1.19

voltage range boost converter is added here. But after analyzing the total circuit it has been found that the boost inductor has a great contribution to improving the input side current of the rectifier shown in Table 4. The investigation of total harmonic distortion and efficiency has been done at different values of the boost inductor, L2=LBoost and capacitor, C1=Cout in the proposed boost rectifier. From Table 4 it has been found that for the same value of L2 when C1 increases then THD increases and efficiency decreases because output voltage, Vo also decreases. Again at fixed filter, C1 when boost inductor, L2 decreasing THD also decreasing but efficiency increasing. From Table 4 it has been found that the harmonic distortion is 0.966% and efficiency is 96% at L2= 0.5mH, C1= 50uF.

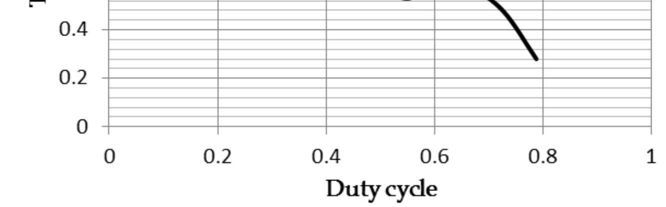

Fig. 9. THD versus duty cycle of the proposed model

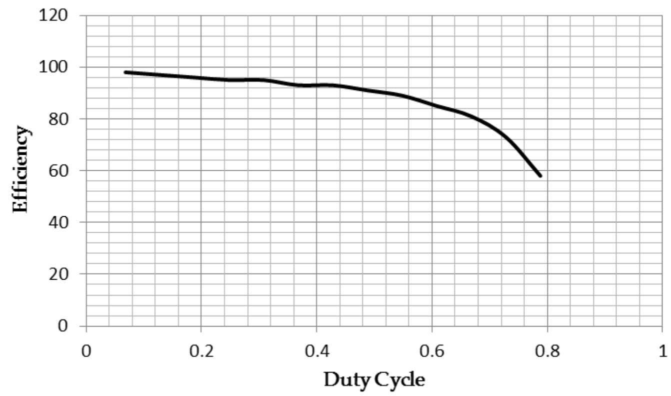

Fig. 10. Efficiency versus duty cycle of the proposed model.

TABLE 5
PROPOSED MODELS THD AND EFFICIENCY AT DIFFERENT DUTY CYCLE (C_{OUT}= 50uF AND L_{BOOST}= 0.005H)

Duty Cycle (k)	V_o(peak)	I_{in}(peak) (Amp)	η (%)	THD (%)
0.788	58	10	58	0.280
0.728	69	10.5	73	0.475
0.668	90	10.5	81	0.575
0.608	110	10.5	85	0.612
0.548	123	10.7	89	0.530
0.488	140	11	91	0.619
0.428	155	11	93	0.654
0.368	175	12	93	0.786
0.308	200	12.5	95	0.804
0.248	220	13.5	95	0.912
0.188	252	15.5	96	0.982
0.128	270	17	97	0.985
0.101	300	20	98	0.986

To verify the effect of the active switching on the THD, different duty cycle is used at the MOSFET shown in Table 5. When duty cycle, k is increases then the THD are decreases and always have the values less than 1% shown in Fig. 9. Again the efficiency is increasing when k is decreasing, which means the switching loss is minimized due to small duty cycle shown in Fig. 10. From Table 5 it has been found that the THD is 0.65% to 0.97% for duty cycle 0.42 to 0.1 when the rectifier output voltages range is 155V to 300V and efficiency 93% to 98%

3 DISSCUSSION AND CONCLUSIONS

First of all it had been studied the uncontrolled single phase rectifier with and without output filter capacitor. Without filter capacitor the THD value of the rectifier is 0.33% with rippled output voltage. To get pure dc output voltage large capacitor is included at the output but THD rise to 200%. Another drawback of this circuit is that it does not have any voltage control option. To minimize the input current THD, an inductive filter is used in series at the input-side of the rectifier. This inductive filter can minimize input-side THD but it makes more rippled dc voltage at the output-side. To overcome this filtering problem a capacitive filter is used in parallel with the inductor. This LC filer combination makes the THD less than 1% and output voltage becomes pure dc. Now to regulate the output voltage a boost converter in added between the load and rectifier but its high frequency switching makes distortion in the input current. To solve this problem an analysis has been done with different values of boost inductor and capacitor. And get an optimum condition at which again THD becomes less than 1%.

Finally, boost rectifier with active switching has been studied for different duty cycle. The best operating point is at the range of duty cycle 0.482 to 0.068. At this range the output voltage can be regulated from 155V to 300V, efficiency from 93% to 98% and THD is always less than 1%. ORCAD 9.2 release version [15], very powerful Electrical & Electronic design software is used to design all the circuits for this work.

REFERENCES

[1] A.R. Prasad, P.D. Ziogas, and S. Manias, "A novel Passive wave-shaping method for single phase Diode Rectifiers", IEEE Trans. on Industrial Electronics, Vol.37, No.6, Dec.1990, pp. 521-530.

[2] Tella, P. C. 2008 The Study of Single Phase Diode Rectifiers with High Power factor and Low Total harmonic Distortion. M.Sc. Thesis. University of Missouri – Coloumbia.

[3] Basu, S. 2006 Single Phase Active Power Factor Correction Converters: Methods for Optimizing EMI, Performance and Costs. M.Sc. Thesis. Chalmers University of Technology – Sweden.

[4] S.B. Dewan, "Optimum input and output filters for a single-phase rectifier power supply", IEEE Trans. Industry Appl., vol. IA-17, no. 3, pp. 282-288,June 1981.

[5] K. Anne, S. Wunna and Z. Aung, "Analysis of Harmonic Distortion in Non-linear Loads", The First International Conference on Interdisciplinary Research and Development, 31 May - 1 June 2011, Thailand.

[6] M.A. Khan, A.A. Pavel, M.R. Khan and M.A. Choudhury "Design of a single phase rectifier with switching on AC side for high power factor and low total harmonic distortion", IEEE Region 5 Technical Conference, April 20-21, 2007, Fayetteville, AR.

[7] P.V. Prasuna, J.V.G. Rao and C.M. Lakshmi, "Improvement in Power Factor & THD Using Dual Boost Converter", International Journal of Engineering Research and Applications, 2012, ISSN: 2248-9622.

[8] M.H. Rashid , Power electronics: Circuits, Devices, and Applications, Pearson, Prentice Hall, USA (2001)

[9] N. Mohan, T.M. Undeland and W.P. Robins, Power electronics: Converters, Applications, and Design, John Wiley & Sons, New York, USA (1995).

[10] K. K. Sen and A. E. Emanuel, "Unity power factor single phase power conditioning," IEEE Power Electronics Specialist Conf, pp. 5 16-524, 1987.

[11] R. Martinez and P.N. Enjeti, "A High-Performance Single-phase Rectifier with Input Power Factor Correction", IEEE transactions on power electronics, Vol. 11, no. 2, March 1996.

[12] I. Barbi and S. Silva, "Sinusoidal line current rectification at unity power factor with boost quasi-resonant converters", IEEE Applied Power Electronics Conf (APEC), pp 553-562, 1990.

[13] N-Channel MOSFET IFR540 [online], Available: http://www.datasheetcatalog.org/datasheet/stmicroelectronics/9387.pdf

[14] Pulse Width Modulation [online], Available: http://en.wikipedia.org/wiki/Pulse-width modulation.

[15] OrCAD Capture user manual available from: www.seas.upenn.edu/~jan/spice/PSpice_CaptureGuideOrCAD.pdf