Journal of Electrical Engineering
The Institution of Engineers, Bangladesh
Vol. EE 36, No. II, December 2009

Power Factor Improvement of a Three Phase Rectifier by Boost Regulator

Ruma[1] and Mohammad Ali Choudhury[2]

[1]Department of Electrical and Electronic Engineering, DUET, Gazipur, Bangladesh
[2]Department of Electrical and Electronic Engineering, BUET, Dhaka, Bangladesh
E-mail: rumaduet@yahoo.com

***Abstract*—In this paper, a Boost regulator based three phase rectifier for unity power factor is analyzed and described. To implement the proposed model requires a single switch Boost regulator between the three phase diode rectifier and load. Pulse width modulation (PWM) technique is used to control of Boost regulator. Power factor improvement is accomplished by using PWM technique and passive LC high frequency harmonics filters. This paper shows that when harmonics filter is attached with input LC filter then input current becomes sinusoidal input current and power factor improves notably. By reduction of undesirable harmonics this model is able to remove possibility of unwanted resonance. The performance of the rectifier improved than that reported in previous works through Boost preregulator.**

***Index Terms*—Three phase rectifier input current, Boost preregulator, harmonics filter.**

I. Introduction

MOST electronic equipments are supplied by dc voltage. All these equipments are fed from single phase or three phase ac utility lines. So, ac to dc conversion is very common. Traditionally, ac to dc conversion [1] is achieved using single-phase or three-phase diode bridge rectifier [2-5]. But, a diode bridge rectifier is affected by high THD, large ripple and low power factor. The input current with large harmonics may cause excess heat and unstable operation. Low power factor leads high reactive power requirement and reduces voltage at the load [6-7]. As a result line and equipment losses increase. For stable and reliable operation loads require regulated dc voltage. In this respect switching regulators are available to perform regulation of dc voltage. Recently works have been proposed on switching regulators with single phase or three phase diode bridge rectifier between sources and loads. But non sinusoidal input current, high harmonic distortion, low power factor, large ripple and lower efficiency are the major drawbacks of these regulators [9]. The problem can be solved by adding filter in input and output side of regulators. Some regulators has been developed recently with input and output filter which provides power factor near to unity at reduced THD [10-12]. But their sizes are the main advantages. To combats such problems, in this paper a Boost regulator has been analyzed with a three phase diode bridge rectifier. It is possible to improve power factor by this arrangement. Boost also offers large variation of output voltage with small variation of duty cycle. The objective of this work is to improve power factor keeping input current sinusoidal with low THD and improve the performance of the Boost rectifier using additional harmonic filter to maintain input current sinusoidal even with the variation of duty cycle which is necessary for voltage control purposes in variable voltage applications.

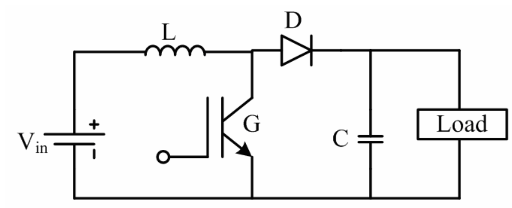


Fig. 1. Circuit diagram of a typical Boost regulator

II. Principle of Operation

In this paper a Boost regulator has been analyzed with a 3-φ diode bridge rectifier for the purpose of power factor correction. Because at present it is one of the most important research topics in power electronics. The rectifier is best suitable in industrial and commercial application which can provides pure sinusoidal input current with unity power factor. The circuit diagram of a typical Boost regulator is shown in figure 1. It consists of an inductor, a capacitor, a switch (IGBT) and a diode. Inductor is used as an energy storage element which has the tendency to resist the changes in current. When being charged it acts as a load and absorbs energy, when being discharged it acts as an energy source. The voltage it produces during the discharge phase is related to the rate of change of current, and not to the original charging voltage, thus allowing different input and output voltages. Capacitor C is used for filtering purposes.

In this paper a Boost regulator has been analyzed with a 3-φ diode bridge rectifier for the purpose of power factor correction. Because at present it is one of the most important research topics in power electronics. The rectifier is best suitable in industrial and commercial application which can provides pure sinusoidal input current with unity power factor. The circuit diagram of a typical Boost regulator is shown in figure 1. It consists of an inductor, a capacitor, a switch (IGBT) and a diode. Inductor is used as an energy storage element which has the tendency to resist the changes in current. When being charged it acts as a load and absorbs energy, when being discharged it acts as an energy source. The voltage it produces during the discharge phase is related to the rate of change of current, and not to the original charging voltage, thus allowing different input and output voltages. Capacitor C is used for filtering purposes.

During high switching pulses switch gets turned on, the power flows from input side to the load side. At this time current through the inductors start rising linearly and it gets stored. The resulting output voltage is in positive phase of the input voltage. The mathematical expressions in these modes are

$$V_{in} = V_L = L\frac{dI}{t_{on}} \tag{1}$$

$$V_{in} t_{on} = LdI \tag{2}$$

During low state of switching pulse switch gets turned off and inductor released its stored energy to the load through diode and bypass capacitor C. It is a continuous conduction process and power flow bidirectionally. The mathematical expressions in these modes are,

$$V_{in} - V_o = -L\frac{dI}{t_{off}}$$

$$(V_{in} - V_o)t_{off} = -LdI$$

$$(V_o - V_{in})t_{off} = LdI \tag{3}$$

From equations (2) and (3)

$$V_{in} t_{on} = (V_o - V_{in})t_{off} \tag{4}$$

$$V_o t_{off} = V_{in}(t_{on} + t_{off})$$

$$V_o = V_{in}\frac{T}{(T - t_{on})}$$

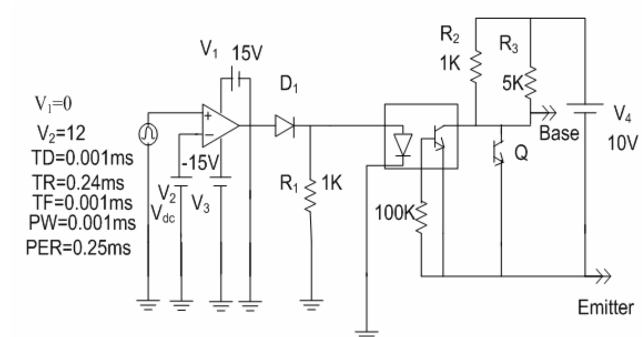
$$V_o = V_{in}\frac{1}{(1 - D)} \tag{5}$$

From equation (5) it is seen that the output voltage is always higher than input voltage. The output voltage is controlled by varying duty cycle (D) with variation of dc reference voltage.

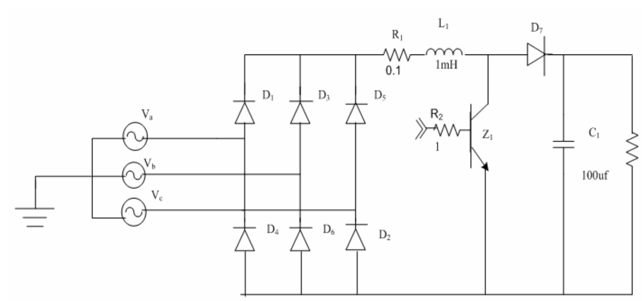
The simulated results are shown in table I. From the above analysis it is seen that input current and output voltage are highly distorted. For high frequency switching action output voltage ripple increases with variation of duty cycle which is represented as current harmonics in input size.

III. Analysis

At first a single switch Boost regulator with three phase diode bridge rectifier is analyzed. The circuit diagram of a control circuit (a) and Boost rectifier (b) is shown in figure 2. Here a Boost regulator is attached to a 3-φ rectifier with a resistive load. Rectifier is fed from a 3-φ ac utility lines having constant amplitude at constant frequency. The diodes of each phase conducts sequentially through highest positive input phase voltage. The control circuit generated a switching voltage of limited amplitude which is applied to turn on/off the switching element with low switching stress. The pulse width modulation (PWM) technique has been implemented to generate switching pulses comparing a dc reference voltage with a carrier saw tooth wave. PWM technique is used for its simplicity and low cost. The input and output voltage wave shapes are shown in figures 3 and 4.



(a) Control Circuit



(b) Boost rectifier

Fig. 2. Circuit diagram of a typical Boost regulated 3-phase rectifier

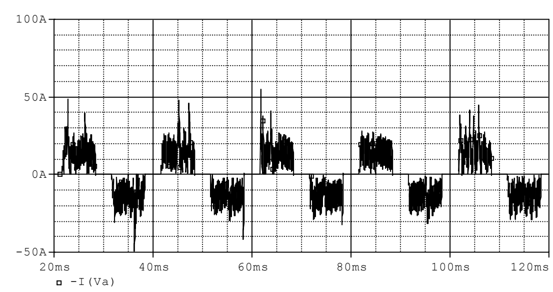


Fig. 3. Input current wave shape of Boost regulated three phase rectifier at D = 0.8

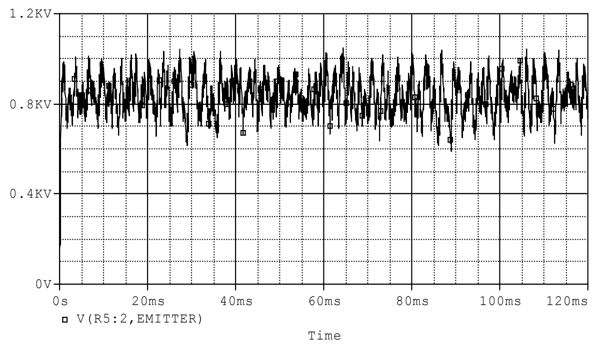


Fig. 4. Out put voltage wave shape of Boost regulated rectifier at D = 0.5

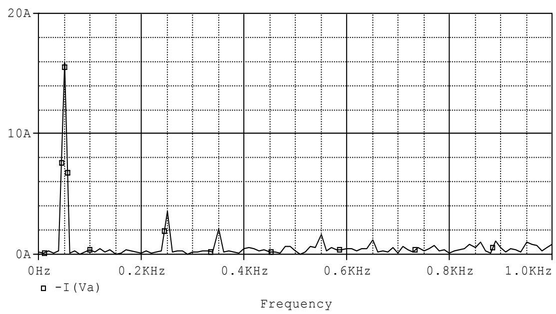


Fig. 5. Frequency spectrum of Boost regulated three phase rectifier at D = 0.8

TABLE I: PERFORMANCE PARAMETER OF A THREE PHASE BOOST REGULATED RECTIFIER

Duty Cycle (D)	THD	PF (cosθ)	Iin (rms) amp	Vout (dc) volt	Efficiency% (η%)
0.2	0.3291	0.545	49.49	800	48.08
0.3	0.3981	0.621	40.21	890	88.53
0.4	0.4903	0.702	37.35	1000	98.54
0.5	0.55	0.767	29.69	900	98.86
0.6	0.5749	0.869	22.62	780	97.23
0.7	0.5903	0.841	17.15	700	99.06
0.8	0.6205	0.903	12.72	600	98.41
0.85	0.6392	0.86	11.45	560	100
0.9	0.5939	0.847	11.17	550	100
0.95	0.7135	0.819	10.46	520	100

The simulated results are shown in table I. From the above analysis it is seen that input current and output voltage are highly distorted. For high frequency switching action output voltage ripple increases with variation of duty cycle which is represented as current harmonics in input size.

The input current is observed highly distorted and non sinusoidal in nature with low power factor. The THD% is calculated with equation (6).

$$THD\% = \frac{\sqrt{\sum_{h=2}^{h=\infty}(I_h)^2}}{I_1} \times 100\% \qquad (6)$$

where $\mathbf{I}_h$ is the magnitude of current harmonic Component and $\mathbf{I}_1$ is the magnitude of the component of current. Putting the values in the equation THD% is found to be 71.35% which is not acceptable. Filtering is required to improve the input current to sinusoidal by reducing the harmonics components and to make the power factor unity. Passive filter is a common solution in this case. But the size of filter is an important issue to design a filter. Now, the Boost regulated rectifier is analyzed with an input passive filter having parameter L=10mH and C=5uFand with an output filter having parameter L=5mH and C=200uF. The circuit diagram of a Boost regulated three phase rectifier with passive filter is shown in figure 6. The simulated results are shown in table II.

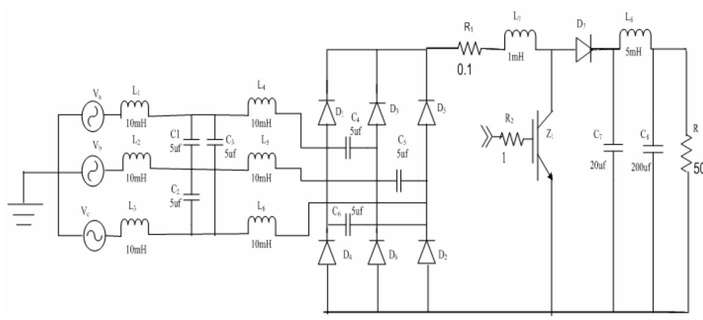


Fig. 6. Circuit diagram of Boost regulated three phase rectifier with passive filter

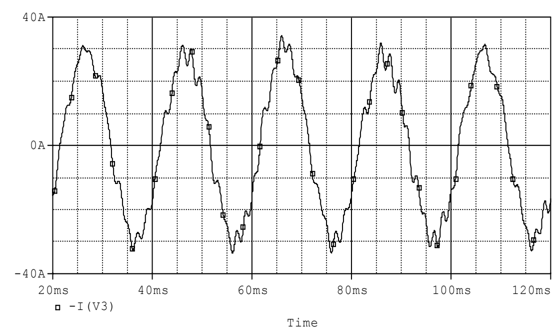


Fig. 7. Input current wave shape of Boost rectifier with passive filter at D = 0.5

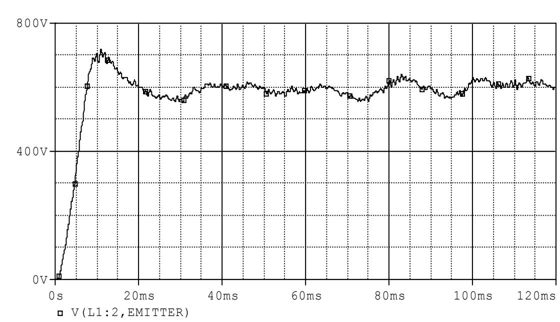


Fig. 8. Output voltage wave shape of Boost rectifier with passive filter at D = 0.8

It is seen that the amount of THD% is reduced than the previous condition and the input current is also found almost

TABLE II: PERFORMANCE PARAMETER OF A THREE PHASE BOOST REGULATED RECTIFIER WITH PASSIVE FILTER

Duty Cycle (D)	THD	PF (cosθ)	Iin (rms) amp	Vout (dc) volt	Efficiency% (η%)
0.2	0.0435	0.488	36.8	550	57.2
0.3	0.0651	0.623	32.20	650	66.13
0.4	0.0716	0.746	28.06	700	73.5
0.5	0.0917	0.805	24.79	750	88.5
0.6	0.121	0.914	17.55	690	93.2
0.7	0.145	0.972	13.90	650	98.15
0.8	0.1813	1	10.6	560	92.5
0.85	0.2078	1	9.75	550	97.4
0.9	0.2248	1	9.05	520	94.7
0.95	0.2426	1	8.13	500	96.6

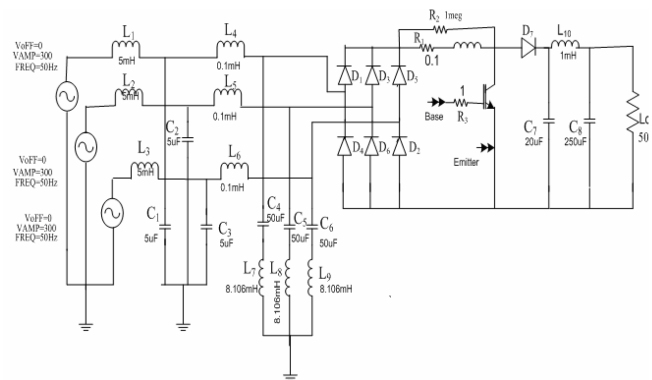


Fig. 9. Boost regulated three phase rectifier with passive high frequency and resonant filter.

sinusoidal. But, the power factor has not improved satisfactorily. Another drawback is large harmonics peak is observed at 250Hz. In this perspective a harmonics filter is developed using formula $X_L = X_C$. Putting the resonating frequency the product of LC is calculated $4.053*10^7$. Changing the various values of L and C it is closely observed that better performance of the filter is found by L=8.106mH and C=50uF. This harmonics filter permits power quality to improve satisfactorily. An output filter with low parameter (L=1mH and C=250uF) is added before load to eliminate the ripple of output voltage. Then the simulation results of Boost rectifier is shown in table III. The proposed model consists of the following parts as follows: (a) a fixed 3-φ ac sources (b) rectifying stage (c) control circuit (d) PFC stage (e) filtering stage and (f) load. The schematic circuit diagram of Boost rectifier with passive high frequency and resonant filter is shown in figure 9. Typical output voltage, output current, input voltage and input current of this proposed scheme are shown in figures 10 and 11 respectively.

TABLE III: THD AND EFFICIENCY WITH DUTY CYCLE IN THREE PHASE SINGLE SWITCH BOOST RECTIFIER WITH HARMONIC FILTER.

Duty Cycle (D)	THD	PF (cosθ)	Iin (rms) amp	Vout (dc) volt	Efficiency% (η%)
0.1	0.044	0.963	50.91	550	19.39
0.2	0.045	0.972	48.08	720	31.51
0.3	0.025	0.991	42.42	860	55.28
0.4	0.028	1	34.08	900	75.00
0.5	0.030	1	28.28	890	88.01
0.55	0.039	1	25.59	860	90.80
0.6	0.045	1	24.04	840	92.23
0.65	0.047	1	21.21	800	94.81
0.7	0.051	1	18.95	760	95.15
0.75	0.072	1	18.38	730	89.22
0.8	0.089	1	15.90	680	91.33
0.85	0.125	0.99	13.43	650	99.82
0.9	0.147	0.99	12.37	600	92.35
0.95	0.129	0.98	10.60	560	96.50

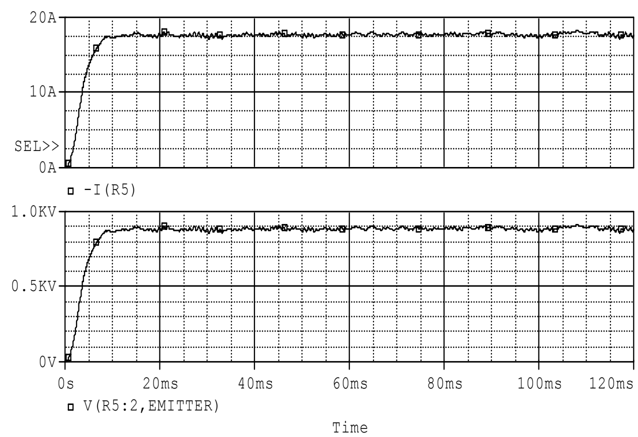


Fig. 10. Typical output voltage and output current at D = 0.5 with harmonics filter

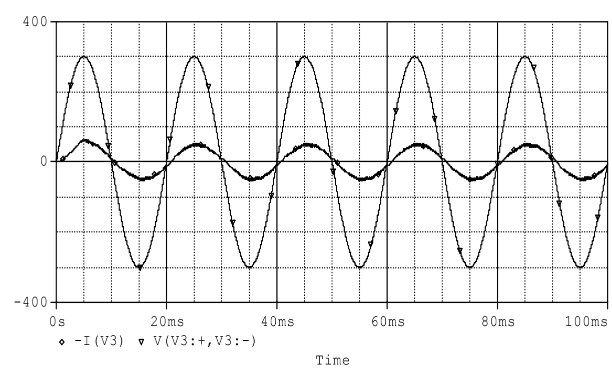


Fig. 11. Typical input Voltage and input current at D = 0.4 with harmonics filter

IV. Results

THD values, efficiency and output voltage for different values of duty cycle are shown in figures 12, 13 and 14 respectively. It is seen that when references reaches to near carrier voltage the THD tends to increases. Figure 13 shows that, efficiency gradually increased with variation of duty cycle. Figure 14 shows that output voltage increases for a certain range of duty cycle then it gradually decreases. The variation of output voltage with efficiency is shown in Figure 15. It is seen that for a certain range of D the variation of output voltage is linear with efficiency. Wave shapes of input current at different duty cycles are shown in figure 16.

The variation of power factor with different duty cycle is shown in Fig 17. It is seen that the power factor remains almost unity with variation of duty cycle. Thus power factor improvement is achieved with proposed model.

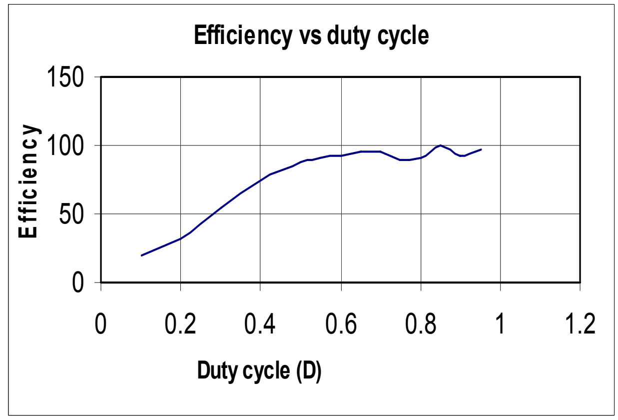


Figure 13: The efficiency vs duty cycle curve with the proposed model

V. Conclusion

The proposed Boost rectifier is able to improve power factor and over all performance. With the harmonics filter and Boost switching action it is able to draw sinusoidal input current and almost unity power factor with various duty cycle. The efficiency is also improved and it is found above 80% from 0.5 to 0.95 duty cycle. The other advantages of this model are reduction of switching stresses, elimination of resonance problems and use of small input filter. Moreover, it is able to eliminate odd and even harmonics components thus total harmonics distortion is found in the range of maximum 14.7% and minimum 2.5%. Even though power factor is unity and performance is improved, it has some problems such that, the values of input current is higher in the beginning of duty cycle. The output voltage is found always greater than input voltage.

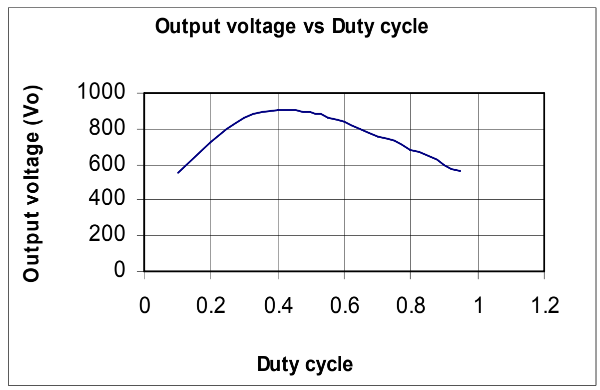


Fig. 14. The output voltage vs duty cycle curve with the proposed model

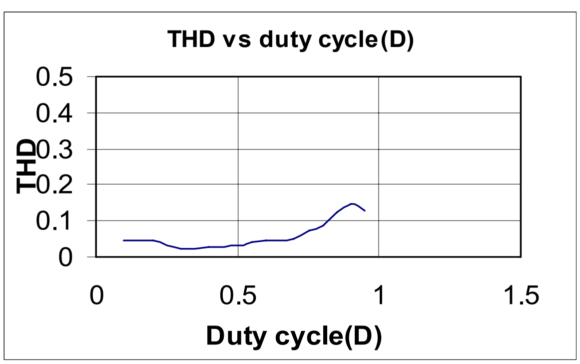


Fig. 12. THD vs duty cycle curve with the proposed model

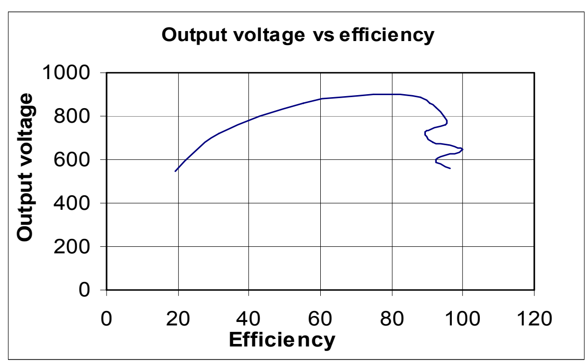
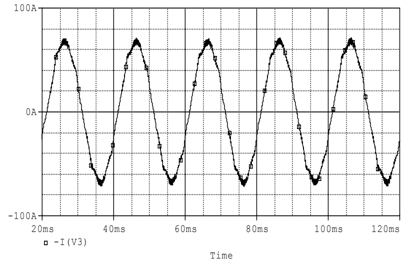
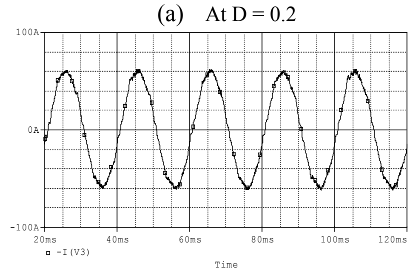


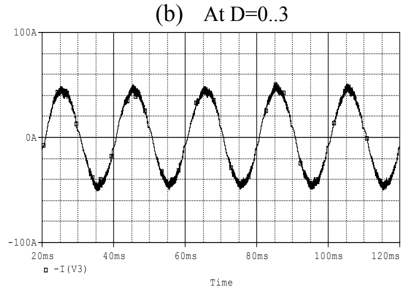
Fig. 15. Efficiency vs output voltage with the proposed model



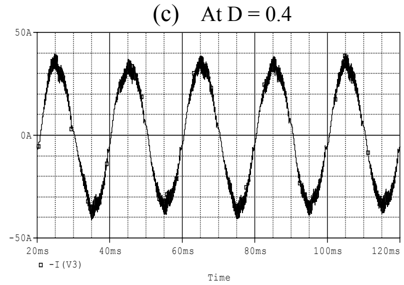
(a) At D = 0.2



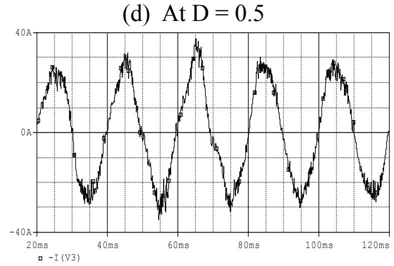
(b) At D=0..3



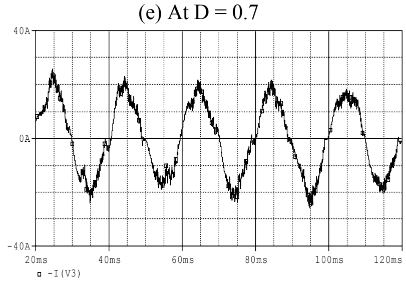
(c) At D = 0.4



(d) At D = 0.5



(e) At D = 0.7



(f) At D = 0.8

Fig. 16. Input current of the proposed model at various duty cycle.

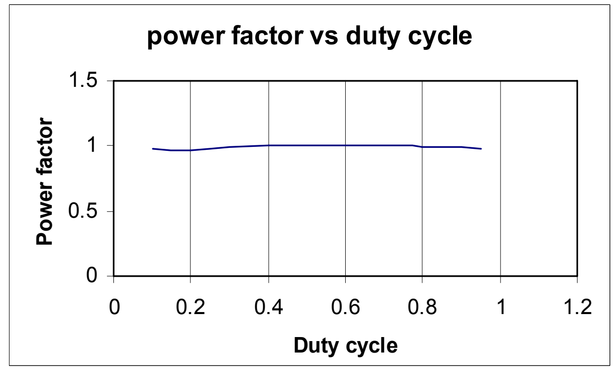


Fig. 17. Power factor vs duty cycle with the proposed model.

REFERENCES

[1] Pan Ching-Tasai, & Sheih Jenn-Jong , " A single-stage three phase boost-buck AC/DC converter based on generalized zero space vectors.", IEEE Transactions on Power Electronics, Vol.14, N0.5, September 1999, . 949-947.

[2] Prasad A.R., Phoivos D.Ziogas, senior member, IEEE, and stefanos Manias, " An active power factor correction technique for three phase diode rectifiers.", IEEE Transactions on Power Electronics, Vol.6, No.1, January 1999, pp. 83-91.

[3] N.R. Zargari, P.D. Ziogas, and G.Joos, " A two-switch high-performance current regulated dc/ac converter module.", IEEE Transactions on Industrial Applications, Vol.31, May/June 1995, pp.583-589

[4] Ghanemm M. Haddas, K.A, and Ray G., " A new single phase buck-boost converter with unity power factor.", in IEEE APEC, 1993, pp. 785-792.

[5] He Jin Jacobs Mark E, " Two stage, three phase split boost converter with reduced total harmonic distortion.", http://www.patentstorm.us/patents/6031739-description.html.

[6] Wang Chein-Ming, " A novel single-stage full bridge buck-boost inverter.", IEEE, Transactions on Power Electronics, Vol.19, No.1, January 2004, pp. 150-158.

[7] Chan Chok-You, " A nonlinear control for DC-DC power converters.", IEEE Transactions on Power Electronics, Vol.22, No.1, January 2007, pp. 216-221.

[8] Kikuch Jun, and Lipo Thomas A., " Three-phase PWM boost-buck rectifiers with power regenerative capability.", IEEE Transactions on Industry Application , Vol.1, No.5, September/October 2002, pp.1361-1368.

[9] Abedin A.H, A.Raju and Alam M.J., " Improvement of input side currents of a three phase rectifier combining active and passive filters.", Journal of Electrical Engg., IEB, Vol.EE33, No.1&11, December 2006, pp. 87-90.

[10] J.-J. Shieh, " SEPIC derived three-phase switching mode rectifier with sinusoidal input current.", Proc. IEE-Elect. Power Applicat., Vol.147, No.4, 2000.,pp.286-294.

[11] R.W. Ericksion, " Some topologies of high quality rectifiers.", in Proc. 1st Int. Conf. Energy, Power, and Motion Control, 1997, pp. 1-6.

[12] Tasi F.S., et al, " Low cost AC to DC converter having input current with reduced harmonics.", U.S. patent no. 5,652, 700, July,29,1997.