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High Power Factor AC/DC Converter

A. S. Alsheraidah **R. S. Fyath** **M. M. Ibrahim**
Dept. of Electrical Eng –College of Engineering–University of Basrah
Basrah - IRAQ

ABSTRACT

A single phase boost rectifier circuit is studied with and without feedforward techniques. The circuit is implemented and tested experimentally. It can be operated at high power factor (greater than 0.99), and at line current total harmonic distortion (THD) (less than 0.06), by selecting a suitable control parameters at the desired output power.

مغير القدرة المتناوبة الى مستمرة ذو القيمة العالية لمعامل القدرة

الملخص

تضمن البحث دراسة مغير القدرة المتناوبة الى مستمرة أحادي الطور، رافع للجهد باستخدام تقنية التغذية الأمامية (feedforward) أو بدونها. لقد تم تصميم و بناء الدائرة عمليا" للحصول على معامل قدرة أعلى من 0.99 و تشويه كلي لتوافقيات التيار أقل من 0.06 . يتحقق ذلك من خلال اختيار عناصر دائرة السيطرة لمدى معين من قدرة الأخراج .

Key words: AC-DC converter, Power factor improvement.

List of Symbols

C_s	: Snubber circuit capacitor (F).	PF	: Power factor.
i_o	: Load current (A).	r	: Inductor resistance (Ohm).
i_s	: Line current (A).	R_L	: Load resistance (Ohm)
L	: Rectifier inductance (H).	THD	: Total harmonic distortion.
L_s	: Snubber circuit inductance (H).	V_o	: Output voltage (V).
M	: Modulation index.	V_{ac}	: AC input voltage (V).

1. Introduction

It is well known that conventional ac-dc power supplies are characterized by high input current total harmonic distortion (THD) and low power factor (PF) [1]. Several techniques have been proposed and demonstrated to overcome these drawbacks, and they have essentially based of pulse width modulation (PWM) scheme [2]. For example, the input current THD of a boost rectifier has been reduced by intentionally introducing a lagging power factor current command [3]. The goal has been achieved in a single phase rectifier by using current mode control technique [4-6]. Different control circuits employing either compensator, current control, and multiplier, or nonlinear carrier control scheme have been proposed to overcome the problem [7-9].

In this paper, a single phase boost rectifier circuit supported by a simple feedforward control circuit is proposed to achieve high power factor and low THD. The rectifier circuit can be used with different ranges of output power by changing the control circuit parameters. The proposed circuit is implemented and tested experimentally. The experimental results are found in good agreement with theoretical predictions, and with the results obtained in [6] ,[10], and [11].

2. The Proposed Circuit

2.1. Circuit Operation

The proposed circuit is shown in Fig.(1). It consists of four diodes (D_1 to D_4), two switches MOSFET transistors (S_1 and S_2), two inductors (L), and a smoothing capacitor (C_o). The switching operation of the main diodes and switches can be described by two modes of operation for each half cycle as follows:

During positive half cycle of the input supply voltage, the transistor S_1 is switching on and off repeatedly according to the switching frequency signal. So the operation of the rectifier circuit during this cycle is consists of two modes.

Mode 1

In this mode of operation, the switching transistor S_1 is on, and the supply current flows through S_1, D_4 and L, while the capacitor (C_o) discharging through the load as shown in Fig.(2). The following two equations describe the operation of this mode.

$$V_{ac} = L\, di_s/dt + r\, i_s \qquad \text{-------(1)}$$

$$i_o = C_o\, dV_o/dt \qquad \text{-------(2)}$$

Mode 2

When the transistor S_1 is switched off, the operation is transferred from mode 1 to mode 2 . In this mode, the input line current flows through the inductor L, the two diodes D_1 and D_4, then the load and the smoothing capacitor, C_o, as shown in Fig.(3). The operation of this mode can be described by the following two equations:

$$V_{ac} = L\, di_s/dt + r\, i_s + V_o \qquad \text{-------(3)}$$
$$i_s = i_o + C_o\, dV_o/dt \qquad \text{-------(4)}$$

At the negative half cycle of the supply, mode 1 and mode 2 are repeated with transistor S_2 and the two diodes D_2 and D_3.

2.2. The Control Circuit

Different PWM techniques have been used to improve the power factor and THD of a rectifier circuit [2,12]. These techniques are used in the case of open loop control, but the improvement is not significant. For that reason a feedforward control technique has been used to get high input power factor and low THD [6,7 and 10] and this technique is adopted here.

A simple control circuit is suggested and implemented, Fig.(4) show the complete diagram of the power circuit as well as the suggested control circuit. The control circuit consists of integrator, adder, and subtractor circuits, and has the benefit that it is not requiring any multiplier or divider circuits. The output voltage of the rectifier is sensored with gain of K_o, which is compared with a reference voltage, V_{ref}. The result of comparison is injected through an appropriate voltage controller. The current I_s, is sensored with gain K_i, and subtracted from the voltage controller output.The rectifier input AC voltage is rectified by two diodes, sensored with gain K_s, and then added to the subtractor output. The output of the adder is fed into a PWM circuit with a high frequency triangular waveform to produce the switching transistors.

3. Simulation Results

The open loop operation of the proposed boost rectifier is analyzed using sine pulse width modulation (SPWM) technique. The feedforward operation is analyzed by simulating the function of the control circuit shown in Fig.(4). In both cases, equations 1-4 are solved numerically using fourth-order Runge-Kutta method [13].

The operation parameters of the rectifier circuit are:

V_{ac} = 30 V (rms)
L = 1 mH
r = 0.1 Ohm
C_o = 4700 uF
S_1 and S_2 : IRF840
D_1 ..D_4, D_s : BYX71
D_5,D_6 : 261-536

The snubber circuit parameters are: L_s =7 uH, and C_s=47 nF. The feedforward control circuit has three parameters, K_o, K_i, and K_s. K_o is kept constant (K_o=0.1), while K_i and K_s are varied according to the output load power.

3.1. Open Loop Operation

Fig.(5) shows the simulated output voltage of the rectifier as a function of the modulation index (M) of the SPWM and for different values of load resistance at open loop operation. The variations of the input power factor and the line current THD against modulation index are depicted in Figs.(6) and (7) respectively. Note that, the variations of power factor and THD with modulation index are very small when the modulation index is less than one and they are have poor values when modulation index is greater than one. Fig.(8) presents the power factor and THD of the circuit against output power when the output voltage is kept constant (V_o=60 V). Fig.(8) reveals that both power factor and THD are almost constant during the large variation of the output power, and they also have a reasonable values.

3.2. Feedforward Operation

The feedforward technique is simulated using different values of gain parameters, K_i and K_s. The power factor and THD are calculated against output power for K_s=0.2 and for different values of K_i and the results are shown in Figs.(9) and (10) respectively. From these two figures it is shown that, to keep the values of the power factor and the THD around a reasonable values when the output power is varied, the current gain K_i must be changed accordingly to match the desired values. Fig.(11) illustrates the variation of K_i against the output power, when the power factor and the THD are simultaneously desired to be greater than 0.99 and less than 0.06 respectively and for two values of K_s. The waveforms of the input line current and voltage are shown in Fig.(12). It is seen that the waveform of the current is approximately sinusoidal. In Fig.(13), the waveform of the output voltage at K_s=0.2, K_i=2.6, and load resistance (R_L=25 Ohm) is plotted. It is seen that the ripple voltage is very small compared to the average output voltage.

4. Experimental Results

The proposed single phase boostrectifier circuit is implemented and tested at both open loop mode and with feedforward technique. In Figs.(14-17), we compare the experimental data with theoretical results to asses the performance of the practical circuit. Fig.(14) illustrates the variation of output voltage with modulation index at open loop operation with SPWM technique and assuming R_L=100 Ohm. Fig.(15) shows the dependence of the power factor on the output power when the output voltage is kept constant equal to 60V and at open loop operation. Data related to the variation of power factor and rectifier efficiency under feedforward operation are plotted in Figs.(16) and (17), respectively. These results indicate clearly that the experiment results are in agreement with theoretical data. Note that the practical circuit is able to deliver an output power up to 135W with power factor greater than 0.94 and efficiency greater than 86%. The theoretical calculated efficiency is greater than the experimental results, because

6-A. F. Souza, and I. Barbi,"High power factor rectifier with reduced conduction and communication losses", IEEE INTELEC Records, 1999, pp.8-1.

7-J. G. Cho, J. W. Baek, D. W. Yoo, and H. S. Lee,"Reduced conduction loss zero-voltage-transition power factor correction converter with low cost,"IEEE Trans. on Industrial Electronics, Vol.45, June 1998, pp.395-400.

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11-F. S. Mendes, and I. Barbi,"A new 12kW three-phase 18-pulse high power factor AC-DC converter withregulated output voltage for rectifier units", IEEE INTELEC 1999, pp.14-2.

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13-J. L. Buchanan and P. R. Turner,"Numerical methods and analysis",McGraw-Hill, Inc., 1992, pp. 515-530.

the switches and diodes are assumed to be ideal devices in the theoretical calculation. The experimental oscillograph of the line current and voltage are shown in Fig.(18), while the output waveform voltage is shown in Fig.(19). Fig.(20) illustrates that the transistor voltage of the rectifier does not exceed the output voltage value.

5. Conclusion

In this paper a single phase boost rectifier circuit is proposed and implemented with and without feedforward technique. A simple control circuit is used to improve the power factor and THD of the input supply. The operation of the circuit is analyzed and then simulated using Runge-Kutta fourth order method. The operating power of the rectifier can be increased by selecting suitable control parameters. The analytical and experimental results show a good agreement.

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13-J. L. Buchanan and P. R. Turner,"Numerical methods and analysis",McGraw-Hill, Inc., 1992, pp. 515-530.

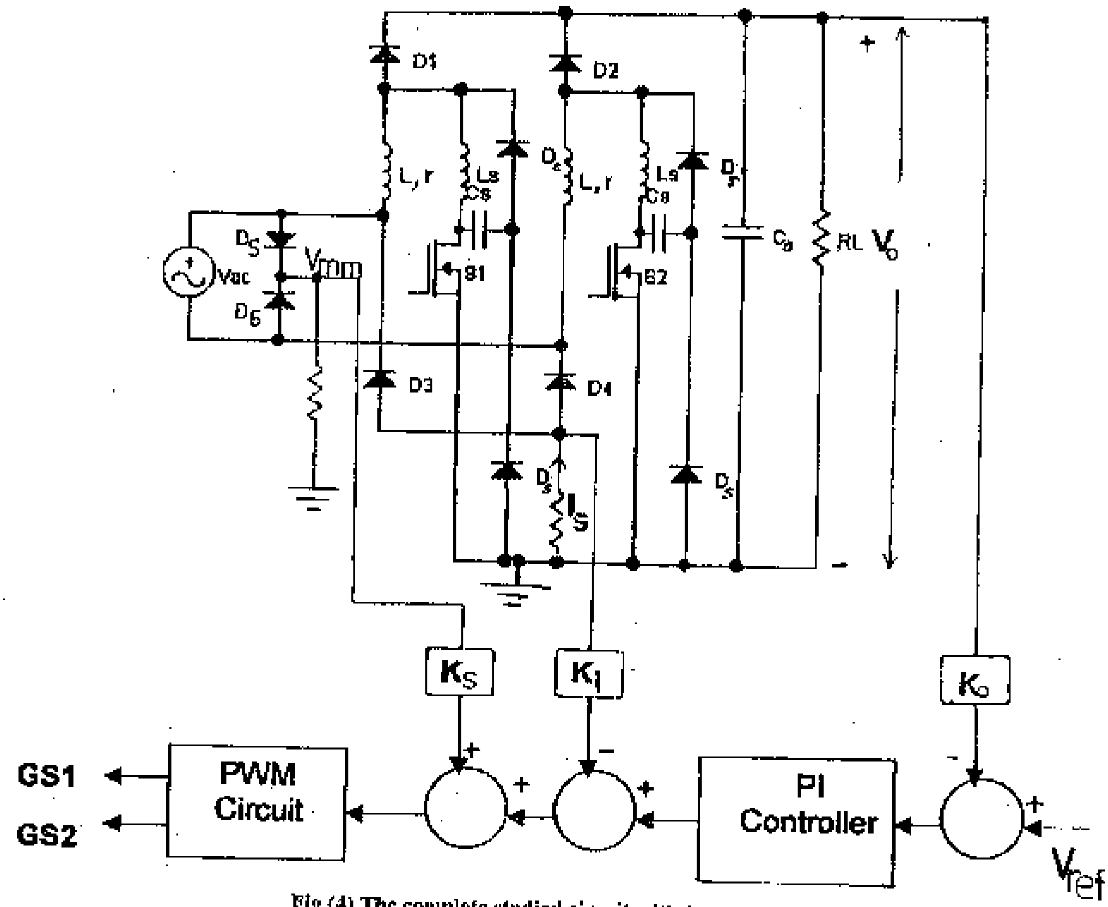
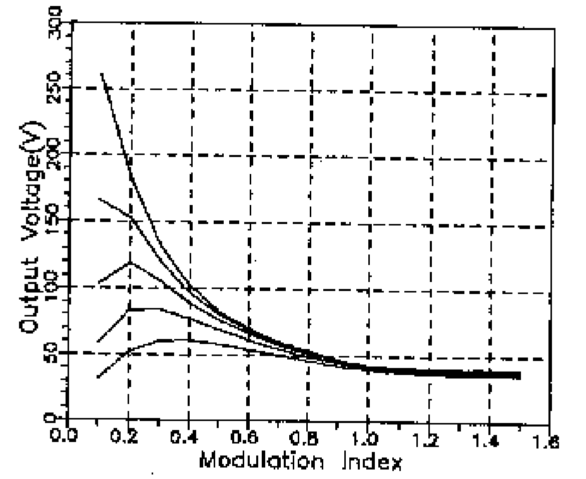


Fig.(4) The complete studied circuit with feedforward Control circuit.



Fig(5) Output voltage against modulation index for different load resistance(RL=100,40,20,10,and 5(Ohm) from top to down).

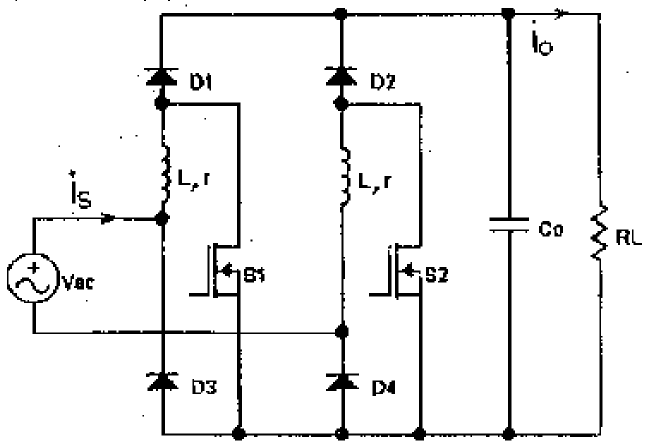


Fig.(1) The studied system

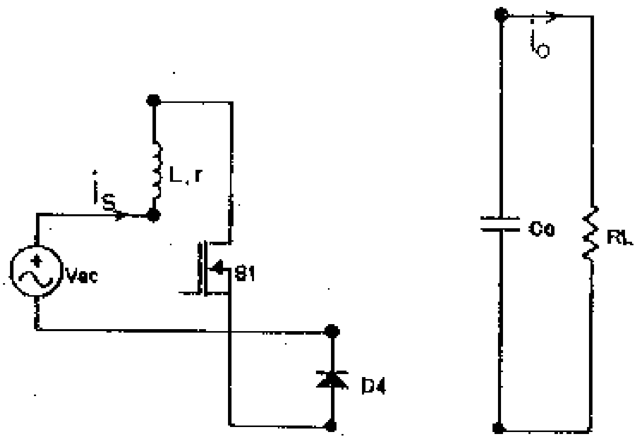


Fig.(2) Mode 1 of operation.

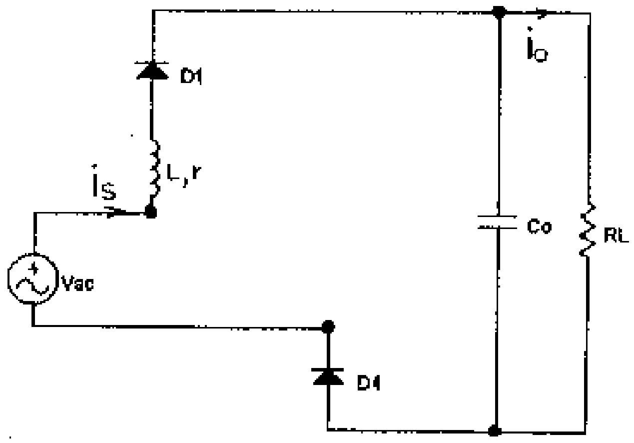
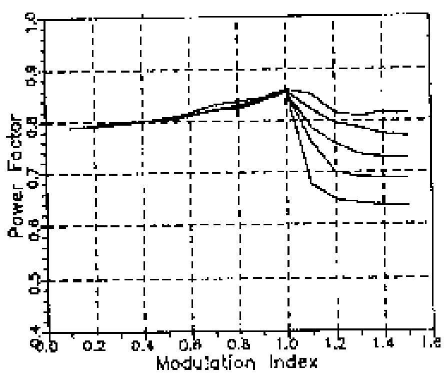
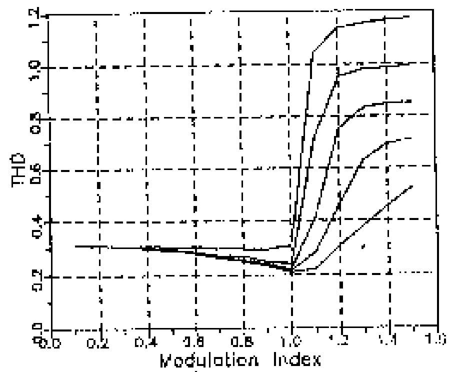


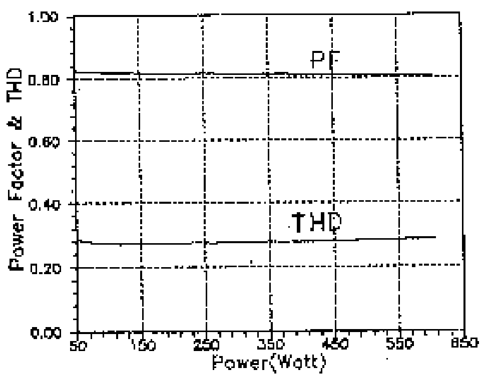
Fig.(3) Mode 2 of operation.



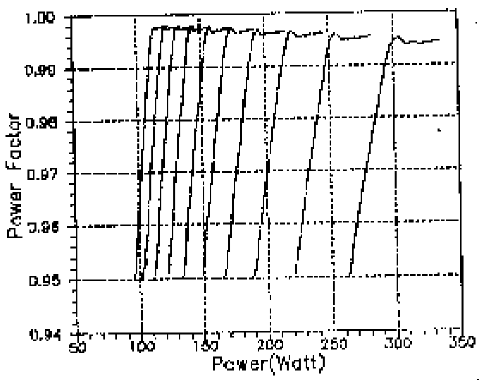
Fig(6) Power factor against modulation index for different load resistance(RL=5,10,20,40,and 100(Ohm) from top to down).



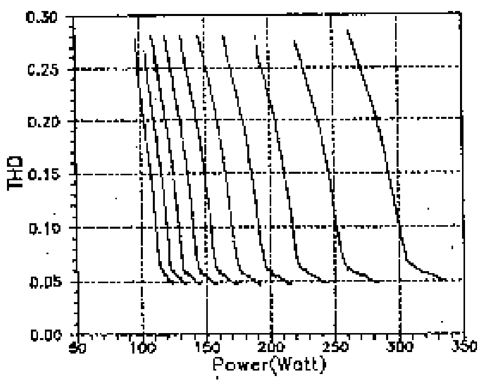
Fig(7) Total harmonic distortion against modulation index for different load resistance(RL=100,40,20,10,and 5(Ohm) from top to down).



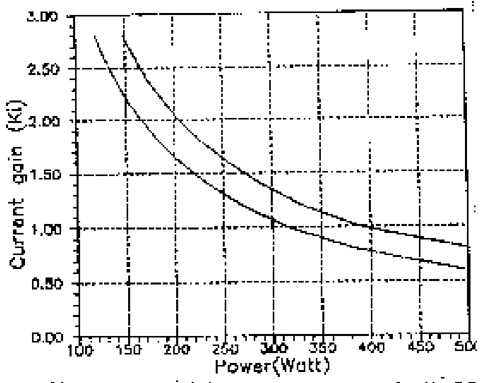
Fig(8) Power factor and total harmonic distortion factor against output power at open loop and for Vo=60W.



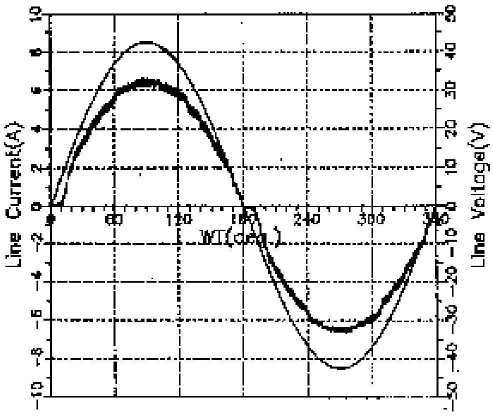
Fig(9) Power factor against output power for K=0.2 and for K=1.0 to 2.8 step 0.2 (from right to left).



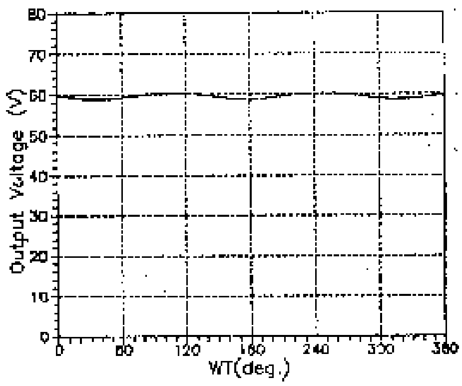
Fig(10) THD factor against output power for Ks=0.2 and for Ki=1 to 2.8 step 0.2 (from right to left).



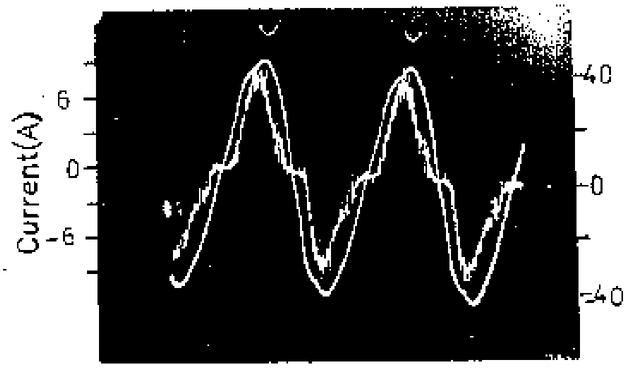
Fig(11) Current gain (Ki) against output power for Ks=0.3 (upper curve), Ks=0.2(lower curve), while P.F greater than 0.98, THD less than 0.08, and VO=60 Volt.



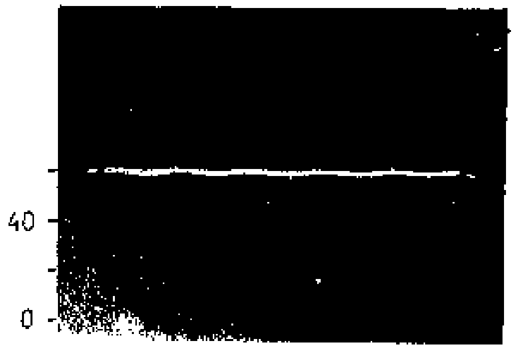
Fig(12) Line voltage and current of the converter for Ks=0.2,Ki=2.8 and RL=25(ohm).



Fig(13) Output voltage of the converter for Ks=0.2, Ki= 2.8 ,and RL=25(Ohm).



Fig(18) Experimental line voltage and current of the converter for Ks=0.2,Ki=2.8 and RL=25(ohm).



Fig(19) Experimental Output voltage of the converter for Ks=0.2, Ki= 2.6 ,and RL=25(Ohm).

Fig(20) Experimental transistor voltage