Power factor improvement of a boost converter supplying a DC motor

A. A. Khalil
akhalil@aast.edu

H. A. Ashour
hashour@eng.aast.edu

Y. G. Desoki
ygd@aast.edu

Arab Academy for science & Technology and Mritime Transport
Department of Electrical and Control Eng.

Abstract

A study of boost-converter circuit utilized to drive a DC motor as a load while improving the supply power factor is demonstrated through this paper. A computer simulation of the proposed circuit has been assessed using simulink under matlab version (6) to show circuit behavior for different operation modes: speed and voltage control. Experimental investigation has been carried out to analyze the effect of circuit parameter variations on the motor response.

Keywords: boost-converters, power factor correction

1 Introduction

The growing number of power electronic-based equipment, both in the industrial and domestic sectors, tends to have undesirable impacts on the quality of distribution and line voltage networks. Single-phase dc power supplies usually composed of a diode rectifier with capacitor filter. This circuit generates a pulsed current with high harmonic content. To reduce the harmonic distortion several methods are widely used active power filter (APF), power factor correction systems (PFC), various boost topologies and others [1-3]. The boost topology is usually accomplished by inserting a boost converter between the rectifier and the filtering stage. With proper control, the boost converter permits to absorb a sinusoidal line current in phase with the supply voltage. Generally the control of the boost converter is made up of two loops [4-11]:

- Current loop which compares the input current to the reference current. This reference is often made proportional to the input voltage.
- Voltage loop which regulates the output voltage to the desired reference voltage by adjusting magnitude of the reference current.

Simulation results achieved using Matlab-Simulink software are presented. Simulation results show the effectiveness of the proposed setup to improve the system power factor while delivering a constant output voltage.

2 Circuit Operation principle

Circuit configuration of a boost-converter DC drive is shown in fig(1). An AC supply is applied to an uncontrolled bridge rectifier containing four diodes to supply the chopper circuit with a full-wave rectified voltage V_s. The circuit has two modes of operation depending on the chopper switch (SW) condition, as shown in fig(2) and fig(3). When the chopper switch is turned on, the rectified voltage (V_s) supplies the inductor (L) with energy. Therefore when the chopper switch is turned off, the energy is transferred from both the input voltage and the inductor to supply the capacitor (C) and the DC motor. In case of the chopper switch is turned on, the diode (D) is reverse biased hence the motor is supplied from the energy stored in the capacitor .

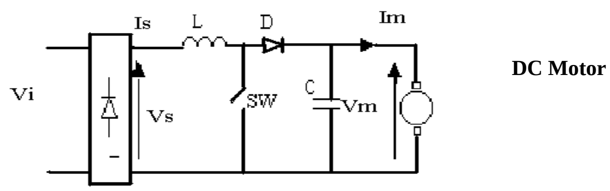


Fig (1) Circuit diagram of a Dc motor drive.

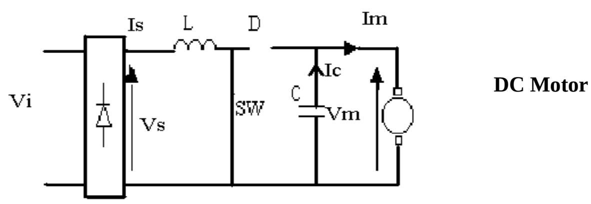


Fig (2) Circuit diagram when the switch is on

system equations when the chopper switch is turned on could be given as:

$$v_s = L \frac{di_s}{dt} \quad (1)$$

$$i_c = i_m \quad (2)$$

$$vm = \frac{1}{c} \int i_c \, dt \quad (3)$$

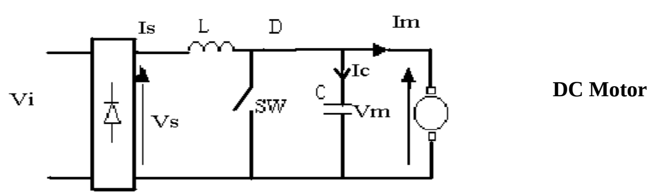


Fig.(3) Circuit diagram when the switch is off

And when the switch is turned off the system equations could be written as:

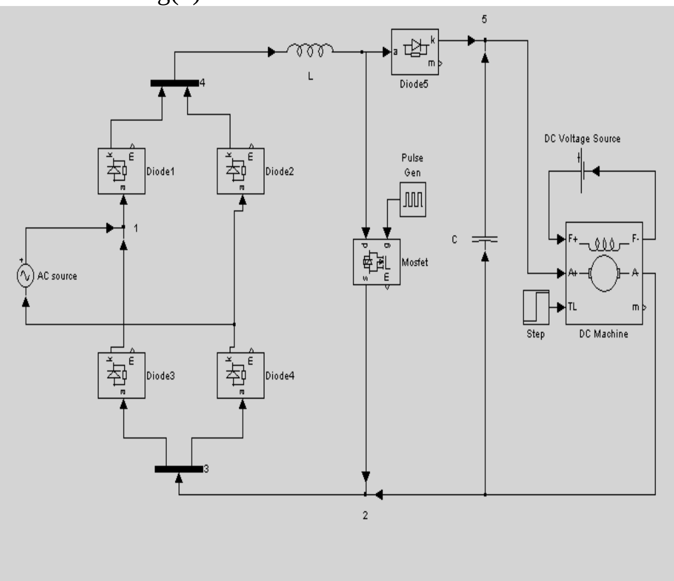
$$v_s = L\frac{di_s}{dt} + v_m \qquad (4)$$

$$i_c + i_m = i_s \qquad (5)$$

$$v_m = \frac{1}{c}\int i_c\,dt \qquad (6)$$

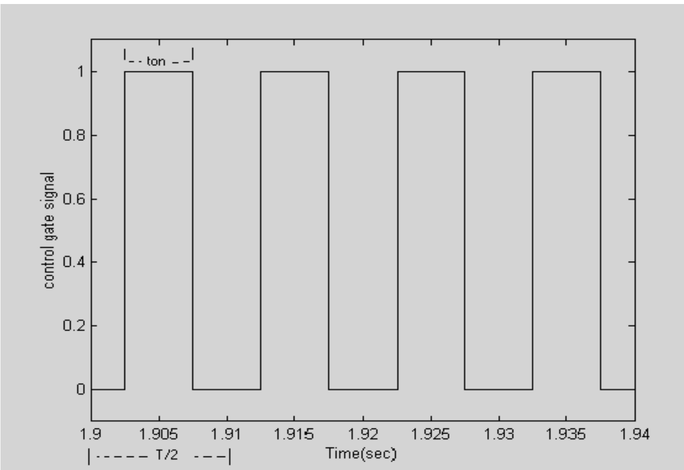
3 Simulation analysis of the boost-converter

The computer simulation of the boost-converter DC motor drive system has been carried out using Simulink under matlab version (6), where the power cicuit diagram is illustrated in fig(4).

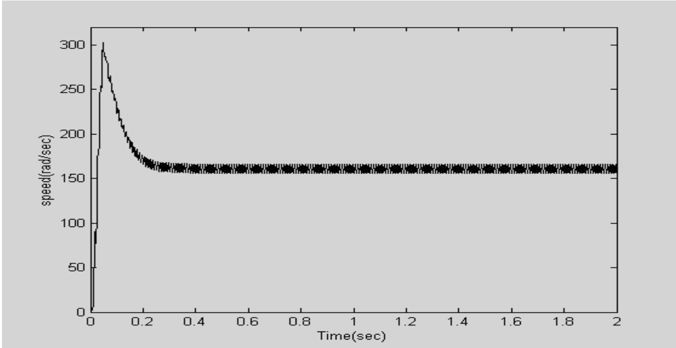


Fig(4) Simulink circuit diagram of the open-loop system

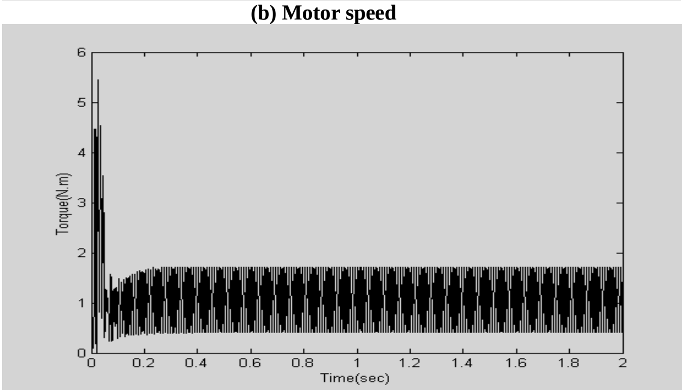
A pulse generator with 50 Hz frequency and 50% duty cycle ratio is applied to control the chopper switch. The simulation was carried out with the following parameters: a load torque of 1 N.m, a capacitance of 150µF, an inductance of 0.184 H, a supply voltage 150V and a filed voltage of 150V. The Switch gate signal, motor speed, motor torque, motor current and motor voltage are shown in fig(5).



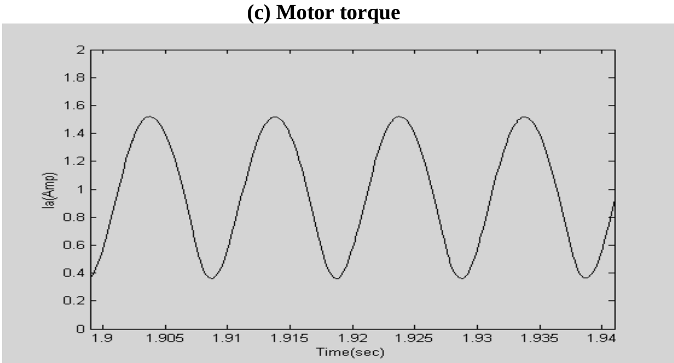
(a) MOSFET gate Signal



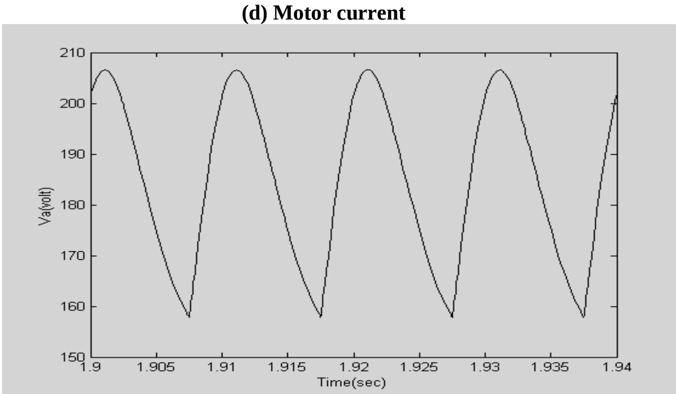
(b) Motor speed



(c) Motor torque



(d) Motor current



(e) Motor voltage

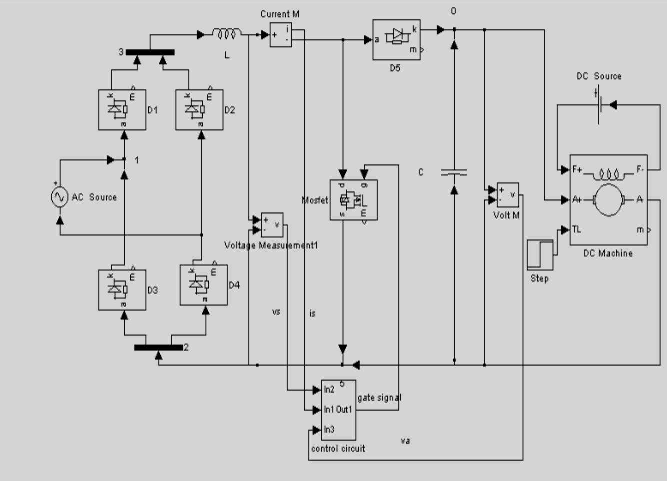
Fig(5) Simulation waveforms of the boost converter.

4 Simulation results of the power factor correction

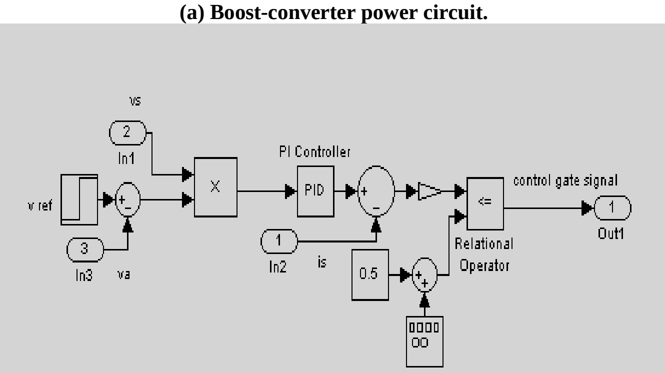
The computer simulation of the boost converter DC motor drive in closed-loop control mode to improve the supply power factor was carried out using Simulink under Matlab version (6). The model of the system enables a close look at the system response while circuit parameters were adjusted to obtain adequate results.

4.1 Closed-loop motor voltage control

The power circuit diagram of a boost-converter DC motor drive is shown in fig(6-a), and the chopper switch control circuit is illustrated in fig(6-b)..



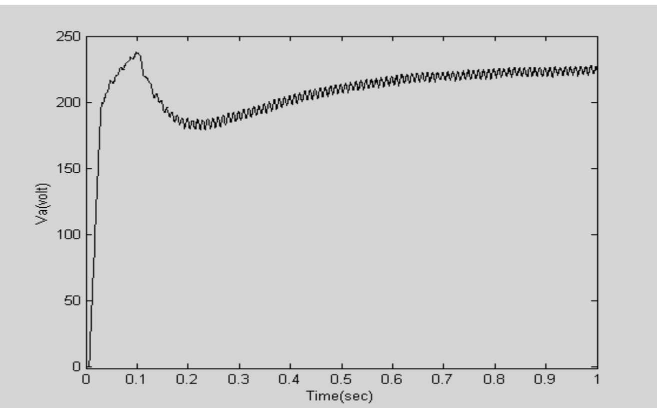
(a) Boost-converter power circuit.



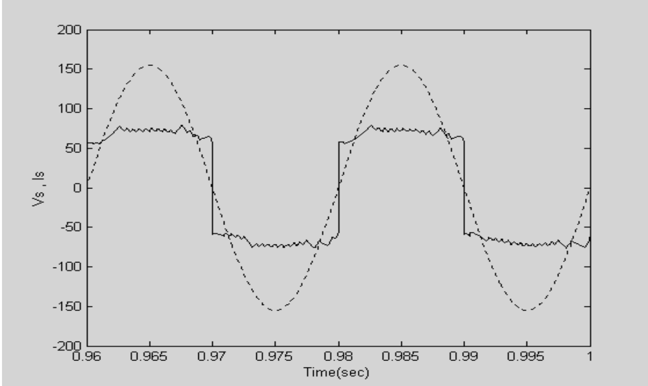
(b) Chopper switch control circuit.

Fig(6) Closed-loop armature voltage control

The motor armature voltage feedback signal (v_m) is compared with a command voltage signal (V_{ref}) of 225 volt then multiplied by the rectified sinusoidal voltage V_s. A PI controller is used to control the voltage error signal. Therefore, the controller output is compared with the rectifier output current (I_s) and the current error signal is applied to a PWM circuit with 20KHz frequency to drive the chopper switch. The objective of this converter is to control the voltage applied to the DC motor while improving the system power factor by controlling the supply current waveforms to be nearly as the input supply voltage. Fig(7-a) shows the motor armature voltage response which satisfies the command input voltage of 225 volt. The source voltage and current response with improved power factor is also shown in fig(7-b).



(a)

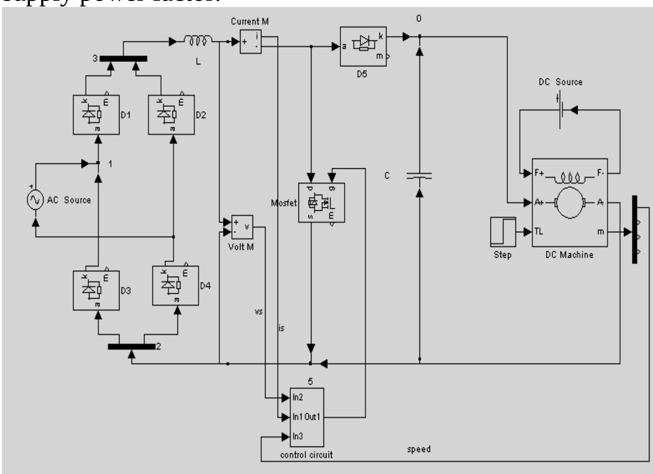


(b)

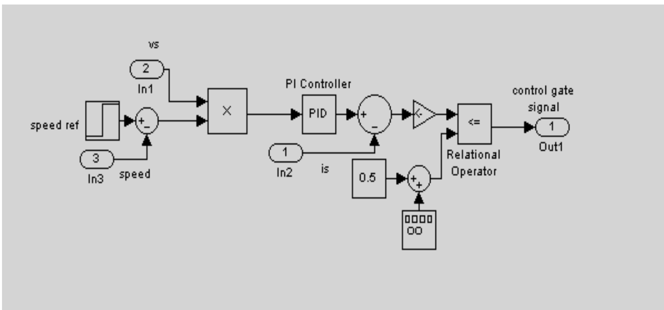
Fig(7) (a) Motor armature voltage response.
(b) (----) Source voltage, and (___) current.

4.2 Closed-loop motor speed control

The objective here is to control motor speed with improving supply power factor.



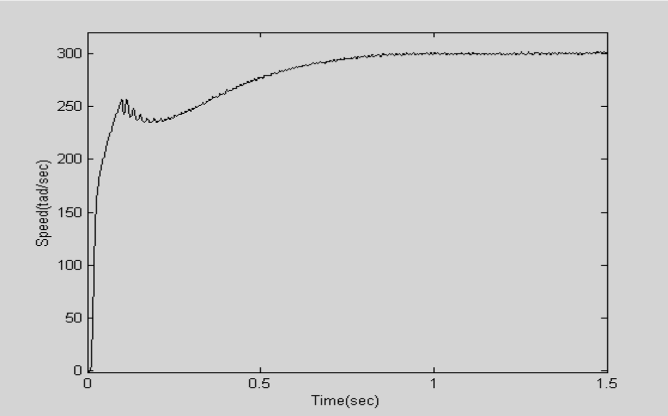
(a) Boost-converter power circuit.



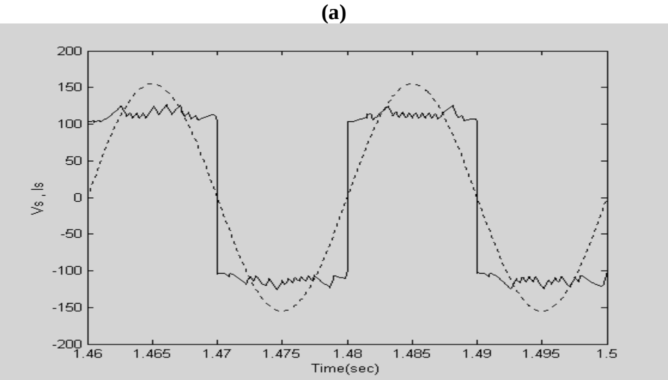
(b) Chopper switch control circuit.

Fig(8) Closed-loop speed control.

As shown in fig(8), the motor speed feedback signal is compared with a command speed signal(w_{ref}) then multiplied by the rectified sinusoidal voltage V_s. A PI controller is used to control the speed error signal. Therefore, the controller output is compared with the rectifier output current (I_s) and the current error signal is applied to a 20 kHz PWM circuit to drive the chopper switch. Fig(9-a) shows the motor speed response which satisfies the command speed signal. The source voltage and current response with improved power factor is also shown in fig(9-b).



(a)



(b)

Fig(9) (a) Motor speed response.

(b) (----) Source voltage, and (___) current.

5 Experimental Investigation

The experimental control circuit of the chopper switch is shown in fig(10). A voltage transformer is used to step down the AC voltage source from 220V to 6V, which is then connected to the input terminals of an uncontrolled bridge rectifier. This rectified signal is compared using an LM311 comparator with a variable DC voltage using a variable resistance to produce the control signal applied to the gate drive circuit of the boost-converter chopper switch (MOSFET). The analysis curves which represents motor current, load torque, and motor voltage versus motor speed at different operating conditions such as duty cycle, inductance and capacitance variations, were drawn from the experimental results.

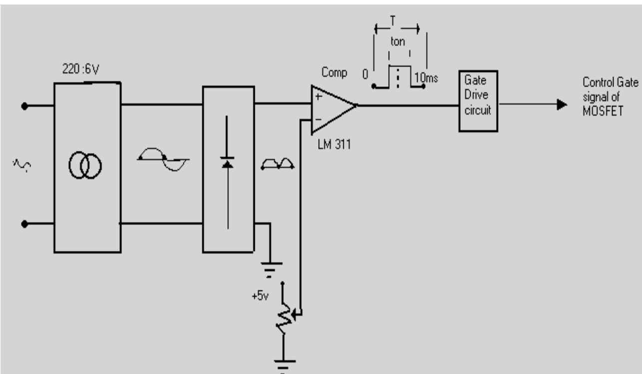


Fig.(10) Experimental Chopper control circuit

5.1 Effect of variable duty cycle ratio.

The supply voltage was adjusted to 150V & the motor field voltage to150V. The experimental investigation of the motor armature voltage, armature current and motor load torque was carried out for different duty cycle ratio of the chopper.

The voltage across the load can be controlled by varying the duty cycle ratio (K). The minimum value of the motor voltage that can be obtained when the duty cycle ratio (K=0). The capacitance value is 150µF and the inductance value is 0.184 H.

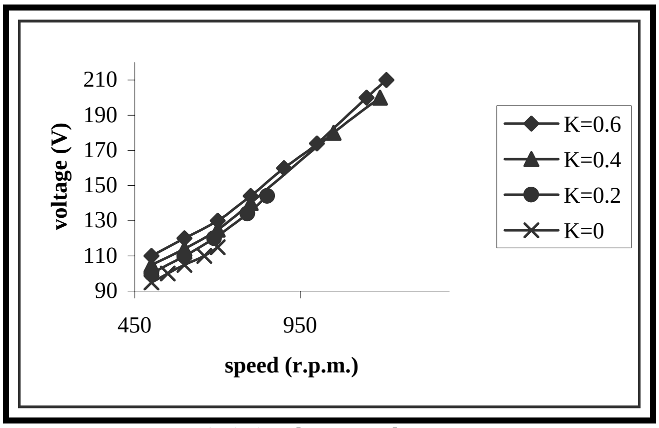


Fig (11) Voltage-speed curve

Fig (11) shows a directly proportional relation between the motor voltage and the speed of the machine. For a zero value of duty cycle ratio (K=0) The armature voltage is at its smallest value so, the rated speed cannot be achieved.

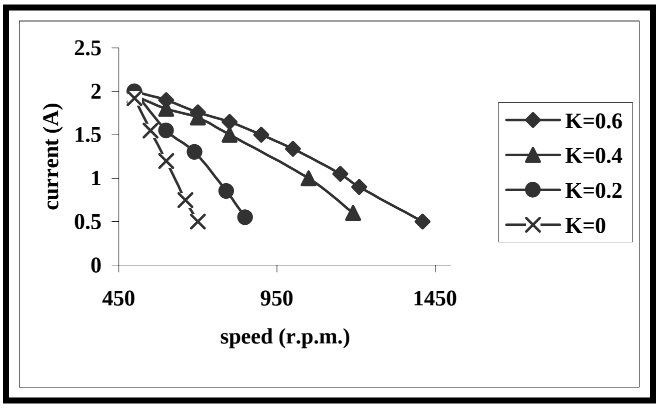


Fig.(12) Current-speed curve

Fig.(12) shows an increase in motor current with an increase of duty cycle ratio, thus improving the performance of the motor. The armature current value at starting is the same for all values of duty cycle ratios; for lower values of duty cycle ratio the current slope is much sharper.

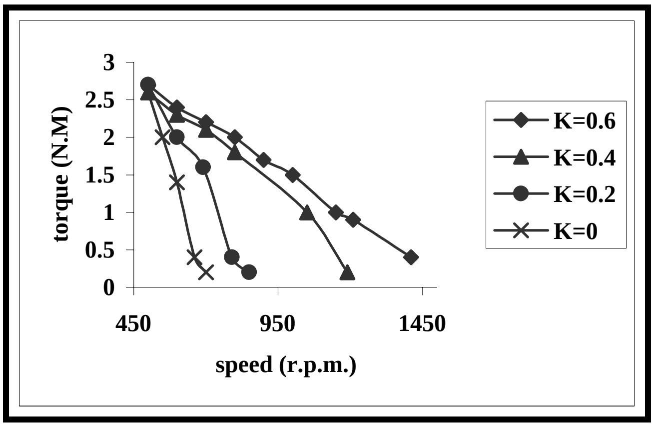


Fig.(13) Torque-speed curve.

An inversely proportional relation between the motor torque and speed is noted from fig.(13). For a fixed speed value the torque curve is pushed upwards with an increase in the duty cycle ratio. However, it could be concluded that the effect of increasing the duty cycle ratio is equivalent to increasing the armature voltage in the conventional drive.

5.2 Effect of inductance variation

At a fixed duty cycle ratio (K=0.4) and capacitance value is 150μF.The experiment was done using two values of the Inductance: L_1=0.184 H, L_2=0.368 H. The armature voltage, armature current, and load torque versus motor speed are shown in fig(14), fig(15) and fig(16) respectively.

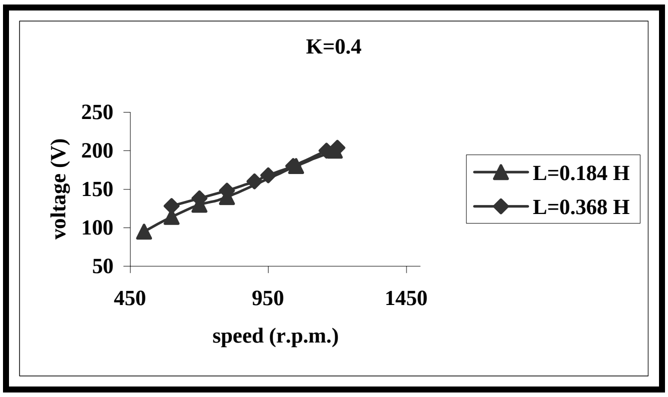


Fig .(14) Voltage-Speed curve

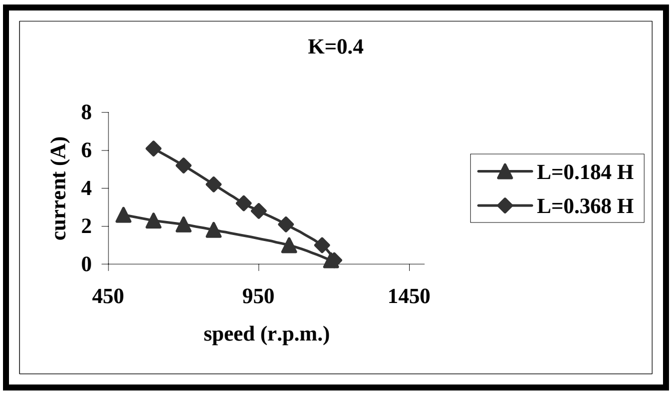


Fig.(15) Current-Speed curve

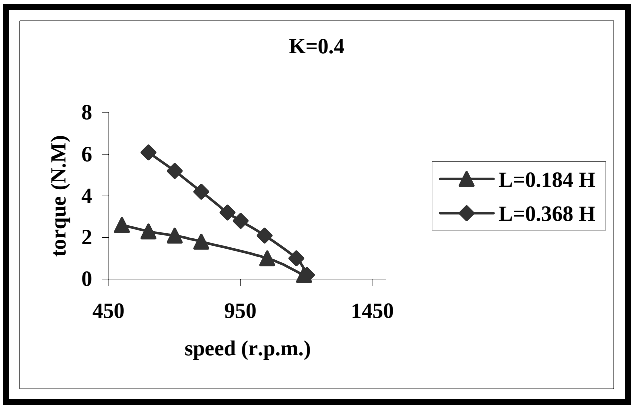


Fig.(16) Torque-Speed curves

From fig(14) it can be seen that the variation of the inductance does not much affect the voltage and speed values. The armature current increase with the increase in the inductance value as shown in fig(15). Increasing the Inductance will result in an increase of the torque as illustrated in fig(16) at the same speed level. This could be considered a method to provide a higher torque for heavy loads. It could be concluded that the effect of increasing the inductance is equivalent to increasing the armature voltage in the conventional drive.

5.3 Effect of capacitance variation

At a fixed duty cycle ratio (K=0.4) and the inductance value is 0.184H with two capacitance values C_1=150μF, C_2=60μF. The armature voltage, armature current, and load torque versus motor speed are shown in fig(17), fig(18) and fig(19) respectively.

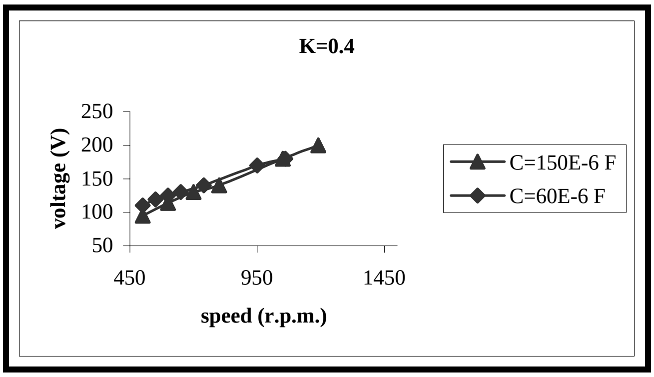


Fig.(17) Voltage-Speed curves

The variation of the Capacitance value will neither affect the voltage nor the speed of the motor as shown in fig(17).

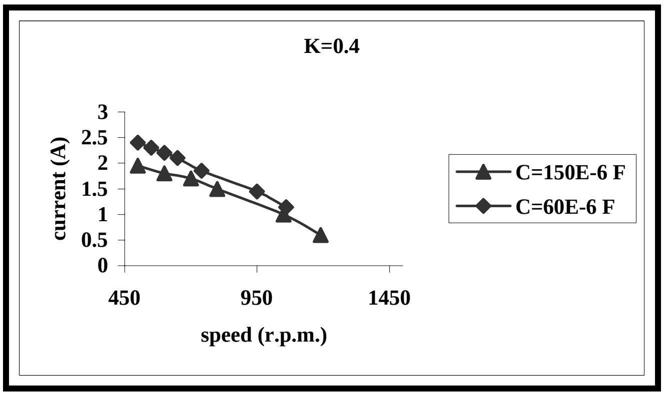


Fig.(18) Current-Speed curve

Decreasing the Capacitance will result in an increase of the armature current as shown in Fig.(18).

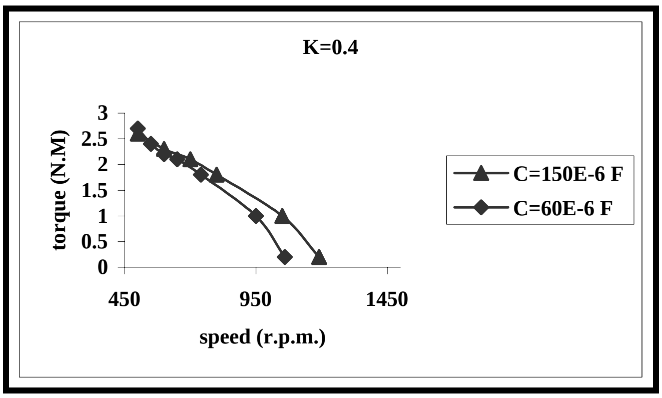


Fig.(19) Torque-Speed curves

Increasing the Capacitance will slightly shift the torque speed curve upwards as shown in Fig.(19). Similarly here, it could be concluded that, the effect of increasing the capacitance is equivalent to decreasing the armature voltage in the conventional drive.

6 Conclusion

Simulink under Matlab version (6) has been used to simulate a boost-converter driving a DC motor as a load while improving the supply power factor. Effect of boost-converter parameter variations, such as duty cycle, inductance and capacitance on the motor voltage, current and speed have been experimentally studied. Simulation results validate the use of the boost-converter to drive the DC motor with improving power factor in both speed and voltage control modes.

7 References

[1] J. Dixon and B. T. Ooi, "Indirect current control of a unity power factor sinusoidal boost type 3 phase rectifier," IEEE Trans. Ind. Electron., vol. 35, Nov. 1988.

[2] E. Wernekinck, A. Kawamura, and R. Hoft, "A high frequency ac/dc converter with unity power factor and minimum harmonic distortion," IEEE Trans. Power Electron., vol. 6, Jully. 1991.

[3] Karel Jezernik, "VSS control of unity power factor", IEEE Trans. Ind. Electron.,, vol. 46, April 1999.

[4] Alexander E. Emanuel and Kalyan K. Sen, "Steady-State Performance of the DC Motor Supplied from Single-Phase Rectifier with Step-Up Converter. A Unity Power Factor Converter", IEEE Trans. on Energy Conversion, Vol. 3, No. 1, March 1988.

[5] Simone Buso, Paolo Mattavelli, Leopoldo Rossetto, and Giorgio Spazzi, "Simple Digital Control Improving Dynamic Performance of Power Factor Preregulators", IEEE Trans. on Power Electronics, Vol. 13, No. 5, Septemper 1998.

[6] Ahmed A. Elwogoud, "Single Phase Unity Power Factor Rectifier", M.sc. Thesis, Alexandria University, Novamber 1998.

[7] Sam Ben-Yaakov, and Ilya Zelter, "The Dynamics of a PWM Boost Converter With Resistive Input", IEEE Trans. on Industrial Electronics, Vol. 46, No. 3, June 1999.

[8] Jee-Woo Lim and Bong-Hwan Kwon,"A Power-Factor Controller for Single-Phase PWM Rectifiers", IEEE Trans. on Industrial Electronics, Vol. 46, No. 5, October 1999.

[9] Atsushi Nakajima, Shin-ichi Motegl and Akeshi Maeda, " Comparison of the Characteristics between Buck and Buck-Boost High-Power-Factor Converters with Pulse-Space-Modulation", IEEE IECON '99 Conference.

[10] J.Ch. Le Bunetel, and M. Machmoum, "Control of Boost Unity Power Factor Correction Systems", IEEE IECON '99 Conference.

[11] Jun-ichi Itoh and Kouetsu Fujita, "Novel Unity Power Factor Circuits Using Zero-Vector Control for Single-Phase Input Systems**",** IEEE Trans. on Power Electronics, Vol. 15, No. 1, January 2000.