A microprocessor-controlled of an AC chopper for speed control of universal motor

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Abstract

AC choppers or ac voltage regulators have been widely used to obtain variable ac voltage from a fixed ac source. The purpose of this paper is to control on-line the speed of universal motor by using an ac chopper. A developed control strategy is based on Bang-Bang control of an ac chopper using two MOSFETs, which allows the supply voltage to be applied to motor. Using a microprocessor as a controller makes it possible to drive MOSFETs in real time. The analytical results are compared with the experimental results of the control system, good agreement has been achieved for a wide range of speed variations. Also, results demonstrate the robustness of the proposed control method in contending with varying speed command.

1. Introduction

In the field of a-c motor drives and high-performance systems, where fast response and high accuracy characteristic are needed, a PWM inverter is widely used, especially a closed-loop controlled PWM [1].

Normally, the electronic control circuit drives the inverter power devices for generating pulse width modulated terminal voltage is necessary for providing the desired wave shape to the load [2].

To obtain variable a-c voltage from a constant a-c voltage source, phase control a-c choppers have been widely used in a-c power control applications such as light dimmer, heater control and a-c motor speed control. However, the retardation of firing angle causes a lagging power factor at the input side even if the load is purely resistive. Also there are plentiful harmonics in both output voltage, and current and discontinuity of power flow appears at both the input and output sides. The solutions that have been proposed to improve these defects are generally falling in two categories: first is to modify the power circuit by adding a freewheeling path, this improves the power factor slightly but cannot control the harmonics, second, by using the circuit of a-c chopper and operated such that to give switching method [3].

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The developments achieved recently in the field of power electronics made it possible to improve the performance of electrical system utilities usually inverters, converters, choppers and regulators [4].

A microprocessor-controlled an a-c chopper fed motor is more useful, effect and accurate. A chopper or a-c regulator has been widely used to obtain variable a-c voltage from a fixed a-c source [5-7].

The theory of hysteresis control for voltage source inverters is well documented and this technique has been widely, particularly in the field of drives [8]. The proposed system is novel in that it uses an a-c chopper rather than an inverter topology and that it uses on-line speed control of a universal motor using real-time microprocessor control to implement the scheme. Unlike most PWM schemes, hysteresis control has no fixed switching frequency, and the switching harmonics are spread over a wide spectrum. The average and maximum switching frequencies are dictated by supply voltage, load impedance, hystersis switching limits, and switching times of devices.

2. System description

The proposed drive circuit for speed control of universal motor is given in Fig. 1. The system consists of two MOSFETS (Main and freewheeling), two uncontrolled bridges, synchronization circuit (as shown in Fig. 2a), universal motor, tacho generator, driver circuit (as shown in Fig. 2b) and microprocessor. The error difference (**e**) between reference speed and actual motor speed passes through A/D converter to the microprocessor. An assembly program is written for generating pulses from its port to deliver MOSFETS. According to Bang-Bang control rules as follows:

If **e** > zero hence turn on Main MOSFET and turn off Freewheeling MOSFET
In otherwise if **e** ≤ zero hence turn off Main MOSFET and turn on Freewheeling MOSFET (1)

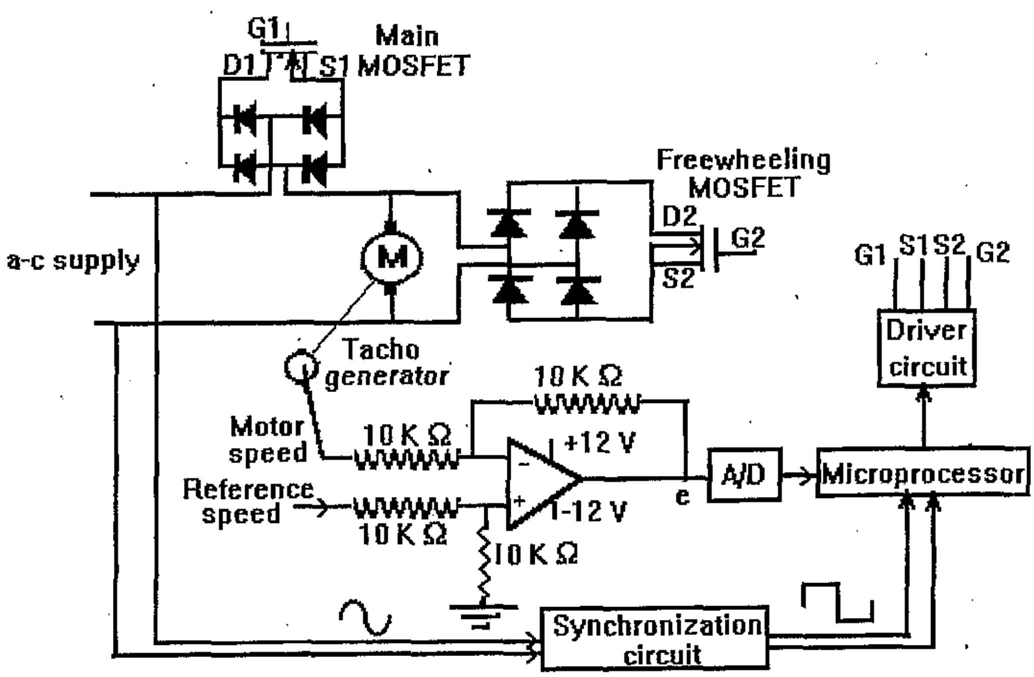

Fig.1 A proposed control system

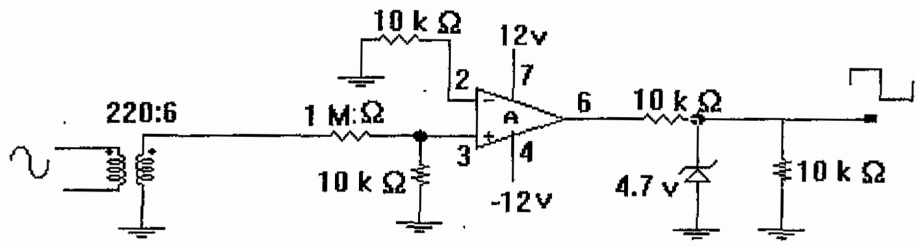

Fig. 2a Synchronization circuit

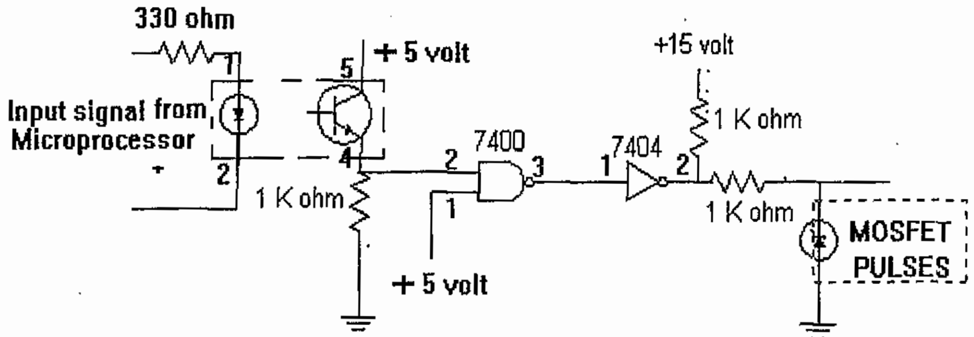

Fig. 2b Driver circuit for MOSFET

3. Mathematical model

The electrical machine market has a large quantity of small electric motors. A great portion is the fractional power universal motors, which are widely used in domestic appliances such as: electric drills, washing machines, vacuum cleaners, sewing machines, conveyors, traction, and mining. Universal motor is simply one of the uncompensated machines family, built only in fractional horse-power sizes. The inherent high operating speed of the universal motor, which means high power to weight ratio, and its series torque to speed characteristics makes it more suitable for such applications [9]. The motor is represented as shown in Fig.3

The state equations of the motor [10] are given as follows :

$$V_L = L_{eq} \frac{di_L}{dt} + R_{eq} \, i_L + E_b \qquad (1)$$

$$E_b = -K_1 \, \omega_m \, {}^* i_L \qquad (2)$$

$$T_e = T_L + J \frac{d\omega_m}{dt} + K_2 \, \omega_m \qquad (3)$$

$$T_e = -K_1 \, i_L^2 \qquad (4)$$

The motor parameters are given in Appendix (1).

In case of turning ON main MOSFET load voltage is nearly equals to supply voltage. In the other hand, at turning ON freewheeling MOSFET, Load voltage is nearly equals to zero and hence a freewheeling path permits motor current to pass through freewheeling MOSFET (neglect voltage drop across diode bridge).

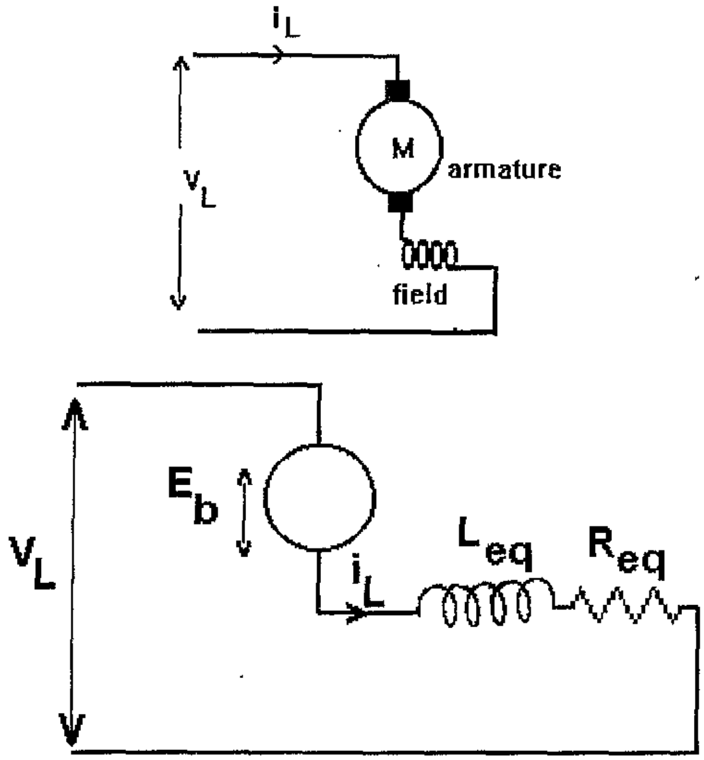

Fig. 3 The Universal Motor

4. Results

In this section, the results obtained from simulation program and experiments are presented. A simulation program is written to investigate theoretically the characteristics of the proposed control method. The performance Equations (1) --- (4) were solved numerically for a desired reference speed and applying Bang-Bang control technique using 4 th order Runge-Kutta method. A flowchart in Fig. 4 describes the step by step method to obtain the performance of the motor at a desired reference speed. An experimental setup is built using a microprocessor 8085 because of its low cost in order to verify the feasibility and the validity of the computed results for the proposed control system. Figures 5-11 show the simulation and experimental results for both the MOSFETS pulses and motor performance at different references desired speed (on line control). It can be seen from these Figures that the system under consideration exhibits some supply oscillation due to turn ON and OFF the Main MOSFET. A good agreement between experimental and analytical results has been obtained. It is required to increase the number of pulses per cycle to improve the waveform of the load current close to pure sine wave. So, total cost of the actual control system increases or decreases depending upon the capability of selecting IGBT or MOSFETs and replaces fast microprocessor or microcontroller instead of the 8085 microprocesser in the proposed system. An Experiment was performed in order to verify the feasibility of the proposed control system on line Bang-Bang speed control system. Motor trasient performance is shown in Figs. 12-13 as a step change in reference speed by 20% , a fast dynamic response has been scuccessfuly implemented. The software used in experimental prototype is an assembly program designed by the author is given in appendix II, It is stored into EPROM chip. Using only one microprocessor chip, the error between reference speed and actual motor speed fed through A/D converter to microprocessor and according to Bang-Bang control technique, the driving pulses for main and freewheeling MOSFETs are generated..

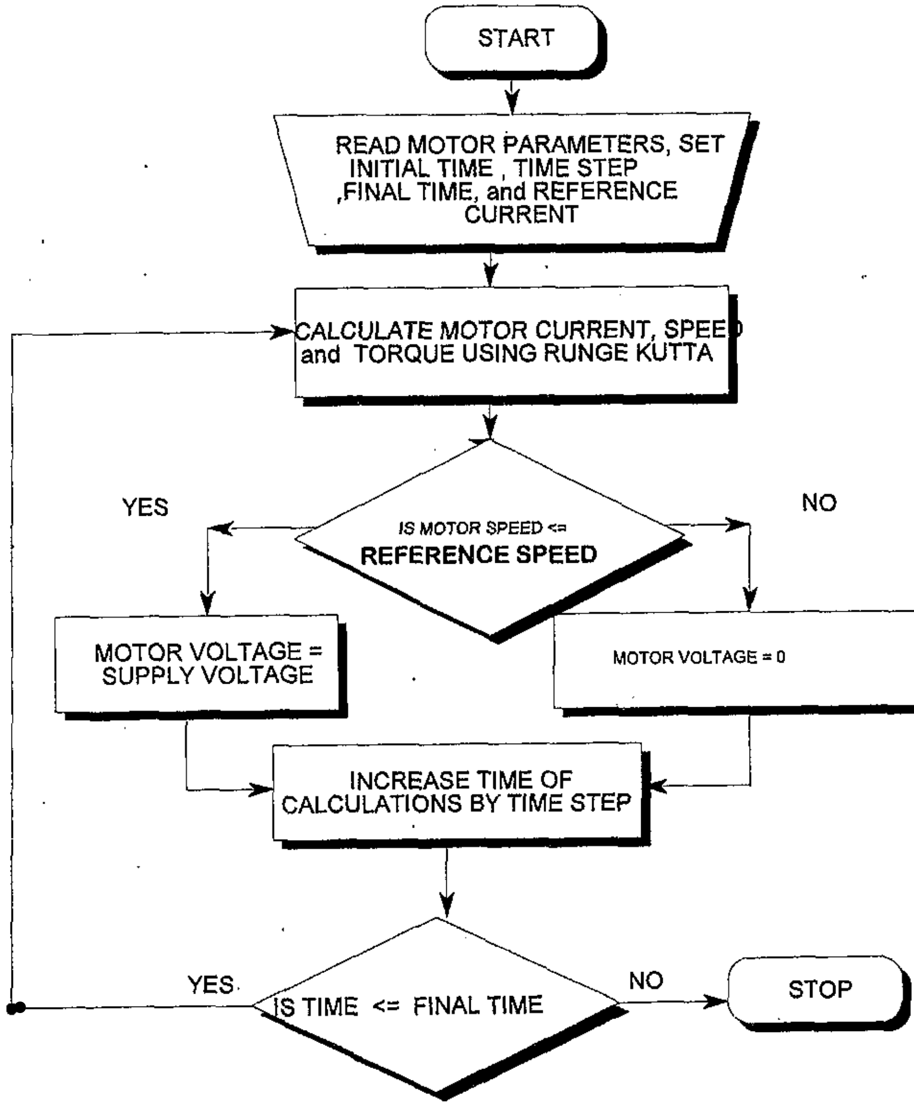

Fig. 4 the simulation flowchart of the system

4. Conclusion

Bang-Bang control of an a-c chopper is fast, low cost, and accurate in case of speed control of universal motor and using microprocessor to generate a required pulses for main and Freewheeling Mosfets. Motor current is nearly sinusoidal in case of high reference speed. A simulation result verifies the experimental results.

Appendix 1

The universal motor has the following ratings and parameters :

1/3 HP, 1.9 Amp., 110 volt., $R_{eq.}$= 57 ohm, $L_{eq.}$=50.08 m.h, K_1= -0.215 n.m./amp², K_2=1E-05 n.m./rad/sec. , J= 3E-05 kg.m²

Appendix II

An assembly program is written to achieve Bang-Bang speed control of universal motor as follows:

Address	Instructions	Code	Note
7000	MVI A,FF	3E FF	Initialize A/D converter
7002	OUT 30	D3 30	
7004	IN 90	DB 90	*Test for zero crossing of synchronization*
7006	ANI 01	E6 01	signal.
7008	JZ 7004	CA 04 70	
700B	IN 90	DB 90	
700D	ANI 01	E6 01	
700F	JNZ 700B	C2 0B 70	
7012	IN 90	DB 90	
7014	ANI 01	E6 01	
7016	JNZ 701F	C2 1F 70	
7019	CALL 7050	CD 50 70	
701C	JMP 7012	C3 12 70	Call subroutine for generating MOSFET pulses .
701F	CALL 7050	CD 50 70	
7022	IN 90	DB 90	
7024	ANI 01	E6 01	
7026	JNZ 701F	C2 1F 70	
7029	JMP 7012	C3 12 70	
7050	IN 80	DB 80	Subroutine is used to deliver Main MOSFET
7052	CMA	2F	and freewheeling MOSFET with pulses
7053	ANI 80	E6 80	according to input e
7055	JZ 705F	CA 5F 70	where e = reference speed - motor speed
7058	MVI A,01	3E 01	
705A	OUT A0	D3 A0	
705C	JMP 7063	C3 63 70	
705F	MVI A,00	3E 00	
7061	OUT A0	D3 A0	
7063	RET	C9	

SYMBOLS

E_b : Back e.m.f.
i_L: Motor current
J : inertia in $Kg.m^2$
K_1: back e.m.f. constant. in n.m./$amp.^2$
K_2 : Damping constant in n.m./rad/sec.
L_{eq}: Equivalent inductance of motor armature and field.
R_{eq} : Equivalent resistance of motor armature and field.
T_L : Load torque.
V, : supply voltage
V_m,V_L Amplitude of a.c. Input voltage and motor terminal voltage resp.

ω_m : motor speed in rad./sec.

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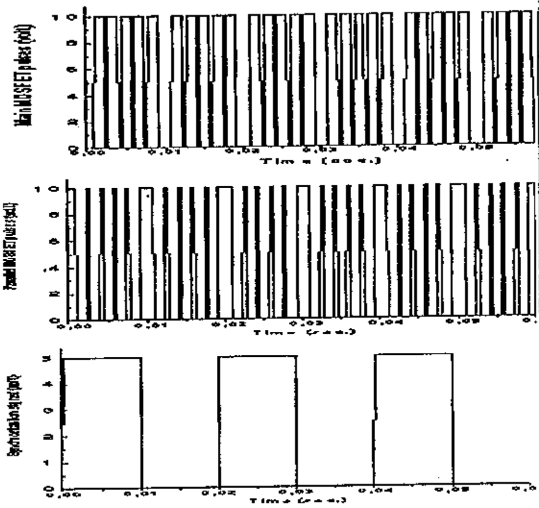
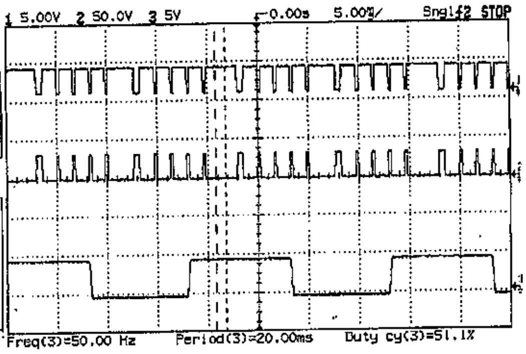
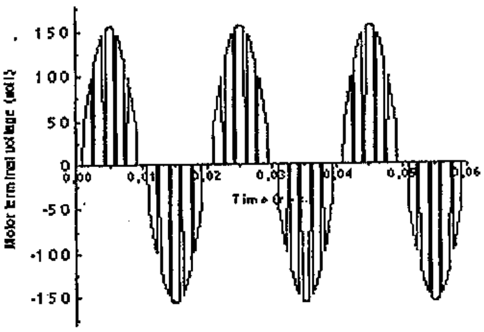
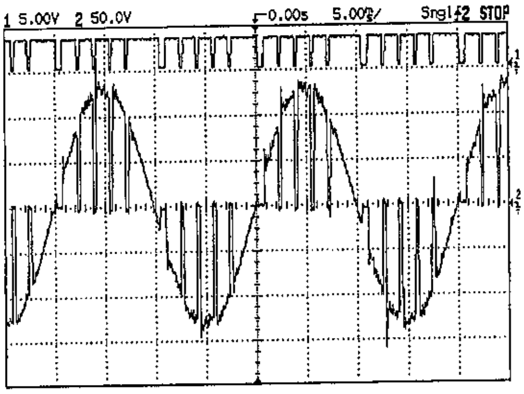


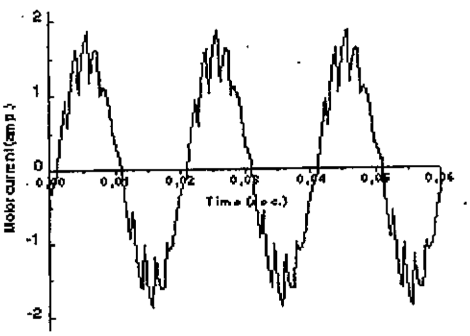


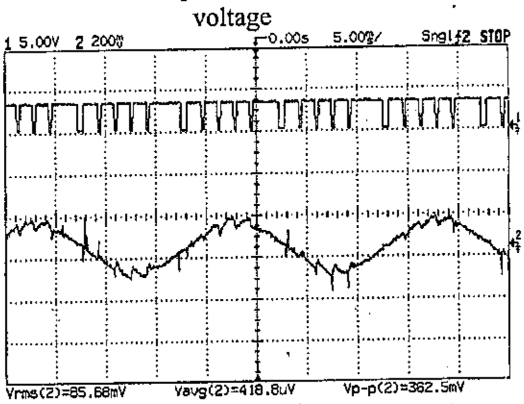
Main MOSFET pulses, Freewheeling MOSFET pulses and Synchronization signal



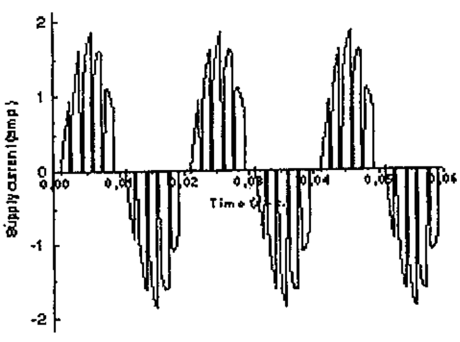


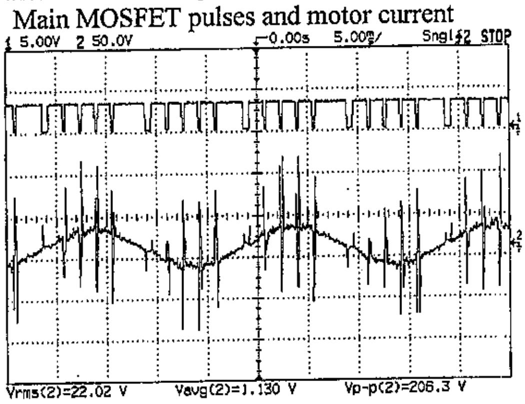
Main MOSFET pulses and motor terminal voltage





Main MOSFET pulses and motor current



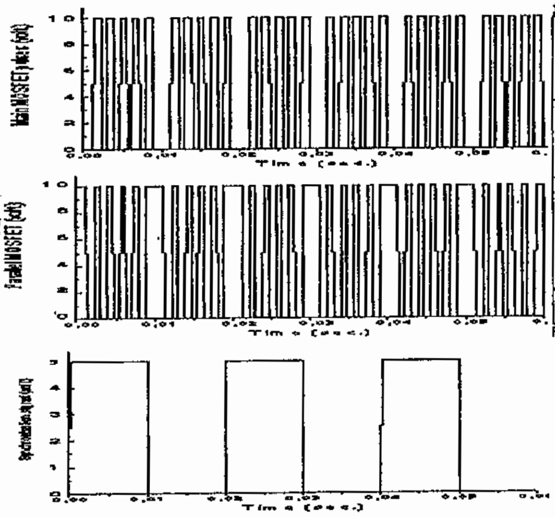


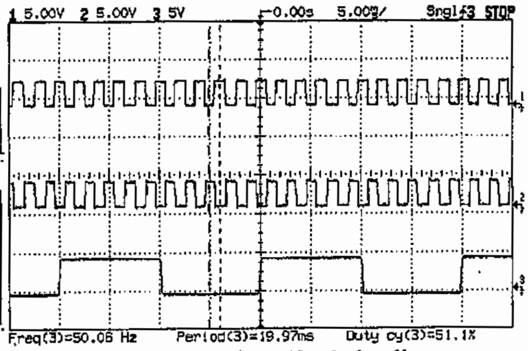
Simulation Results

Fig. 5 System performance at reference speed = 8000 r.p.m.

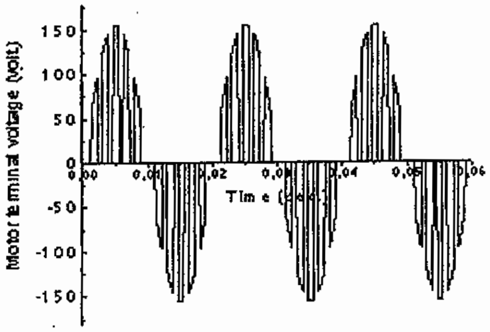
Main MOSFET pulses and supply current

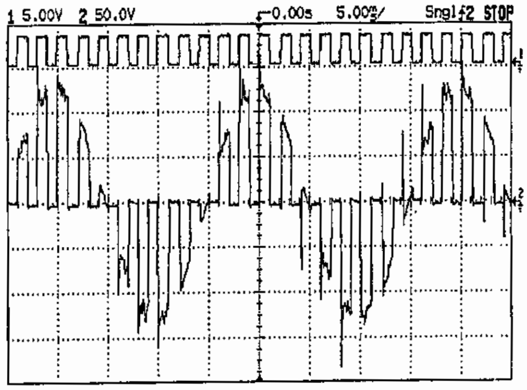
Experimental results



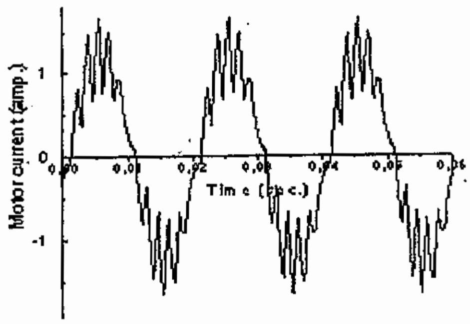


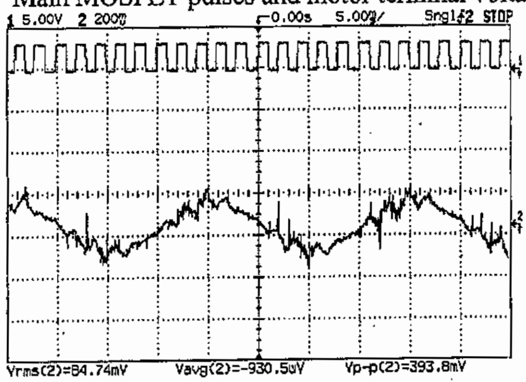
Main MOSFETpulses, Freewheeling MOSFET pulses and Synchronization signal



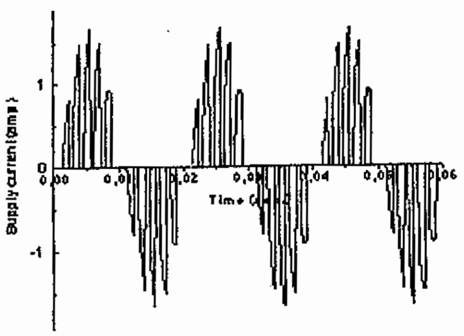


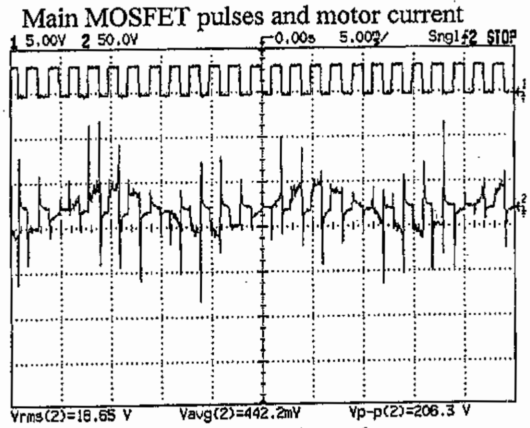
Main MOSFET pulses and motor terminal voltage





Main MOSFET pulses and motor current



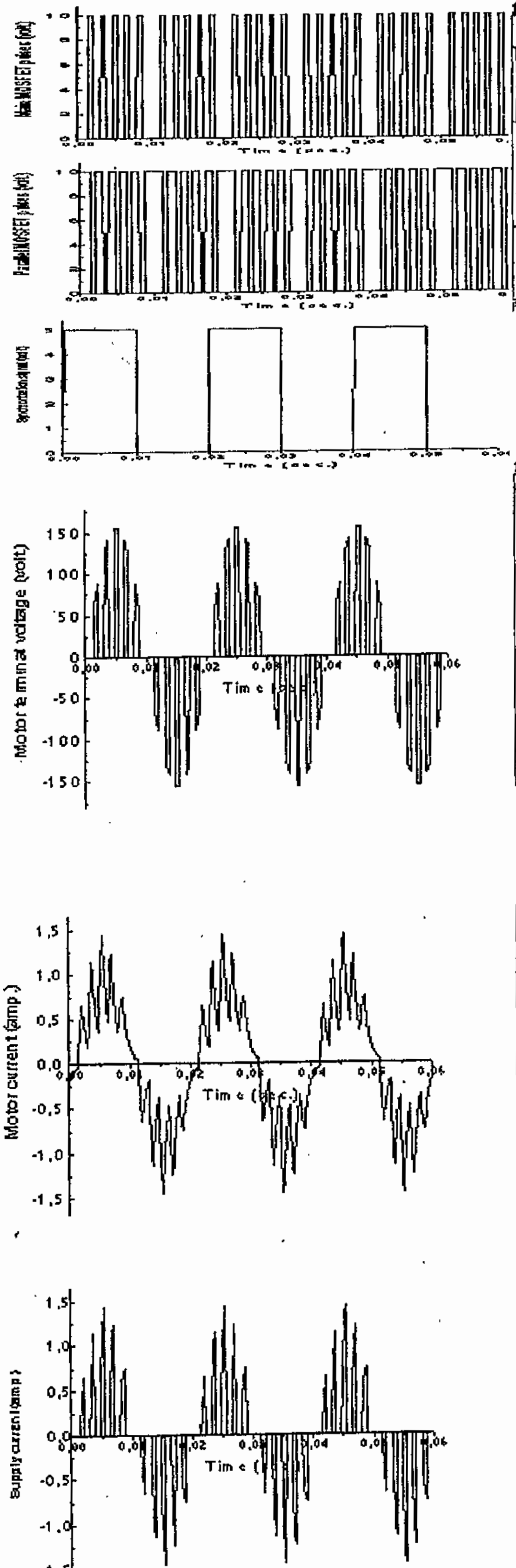


Main MOSFET pulses and supply current

Experimental results

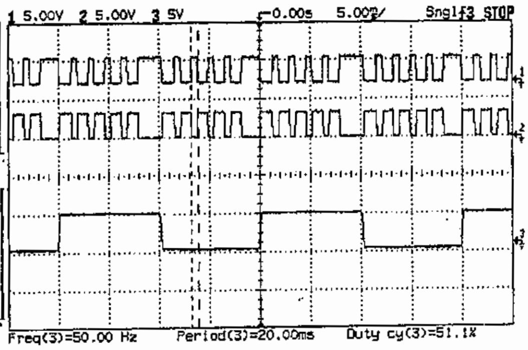
Simulation Results

Fig. 6 System performance at reference speed = 7300 r.p.m.

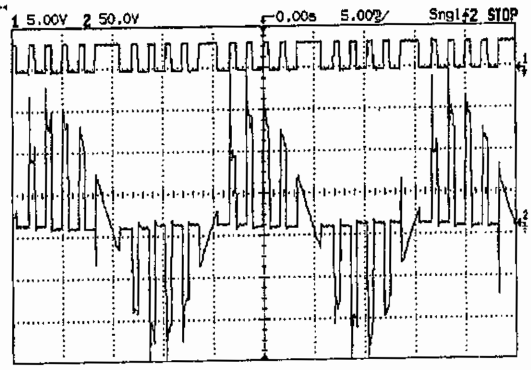


Simulation Results

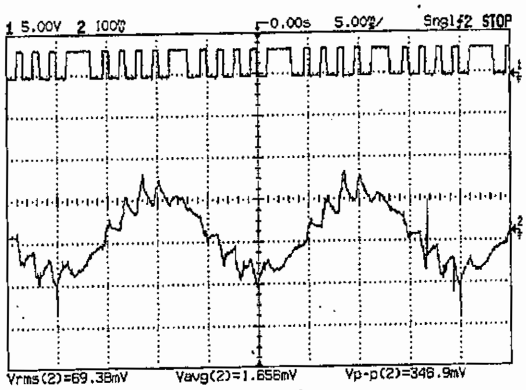
Fig. 7 System performance at reference speed = 5500 r.p.m.



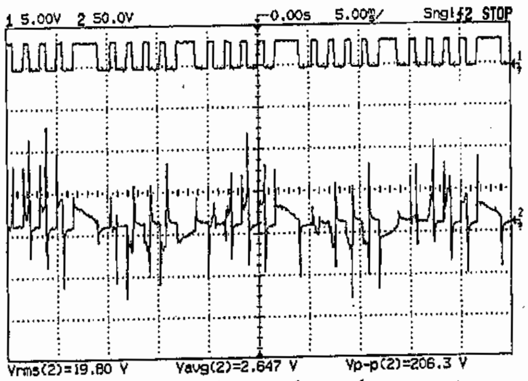
Main MOSFET, Freewheeling MOSFET pulses and Synchronization signal



Main MOSFET pulses and motor terminal voltage



Main MOSFET pulses and motor current



Main MOSFET pulses and supply current

Experimental results

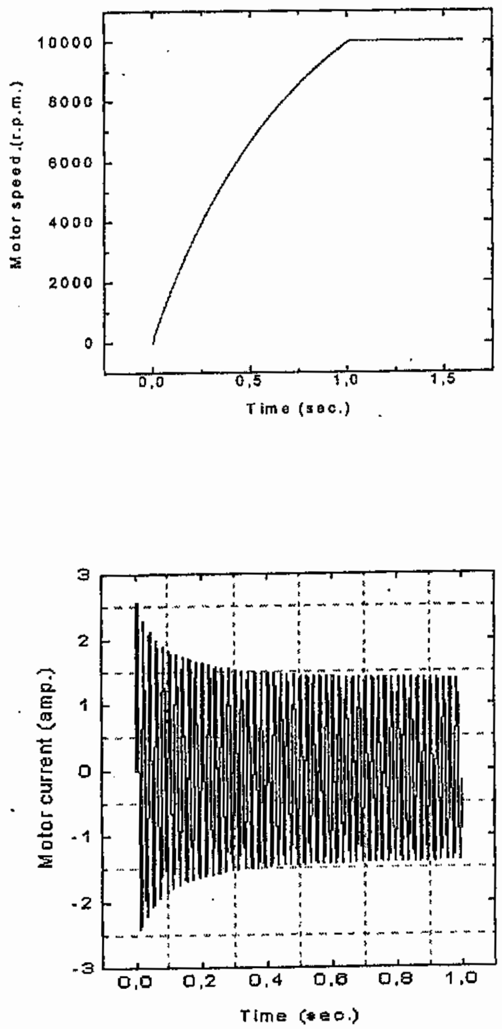


Fig.8 Simulation results of start-up of universal. motor without controller (supply voltage=110 volt.)

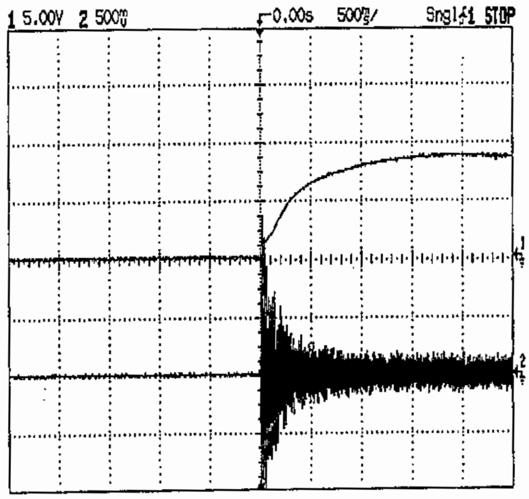


Fig.9 Motor start-up performance (without controller)

Ch.1 Motor speed

Ch.2 Motor current

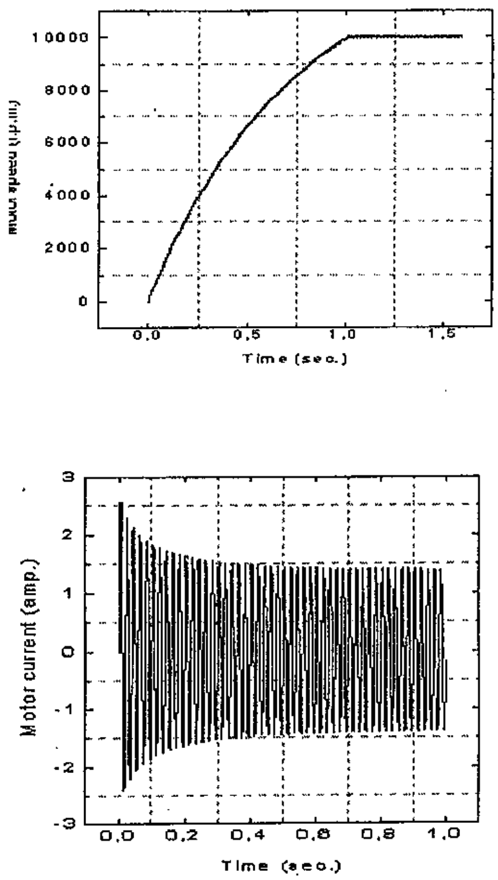


Fig. 10 Simulation results of start-up of universal. with controller (supply voltage= 110 volt.) and reference speed = 10000 r.p.m.

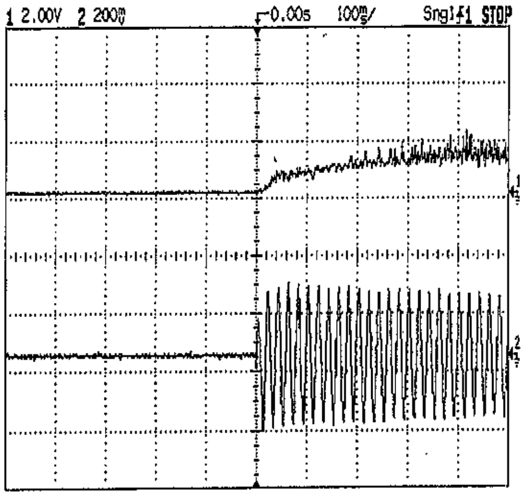


Fig.11 Motor start-up performance (with controller) at reference speed= 10000 r.p.m.

Ch.1 Motor speed

Ch.2 Motor current

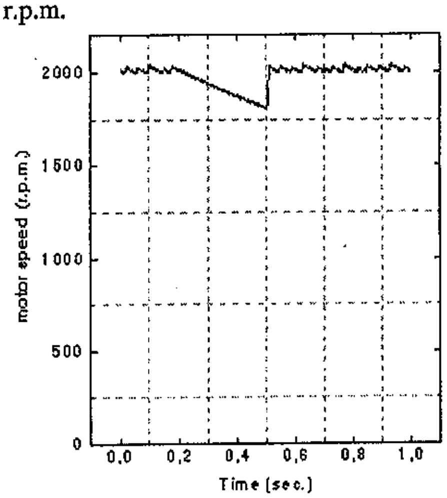


Fig. 12 Simulation result of motor speed performance as the variation of reference speed by 20 %

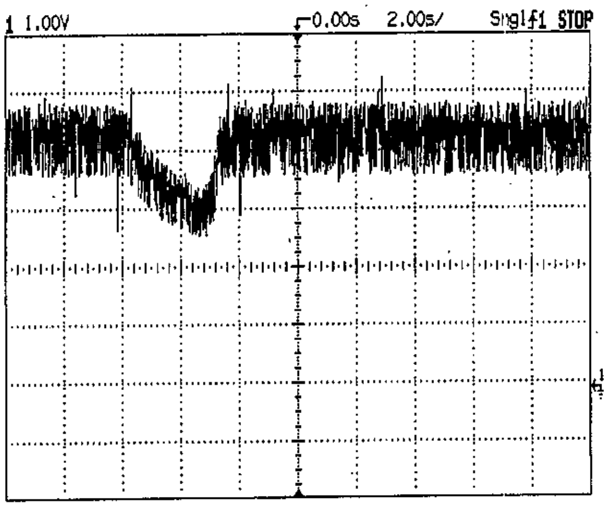


Fig.13 Experimental result of motor speed performance as the variation of reference speed by 20%

التحكم بالميكروبروسيسور فى سرعة محرك متعدد التغذية
بإستخدام مجزئ الجهد المتغير

د٠اشرف زين الدين
قسم الهندسة الكهربية – كلية الهندسة بشبين الكوم
جامعة المنوفية

ملخص البحث

يتناول هذا البحث طريقة تحكم فى سرعة محرك متعدد التغذية عن طريق تقطيع جهد المنبع المغذى للمحرك وفقا لطريقة تحكم تسمى BANG-BANG وفى هذه الطريقة يتم مقارنة سرعة المحرك بسرعة قياسية يمكن إختيارها ويكون الفرق بينهما يسمى الخطأ "e" ويمرهذا الخطأ إلى الميكروبروسيسور من خلال دوائر تحويل A/D وعن طريق برنامج تم عمله بلغة التجميع ومخزن على الذاكرة EPROM والمتصلة بالميكروبروسيسور يتم إخراج نبضات كهربية تغذى عدد إثنان ترانسيستور من النوع MOSFET إحداهما متصل على التوالى بالمحرك بينما الاخر متصل على التوازى على أطراف المحرك ويكون إحداهما فى حالة تشغيل بينما يكون الآخر فى حالة عدم تشغيل وبهذا يمكن تنظيم الجهد على أطراف المحرك وفقا للسرعة المطلوبة وقد تم عمل النموذج الرياضى للنظام المقترح وتم مقارنة النتائج النظرية بالنتائج العملية ووجد تتطابق بينهما ويمتاز النظام المقترح بالسهولة والدقة والمرونة فى ضبط سرعة المحرك ٠