# Microprocessor-based closed loop current control of universal motor

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**ABSTRACT**

This paper presents a comparative simulation and experimental study of a microprocessor-based closed loop current control of universal motor when fed from either a d.c. power supply or an a.c. power supply via a MOSFET transistor. The current control or torque control is achieved on line using Bang-Bang (ON/OFF) control technique. This method is simple, cheap and fast. Only one transistor is used for chopping d.c. Supply or sinusoidal input voltage to the motor. The proposed control technique for current can be used in industrial application required a constant torque such as electric traction. An extensive simulation and experimental studies are carried out for the two proposed systems and results are presented. An acceptable agreement between measured and calculated results is obtained.

**KEYWORDS**

Microprocessor, ON/OFF control, MOSFET and Universal motor

## 1. INTRODUCTION

Universal motor is simply one of the series uncompensated machines family, built only in fractional horse-power sizes. Being intended for operation from either direct or alternating current supplies, they are frequently referred to as universal motor [1]. Such type of motors has been efficiently used to drive the portable apparatus such as vacuum cleaners, electric drills, conveyors, traction, mining, ...... etc. This is due to the comparable torque/speed characteristic produced with both dc and ac power sources of the same r.m.s. value [2]. The commonly used electric drive systems can be classified into:

1- Analog systems.
2- Digital systems.
3-Microprocessor or microcomputer-based systems.

The latest system should have sufficiently fast sampling rates and program execution time in order to provide the

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optimal performance of the current control and the firing circuits. Several analytical and practical procedures have been proposed in the literature for the synthesis of the load torque control of the DC drives. A brief description [3] of the widely known techniques are given as follows:
The technique proposed in [4,5] was based on using a current command for high efficiency torque control of a dc motor taking the effects of the magnetic saturation and armature reaction into account (Analog system).

The method presented in [6] which concern controlling the torque of a separately excited d-c motor using a thyristor chopper in the armature circuit for the low-speed range and a transistor chopper in the field for high-speed range. The microcomputer method used in [7] to control the torque of a separately excited d-c motor of an electric vehicle drive by controlling the armature current in either direction to check the motoring and regeneration torque of the vehicle. Between zero and base speed of the motor, the armature current was controlled by a two-quadrant transistor chopper with the field current maintained constant, whereas at higher speed range, the field current is regulated to control the armature current. The method of estimating parameters of a control loop with an observer for the unmeasurable variable that influence the load of the motor was described in [8], This method presented a robust control algorithm that greatly enhances the control of the plants with variable parameters.

A modelling and simulation study [9] of a closed loop speed control scheme for a MOSFET chopper-fed series motor, using a non-linear discrete model has been presented. In that study, conventional analog PI controller parameters for speed are determined using recurrence matrix. The scheme is suitable for battery urban electric vehicles and small traction systems. A microcomputer based digital closed loop speed control for universal motor using ON/OFF control method for adopting the motor input voltage to keep its speed within the desired value was employed [10]. It is useful for industrial applications which need variable speeds with good motor performance.

Microprocessor control of power electronic equipment is commercially attractive because it offers the possibility of improved reliability and increased flexibility.
In this paper, a Bang-Bang control technique to control the universal motor's current or torque is presented in two proposed systems using only one MOSFET transistor for chopping the input voltage of the motor to achieve the desired reference current. One of them is developed when the motor is operated from d.c. power supply via MOSFET transistor, and the other system is proposed when the motor is fed by a.c. power supply via MOSFET and fully uncontrolled bridge. A microprocessor is used to turn ON or OFF MOSFET transistor depending on input error signal between reference current and actual instantaneous value fed through A/D converter.

## 2. UNIVERSAL MOTOR ANALYSIS

The uncompensated universal motor is represented as shown in Fig. 1. The following equations [1] can be written in transient domain as :

$$v = L_{eq.} \frac{di_a}{dt} + R_{eq.} \; i_a + E_b \qquad (1)$$

$$E_b = - K_1 \; \omega_m \; i_a \qquad (2)$$

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

$$T_e = - K_1 \; i_a^2 \qquad (4)$$

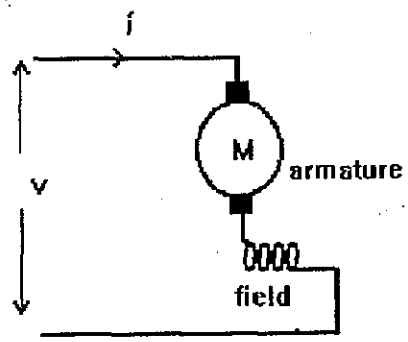



**Figure 1 The Universal Motor**

The motor parameters are given in the Appendix. In case of d.c. input voltage v = E, but in case of a.c. input voltage $v = V_m \sin \omega t$.

### 3. DESCRIPTION AND MODELING OF FIRST PROPOSED SYSTEM

When the motor is fed from a d.c. power supply, the purpose of the current loop is to make the actual motor current follow the current reference signal ($I_{ref}$) shown in Fig.2a This is done by comparing a feedback signal of actual motor current ($i_a$) with the current reference signal. The error signal ($e = I_{ref} - i_a$) is fed through an Analog/Digital converter to a microprocessor 8085. An assembly program is written to receive the error signal (e) and compare it with zero according to Bang-Bang control technique as the following rules:

| | | |
|---|---|---|
| If | $e > 0$ | Turn on MOSFET transistor ($v = v_L$) |
| but when | $e \leq 0$ | Turn off MOSFET transistor ($v = v_L - v_C$) |

Where $$v_C = R_s \; i_c + \frac{1}{c} \int i_c \; dt \qquad (5)$$

The microprocessor output port and MOSFET driving circuit are shown in Figure 2b.
Since the electromagnetic torque is proportional to motor current so, this method of current control is the same as torque control.

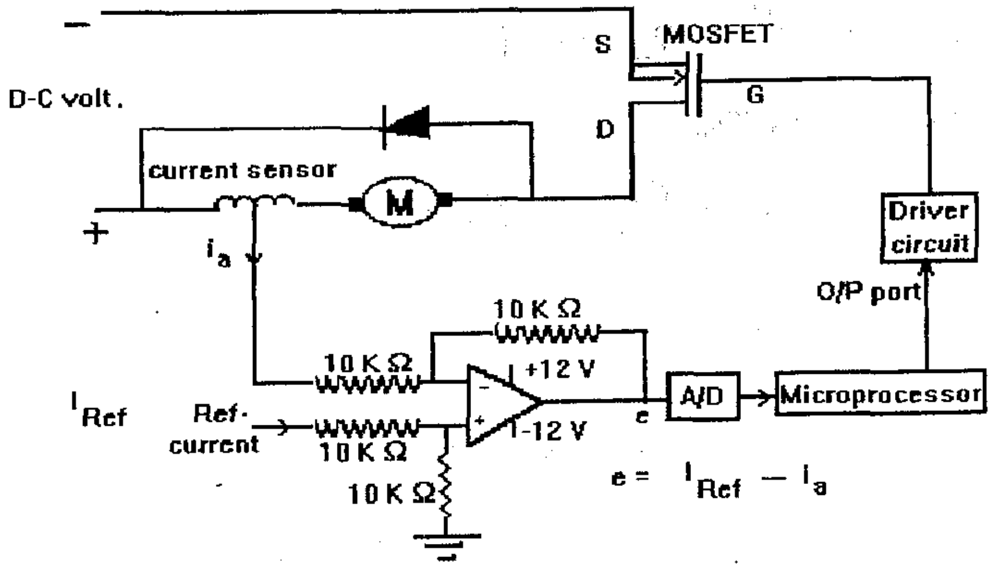



**Figure 2a Closed loop current control of universal motor fed by a d-c supply**

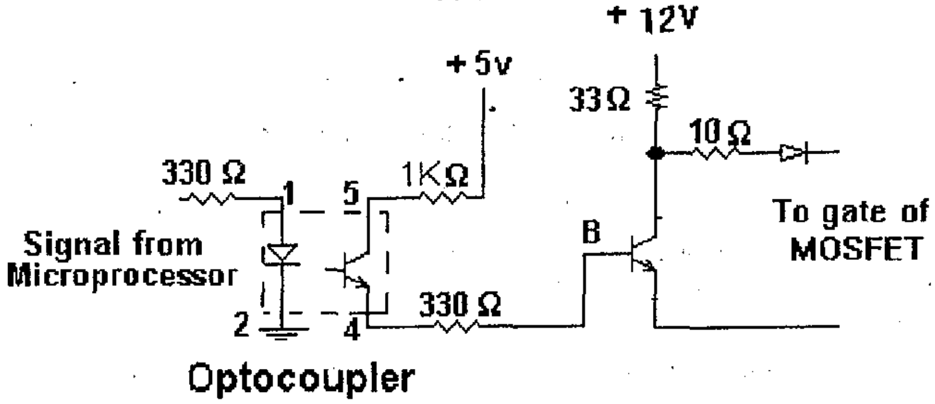



**Figure 2b Driver circuit and interface circuit between microprocessor and MOSFET transistor**

#### 4. SIMULATION AND EXPERIMENTAL STUDY OF FIRST PROPOSED SYSTEM

A mathematical model program has been built and represented by equations 1-5. This program solves the nonlinear equations using 4th order Runge-Kutta numerical method with step = 0.1m.sec. and v =E (constant d.c. voltage).
The flowchart of Fig.3 indicates the simulation program.

Experimental and simulation results of motor terminal voltage is given in Fig.4 at fixed reference current (0.361 amp.) and different values of input voltage. Because of the snubber circuit (which is used to protect MOSFET transistor and the smallest OFF period of MOSFET transistor), the motor terminal voltage does not reach zero voltage value. On the other hand, at fixed input voltage and varied reference current, the motor terminal voltage is shown in Fig. 5 A good agreement between Experimental and simulation results are obtained.

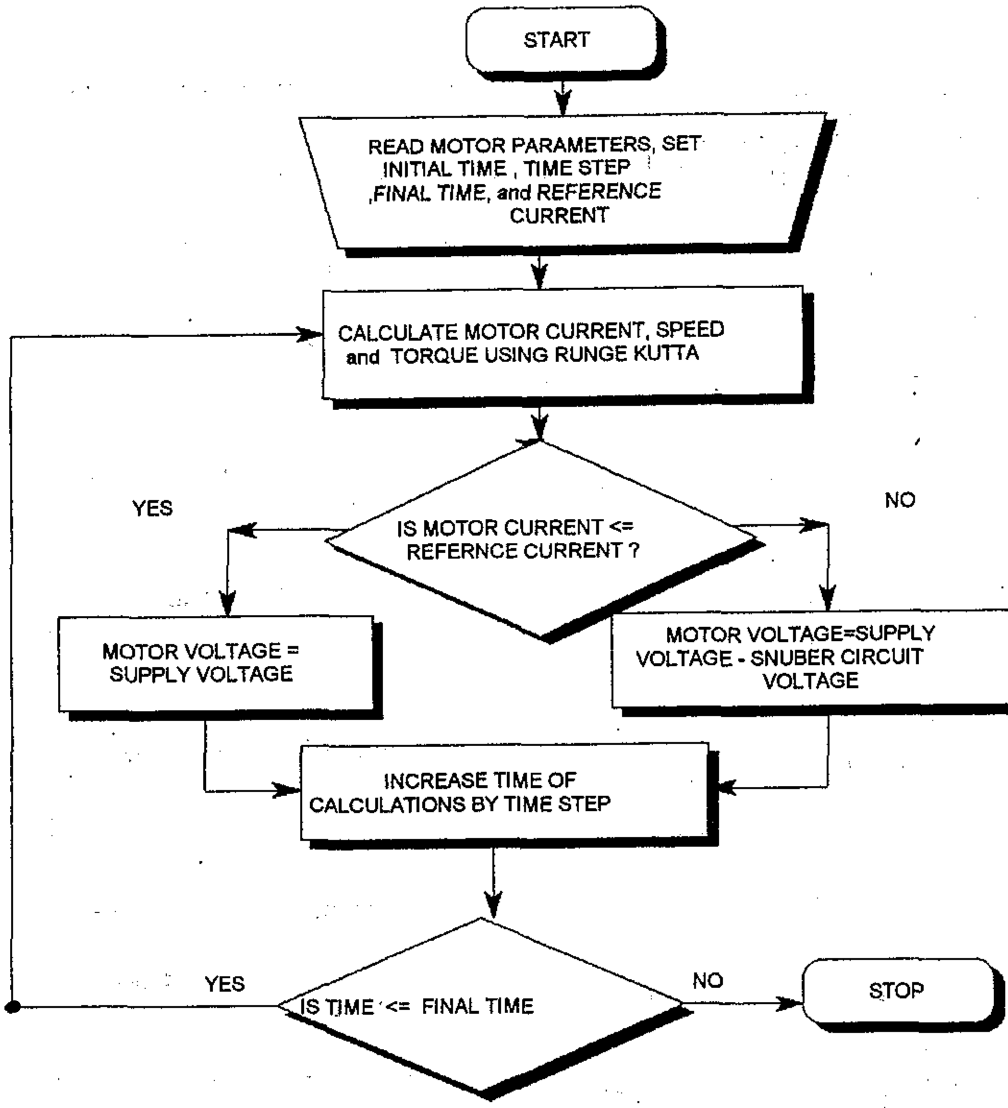
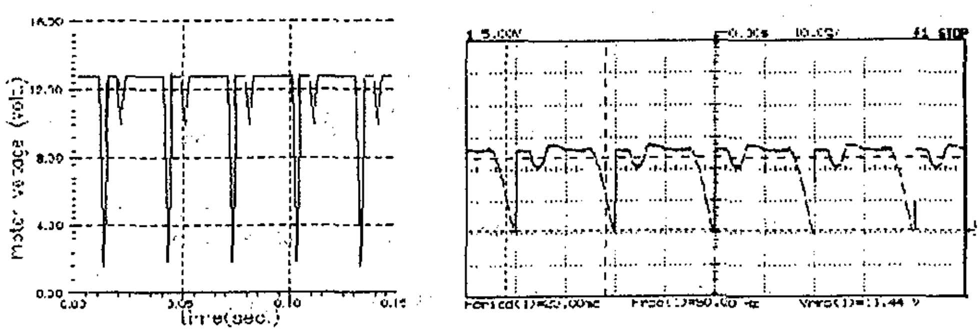
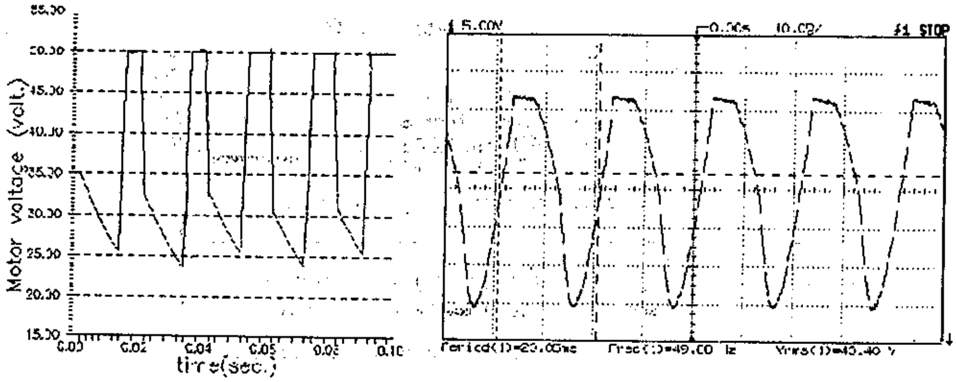



Figure 3 A flowchart indicates simulation results of closed loop control of the motor fed by a d-c supply



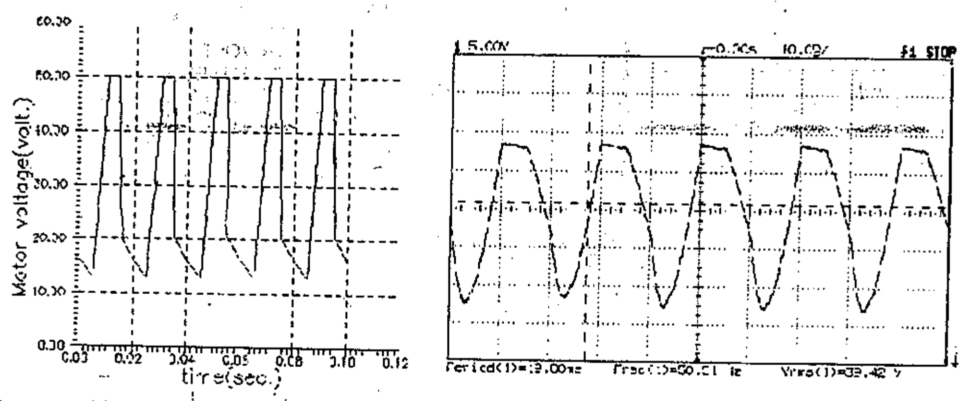

Simulation Experimental

at Input voltage = 12.7 volt., Motor speed = 477 r.p.m.



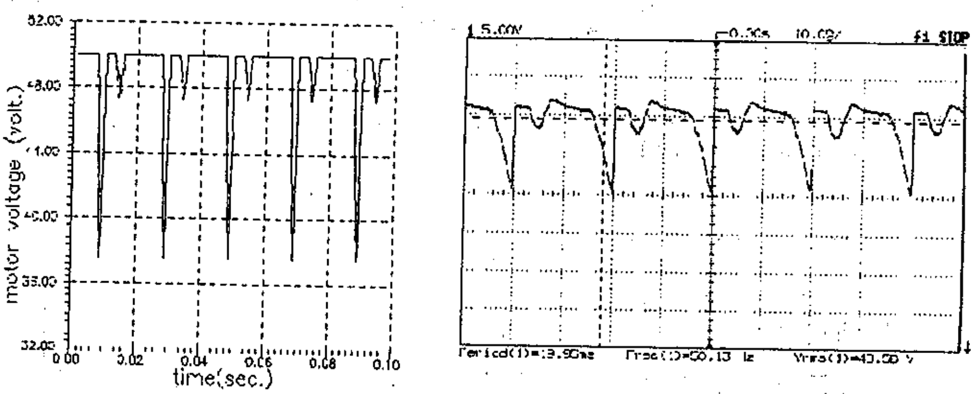

Simulation                                        Experimental

at Reference current = 0.17615 amp., Motor speed = 1228 r.p.m.




Simulation                                        Experimental

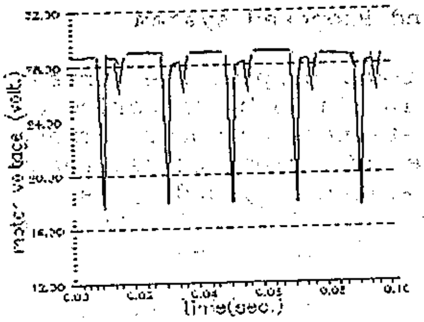
at Reference current = 0.26367 amp., Motor speed = 2059 r.p.m.

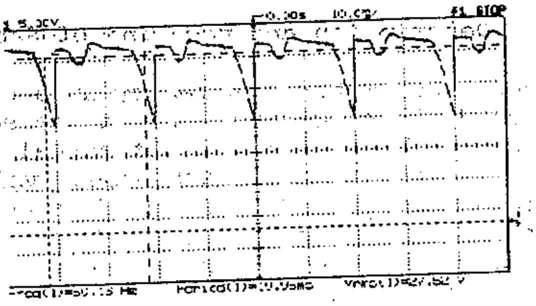



Simulation                                        Experimental

at Reference current = 0.366 amp., Motor speed = 2906 r.p.m.

Figure 5 Input voltage, and variable reference current

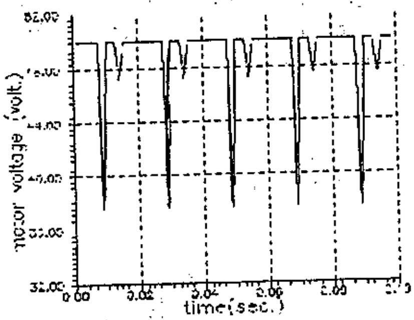


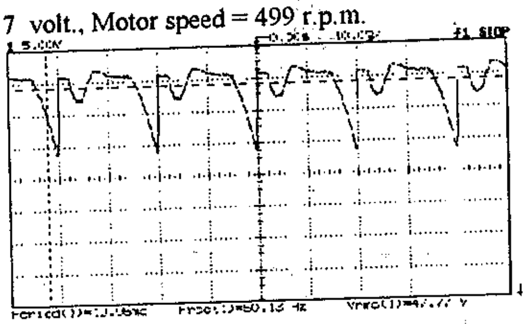



Simulation

Experimental

at Input voltage = 28.7 volt., Motor speed = 499 r.p.m.

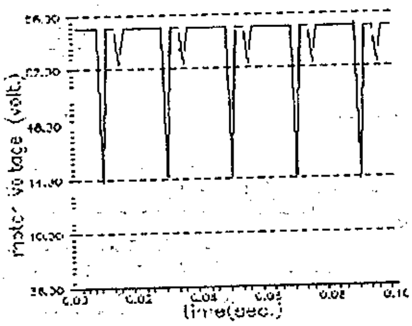


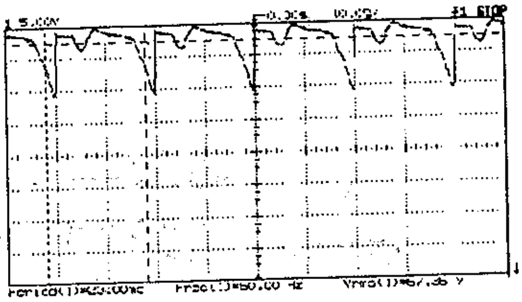



Simulation

Experimental

at Input voltage = 50 volt., Motor speed = 2160 r.p.m.

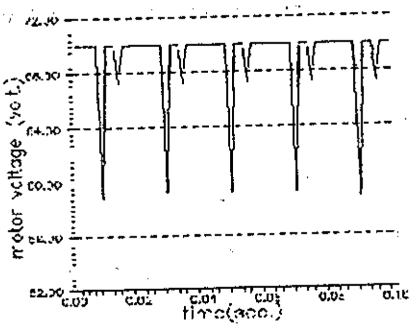


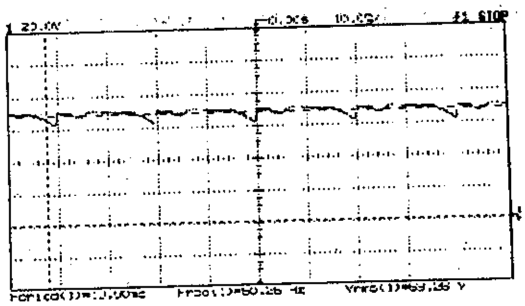



Simulation

Experimental

at Input voltage = 59.5 volt., Motor speed = 2378 r.p.m.



Simulation

Experimental

at Input voltage = 70 volt., Motor speed = 2912 r.p.m.

Figure 4 Motor terminal voltage at Reference = 0.361 Amp., and Variable input voltage

## 5. Description and modeling of Second Proposed system

When the motor is fed by an a.c. power supply, the current closed loop control is achieved in Fig. 6 by comparing on line feedback signal of actual instantaneous motor current ($i_a$) with the instantaneous value of sawtooth reference signal $I_{ref}$ and the difference between $I_{ref}$ and $i_a$ is e and compare it with zero. Synchronization circuit is shown in Fig.7 , the output square signal is necessary for microprocessor .
so if e $\leq$ zero output of 5 volt from microprocessor output port to turn off MOSFET transistor through its driver circuit. On the other hand, if e > zero Zero volt go out from microprocessor output port to turn on MOSFET transistor through its driver circuit . The study investigates the variation of reference frequency and amplitude.

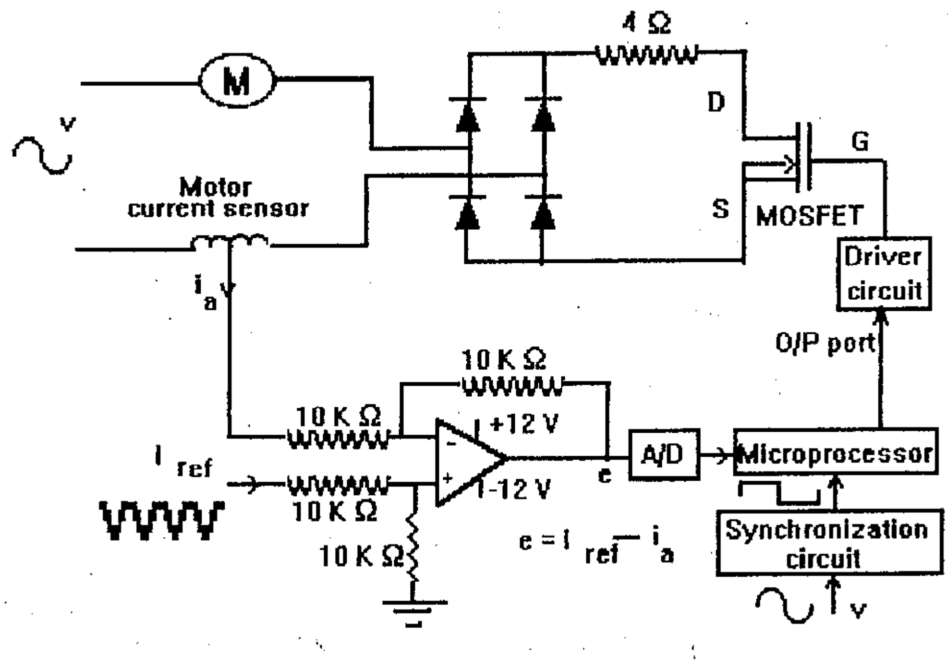



**Figure 6 Closed loop current control of universal motor fed by a-c supply**

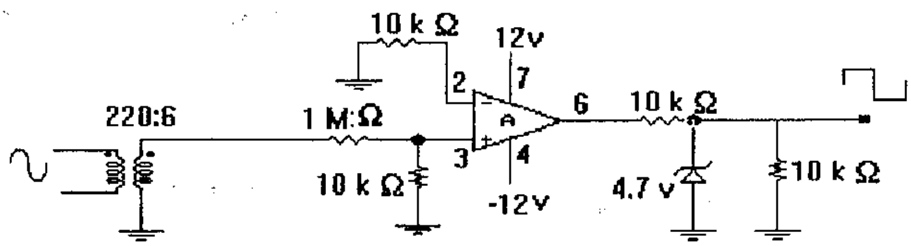
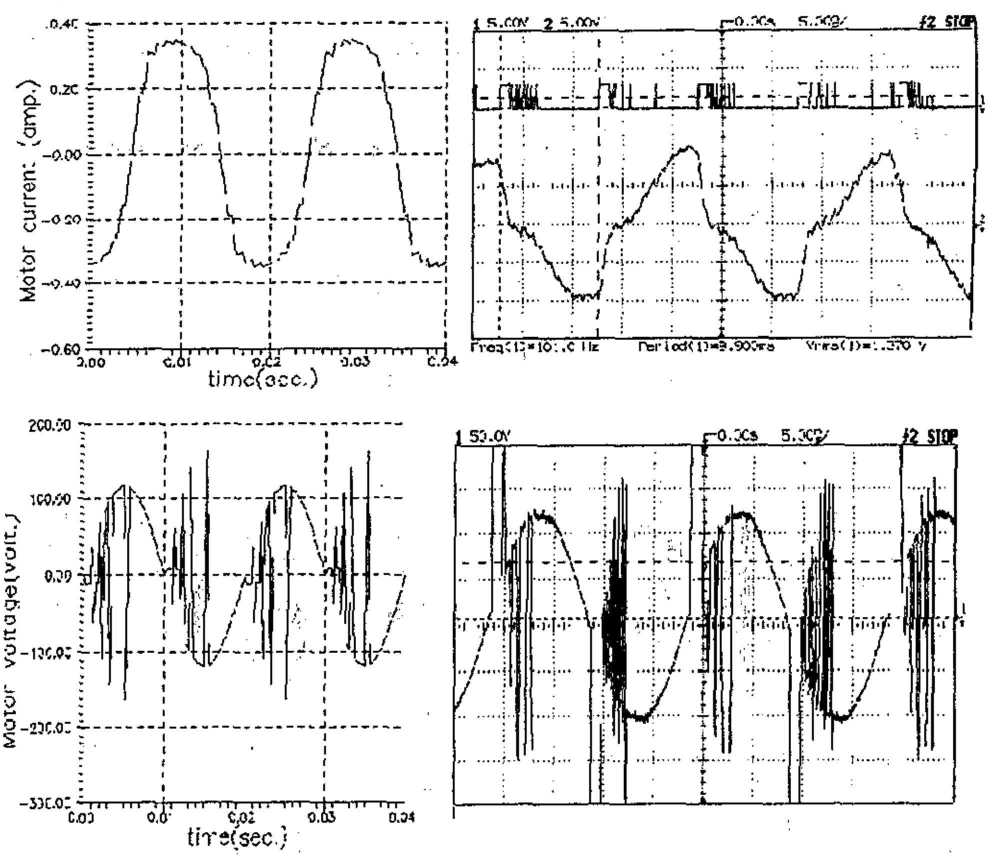



**Figure 7 Synchronization circuit**

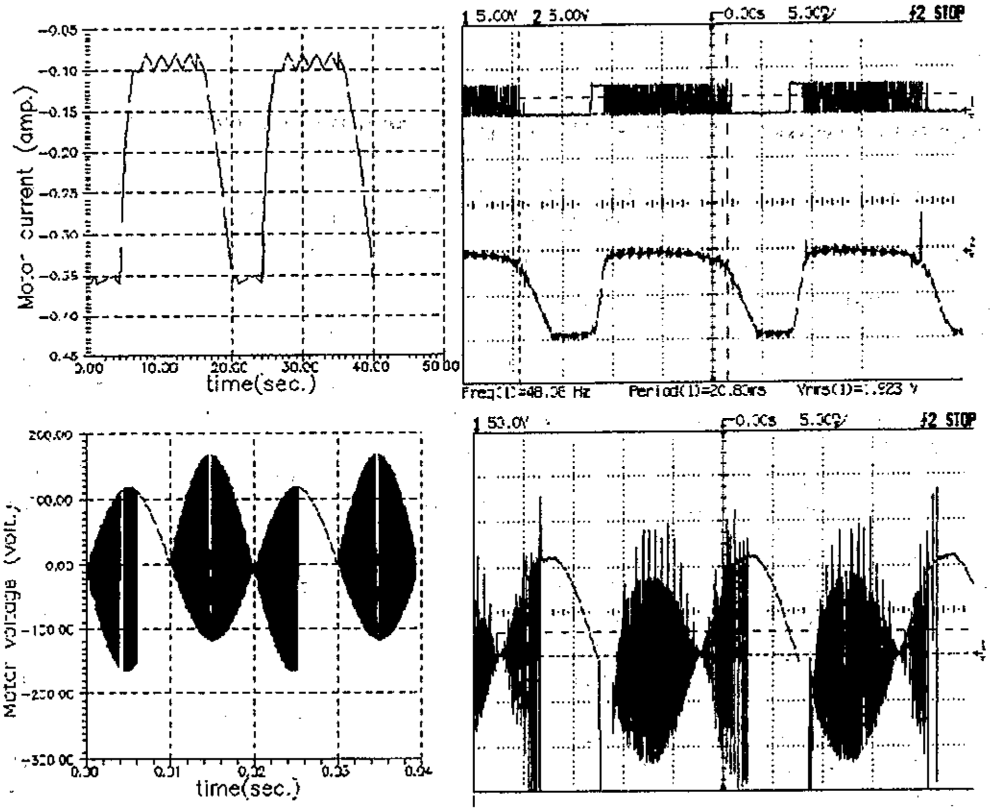
## 6. SIMULATION AND EXPERIMENTAL STUDY OF SECOND PROPOSED SYSTEM

A computer simulation program has been built based on the same rules as the last program used to simulate the first method except replacing input motor voltage with $v = V_m \sin\omega t$ replacement of E and reference current is sawtooth instead of constant value in first method of control. On line comparison between instantenous motor current and reference voltage and the difference between them is fed to the microprocessor through A/D converter. The Machine language program is stored to memory module connected to microprocessor interface and hence output signal from microprocessor according to the previous rules of Bang-Bang control to turn on or turn off MOSFET and hence energise motor or not. The results are carried out analytically and practically. The required pulses to MOSFET, motor terminal voltage and current are shown in Fig.8 at a constant input voltage, constant amplitude but with variable frequency of reference voltage. The motor speed decreases with increasing frequency of the reference voltage. A good performance of motor current has been obtained at frequency of reference current = 2 Khz. A good agreement between practical and analytical results has been obtained.




Simulation                                        Experimental

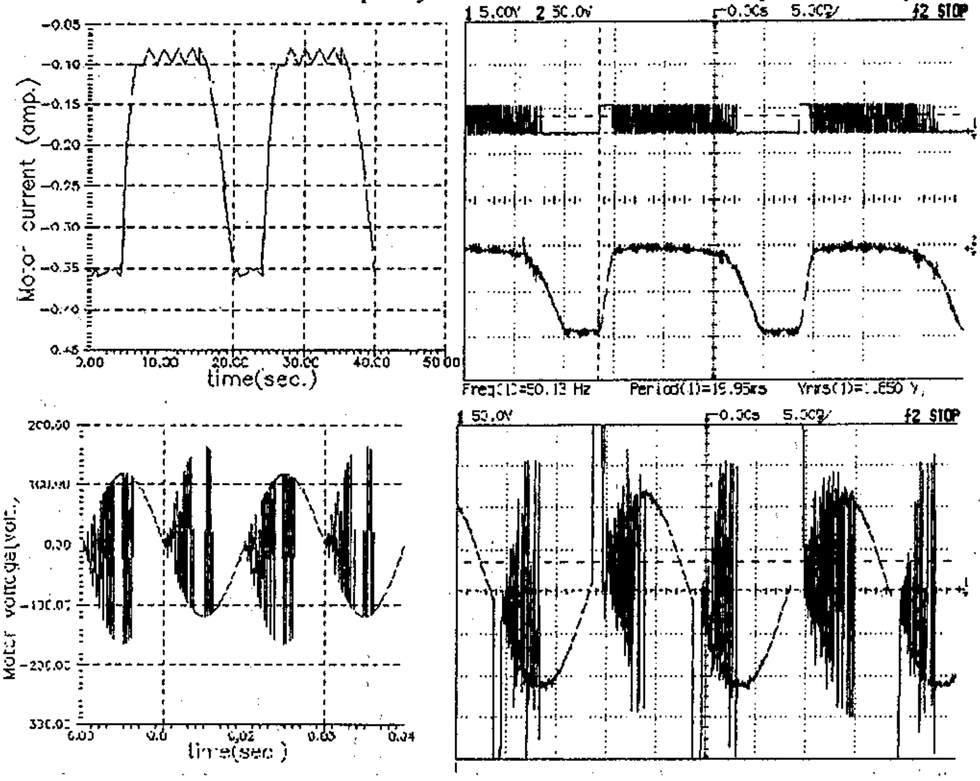
at frequency = 2 Khz      and      Motor speed = 580 r.p.m.




Simulation

Experimental

at frequency = 10 Khz and Motor speed = 250 r.p.m.




Simulation

Experimental

ch1. MOSFET pulses

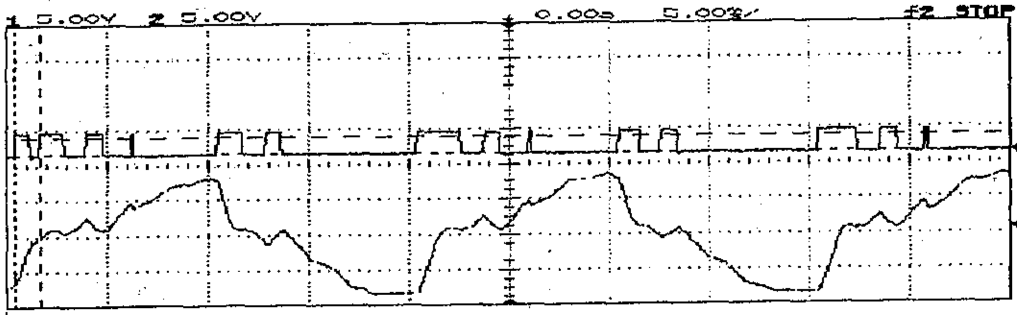
ch2. Motor current

ch3. Motor terminal voltage

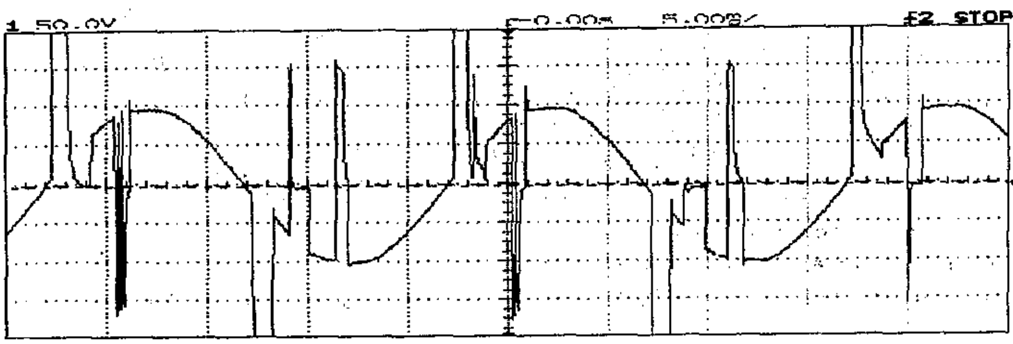
at frequency = 20 Khz and Motor speed = 219 r.p.m.

Figure 8 Motor current and terminal voltage at i/p voltage = 83 volt and amplitude reference current = 0.5049 amp

.Another pracitcal results has been represented in Figures 9, 10, 11, and 12. Thses Figures show MOSFET pulses, motor current, and terminal voltage at different control conditions..

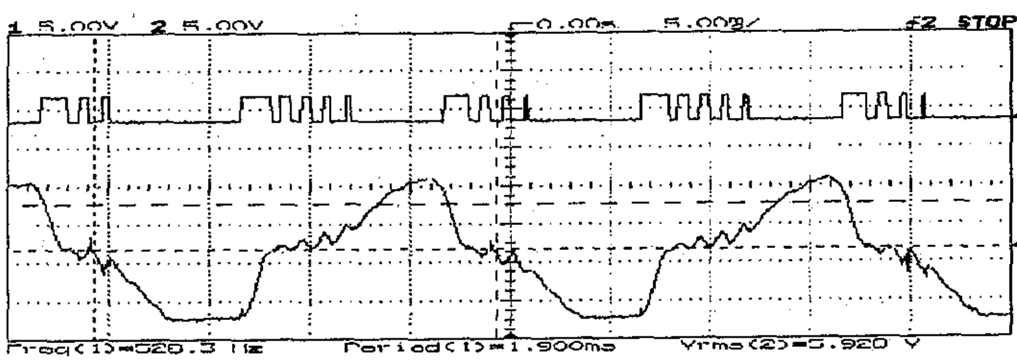



ch1. MOSFET pulses
ch2. Motor current

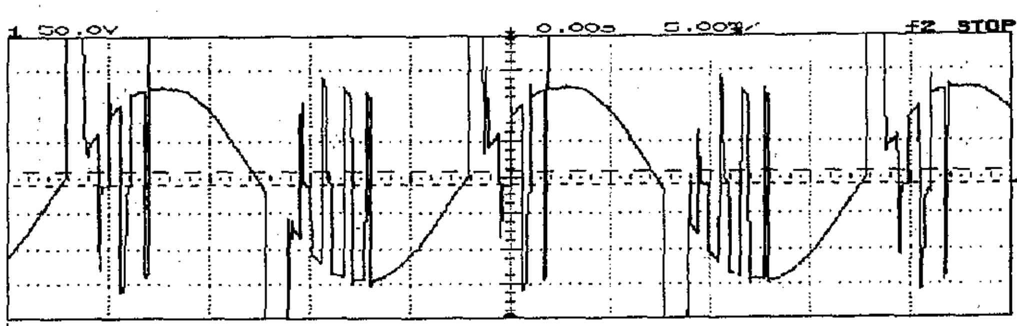



ch1. Motor terminal voltage

Fig. 9 Experimental results at input votage = 72.5 volt, Reference frequency = 500 Hz., and Reference current with amplitude = 0.5049 Amp. and motor speed = 179 r.p.m.

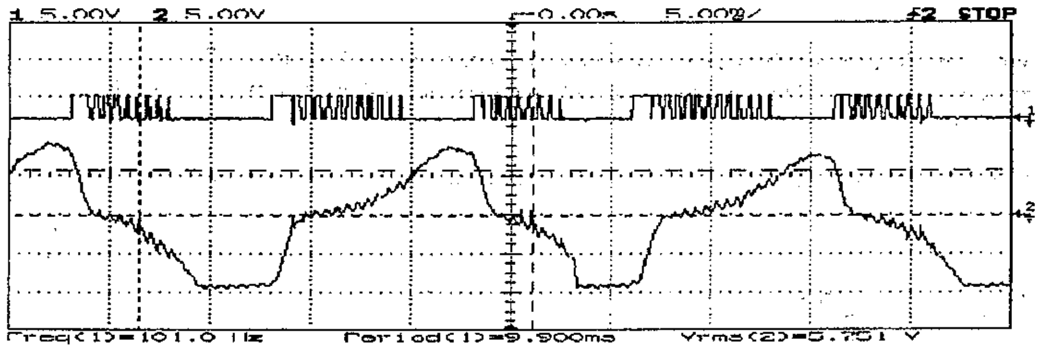



ch1. MOSFET pulses
ch2. Motor current

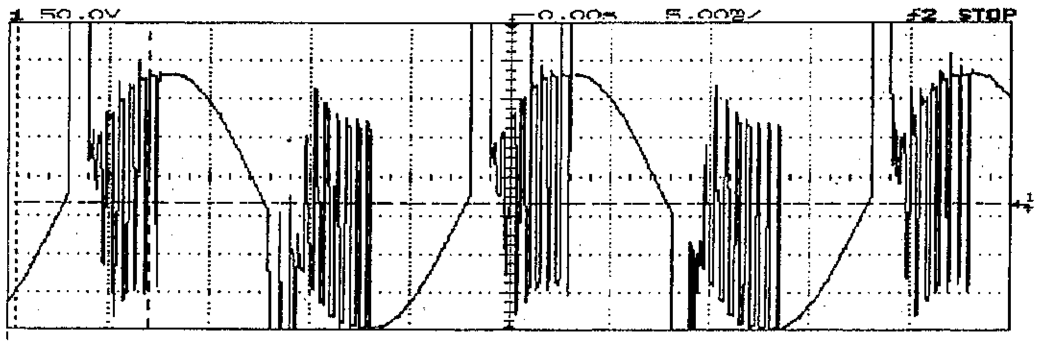



ch1. Motor terminal voltage

Fig. 10 Experimental results at input votage = 98.5 volt, Reference frequency = 1K Hz., and Reference current with amplitude = 0.5049 Amp. and motor speed = 996 r.p.m.

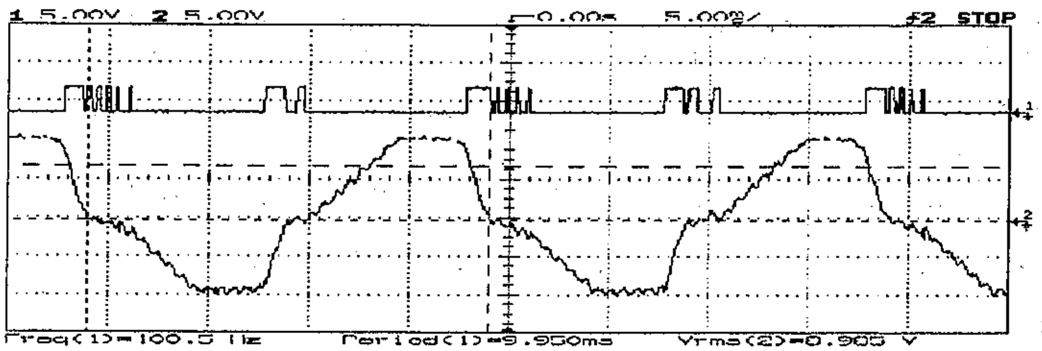



ch1. MOSFET pulses
ch2. Motor current

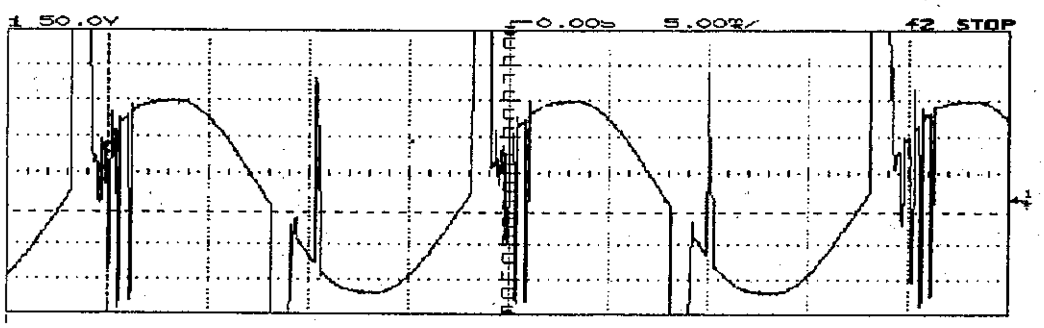



ch1. Motor terminal voltage

Fig. 11 Experimental results at input votage = 121 volt, Reference frequency = 2K Hz., and Reference current with amplitude = 0.6732 Amp. and motor speed = 2250 r.p.m.




ch1. MOSFET pulses
ch2. Motor current




ch1. Motor terminal voltage

Fig. 12 Experimental results at input votage = 97.6 volt, Reference frequency = 20K Hz., and Reference current with amplitude = 0.5049 Amp. and motor speed = 1655 r.p.m.

## 7. CONCLUSION

In many industrial applications, constant torque is required. Two models of a closed loop current control of universal motor using Bang-Bang control (hysteresis control) are proposed. Model one is such that when a d-c power supply fed the motor but model two is obtained when an a-c power supply fed the motor. Analytical and computed results has been obtained. A comparison between simulation and experimental results is acceptable and in good agreement. Because motor torque is proportional to motor current, hence torque control is achieved when motor current is known. The present study shows that only one MOSFET transistor is used for chopping input d-c or a-c voltage to motor to achieve current control using microprocessor. This method of control gives us some important advantages such as simplicity, less expensive and high acuracy.

## 8. REFERENCES


1.Charles V.Jones (book), "The unified theory of electrical machines", London Butterwoths, Plemun publishing Corp.,1967.

2. Taylor E.Openshaw (Book),"The performance and design of A.C. commutator motor", Pitman, 1958.

3. Salem, S.A., and Bahgat, M.E., "Microcomputer-based control technique for dc drives", AEIC'95, volume 5, pp. 396-407, Cairo, Egypt, 1995.

4. Funabiki, A. and Fukushima, T.,"High-efficiency torque control of dc motor taking account of magnetic saturation and armature reaction", Int. PCIM, pp 62-70, 1988.

5.Funabiki, A. and Fukushima, T., "Current command for high-efficiency torque control of dc shunt motors", IEEE proceedings-B, vol. 138, No.5, pp227-332, 1991.

6.Bose, B.K. and Steigerwald, R.L., "A dc motor control system for electric vehicle drive", IEEE trans. on IA, vol. 14, No.6, pp 565-572, 1978.

7.Bose, B.K. and Sutherland, H.A., "A microcomputer based real time feedback controller for an electric vehicle drive system", IEEE-LAS, pp.743-748., 1979.

8.Milanovic, M., Jezernik, K. and Planing, A., "Estimation of parameters and load torque of a thyristor driven dc motor drive", European conference on power electronics & application, pp. 1345-1349, 1989.

9.Shokralla, S.S., Abdel Ghafar, A.S. and Sharaf, A.M., "Closed loop speed control of dc series motor for traction applications", AEIC's95, Cairo, Egypt, December 16-19, pp.284-297, 1995.

10.EL-Shebiny,M.E., Zein El-Din, Ashraf and Khater, M.M., "Microcomputer-Controlled Universal Motor", Engineering Research Bulletin, Volume 19, Number 2, Menoufiya University, Faculty of Engineering, Shebin El-Kom, Egypt, pp.157-167, May-June 1996.

**SYMBOLS**

c: Snubber circuit capacitor
E: d.c. input voltage
$E_b$ : back e.m.f.
$i_a$ : armature current.
$i_c$ : Snubber circuit 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.
$R_s$: Snubber circuit resistance
$T_L$ : Load torque.
V : supply voltage
$V_c$: Snubber circuit voltage
$V_m$: Amplitude of a.c. input voltge
$V_L$: Motor terminal voltage.
$\omega_m$ : motor speed in rad./sec.

APPENDIX

The universal motor ratings and parameters (1/3 HP, 1.9 Amp., 6000 r.p.m., 220 volt.) has the following :
$R_{eq}$.= 13.7 ohm, $L_{eq}$.=522 m.h, $K_1$= 0.42097 n.m./$amp^2$, $K_2$=1.127E-03 n.m./rad/sec. , J= 0.003 $kg.m^2$

التحكم المغلق فى تيار محرك متعدد التغذية بإستخدام الميكروبروسيسور

د٠أشرف زين الدين ، د٠مصطفى الشبينى
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ملخص البحث

يتناول هذا البحث إستخدام طريقتين من طرق التحكم فى تيار محرك متعدد التغذية بإستخدام الميكروبروسيسور إحداهما عند تغذية المحرك من مصدر جهد مستمر والأخرى عند تغذية المحرك من مصدر جهد متغير ويتم تقطيع الجهد المغذى للمحرك طبقا لطريقة التحكم المستخدمة وهى ON/OFF مع إستخدام ترانزيستور واحد MOSFET يقوم بتوصيل الجهد الكهربى للمحرك لحظيا فى حالة مايكون تيار المحرك أقل من التيار المحدد بينما يكون الترانزيستور فى حالة عدم توصيل عندما يكون تيار المحرك أكبر من التيار المحدد ويتم التحكم فى توصيل الترانزيستور عن طريق نبضات ترسل إليه من الميكروبروسيسور خلال دوائر تربط بينهما وطبقا لبرنامج التحكم المصمم بلغة التجميع وتم تكوين نموذج معملى للنظام المقترح ثم أخذت النتائج المعملية لجهد الأطراف على المحرك وتيار المحرك وتم مقارنتها بالنتائج التحليلية ووجد تقارب بينهما ومن مميزات النظام المقترح للتحكم هو قلة تكلفته مع فاعليته ودقته مما يجعل إمكانية إستخدام طريقة التحكم فى الصناعة٠