SELF ADAPTIVE RULE-BASED SPEED CONTROLLER FOR A SYMMETRICAL ANGLE CONTROLLED DC MOTOR

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ABSTRACT:

This paper presents modeling, numerical simulation and experimental behavior for dynamic and steady state performance of a separately excited DC motor. The motor is fed from AC to DC symmetrical angle controlled converter. An intelligent variable gain rule-based speed controller for speed reference tracking is proposed. The error-driven error-scaled adaptable gain speed controller allows flexible and robust control of this system. The control scheme has been implemented using Digital Signal Processor.

LIST OF MAIN SYMBOLS:

A	: Maximum voltage signal.
B	: Viscous friction coefficient.
C_f	: Filter capacitance.
F	: Supply frequency
i_m	: Instantaneous armature current.
i_s	: Instantaneous supply current.
J	: Moment of inertia.
K_0	: Fixed gain.
L_m, r_m	: Armature inductance and resistance.
K_m	: Back e.m.f. Constant.
L_f, R_f	: Filter inductance and resistance.
T_L	: Load torque.
T_s	: The sampling period.

V_s : Instantaneous supply voltage.
V : Peak value of supply voltage.
V_c : Control voltage.
V_m : Motor voltage.
ω : Supply angular velocity.
ω_m : Motor angular velocity.
ω_{ref} : Reference angular velocity.
ω_{base} : Base angular velocity.
$\gamma_1, \gamma_2, \gamma_3$: Fixed gains optimized off-line.

INTRODUCTION:

Direct current motor drives are used extensively in industries such as steel mill; paper mill, conveyors, chemical, etc.... In many drive applications, the mechanical load varies considerably during operation. Robots and machine tools are two examples. When a fixed controller setting is used for a DC drive system with wide load changes, unsatisfactory performance is often produced [1-2].

High performance DC motor drives are important for multitude of industrial applications [3-5]. Precise, fast, effective speed reference tracking with minimum overshoot/undershoot and small steady-state error are essential control objectives. Conventional controllers are usually used for fixed structure, and fixed parameter design [6-8]. Tuning and optimization of these controllers are challenging and difficult task, particularly under varying load conditions, and abnormal operation.

An artificial intelligent system based on fuzzy logic and neural network techniques was reported for a high performance DC drive [9]. A simulation study for an intelligent rule-based error driven gain scheduling controller for a chopper fed DC series motor was proposed in reference [10]. Alternatively, an intelligent self-adaptive rule based speed regulator for a permanent magnet DC motor drive is implemented in reference [11]. The dynamic and steady state performance of a symmetrical angle controlled DC motor is investigated, and the power factor of the system is improved using this technique. Also, the conventional analog proportional-integral controller is used for speed control[12].

In this paper, a new concept of intelligent error driven controller is proposed, where the control action is scaled on line and adjusted based on the excursion error magnitude and location in the error phase portrait. The results confirm the robustness of this controller to limit inrush current and also provide fast dynamic speed reference tracking for a DC motor drive.

SYSTEM DESCRIPTION:

Figure (1) shows a schematic diagram for the proposed speed control system. It consists of a cascade combination of a diode bridge rectifier and a symmetrical angle control converter, connected to a single-phase AC supply. The motor voltage is regulated by the control voltage (V_c) from zero to the maximum value (A) of the timing voltage (ω_a) as shown in Fig. (2). The inductance L_f and capacitance C_f are used as an output DC filter. One MOSFT (Type IRFP450) is used, and controlled by an impulse generator. The gate pulses are generated as shown in Fig. (2), where the control voltage is the output from the Rule Based Error Driven Controller. The parameter values of this system are given in Appendix (1).
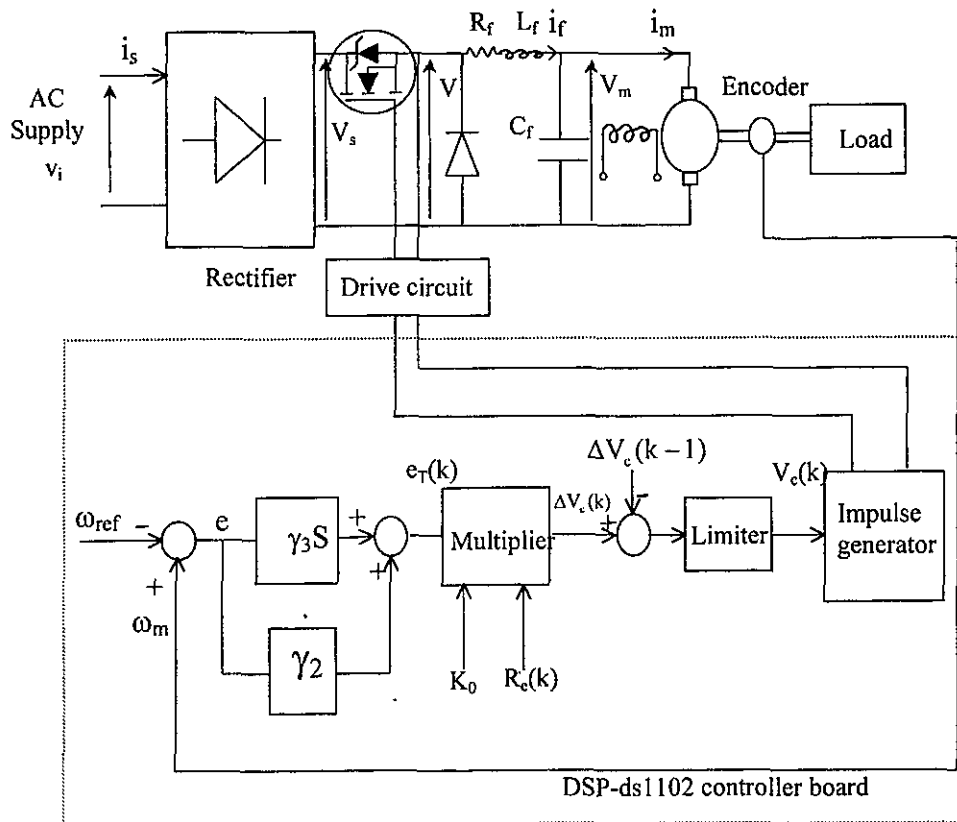

Fig. (1) System configuration

A fully digital control scheme has been implemented with a Digital Signal Processor (DSP-DS1102), and interfaced with a personal computer. The DSP (TMS320C31) controller board uses 40/32 bit floating point/integer multiplier, arithmetic logic unit, 60 MHz clock rate 33.3 n.sec. cycle time, 8 Mbaud serial interface and 4 external interrupts [13]. The circuits, such as logic, isolation, driving and measuring are implemented. The speed feedback signal (ω_m) is converted into a digital value by an incremental encoder interface. The control algorithm is implemented as software using high level C programming

language. The output from DSP is used to drive the MOSFT switch through a driving circuit as shown in Fig. (1).
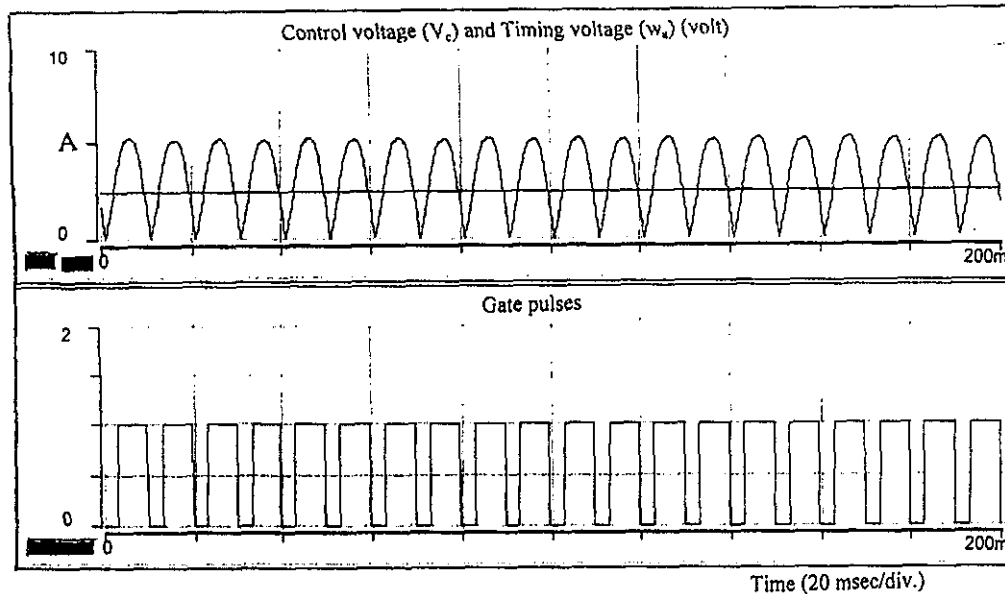

Fig. (2) Experimental result for the output of the pulse generator circuit

SYSTEM MODELING:

The system under investigation has two modes of operation. These modes are represented by the equivalent circuits of Fig. (3). The mathematical model can be obtained as follows:

- **Modeling Of The Power Circuit And Motor:**

Mode (1):

In this mode, the MOSFET is ON. The differential equations·describing this mode are given as follows:

$$L_f\left(\frac{di_f}{dt}\right) = V_s - i_f R_f - V_m \tag{1}$$

$$L_m\left(\frac{di_m}{dt}\right) = V_m - i_m r_m - K_m \omega_m \tag{2}$$

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$$J\left(\frac{d\omega_m}{dt}\right) = K_m i_m - B\omega_m - T_L \tag{3}$$

$$C_f\left(\frac{dv_m}{dt}\right) = i_f - i_m \tag{4}$$

$$i_s = i_f \tag{5}$$

$$V_s = V|\sin(\omega t)| \tag{6}$$

Mode (2):

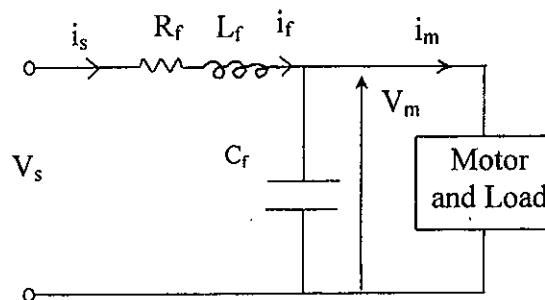In this mode, the MOSFT is OFF as shown in Figure (3). The differential equations describing this mode are given:

$$L_f\left(\frac{di_f}{dt}\right) = -V_m - i_f R_f \tag{7}$$

$$L_m\left(\frac{di_m}{dt}\right) = V_m - i_m r_m - K_m \omega_m \tag{8}$$

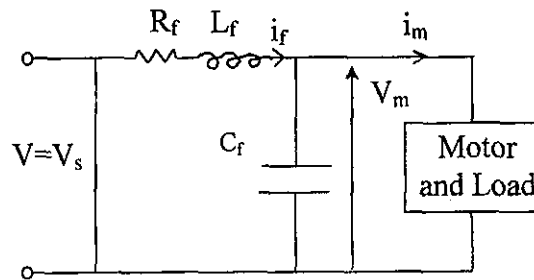$$J\left(\frac{d\omega_m}{dt}\right) = K_m i_m - B\omega_m - T_L \tag{9}$$

$$C_f\left(\frac{dv_m}{dt}\right) = i_f - i_m \tag{10}$$

$$i_s = 0 \tag{11}$$

Mode (1) MOSFET is ON

Mode (2) MOSFET is OFF

Fig. (3) Modes of operation for the system

MODELING OF THE IMPULSE GENERATOR:

From Fig. (2) the equation that represents the timing voltage (ω_a) is given by:

$$\omega_a = A \left| \sin(\omega t) \right| \tag{12}$$

The MOSFET is turned ON when:

$$V_c < \omega_a \tag{13}$$

The MOSFET is turned OFF when:

$$V_c > \omega_a \tag{14}$$

EFFECT OF CONTROL VOLTAGE FOR OPEN-LOOP SYSTEM:

Figure (4) shows the effect of varying the control voltage on the motor speed and supply input power factor for 0.5 and 0.75 full load torque [12]. It is observed that the motor speed is decreased with increasing of the control voltage (V_c). Also, it is noted that the input power factor varies in an acceptable range for such systems compared with thyristor fully controlled rectifier systems [14].
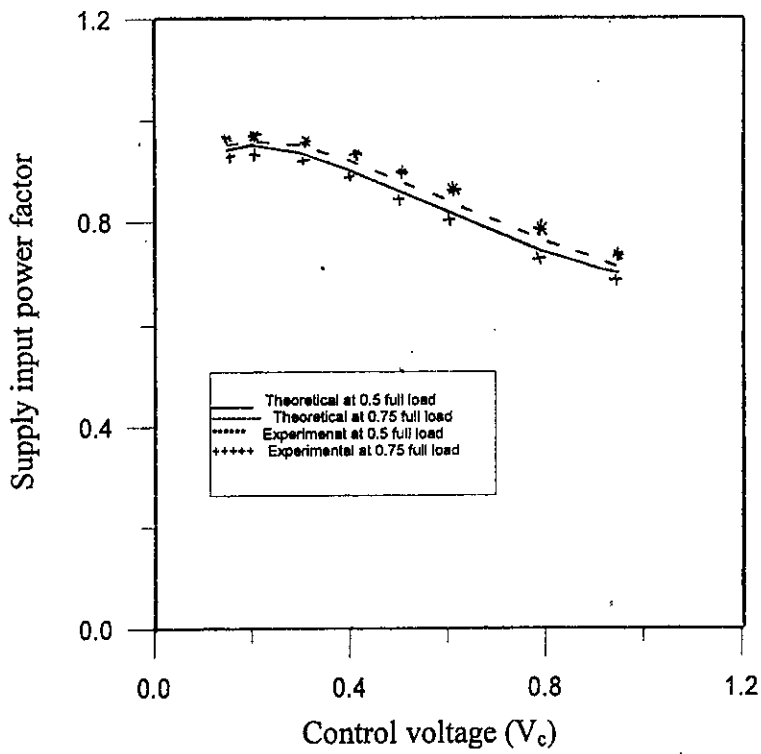
MODELING OF THE RULE-BASED INTELLIGENT SPEED CONTROLLER:

Figure (1) shows the basic control structure. The following equations describe the error (e_ω) based control concept and the self-adaptability of the error driven, error scaled control scheme:

The speed error and its derivative is given by:

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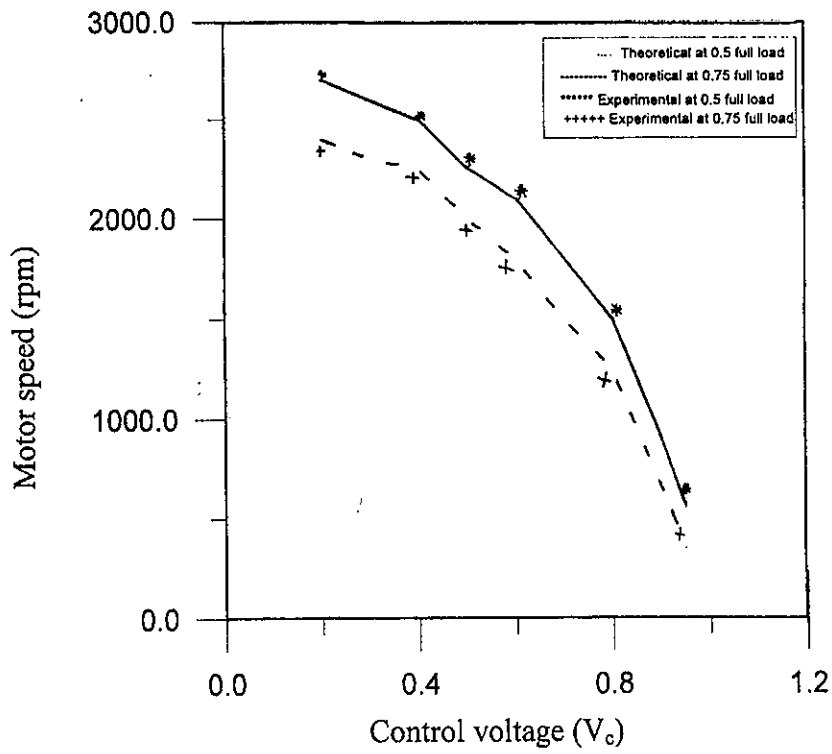
(a) Motor speed

(b) Supply input power factor

Fig. (4) Effect of control voltage on the steady state characteristics

$$e_\omega(k) = \frac{\omega_{ref}(k) - \omega_m(k)}{\omega_{base}} \tag{15}$$

$$e_\omega^\bullet(k) = \frac{e_\omega(k) - e_\omega(k-1)}{T_s} \tag{16}$$

Where, $e_\omega(k)$ and $e_\omega^\bullet(k)$ defines the dynamic error phase portrait coordinates for the rule based intelligent speed excursion based variable gain controller [10-11].

The global error (e_T) at any sampling time period (k) is given by:

$$e_T(k) = \left[\gamma_2 e_\omega(k) + \gamma_3 e_\omega^\bullet(k) \right] \tag{17}$$

The error scaling gain [$R_e(k)$] is given by:

$$R_e(k) = \left[\sqrt{e_\omega^2 + \gamma_1^2 e_\omega^{\bullet 2}} - R_{eo} \right] / \beta\beta \tag{18}$$

Where, R_{eo} is the dead zone to limit control instability and is equal to 0.03

The control modulation step is defined by:

$$\Delta V_c(k) = K_o\, e_T(k)\, R_e(k) \tag{19}$$

The final control action is an equivalent proportional plus integral action

$$V_c(k) = \Delta V_c(k-1) + \Delta V_c(k) \tag{20}$$

Where $V_c(k)$ is the control voltage limited by the converter operation between (zero to A) volts.

SIMULATION AND EXPERIMENTAL RESULTS:

The proposed system is designed and implemented to verify the developed model. The behavior of this system under steady state and transient conditions is determined by solving the nonlinear differential equations using the fourth order Runge-kutta method. The instantaneous values of the supply and the load are obtained from the proposed numerical simulation, as well as from experimental measurements.

- **Steady-State Characteristic:**

Figure (5) shows samples of the steady state waveforms at ω_{ref}=200 rad/sec; for half load torque. It is observed that the motor current and voltage are considered as ripple free. Also, the motor speed is smooth. Moreover, the supply input power factor is improved. It is observed that the agreement between the measured and computed values is reasonable.
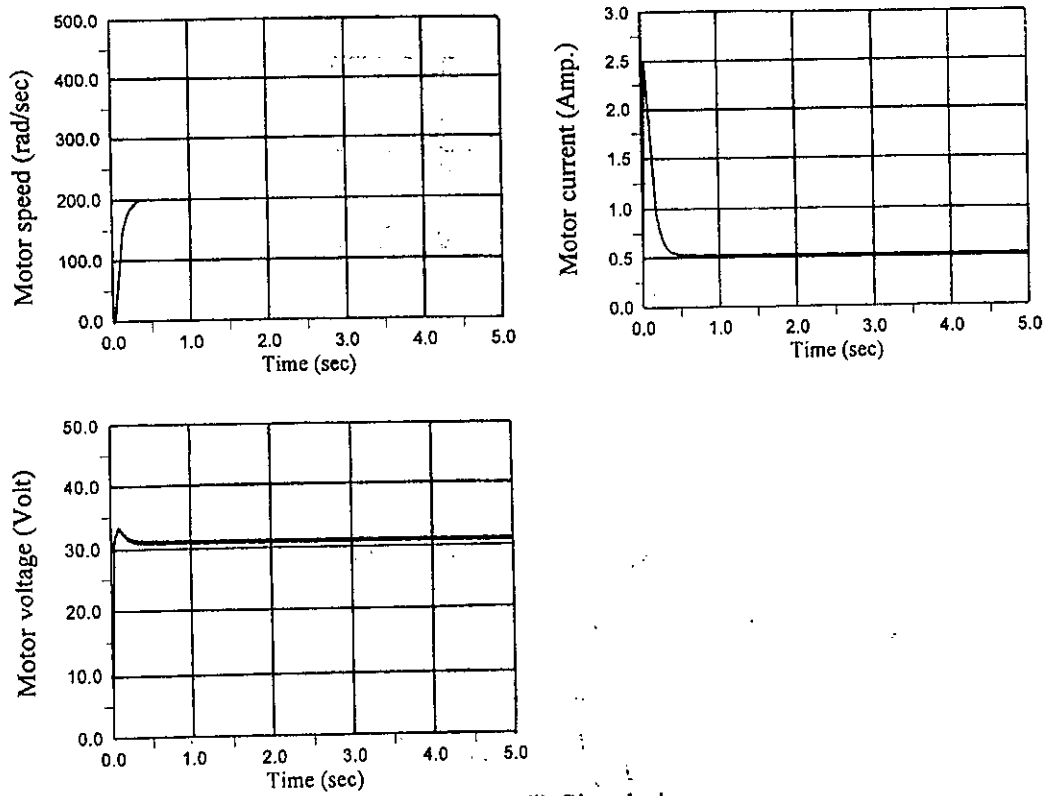

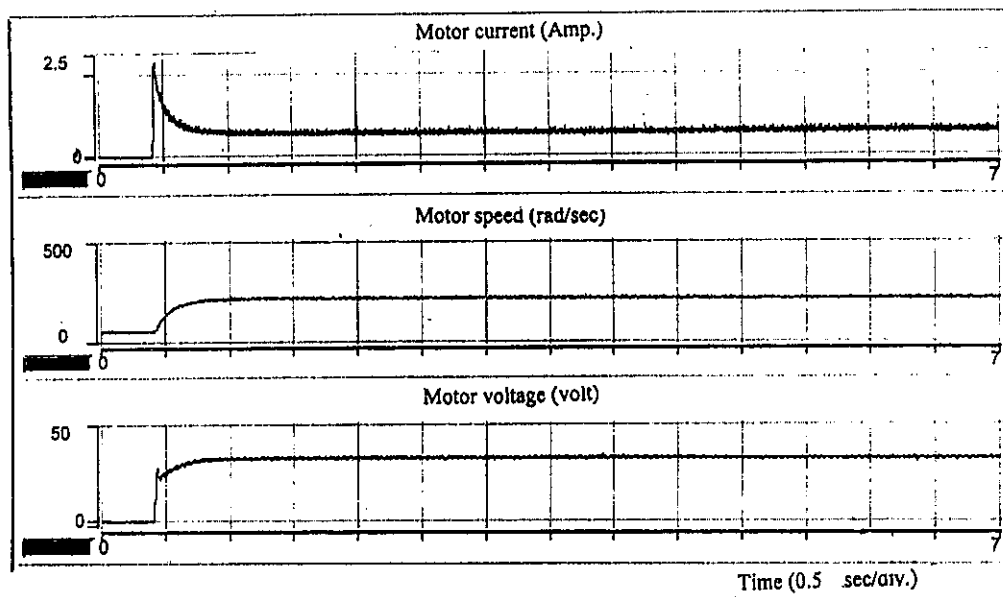(i) Simulation

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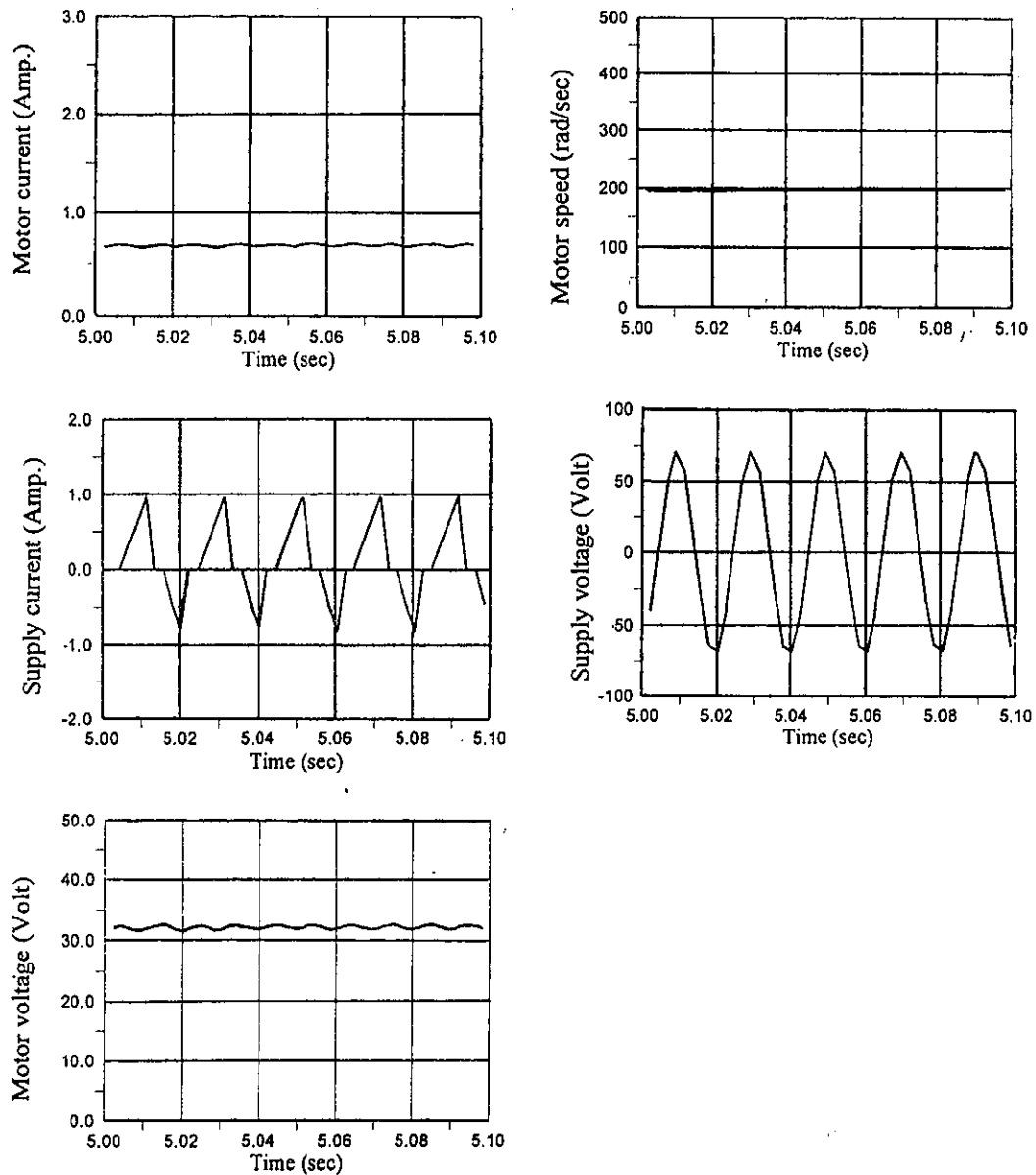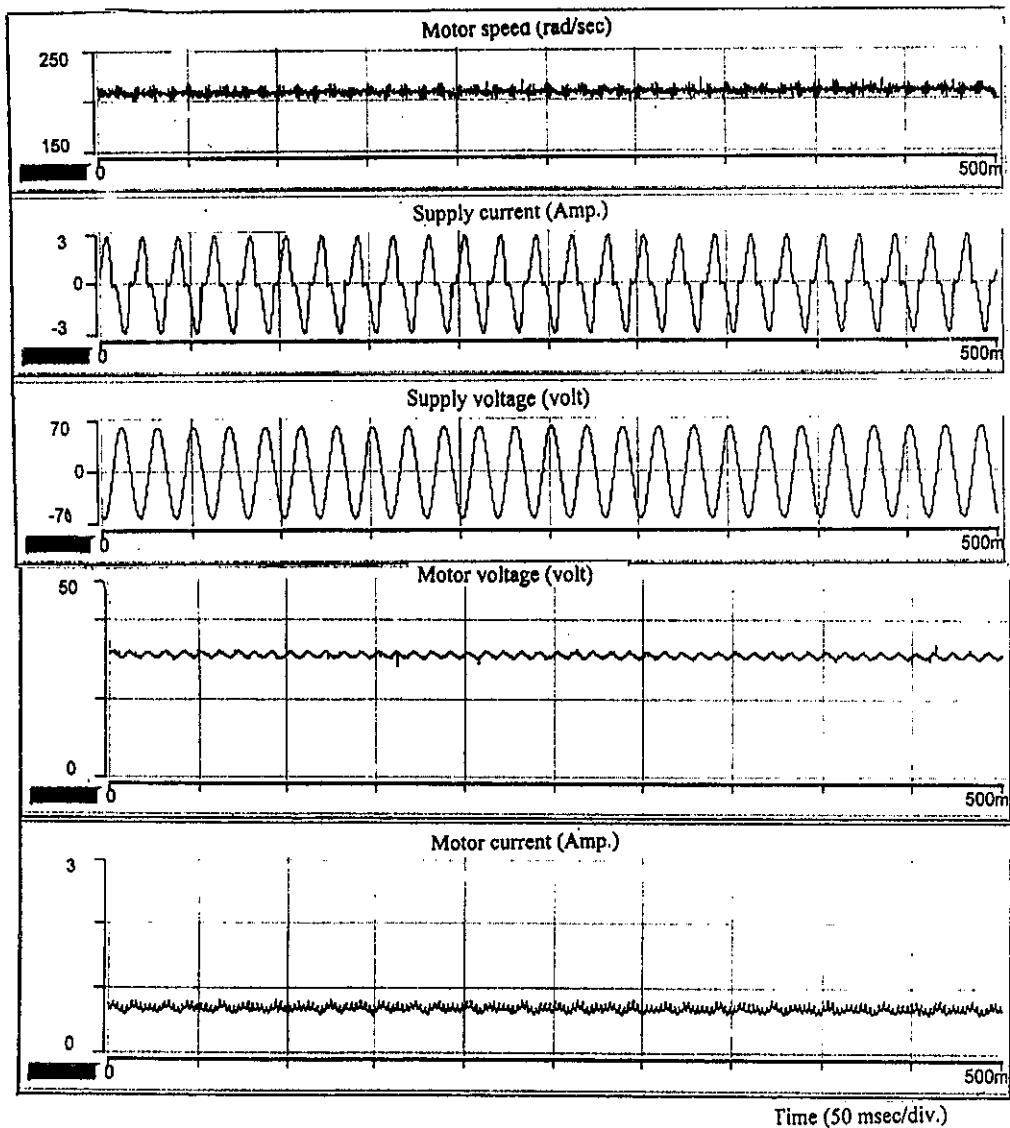
(ii) Experimental

Fig. (5) The steady state waveforms at half load

- **Starting Behavior:**

Figure (6) shows the waveforms of the motor voltage, current and speed during starting-up with half load and ω_{ref}= 200 rad/sec. It is noticed that the transient period is about 0.4 sec, which is considered a relatively long time for the motor under test. This is due to the motor electromechanical time constant which is large compared with the electrical time constant.

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(i) Simulation

(ii) Experimental

Fig. (6) Run-up behavior for half load and ω_{ref}= 200 rad/sec

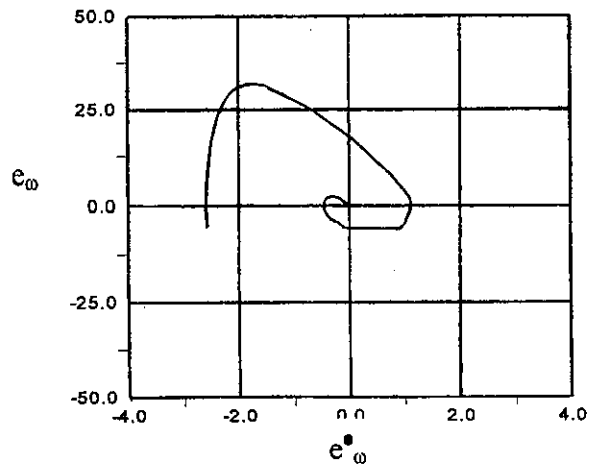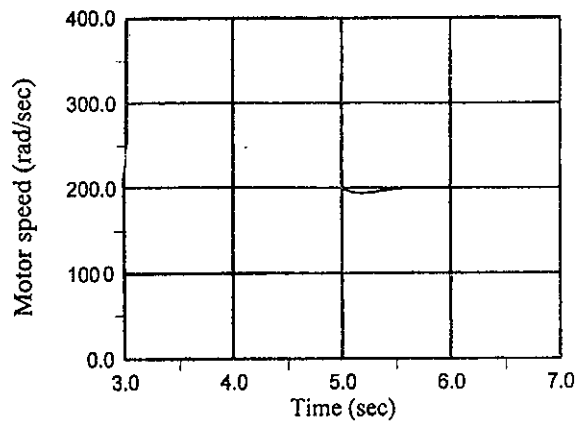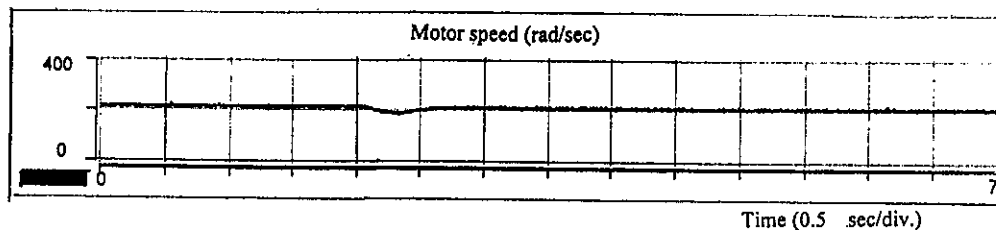Figure (7) shows the (e_ω- $e^\bullet_\omega$) phase portrait.

Fig. (7) The (e_ω- $e^\bullet_\omega$) phase portrait [simulation results]

- **Load Torque Disturbance:**

Figure (8) shows the response of motor speed for an increase of the load torque from 0.5 to 0.75 of the rated value. It is observed that the motor speed has returned to its initial value after 400 msec.
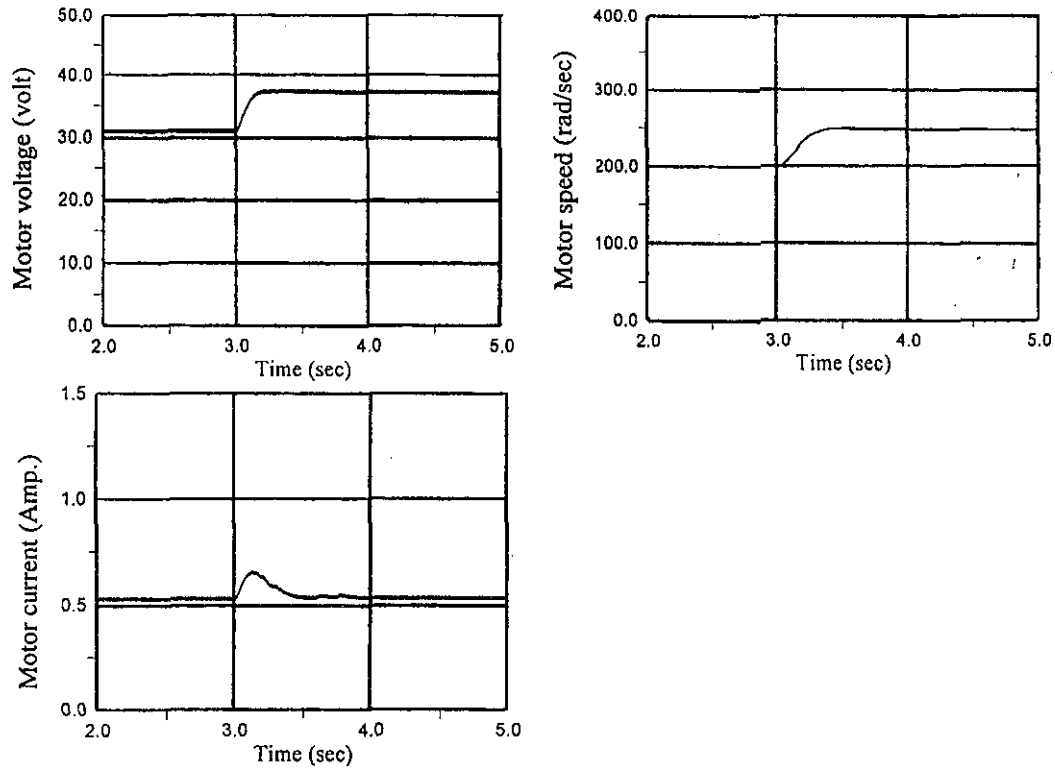
(i) Simulation

(ii)Experimental

Fig. (8) Response to a change in load torque from 0.5 to 0.75 of rated value with ω_{ref}=200 rad/sec.

- **Reference Voltage Step Change:**

Figure (9) shows the motor voltage, current, and speed with a step change in speed reference (ω_{ref}) from 200 to 250 followed by a decrease from 250 to 200 rad/sec at half load. It is observed that the motor can follow the desired speed reference smoothly.

(i) Simulation

Time (0.2 sec/div.)
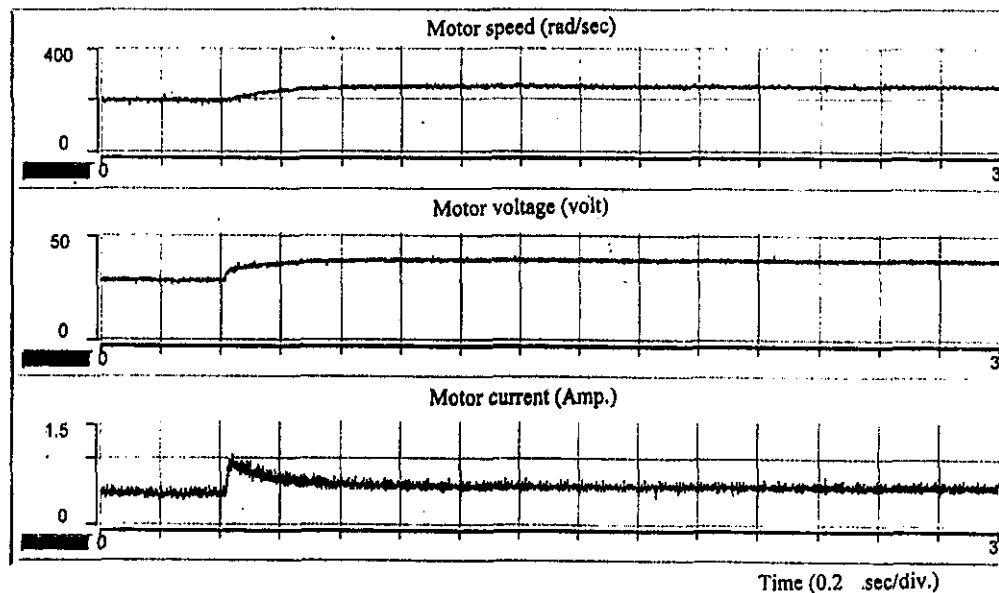
(ii) Experimental
(a) Step up in speed reference

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(i) Simulation

(ii) Experimental
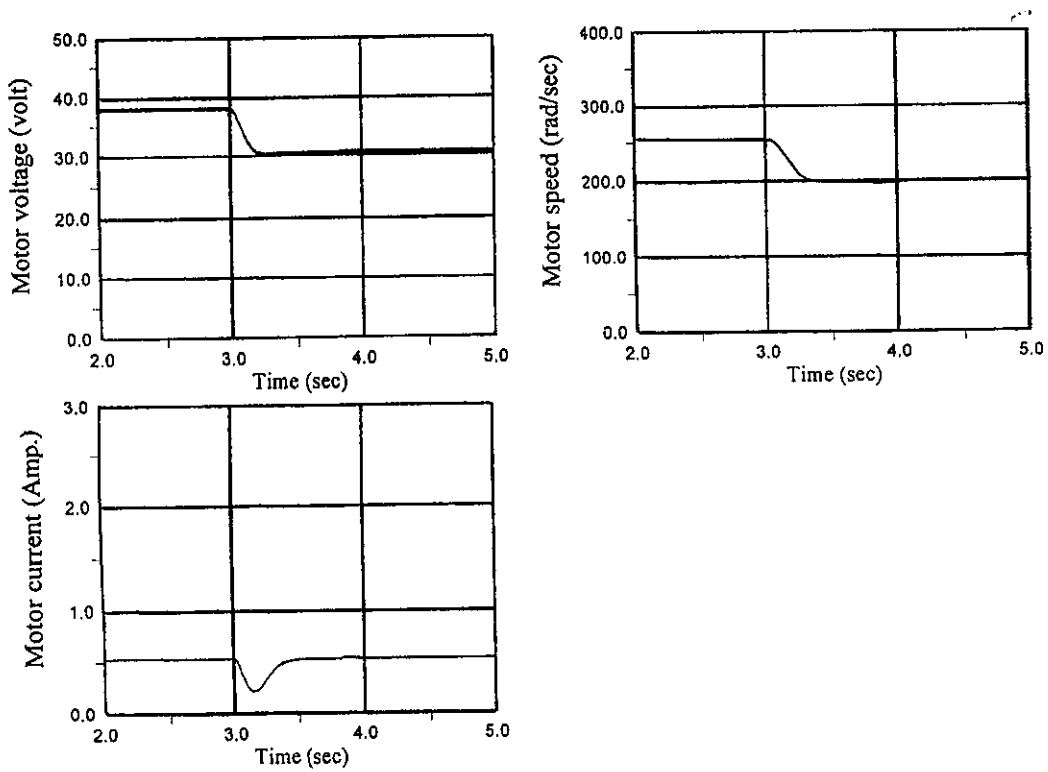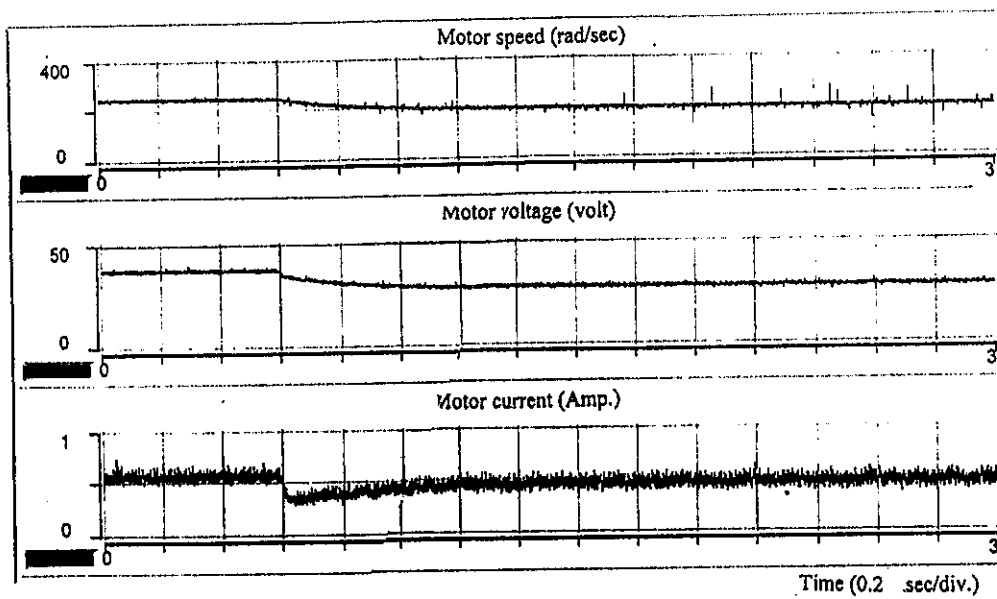
(b) Step down in speed reference

Fig. (9) Responses due to a step change in ω_{ref} from 200 to 250 and from 250 to 200 rad/sec with half full load

CONCLUSION:

The paper presents modeling, simulation, and experimental behavior for dynamic and steady state performance of a separately-exited DC motor fed from a single-phase AC to DC symmetrical angle controlled converter. This system is used to improvement the supply input power factor. The paper presents a rule-based intelligent error driven-error scaled speed controller to ensure speed reference trajectory tracking. The proposed system is fully controlled using the DSP board. The controller is of a robust design ensuring high dynamic adaptation and self-adjusting error driven control action under both parameter and load excursions. The experimental results ensured the controller robustness, simple and powerful control application capabilities.

APPENDICES:

• APPENDIX (1):

The parameters of the designed system are as follows:

$V_{s\,(max)}$ =71 volt	r_f =2 ohm
C_f=1200 µf	L_f=0.222 Henry
A=5 volt	F_s=50 Hz.

• APPENDIX (2):

The test motor is a separately excited DC motor, 55 volt, 50 watt, 1 Ampere, 3000 r.p.m. having the following measured parameters:

r_m =10.5 ohm	R_f=550 ohm
B=0.0001 N.m./(rad/sec)	L_m=0.06 Henery
k_m=0.127 volt/(rad/sec)	J=0.00015 kg.m^2

• APPENDIX (3):

The controller parameters are as follows:

γ_1 = 0.015	γ_2 = 35
γ_3 = 0.015	$\beta\beta$ = 98
k_o= 0.0035	

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توائم ذاتى قائم على قواعد لحاكم سرعه لمحرك تيار مستمر يتم التحكم فيه بالزاوية المتماثلة

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ملخص البحث:

يقدم هذا البحث إقتراحا للنمذجة والتمثيل العددى لمحرك تيار مستمر منفصل التغذية ومغذى بالتيار المتغير عن طريق قنطرة موحدات ذات وجه واحد ومتصلة بمغير يتم التحكم فيه بالزاوية المتماثلة وذلك بالتوائم الذاتى القائم على قواعد لحاكم سرعة ويمكن الحصول على جهد خرج موحد يمكن التحكم فيه ويكون خاليا من التوجات وذلك لتغذية المحرك بغرض التحكم فى سرعته.

تم بناء وتنفيذ النموذج المعملى لحاكم السرعة وذلك لضمان الضبط الذاتى الديناميكى لتتبع السرعة بأقل تجاوز سواء بالزيادة أو بالنقصان ويتم تشغيل الحاكم بواسطة القيمة والوضع الاتجاهى للخطأ فى شكل ذو إحداثيين لمسطح ذو بعدين (الخطأ-التفاضل الأول له). ويتميز الحاكم بأن له قدره تحمل عالية ويمكن الضبط والتوائم الكامل للسرعة ذاتيا مع سرعة الإسناد. كما تم أيضا الحصول على سرعة ثابتة مع تغير الحمل المحمل به الآله.

يتضمن هذا البحث مقارنة بين النتائج المعملية والنظرية وقد وجد تطابقا كبيرا بينهما. مما يؤكد صحة الدراسة النظرية وإستخدامها لدراسة سلوك مثل هذه الأنظمة.