# INPUT POWER MINIMIZATION FOR DC MOTOR USING AN ANN BASED CONTOLLER

Sanaa I. Amer
Electronics Research Institute, Cairo, Egypt

## Abstract:

This paper presents a controller for tracking the minimum input power for a DC motor, enabling the motor for operate at high efficiency over a widerange of operating points. Also the optimal current ratio between the armature current and the field current which gives minimum losses was obtained by the ANN controller without any measurement of parameters. Simulation results are recorded for step change in the reference speed as well as in the load torque. One ANN controller has been utilized . The simulation results show good dynamic performance and an enhancement of the motor efficiency.

## I. Introduction

The energy saving in electric motors can be achieved by either designing energy-efficient motors, or driving the conventional motors under high-efficiency conditions. The system under consideration is a separately-excited dc motor system. This motor system has been used in the industrial field when high accurate speed control is necessary over a wide range, and has been used by controlling the armature impressed voltage under constant field excitation in all motor operating conditions.

In all of speed control methods, with few exceptions the control sequence is not varied specifically to reduce losses. Losses in electric motor drives can be reduced by the following methods:

1- Motor selection and design.
2- Improvement of the motor power supply waveforms.
3- Adjusting voltage, current and/or frequency at each operating point.

---

**Manuscript received from Dr . Sanaa I. Amer**
**Accepted on : 28 / 4 / 2002**
**Engineering Research Journal Vol 25,No 3, 2002 Minufiya University, Faculty Of Engineering , Shebien El-Kom , Egypt , ISSN 1110-1180**

Previous work on loss minimization in electric drives has followed two approaches:
a-Optimal control that minimizes losses for a prescribed speed profile; and
b-Loss minimization at every steady-state operating condition.

The behavior of a dc motor drive is governed by three independent variables: speed N, armature current $I_a$ , $I_f$, and the parameters of the motor and power supply. The optimal current ratio K between the armature current and the field current giving minimum losses was analytically derived as a function of speed [5]. At any operating point, a combination of the armature current and the field current could be found to meet the requirements of the operating point and minimizes the overall losses of the drive.

An open-loop controller can find the minimum point which the motor is operating at high efficiency by measuring the armature current and the speed and calculating the corresponding field current from a set of equations and drive parameters programmed into the controller. An optimizing controller can find the minimum point by calculating or measuring the losses, then adjusting the field current until the losses are minimized [1].

The artificial neural networks (ANN) direct inverse control and the direct adaptive control were presented [5] to control the armature voltage and the field voltage of the separately excited dc motor to yield maximum efficiency. Identical ANN'S have been utilized, one for armature control, the other for field control. An online training algorithm was presented for efficient and stable operation rather than fixed weights and biases for ANN'S.

In this paper, the optimal current ratio K is obtained directly by the ANN controller and the system is tracking the minimum input power condition at any operating point and after any change in speed or applied torque in order to operate the system at high efficiency during all the operating period.

The points at which the maximum efficiency occurs was tracked directly by the ANN without any need for parameters or speed measurements.

## II. Minimum Input Power

An optimizing controller varies one or more variables of the motor drive to test for the change in losses. The controller finally sets the variable for the lowest loss condition. Two approaches are possible:

1- The loss-model controller;
2- The testing controller.

To derive the condition for minimizing the losses, the following components of the motor are considered:

1- Armature copper losses $P_a$ characterized as $I_a^2R_a$, where $R_a$ is the armature resistance including brush contact loss.
2- Field copper loss $P_f$ characterized as $I_f^2R_f$, where $R_f$ is the field resistance.
3- Armature iron loss $P_i$ characterized as $K_h\Phi^2n+K_e\Phi^2n^2$, where $K_h$ and $K_e$ are the coefficient of hystersis loss and eddy current loss, respectively, and n is the speed.
4- Friction and windage loss $P_m$ which is function of n.
5- Stray load loss $P_{st}$.

Assuming that the magnetic circuit is linear and the armature reaction is negligible, the air-gap flux is represented by the linear function of the field current $I_f$. the friction and windage loss and the stray load loss can be regarded as constant. Thus the controllable loss and the torque equation are:

$$P_L=I_a^2 R_a+I_f^2R_f+K'_hI_f^2n_o+ K'_eI_f^2n_o^2 \qquad (1)$$

$$T=K_t\Phi I_a = K'_tI_fI_a \qquad (2)$$

The efficiency can be increased by reducing the iron loss, through reduction of the field current. Then the armature current should be increased to obtain the required motor torque. Due to the increase in both field copper loss and in the armature iron loss and the increase of the armature copper loss, the total losses vary with the combination of the armature current and the field current. Among these combinations, one that shows minimum motor loss is defined as an optimal efficiency condition, which can be derived as follows:- The relation between $I_a$ and $I_f$ is obtained from eq.(2). This result is substituted into eq.(1) to express the controllable loss as a function of the field current only. From the condition $dP_L/dI_f=0$, the field current which represented minimum motor loss is given by

$$I_a^2R_a=I_f^2(R_f+ K'_hn_o + K'_en_o^2 ) \qquad (3)$$

The ratio of the armature current to the field current is constant at a given speed regardless of the load torque. This is defined as an optimal ratio K:

$$I_a/I_f=\{(R_f+ K'_hn_o+ K'_en_o^2 )/(R_a)\}^{1/2} \cong K \qquad (4)$$

The actual optimal ratio may be determined by computation, but it is difficult to obtain the accurate value due to saturation effects. Hence the pretest is carried out to obtain the optimal ratio. The curves of the input power versus the field current are obtained at various operating points, and the ratio of the armature current to the field current is calculated on the point of which the input power is minimum. In order to drive the motor at high efficiency, the optimal ratio for overall speed range should be known. For controlling two currents satisfactorily, the microprocessor is used due to the flexibility and easy adaptation [2].

Tuning of dc drive regulators may be a difficult experience if high closed-loop system performance is required at different operating conditions. For instance, in a variable speed drive application, when fast reference step response with negligible speed overshoot and rapid recovery from speed drop caused by load disturbances are required. This problem is especially pronounced in the speed regulator. The field weakening control is based on the idea presented in [3].

In the region $0<\omega<\omega_c$ the field flux is constant. In the field weakening region $\omega_c \leq \omega$ the back emf is constant $e(t)=e_{max}$. The value of $\omega_c$ depends on the setting point $e_{max}$. In the adaptive control system proposed, estimation of the back emf e(t) is obtained from the measurements of the speed $\omega(t)$ and the field current $I_f(t)$ and by using the experimentally magnetization curve $\Phi(I_f)$[4].

## III. Mathematical Model of The System

The separately excited dc motor is driven system under consideration is shown in fig.1. To realize the principle, the field current and the armature current should be separately. The input variable $V_a$ for the armature circuit power converter and the input variable $V_f$ for the field circuit power converter are considered as the control inputs. The motor speed n(t) is the controlled output variable, the mathematical model of the system is given by:

$$dn(t)/dt = \{- Bn(t) + K_t I_f(t)I_a(t) - T_l(t)\}/ J_m \qquad (5)$$

$$dI_a(t)/dt = \{-R_aI_a(t) - K_bI_f(t)n(t) + V_a(t)\}/L_a \qquad (6)$$

$$dI_f(t)/dt = \{-R_fI_f(t) + V_f(t)\}/L_f \qquad (7)$$

Where;
$J_m$ : moment of inertia
$L_f$ : field inductance
$R_f$ : field resistance
$L_a$ : armature inductance
$R_a$ : armature resistance
B : Friction coefficient
$K_b$ : back emf constant
$K_t$ : torque constant
$T_l$ : load torque

## IV. Optimal current ratio calculation by ANN

In this paper one neural network is used to perform the desired objective. The learning stage of the network is performed by updating the weights and biases using Back Propagation algorithm with the gradient descent method in order to minimize a mean squared error performance index [6]. A complete description

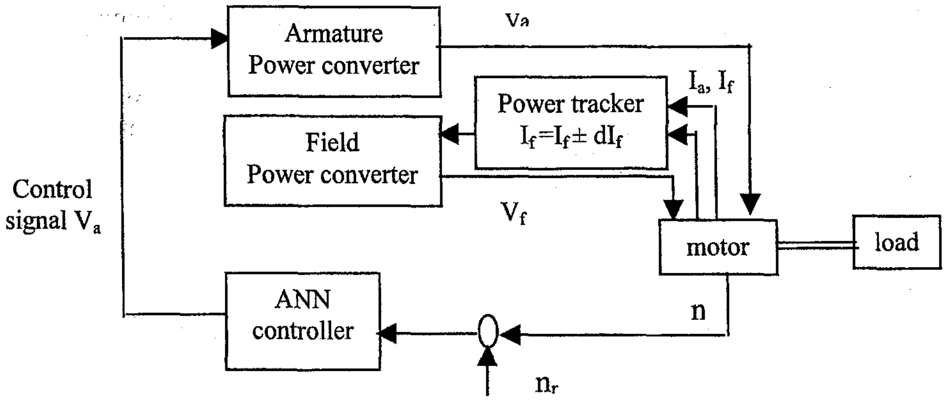


Fig.1 Block diagram of the feed back control system

of this algorithm which is employed to train the network on-line is described in [7].

In the previous work we calculated the optimal current ratio by using equation(4) which depends only on the motor parameters and motor speed. In order to drive the motor of high efficiency, the optimal ratio for the overall speed range should be known, several experimental pretest were carried out from which the constants $K_e$ and $K_h$ were calculated. The optimal ratio K values calculated are not accurate due to the experimental approximation. Therefore, the K values will be calculated by NN controller directly in this work to avoid all system measurements errors.

The control procedure will be performed by defining a reference speed, at start we begin with the random initial values for the weights and biases, then the training algorithm will modify the weights and biases based on the speed control on-line. After the speed is controlled for constant torque (constant output power), the input power is calculated and the field current is changed. This procedure is repeated to obtain the input power, field current characteristic at reference speed as shown in fig.2 which represented the input power for 3-cases (500 rpm,750 rpm and 1000 rpm) versus the field current, showing the minimum input power to ensure the high efficiency. For minimum input power, the ratio of the armature current to the field current is the optimal current ratio. Repeat this procedure for another reference speed to compute optimal current ratio for all range of speed.

Other method to calculate the optimal current ratio K directly by ANN without plotting the minimum input power curve. When the input power reverse the direction, the optimal current ratio is searched at this point and recorded for all speed ranges. By this method we obtain the curve directly between optimal current ratio K and speed as shown in fig.3. this result show the relation between the speed and the optimal current ratio at load =1.5Nm; this is repeated for other load torques. By using this algorithm, the controller will operate on-line during system operation controlling the motor speed and at the same time assuring operation at high efficiency at all the speed range.

Equation (4) shows that the optimal ratio is dependent on the motor parameters and motor speed. Since the motor parameters are effected by saturation, but it is difficult to obtain the accurate value of optimal current ratio by computation due to saturation effects.

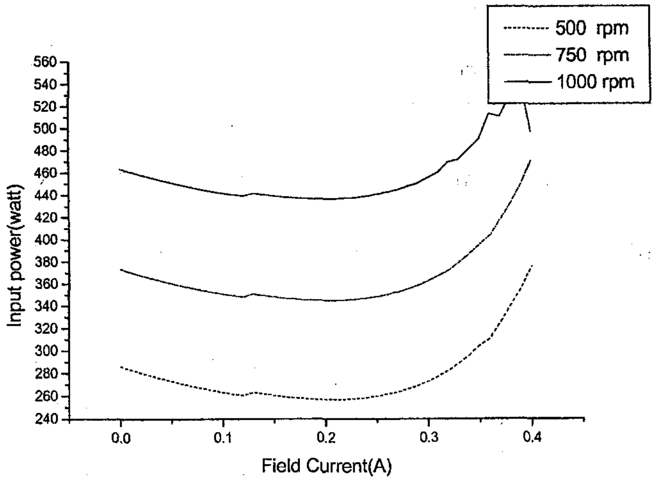


Fig.2 Input Power

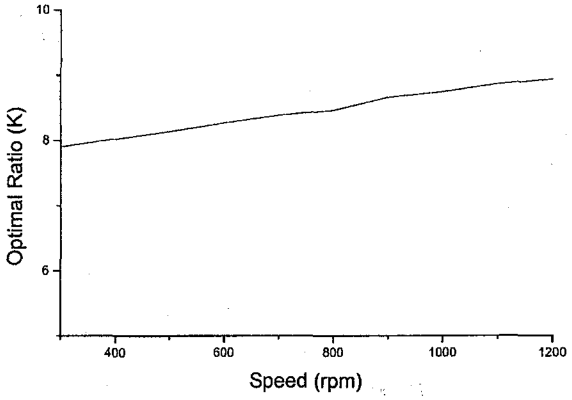


Fig.3 Optimal Current Ratio

## V. Power tracking

The curves of the input power versus the field current are obtained at various operating points using ANN controller which controlled the speed reference and the ratio of the armature current to the field current is calculated on the point at which the input power is minimum and repeated for all range of speed.

As a second step, the ANN system was designed to track directly the minimum input power point at every speed point. The field current is adjusted within the limit range and compared the input power instantaneously with the previous value. Flow chart in fig.4 represent this method which tracking the minimum input power. The system was found to operate up or down the optimal value of field current by .02% for sensor any sudden disturbance occurs and update the optimal value of field current to valid the minimum input power (high efficiency).

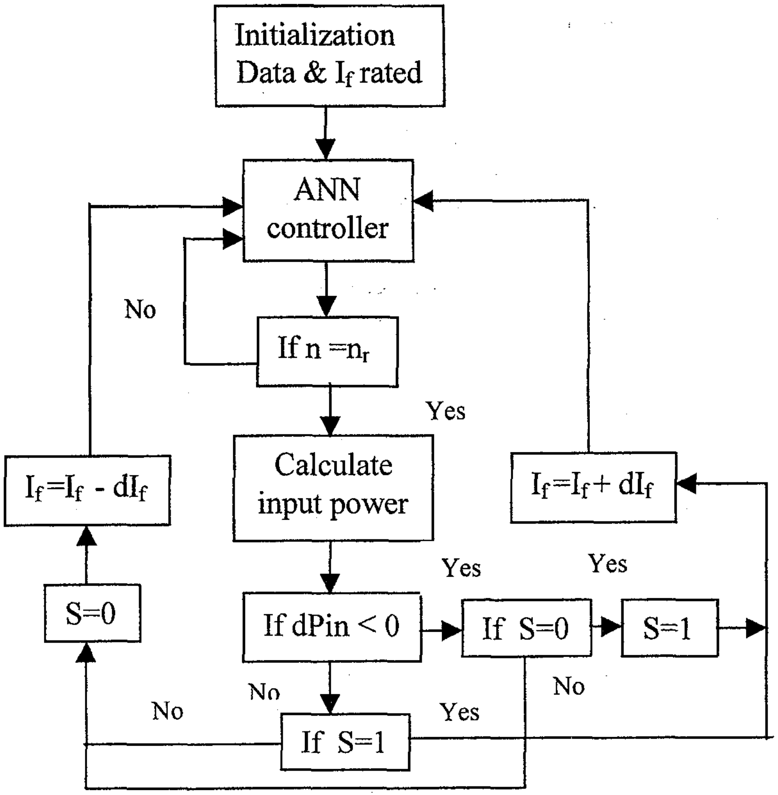


Fig.4 Flow chart for minimum input power tracking

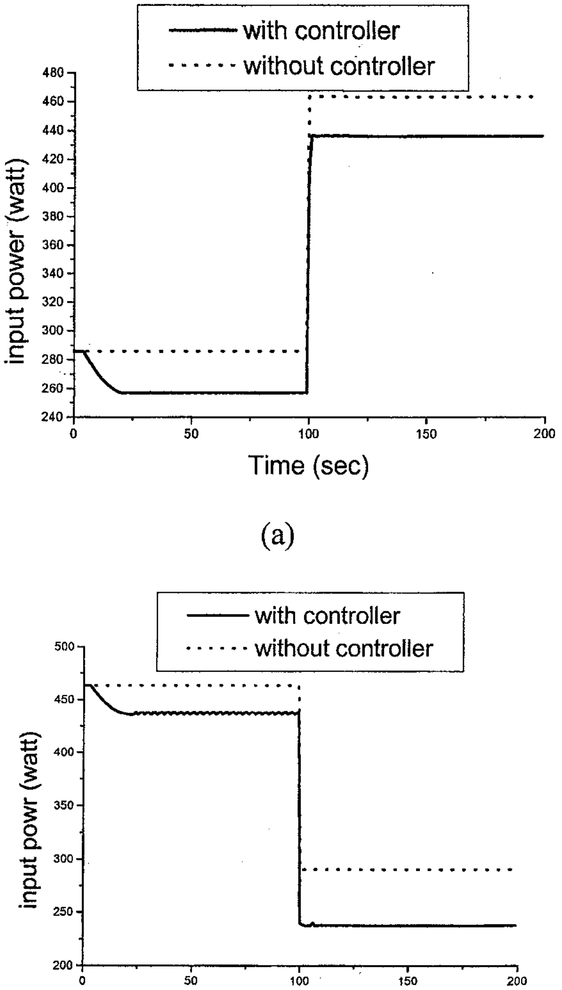
## VI. Simulation results

Simulated results are obtained by a software simulator developed, based on the nonlinear model of the drive. The motor used in the simulation is a separately-excited DC motor of 1 Kw, 1400 rpm. The motor parameters are shown in the appendix.

Simulation results presented in fig.5 shows the given effects of the minimum input power tracking controller for a step change in reference speed from 500 rpm to 1000 rpm at 3 Nm as shown in fig.(5-a). While fig.(5-b) represent the change in load torque from 3 Nm to 1.5 Nm at 1000 rpm.

To examine the system transient performance during on-line efficiency optimization, a simulation study is performed for the system at step change in the reference speed and also for step change in the load torque. Figure 6 shows the system dynamic performance for step change in the reference speed from 1000 rpm to 500 rpm at constant load torque. Figure(6-a) represents the armature current, figure(6-b) represents the field current and figure(6-c) represents the input power. While fig.7 represents the step change in load torque from 4Nm to 3Nm. Figure(7-a) shows the armature current, figure(7-b) shows the field current and figure(7-c) represents the input power.

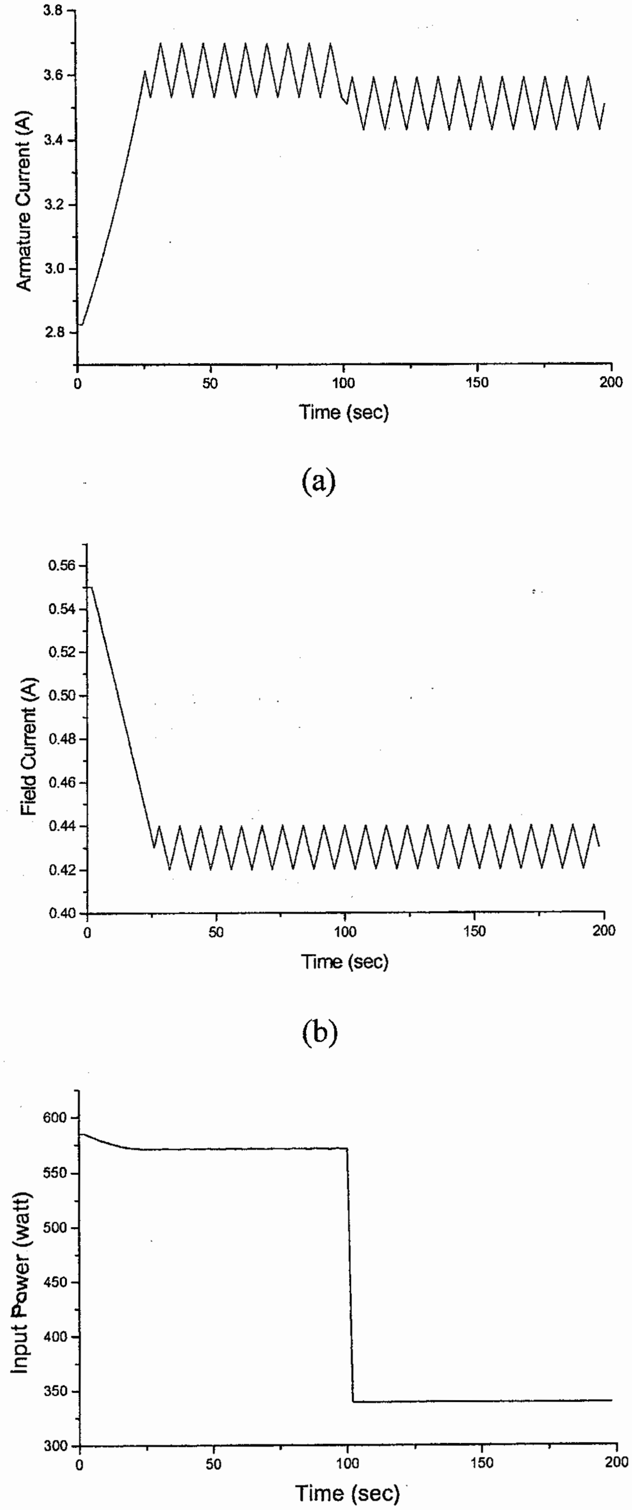
Figure 8 shows the step change in load torque and speed, at first, the step change in load torque ( step up from 3 Nm to 4 Nm) and second step represent the step change in speed (step down from 1000 rpm to 750 rpm). The simulation results show an adequate dynamic performance of the system.



(a)

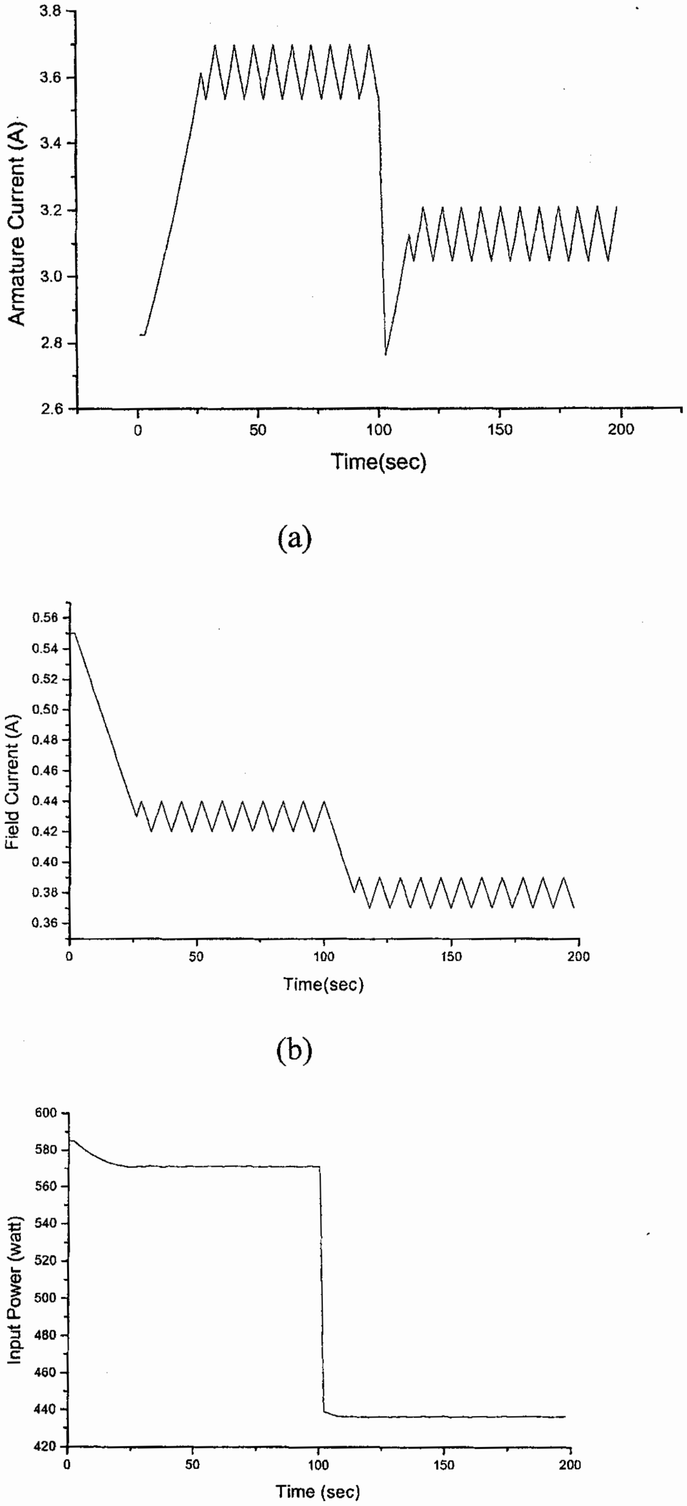
(b)

Fig.5 Input power tracking



(c )

Fig.6 Step change from 1000rpm to 500rpm at 3 Nm

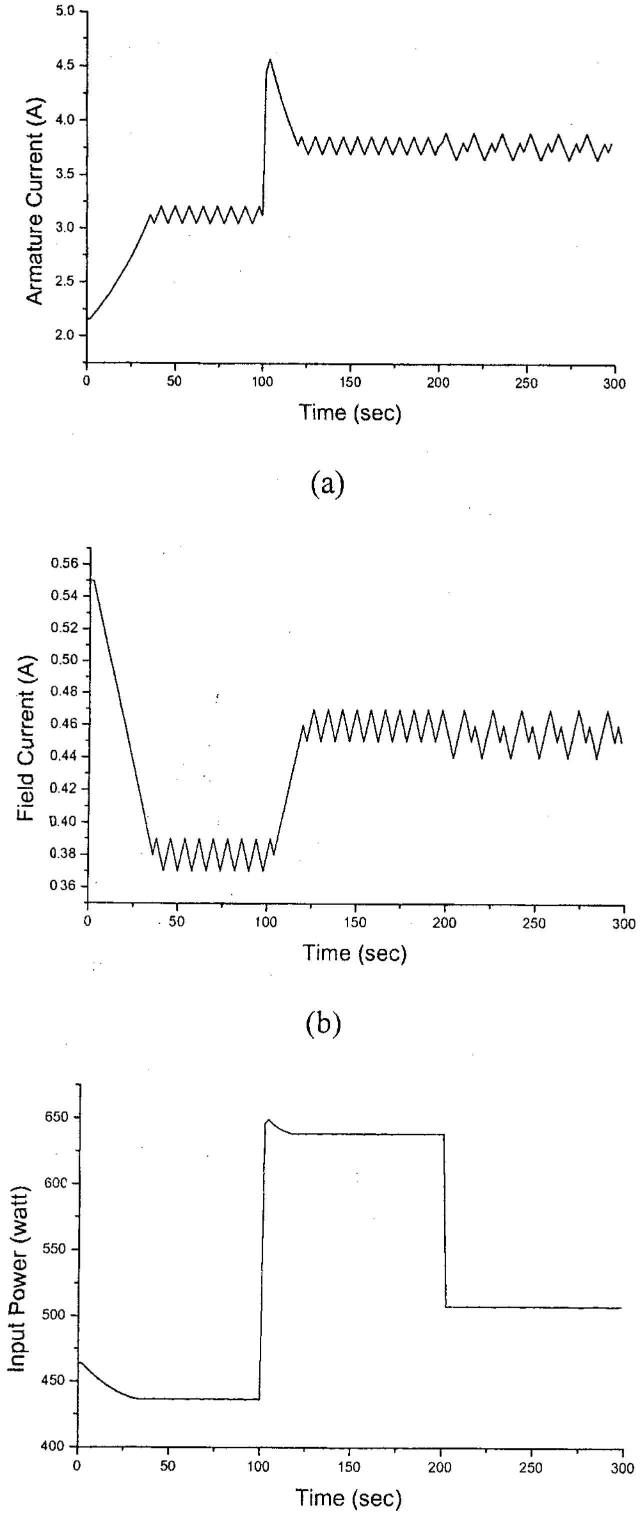


(a)

(b)

(c )

Fig.7 Step change from 4Nm to 3Nm at 1000rpm



(a)

(b)

(c )

Fig.8 Step change in load torque and step change in reference speed

## VII. Conclusion

A neural network efficiency control technique for a separately excited dc motor with speed controller is presented in this paper. The optimal armature-field currents ratio is obtained directly by neural network controller. ANN controller ensures the minimum input power at all operating conditions. The algorithm has proved to give stable operation specially when the system is subjected to a step change in the reference speed and/or load torque and the system dynamic performance is very adequate under various system performance conditions.

## References

[1] A.Kusko and D.Galler, "Control Means for Minimization of Losses in AC and DC Motor Drives " IEEE Trans. on Indust. Appl., Vol. IA-19,NO-4,July/August 1983,PP.561-570

[2] Soon C.Hong, and Min Ho Park, "Microprocessor-Based High Efficiency Drive of a DC Motor", IEEE Trans. on Indust. Elect., Vol. IE-34, No.4,November 1987, PP-433-440.

[3] W. Leonhard, "Control of Electrical Drives ", Heidelberg springer-Verlaz.1985.

[4] M.R. Matusek, B.I. Jeftenic, De,M. Miljkovic and M.Z., Bebic, "Gain Scheduling Control of DC Motor Drive With Field Weakening", IEEE Trans. on Indust.Elect.,Vol.43,No-1 Feb. 1996,PP.153-161

[5] A.M.Zaki, A. A El-sattar, S. Wahsh, H.M. Mashaly and S.I. Amer, "Efficiency-Optimized Speed Control for a Separately-Excited DC Motor Using Adaptive Neurocontroller", PEDES'98 Australia,1-3 December 1998,PP 421-426.

[6] T. Fukuda and T. Shibata, " Theory and Applications of Neural Network for Industrial Control System", IEEE Trans. on Indust.Elect.,Vol.39,No-6 Dec. 1992,PP.472-489.

[7] H.M. Mashaly, A.M.Zaki, S. Wahsh, A. Abdel-Sattar and S. Amer, "Adaptive Network Speed Controller for a Separately Exited DC Motor ", Proc. Of the fourth IEEE intr. Conf. On Electronics, Circuits&System, ICEC'97, Cairo, Egypt, Dec.15-18, 1997, pp.1519-1523

## Appendix

$R_a = 4.95\ \Omega$,
$L_a = .06$ henery,
$R_f = 334\ \Omega$,
$L_f = 37.5$ henery,
$K_b = 1.5$ volt/rad/sec,
$J_m = .026$ Nm/rad/sec and
$B = .0023$ Nm/rad/$sec^2$ .

# تقليل الطاقة المستهلكة لمحرك التيار المستمر
# باستخدام الشبكات العصبية

د/ سناء محمد إبراهيم عامر
معهد بحوث الألكترونيات
الدقى- القاهرة

تستخدم محركات التيار المستمر عامة فى العديد من التطبيقات الصناعية وخاصة عندما تكون هناك حاجة الى مدى سرعة كبير و دقة عالية للتحكم فى هذة السرعة و بالتالى يكون هناك اهمية كبيرة لتحسين الكفاءة و بالتالى ينتج وفر كبير فى الطاقة. و نظرا لان كفاءة محركات التيار المستمر تعتمد على نسبة تيار عضو الانتاج الى نسبة تيار المجال فقد تم أستنباط تلك النسب رياضيا فى العديد من الأبحاث السابقة و قد أستخدم البحث طريقة جديدة باستخدام الشبكات العصبية للحصول على نسبة تيار عضو الأنتاج الى نسبة تيار المجال لتحسين كفاءة المحرك أى مما يؤدى الى توفير الطاقة المستهلكة وذلك مع الأحتفاظ بالتحكم الدقيق فى السرعة و بدون الحاجة لاى قياسات معينة لهذا الغرض.

و من ثم تم أستخدام الشبكات العصبية فى تشغيل المحرك عند أقل طاقة مستهلكة مع المحافظة على التحكم فى السرعة و ذلك بالتحكم المباشر طوال فترة تشغيل المحرك.

و قد أثبتت النتائج فاعلية هذة الطريقة عند حدوث تغيرات مفاجئة فى الحمل أو السرعة و الحفاظ على التحكم فى السرعة.