Speed Control of DC Motor using AC/AC/DC Converter Based on Intelligent Techniques

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Abstract

This paper describes the application of ac/ac/dc and ac/dc converters to control the speed of a separately excited DC motor. Artificial neural network and PI controller are trained to select the desired values of firing angles for triggering thyristors of the ac/ac/dc and ac/dc bridge converters in order to control the speed of the dc motor at a desired value with constant and different load torques in order to obtain the best speed response. Simulation results show that the rising time for ac/dc and ac/ac/dc converters at 250rpm are reduced about 79% and 89% respectively, while delay time it reduced about 69% and 64% respectively. Therefore, speed response of the dc motor is more efficient for closed loop system compared with open loop also the response of ac/ac/dc converter is better than ac/dc converter.

Key words: Speed control, Speed response, DC motor, AC voltage controller, Artificial neural network, PI controller.

السيطرة على سرعة محرك التيار المستمر باستعمال مغير التيار المتناوب/التيار المتناوب/ التيار المستمر بالاعتماد على التقنيات الذكية

الخلاصة

هذا البحث يصف تطبيقَ مغير التيار المتناوب / التيار المتناوب/التيار المستمر و مغير التيار المتناوب/ التيار المستمر من اجل الحصول السيطرة على سرعة محرّك التيار المستمر المنفصل الإثارة. تم تدريب الشبكة العصبية الاصطناعية ومسيطر التكاملي النسبي لاختيار القيم المطلوبة لزاوية قدح ثايرسترات مغير ac/ac/dc و مغير ac/dc لِلُسيطرةَ على سرعة محرك التيار المستمر عند القيمة المطلوبة عند عزم ميكانيكي ثابت ومتغير والحصول على أفضل استجابة للسرعةِ. نَتائِجَ المحاكاةِ بينت بان زمن الصعود للمغير ac/dc والمغير ac/ac/dc عند السرعة 250 دورة/دقيقة قل بمقدار 79% و 89% على التوالي بينما زمن التأخير قل بمقدار 69% و 64% على التعاقب. هذا يعني ان استجابة سرعة محرك التيار المستمر اكثر فعالية في حالة كون النظام مغلق الدارة عنه في حالة النظام المفتوح كذلك كذلك استجابة مغير ac/ac/dc يكون افضل بالمقارنة مع المغير ac/dc.

استجابة مغير ac/ac/dc يكون افضل بالمقارنة مع.

Introduction

A variable speed drive is an electronic device that controls the speed, torque, horsepower and rotation of an AC or DC motor[1]. DC motor drives have occupied a wide spectrum of variable speed applications. Separately excited dc motors have many applications in industries where precise speed control over a wide range is required. Normally closed loop operation with PI controller is employed for speed control [1]. In the last decades, the production of power electronics switches has been plentiful and diverse. Some of these switches are thyristors, GTOs, bipolar junction transistors BJTs, MOSFETs, IGBTs and MCTs[2]. Even with these devices, the basic thyristor still constitutes a robust, simple and economical device that has many applications. Thyristors are widely used for control of power in both AC and DC systems. This is due to their several advantages such as relatively small size, high power, fast switching and can handle high overload current compared with the other types of power switching devices. Due to their excellent speed control characteristics, DC motors have been widely used in industry even though the maintenance costs are higher than the induction motors [3]. The use of neuro-fuzzy network for speed control of dc motor was presented by [1] and the simulation studies show that the variations in torque and plant parameters have negligible effects on the performance of the system. Artificial neural network and fuzzy logic controllers were trained by [4] to select the desired value of firing angles for triggering thyristors, of the three-phase bridge controlled rectifier, in order to control dc drive at desired speed without and with harmonics reduction and simulation results show that the response of the dc motor is more efficient with harmonics minimize compared with conventional type. In this paper, three-phase bridge ac/ac/dc converter and three phase bridge ac/dc controlled converter are used to control the speed of the dc motor, as shown in Fig.(1). Artificial Neural Network (ANN) and PI controller are applied to obtain a wide range of speed control of the dc drive by selecting the optimal value of firing angle (α) for triggering thyristors.

Converter Configuration

If a thyristor switch is connected between an AC supply and load, the power flow can be controlled by varying the r.m.s value of the AC voltage applied to the load. This type of power circuit is known as an AC voltage controller [5]. Three phase AC voltage controller has been used for various circuit configurations. The ac/dc converter feeds the DC motor with armature (rotor winding) voltage while the field winding (stator) is excited with a regulated field current. Many researches analyzed the three-phase ac and dc controlled converter under ac and dc machine load to obtain mathematical and programmable form for the variation of torque, speed and line currents along with firing angle [2]. In this paper, a full bridge ac/ac/dc and ac/dc converters, shown in Fig.(1), are used to control the speed of the dc motor with deferent load torques in order to obtain best speed response and to make comparison between two circuit configurations. The converters system are controlled by the same ANN and PI controller which are trained to select desired values of firing angles for triggering thyristors of ac/ac/dc and ac/dc bridge converters in order to control the speed of the dc motor at a wanted value at constant and different load torques and to obtain best speed response.

DC Motor

The speed control of DC motors has attracted considerable research and several methods have been evolved. Using power system blockset in Matlab/Simulink library to model the dc drive, a DC separately excited motor is taken from the library to prepare high quality model of three-phase DC drive (see Fig. (1)). The equations describing the dynamic behavior of the DC separately excited motor are given by:

$$V_a(t) = R_a * i_a(t) + L_a \frac{di_a(t)}{dt} + kw(t) \ldots..(1)$$

$$T(t) = J \frac{dw(t)}{dt} + \beta * w(t) + T_1 = k * i_a(t) \; (2)$$

Where *w(t)* is rotational speed, $i_a(t)$ armature circuit current, T_1 constant load torque, R_a armature circuit resistance, β coefficient of viscous-friction, *k* torque coefficient, *J* moment of inertia, and L_a armature circuit inductance. The DC motor under study has the following specifications[6] (V_f=200V, 2.3kw, 1250rpm, 220V, and 13A) and parameters (R_a=3.5Ω, L_a=24mH, R_f=256Ω, L_f=0,1mH, J=0.066kg.m2 and β=0.005 N.m.s).

Speed Controller System

ANN Speed Controller

A feed forward ANN controller is used, comprising three neuron layers, the input layer, the hidden layer and the output layer. The hidden layer neurons have log-sigmoid transfer function, and the output layer neurons have a linear transfer function. A supervised back-propagation algorithm has trained the ANN with Matlab that converts the trained ANN points to rules [6]. ANN is trained to select the nearest desired firing angle (α) to trigger thyristors in order to run the dc motor at wanted speed at open and closed loop system as shown in Fig.(2.a).

Closed Loop PI Controller

Proportional-Integral (PI) controllers have been widely used for speed control of DC motor. These controllers enable good ability if a simple control algorithm be implemented [7]. The purpose of the PI compensator is to improve the steady state accuracy of the closed loop system without degrading the stability. When the PI gains (KP & KI) have been properly tuned, PI control is fast-acting, it eliminates the steady-state error (offset) of proportional control, and it reduces the amount of oscillation common with integral control. The closed-loop controller is a very common means of keeping motor speed at the required under varying load conditions. In this study, a closed loop PI controller used to find the optimal value of (α) added to the values selected by ANN in order to improve the step response performance as illustrates in Fig.(2.b).

Simulation Results

Three-phase bridge ac/ac/dc and ac/dc converters, dc motor, ANN, and PI controller are simulated and connected by Matlab/Simulink under open and closed loop system, as shown in Fig.(A) of Appendix(A). Fig.(3) illustrates the waveforms of speed response of the dc motor at constant mechanical load torque for open and closed loop conditions. It is clear that the PI controller with neural network, closed loop system, is more stable and more robust to change according to environments than open loop system. The rising time for the speed response with open and close loop of ac/dc and ac/ac/dc converters at 250rpm is 0.2, 0.042, 0.325 and 0.035sec, the delay time is 0.123, 0.0377, 0.0717 and 0.0258sec and steady state error is 25.6%, 0%, 29.6%, 0% respectively. Hence, the configuration in Fig.(1.a) is more suitable that in Fig.(1.b). Fig.(4) shows the speed response of the dc motor for step change of the reference speed with constant load torque for open and closed loop system. Fig.(5) shows the speed response of the dc motor with different mechanical load conditions, while the required speed is constant for open and closed loop system. Both cases fulfill the requirements of motor operation and perform the dc motor speed performance.

Conclusions

In this paper, to achieve smooth starting and acceleration, closed loop system was used. Based on the simulation results and dependence on ANN and PI controller, a wide range speed variation of a dc motor (250rpm – 1500rpm) can be obtained at different mechanical load, which is also proved that response of the dc motor with closed loop system is better than open loop system. Improvements in the speed response for different load condition can be achieved with closed loop system. Rising and delay times for ac/dc converter configuration at 250rpm are improved and reduced about 79% and 69% respectively; while for ac/ac/dc converter it reduced about 89% and 64% respectively. Therefore, rising and delay times for closed loop system of ac/ac/dc converter is better than ac/dc converter, this means that ac/ac/dc converter configuration is more suitable for obtaining a good speed response than ac/dc converter. The cost of ac/ac/dc converter can be reduced by replacing the two back to back thyristors by triac.

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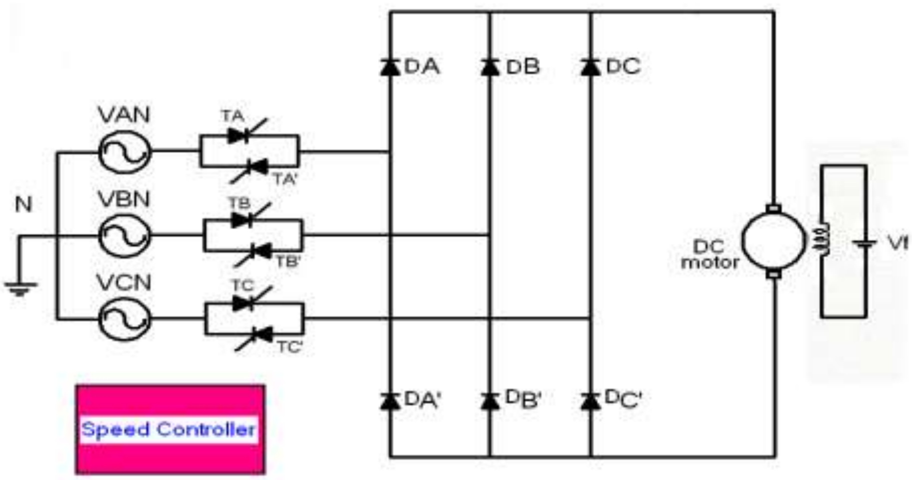
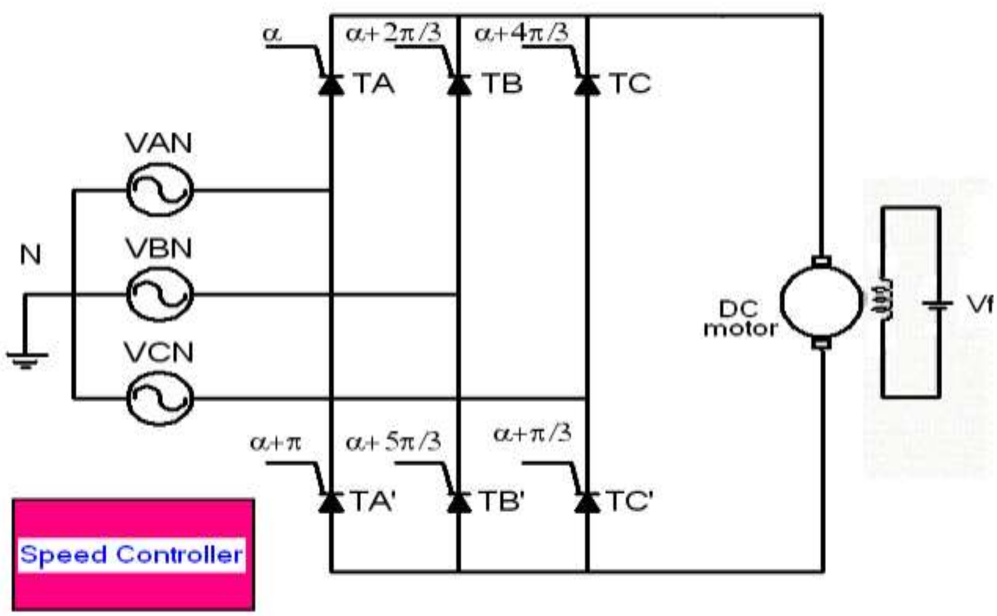


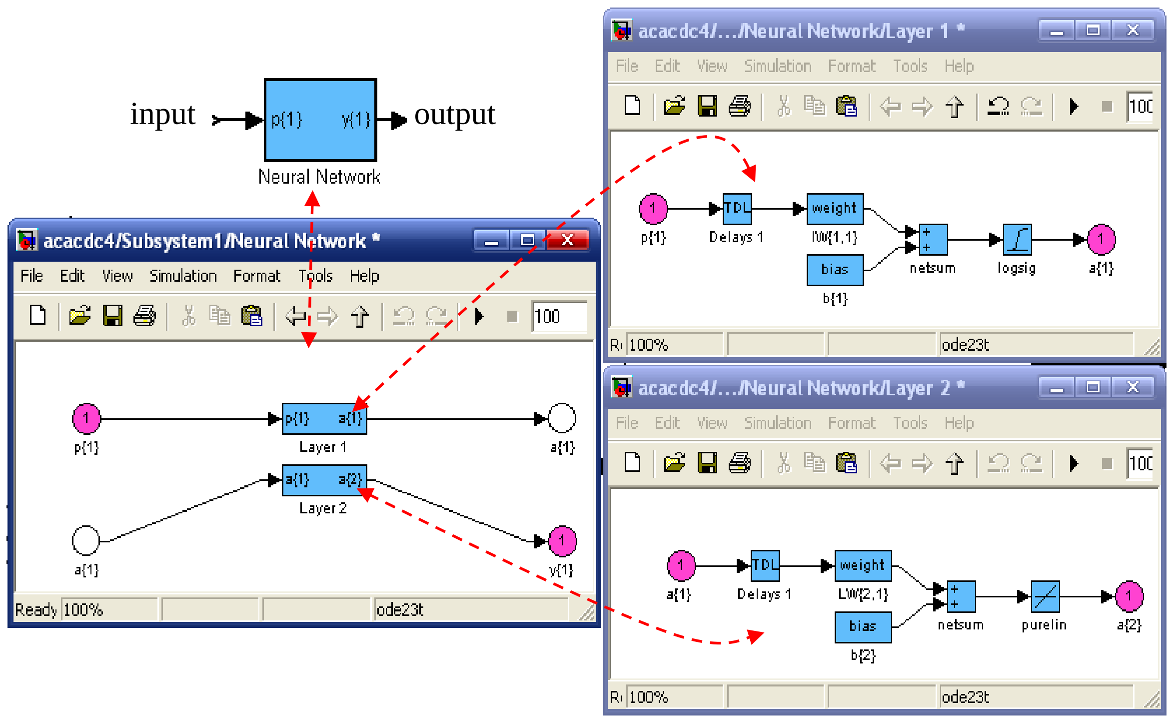
(a)



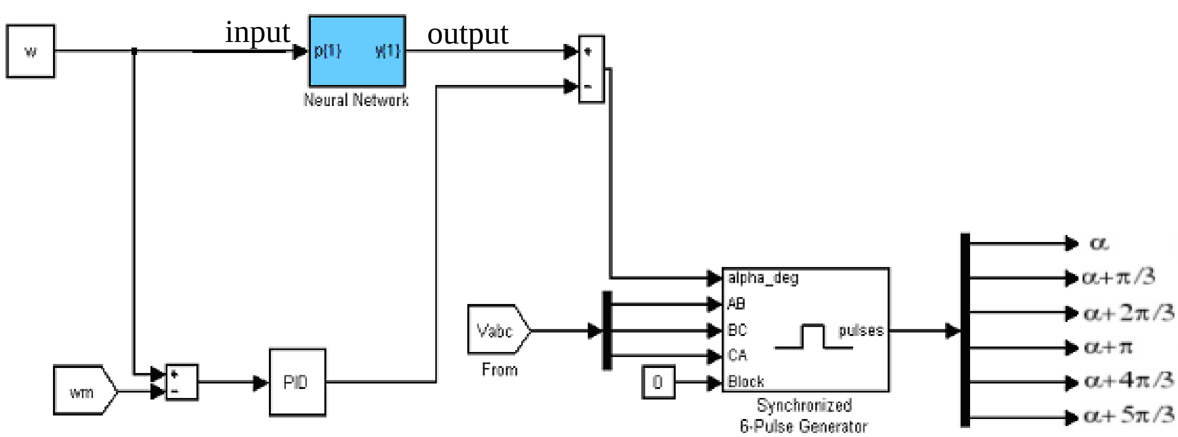
(b)

Fig.(1): The circuits of a three-phase bridge

(a):- ac/ac/dc converter (b):- ac/dc converter

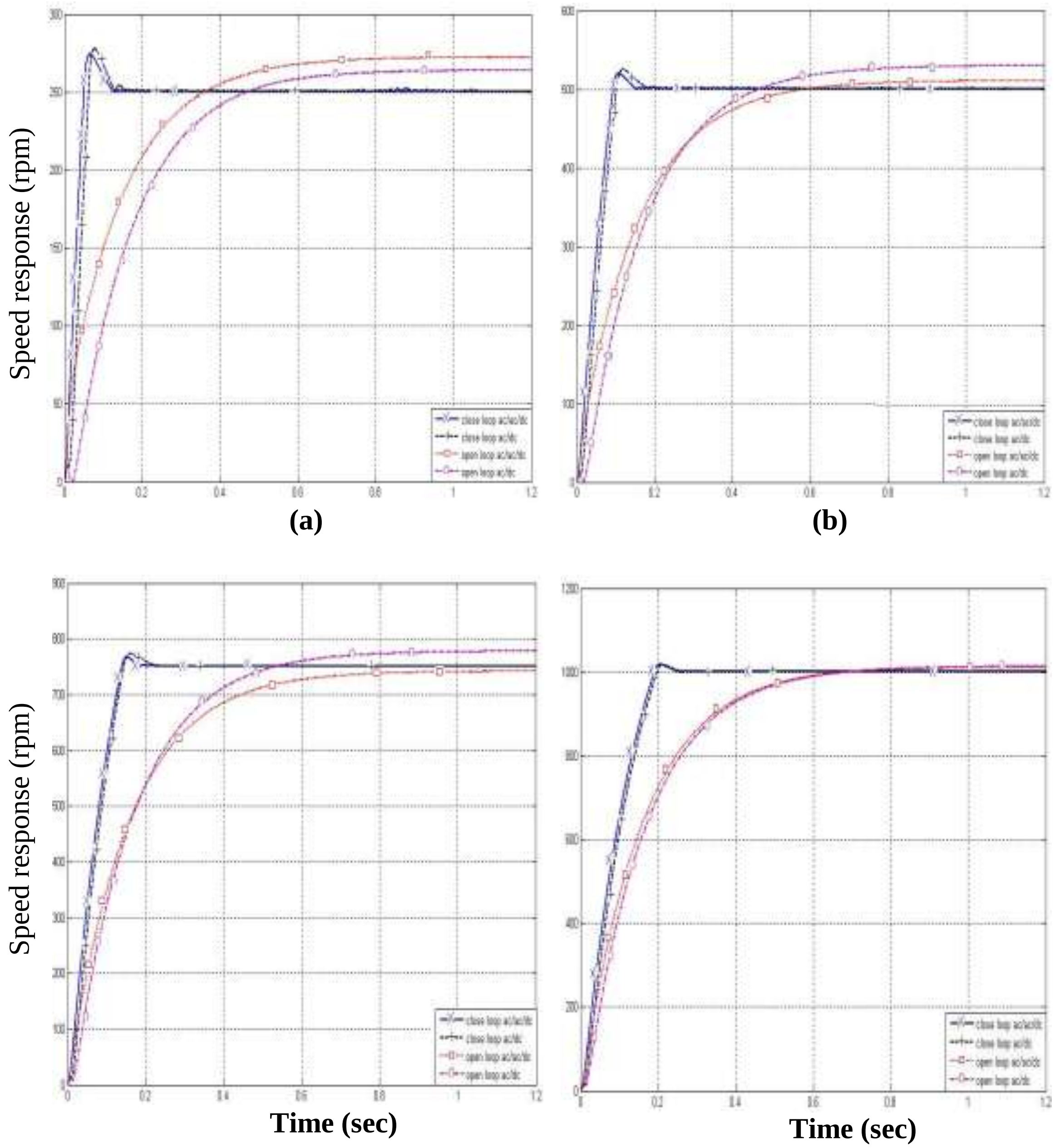


(a)



(b)

Fig.(2): The Matlab model of the controller circuit for
(a):- Artificial Neural Network circuit (b):- Close Loop PI controller



(c) **(d)**

Fig.(3): Speed response of the dc motor at constant load torque for ac/ac/dc and ac/dc converters at: (a): 250 rpm (b): 500 rpm (c): 750rpm (d): 1000rpm

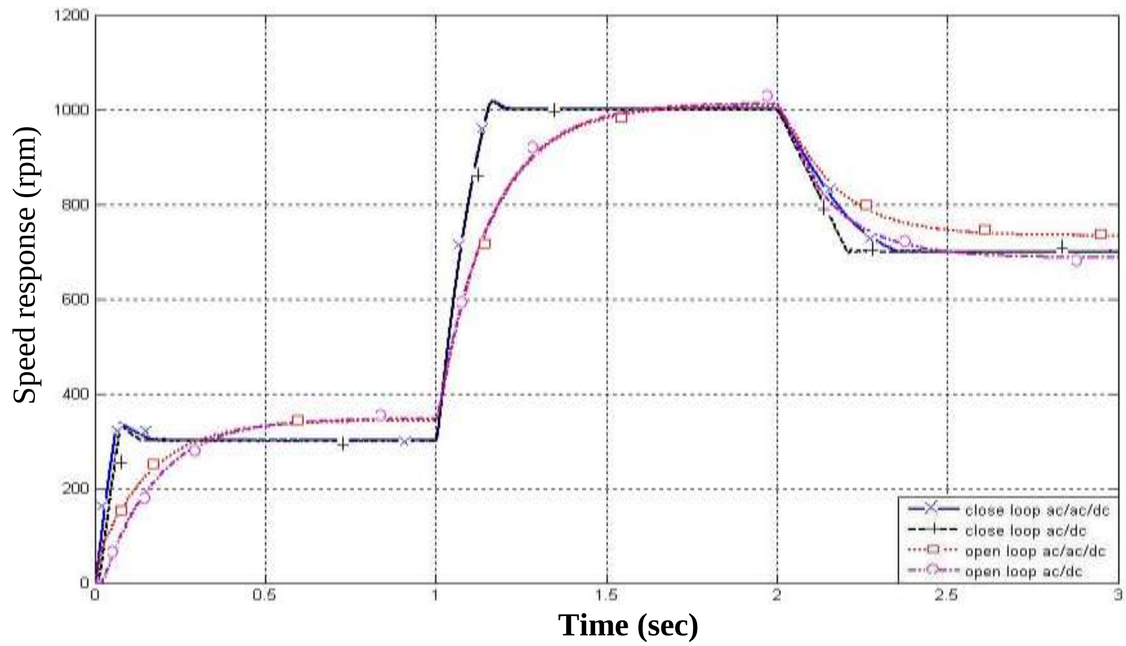


Fig. (4):- Speed response of the dc motor at constant load torque (10N.m).

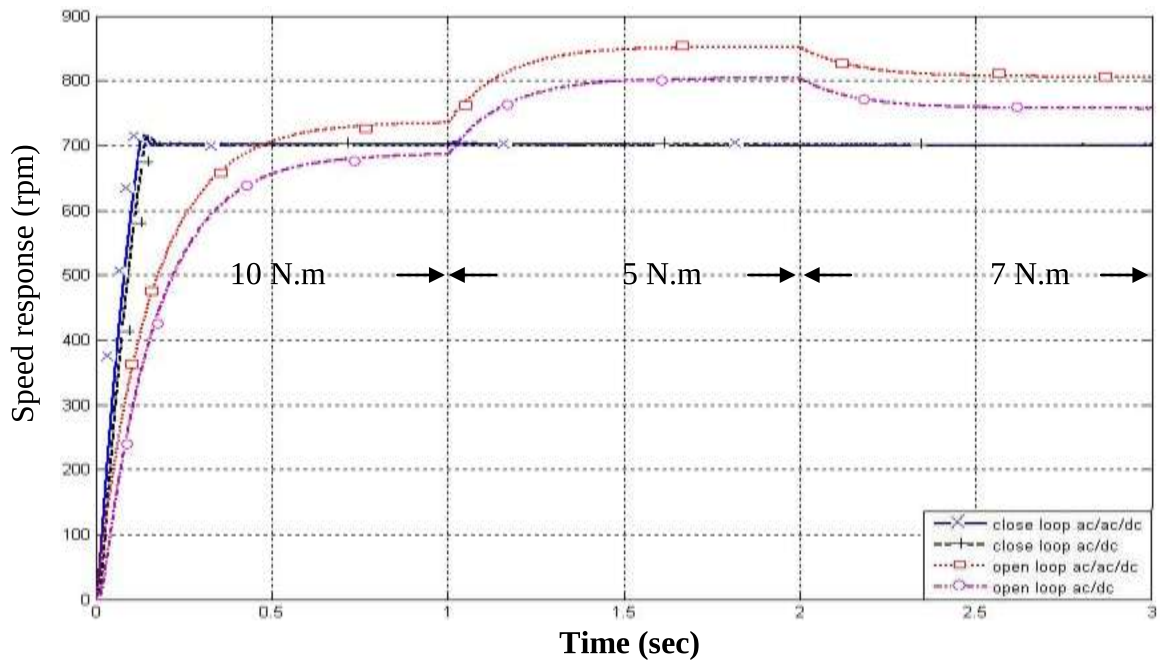
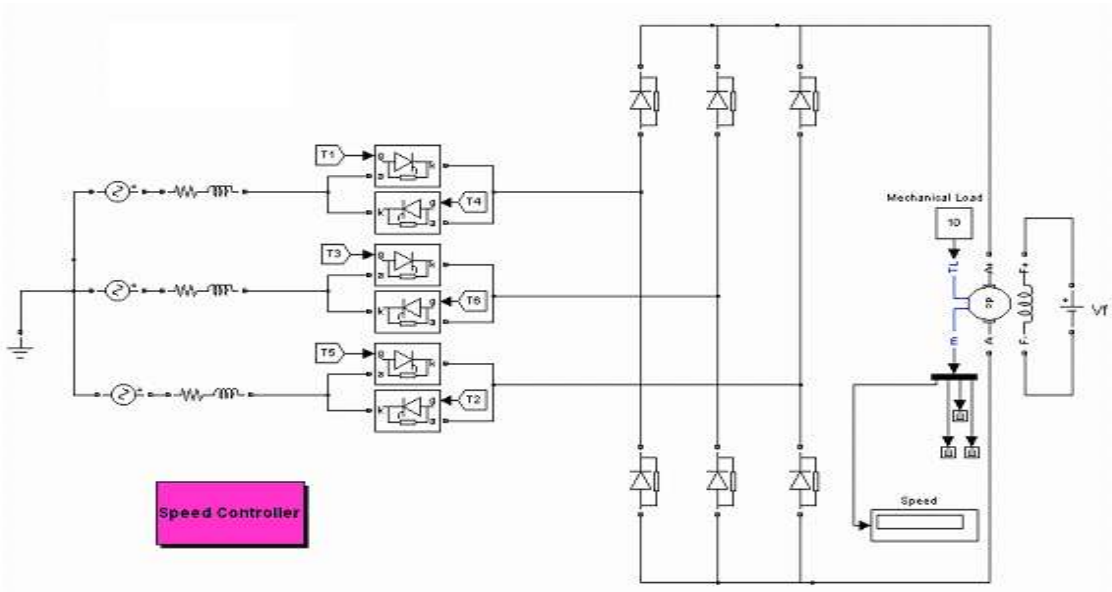
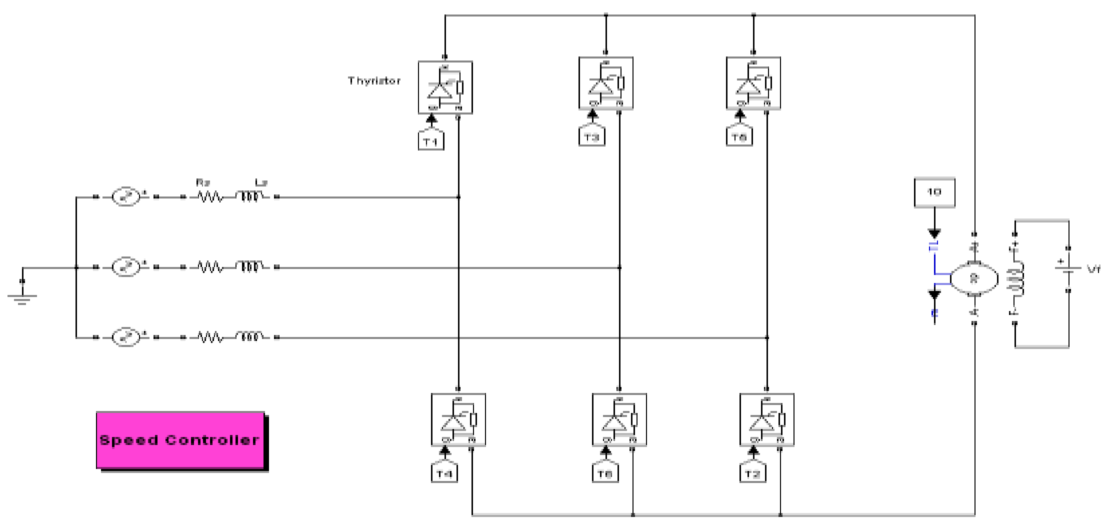


Fig.(5): Constant speed response (700 rpm) of the dc motor with different load torque.



(a)



(b)

Figure (6):- The Matlab model of a three-phase bridge
(a):- ac/ac/dc converter (b):- ac/dc converter