Speed Control of Separately Excited D.C. Motor using Self-Tuned Parameters of PID Controller

Dr. Abdul-Kareem Z. Mansoor   **Dr. Thair A. Salih,**
Power Engineering Department   **Computer Engineering Department**
Dr. Fawaz S. Abdullah
Power Engineering Department
Technical College -Mosul

Abstract

This paper presents a simulation and hardware implementation of a closed loop control of a separately excited D.C. motor using a self-tuning PID controller. The PID controller design is based on using the Field Programmable Analog Array (FPAA) technology. Parameters tuning of the PID controller is achieved by using the genetic algorithm (GA). The FPAA controller based technology gives the advantage of low power, no quantization noise, high bandwidth and high speed response. The practical results show that a self-tuning controller can outperform a hand-tuned solution and demonstrate adaptability to plant drift; also it gives very acceptable results in the reduction of overshoot, stability time and the steady-state transient response of the controlled plant.
Keywords: PID controller, FPAA, Self-tuning, GA.

السيطرة على محرك تيار مستمر ذو الاثارة المنفصلة عن طريق التوليف الذاتي لمتغيرات المسيطر التناسبي–التكاملي–التناظري

الخلاصة

يعرض هذا البحث تحليلا وتطبيقا عمليا للسيطرة المغلقة على محرك تيار مستمر ذو الاثارة المنفصلة بأستخدام مسيطر تناسبي–تكاملي–تفاضلي (PID) ذو التوليف الذاتي. ان تصميم المسيطر (PID) مبني على مبدا استخدام تقنية بوابة المصفوفات التناظرية المبرمجة حقليا (FPAA). وان عملية توليف قيم الثوابت للمسيطر (PID) يمكن تحقيقها باستخدام الخوارزمية الجينية (GA). ان التقنيات المبنية على استخدام المسيطرات التناظرية (FPAA) لها ميزات من حيث قلة استهلاكها للطاقة، قليلة الضوضاء، سعة عرض الحزمة، سرعة استجابة عالية. تبين النتائج العملية بان التوليف الذاتي يمكن ان يحل مسالة التوليف اليدوي ويبين قابليته العالية لاحتواء اي انجراف او انحراف لمنظومة العمل عن عملها الصحيح، وكذلك يعطي نتائج مقبولة جدا من حيث القفزة، زمن الاستقرار، استجابة الحالة العابرة لمنظومة السيطرة.

Introduction

Field Programmable Analog Arrays (FPAAs) are the counterparts of the Field Programmable Gate Arrays (FPGAs) in analog domain. Both devices are now considered as the most modern technologies that are changing the electronic industry because of their reconfigurable nature, shorter development cycles and timing and lower development cost [1].

With dynamically field programmable analog array, the PID controllers are implemented in the analog section, with the possibility of easy reconfiguration and even auto-tuning of the controller parameters,

reducing time for setting and increasing the flexibility [2] .

Proportional-Integral-Derivative (PID) controllers have been widely used for processes and motion control system in industry. Now, more than 90% of control systems are still with PID controllers. The most critical step in the application of PID controllers are parameters tuning. Today, self-tuning PID controller provides much convenience in engineering. The parameter settings of a PID controller for optimal control of a plant depend on the plant's behavior. The tuning method includes online model-free method. This method tunes the PID controller in loop with the given plant using an optimization algorithm such as steepest descent or Newton's method to minimize some cost function .Yet, the above method cannot guarantee to find the global optimum and its calculation is also expensive [3]. With the abilities for global optimization and good robustness, and without knowing anything about the underlying mathematics, Genetic algorithm (GA) is expected to overcome the weakness of traditional PID tuning techniques and to be more acceptable for industrial practice [4]. The DC motors hold the very important status in the electric driving automatic control system. . It was the first choice in the applications which requires a wide range of speed regulation and high-precision speed, and it has been widely used in computerized numerical control machine tools and process control. It has a great significance to study the direct current motor's velocity control [5].

The objective of this work is to control on the speed of a DC motor using self-tuning PID controller.

Section 2 provides the general system model of the work, while section 3 is the discussion of the work, and the final conclusions is given in section 4.

Overall System Model

The overall system model is shown in Fig. 1. In order to find the initial parameters of the PID controllers to be used as a starting point in the Genetic Algorithm operation a Matlab/Simulink model has been built and the trial and error method of finding the PID controller parameters has been used.

System Simulation with Closed Loop Control System

Whenever a reference speed is given, the control system automatically compares the actual speed of the motor which is directly measured from the speed sensor, with the reference speed.

The controlled system objective is to make the motor speed follow the reference input speed change by designing an appropriate controller. The PID controller is used to reduce or eliminate the steady-state error between the measured motor speed and the reference speed to be tracked. At first, a model of PID controller with a 220V separately excited DC motor is designed using Matlab/Simulink. The transfer function model of the motor is then used to design the PID controller to generate a set of coefficients associated with the desired controller characteristics. Fig. 2. shows the Matlab/Simulink System model, which consists of a separately excited dc motor fed from a DC source through a chopper circuit, designed feedback controller, PWM models, in addition to the variable load and voltage source. The PWM generator generates the pulse signal with duty cycle value corresponding to the output error signal presented by the PID controller. The reference speed of the DC motor is

compared with its actual speed signal to produce the error signal.

A fast PID loop tuning usually overshoots slightly to reach the set point more quickly. The PID controller parameters obtained from this method are: $K_P = 22.17, K_I = 0.00013$
$K_D = 0.168$

The speed response obtained from the simulation of the closed-loop system is shown in Fig. 3, the reference speed is set to (1000 rpm) with a sudden load torque applied (6 N.m) at (0.5 sec.) and then removed at (0.9 sec.). The transient-response characteristics (for simulation) obtained from Fig. 3 are: rising time $(T_r) = 0.11$ sec, peck time $(T_p) = 0.18$ sec, settling time $(T_s) = 0.25$ sec, maximum percent overshoot (M_p) = 1.1 % with zero steady-state error (e_{ss}).

Hardware Description

The block diagram for the practical closed loop control system configuration is shown in Fig. 4. The circuit consists of six major parts: Personal Computer (PC), two FPAA kits, firing circuit, buck converter circuit, DC motor, and the ADC interface circuit. All these parts will be discussed in detail in this section.

The DC motor which is used in this work was manufactured by TERCO Company with (2 KW, 220V). The tachogenerator is coupled with the DC motor to convert the motor speed into equivalent AC voltage. The AC voltage is then rectified to DC voltage with specified range. The feedback speed related voltage is applied to the PID controller and to the ADC circuit in order to transport it to PC to be compared with a reference speed. A comparison between the reference signal and the feedback signal will occur to produce the error signal. The error signal is fed to the GA program in order to search for the optimum

parameters values of the PID controller. The output of the PID controller is fed to the PWM circuit. The pulses from the PWM circuit with variable duty cycle are applied to the firing circuit of the DC chopper. The pulse duty cycle variation depends on the error signal and thus the motor runs at a desired constant speed.

PID Controller

The closed loop control system of the self-tuning analog PID controller is shown in Fig. 4. It uses the FPAA to build the analog PID controller and PC to run the tuning software. The PID controller circuit is built as shown in Fig. 5.

PWM generator

The PWM circuit is shown in Fig. 6. It consists of a configurable analog module (CAM) called arbitrary periodic waveform generator unit that generates a triangular wave, which is available within the library window of the FPAA. This unit is useful for creating any type of periodic waveform. Also it contains a lookup table (LUT) to represent the required waveform data. The LUT contains up to 256 voltage values equally spaced in time. The frequency of the PWM output signal is 5 kHz and the modulation index between (4V and -4V).

Buck Converter Circuit

The buck converter circuit is shown in Fig. 7. The output voltage (V_o) equals the input voltage (V_s) when the switch is ON, and equals to zero when the switch is OFF. By varying the duration for which the switch is ON and OFF, it can be seen that the average output voltage can be varied.

One of the methods of controlling the output voltage is by employing switching at a constant frequency, i.e., a constant switching time period (T

$= t_{on} + t_{off}$), hence by adjusting the on-duration of the switch the required control of the average output voltage is obtained. This method is usually called duty cycle control or PWM control. DC motors are most commonly driven by PWM signals with respect to the motor input voltage [6].

Fig. 8 shows the DC output voltage obtained experimentally from the Buck converter circuit with a very low ripple (about 7%) that proves the perfect filter design. The values of L and C are 5.5 mH and 47 μF, respectively.

Analog-to-Digital Conversion (ADC) circuit

An ADC is a circuit that converts an analog voltage into a digital one. The ADC used in this work is (ADC0804) which is a CMOS 8-bit successive approximation converter. The ADC will operate in continuous conversion mode (free-running mode). Only a time delay (not less than 100 μs) must be taken into account for the conversion time needed for the ADC to convert one sample of analog input to digital output [7]. The digital output is connected to the parallel port and the data will be transmitted in nibble mode as shown in Fig. 9.

Implementation of Genetic Algorithm

The idea, for all systems based on GA, was to evolve a population of candidate solution to a given problem, using operators inspired by natural genetic variation and natural selection. There are mainly three affecting parameters in the self-tuning PID controller system. These parameters are (K_P, K_I and K_D). These parameters are used to control the operation of the DC motor. The task for the GA is to find the best values for those parameters by optimizing the search operation of finding the best values using a modeled fitness function. In this work the GA

search operation of the three gains working in parallel (K_P, K_I and K_D are changed at the same time every three seconds until finding the acceptable values). Structure of the proposed GA-PID controller is shown in Fig. 10. The basic objective of the GA is to optimize the fitness function. The fitness value should be calculated to maintain the robustness and accuracy in the proposed algorithm. The GA-PID controller flowchart is shown in Fig. 11. The summary of the GA properties is illustrated in table 1.

Discussion of Self-Tuning Pid Controller Results

From the speed response of the motor with self-tuning operation shown in Fig. 12, it can be seen that the GA provides a new PID controller parameters values during its search operation for optimal parameters gain values for reference speed equal to (700 rpm). The GA depends on the initial values of the PID controller obtained from the simulation as a starting point. The variation of the three gains values leads to change the DC motor speed in a specific time (each 3 sec.) until finding values capable of providing minimum overshoot with minimum steady state error (e_{ss}). Fig. 13 shows the variation of the controller parameters with the chromosomes applied to the PID controller during the search operation. It is shown that chromosome No.(24) provides the best situation with an acceptable value of error (the reference speed is 700 rpm and the actual speed is 704 rpm) after (70 sec.) of training. Fig. 14. shows the speed response of the DC motor after the new parameters of the PID controller are used. The new PID controller parameters values are:

$K_P = 34.35 \ K_I = 0.00026 \ K_D = 0.197$

It can be concluded from figure (14) that the transient-response

characteristics (for practical system) are:

1- Rising time (T_r) = 0.27 sec.
2- Peck time (T_p) = 0.35 sec.
3- Settling time (T_s) = 0.41 sec.
4- Maximum percent overshoot (M_p) = 3.38 %
5- Steady-state error (e_{ss}) = 0.35 %

The transient-response characteristics for simulation is better than the practical system because the MATLAB/Simulink deal with the system as an ideal system with optimum work situation and this can't obtained from the practical system. The self-tuning training operation is shown in Fig. 12 it is applied for a reference speed equal to (700 rpm). The searching operation is done with allowable value of error so as to find the target chromosome as soon as possible. To obtain more accurate results it is recommended to reduce the allowable tolerance of error (from the GA software) but this could make the GA takes longer time to find the best chromosome (best values for K_P, K_I and K_D). Fig. 15. shows a photograph of the practical circuits.While Fig. 16. shows the overall experimental setup of the work.

Conclusions
From the present work the following conclusions are obtained:
1- The genetic algorithm based self-tuning PID controller parameters is quite efficient and fast technique, which gives parameter settlement of the controller after about 65 second. Parameter tuning is needed once for any base speed.
2- The GA tuned parameters of PID controller gives very acceptable speed response parameters such as peck overshoot, rising time and settling time.

3- The speed response shown in the Figures (12) and (14) illustrate that the GA is an efficient technique for tuning the PID controller parameters.
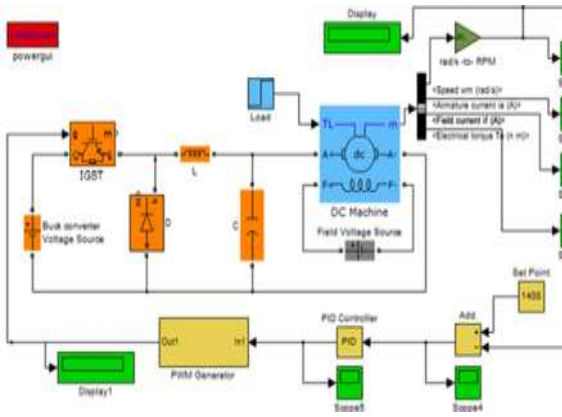
References

1. Mohamed. S. Haji Ali, Maan M. Shaker and Thair A. Salih, "*Design and Implementation of a Dynamic Analog Matched Filter Using FPAA Technology*", World Academy of Science, Engineering and Technology, vol. 48, pp.206-210, 2008.
2. Loan Lita, Daniel Alexandru Visan, Ion Bogdan Cioe, "*FPAA based PID controller with applications in the nuclear domain*", 32nd International Spring Seminar on Electronics Technology, pp. 1-4, 2009.
3. Li Xu-zhou, Yu Fei, Wang You-bo,"*PSO Algorithm based Online Self-Tuning of PID Controller*", International Conference on Computational Intelligence and Security, pp. 128-132, 2007.
4. Mohammed Obaid Ali, S. P. Koh, K. H. Chong, S.K.Tiong and Zeyad Assi Obaid, "*Genetic Algorithm Tuning Based PID Controller for Liquid-Level Tank System*", Proceedings of the International Conference on Man-Machine Systems, 2009.
5. Yongbin Ma,Yongxin Liu,Cun Wang, "*Design of Parameters Self-tuning Fuzzy PID Control for DC Motor*". The 2nd International Conference on Industrial Mechatronics and Automation, pp. 345-348, 2010.
6. Timothy L. Skvarenina, "*The Power Electronics Handbook*", Industrial Electronics Series, CRC Press LLC. ISBN 0-8493-7336-0, 2002.
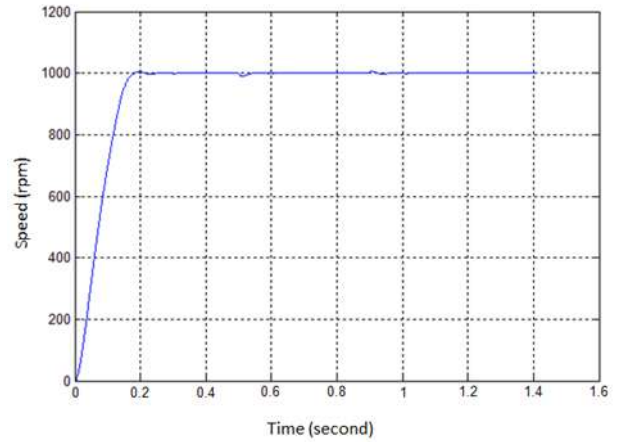
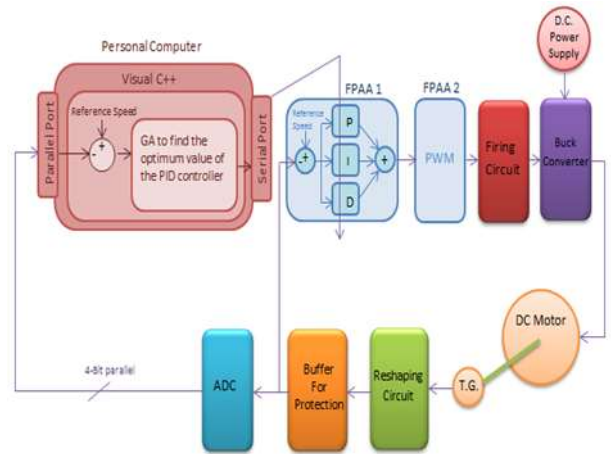7. Philips Semiconductors, datasheet of the CMOS 8-bit ADC0804 converters, 2002.
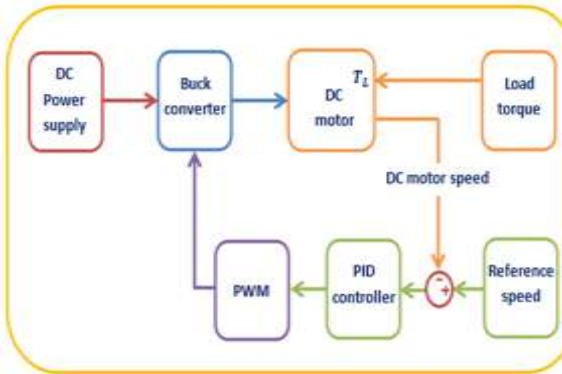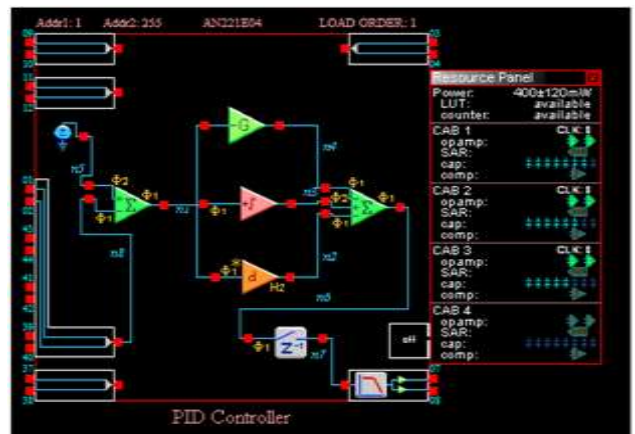

Figure(1) Closed loop system model

Figure(3) Response of the closed-loop system with a sudden load added

Figure(2) Simulation model of the closed-loop DC motor control system.
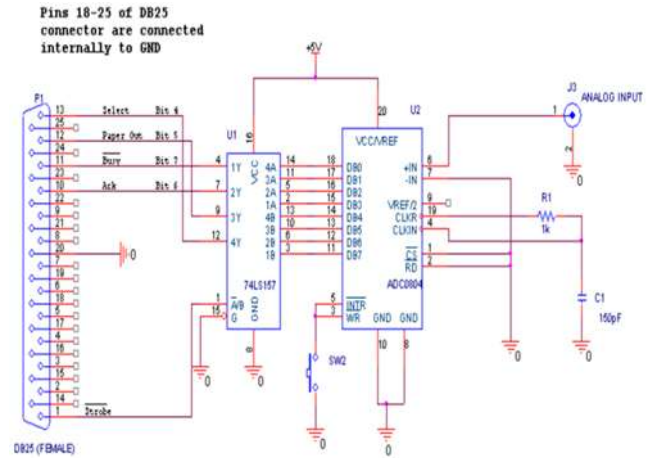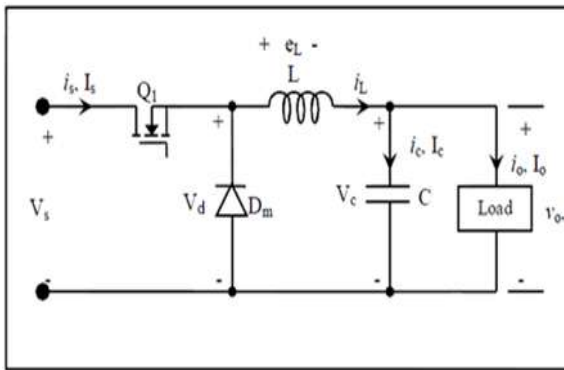

Figure(4) Block diagram of the practical system.

Figure(5) PID controller circuit.
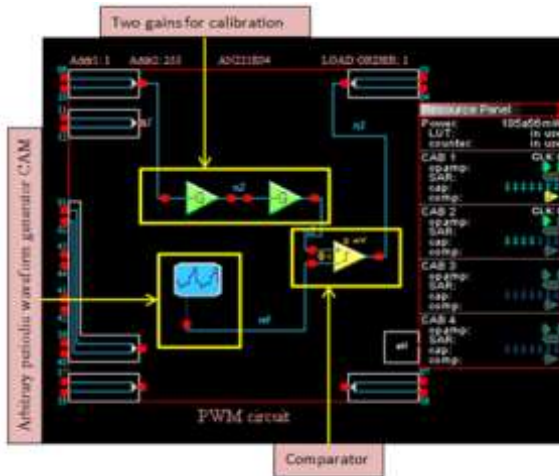
Figure(6) PWM generator circuit.

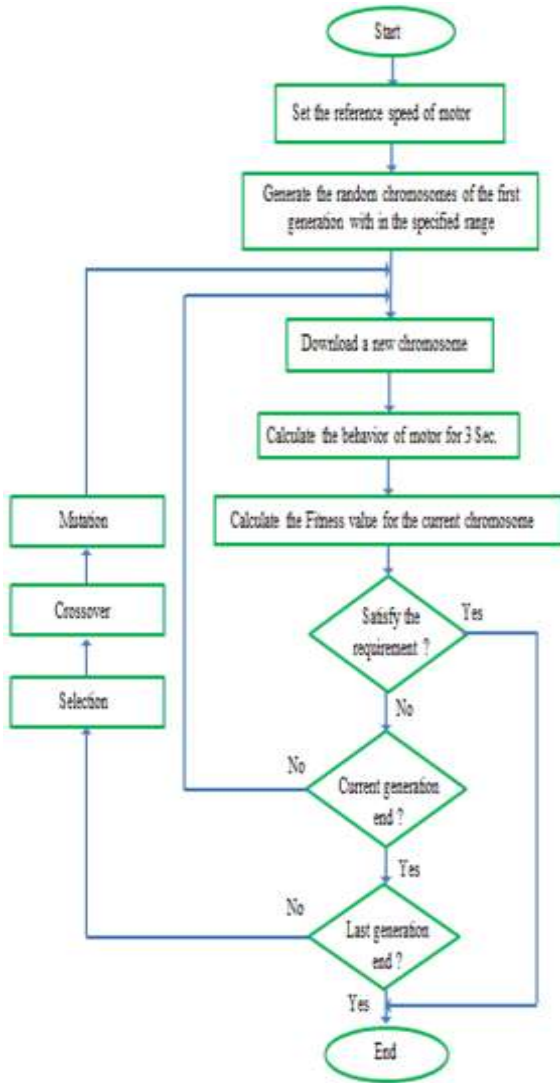**Figure(9) Experimental circuit connecting ADC to a PC through parallel port.**

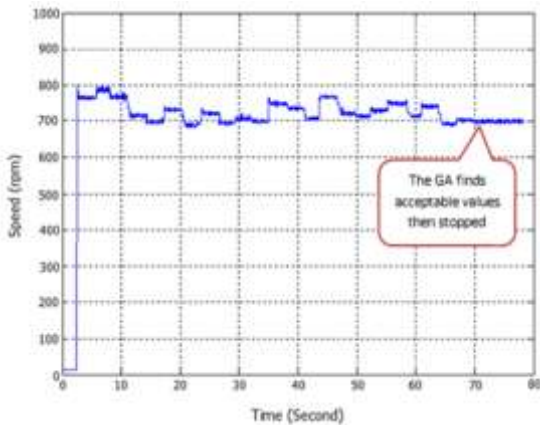**Figure(7) Circuit diagram for buck converter.**
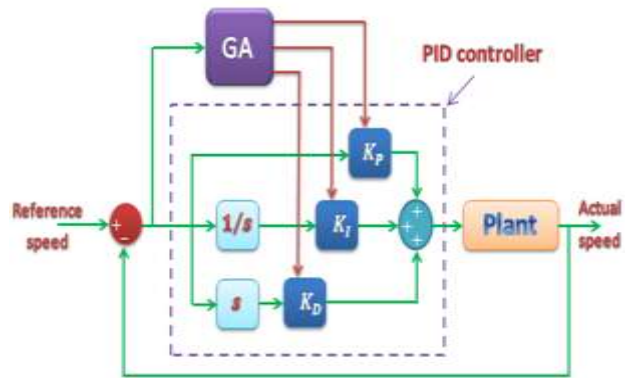
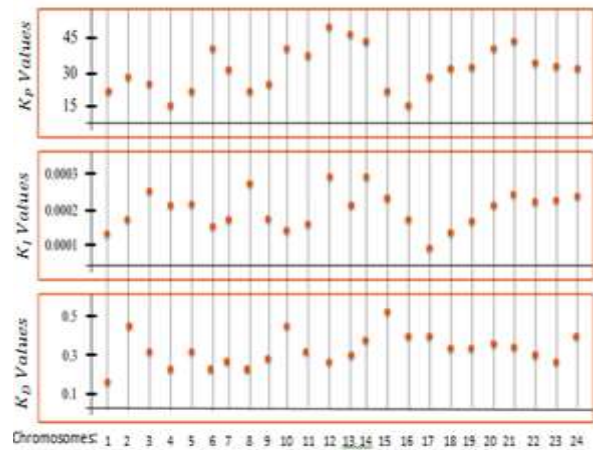**Figure(10) Structure of the proposed GA-PID controller.**
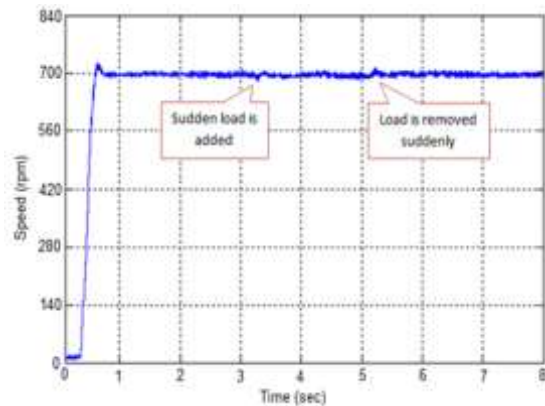

Figure(8) Output of buck converter at 90% duty cycle.

Figure(11) GA-PID controller flowchart.

Figure(13 Chromosomes applied to the PID controller during self-tuning operation.

Figure(14) Practical response of closed loop speed control of the DC motor at (700 rpm) with a given sudden load change equal to 6 N.m.
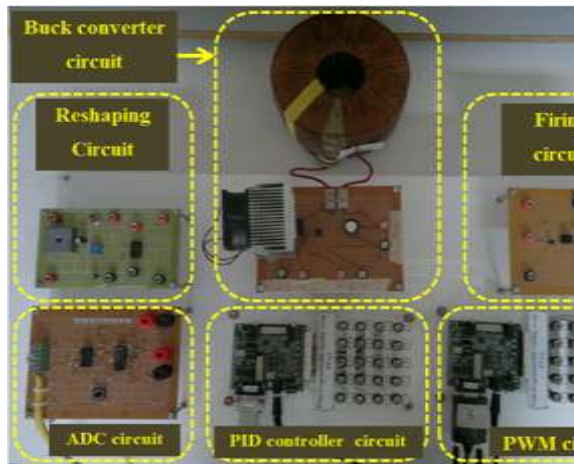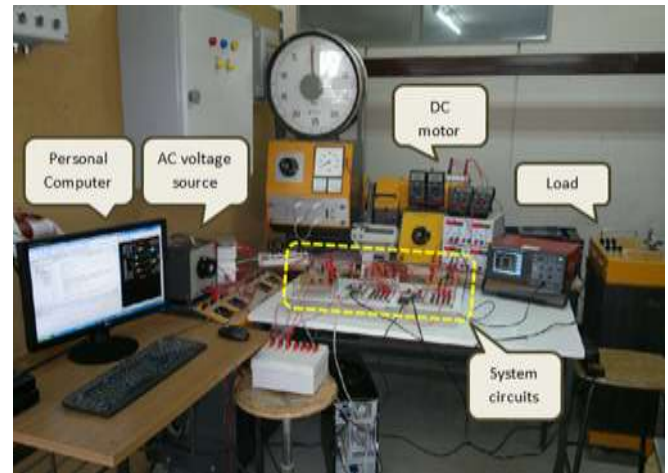

Figure(12)Self-tuning training operation at reference speed=700 rpm.

Figure (15) Photograph of all power electronic circuits of the system.

Figure(16) Photograph of the overall experimental system

Table (1) Genetic algorithm (GA)

GA property	Value/Method
Number of generations	30
Number of chromosomes in each generation	20
Number of genes in each chromosome	3
Performance Index/fitness function	$\dfrac{\text{Integral of Absolute error}}{N}$
Selection Method	Tournament and Roulette wheel Selection
Crossover Method	Arithmetic Crossover
Crossover Probability	75%
Mutation Method	Add-Sub Mutation
Mutation Probability	1%