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Numerous speeds loads controller for DC shunt motor based on PID controller with online parameters tuning supported by genetic algorithm

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ABSTRACT

Direct current (DC) motor is a commonly used motor; its speed is directly affected by applying mechanical load. This paper proposes the design of wide speed-load range controller for a direct current (DC) shunt motor based on proportional integral derivative (PID controller) with genetic system for controller parameters adjusting. The genetic based PID controller is simulated by using Matlab software package and tested with different sudden load values and different working speeds. A present control loop contains the suggested PID controller also pulse width modulation PWM generator and H-bridge inverter. With the genetic system enhancement to parameters of developed PID controller, the results demonstration that this controller has great impact to preserve the profiles of the motor speed and produced torque after applied sudden load, and its intensification the motor performance at different speed and load conditions.

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1. INTRODUCTION

The direct current (DC) motor has broadly applications within the electrical and industrial systems. It is used where continuous speed is required and starting settings are not severe. It serves in many applications such as; rolling grindery, paper factories, machine tools, traction, printing presses, textile factories and cranes, and so on [1]. DC motors can smoothly control to nil speed, directly followed by fast-tracking in the opposite direction [2].

DC motors are like all electric motors; the speed is subjected to troublesomeness and it falls during normal or sudden loads. For this aim, various traditional speed processing techniques such as the PID controller are used. The traditional PID controller has a functional ease that allows engineers to activate it in a simple and direct way. The PID controller is linear and works very well within the bounds of the working point [3-6]. When the motor operates at different speed and load conditions the PID parameters must be retuned to the current operating conditions.

Today, artificial cleverness is a beneficial tool when applied to solving engineering challenges. Several intelligent techniques are employed on the classic PID controller for performance improvment [7-13]. The genetic process is significantly used in the modern control arrangement [14-18]. In this paper, a genetic algorithm is designed, simulated by using Matlab simulation package and used for handling the online parameters tuning of PID controller for shunt type DC motor running under various operating situations.

2. RESEARCH METHOD

2.1. Mathematical representation of the suggested motor

In general, DC shunt motor circuit can be illustrated as in Figure 1.

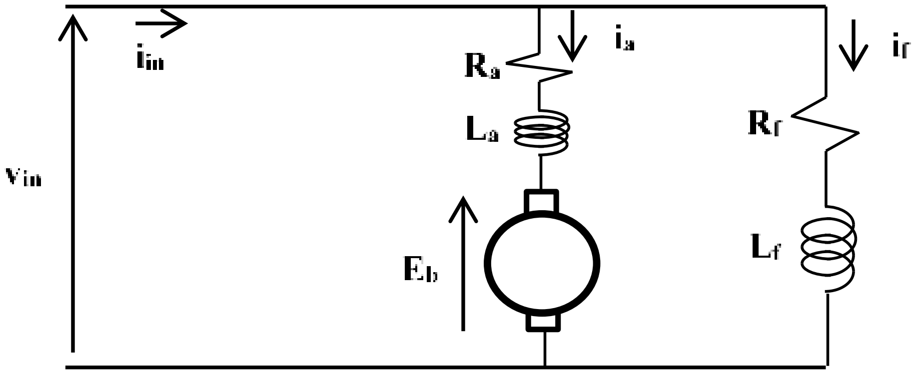


Figure 1. Motor equivalent electrical circuit

The dynamic mathematical model of the motor is given by [19, 20]:

1) The electric representation of the armature circuit is:

$$V_{in} = E + R_a . i_a + L_a . \frac{di_a}{dt} \tag{1}$$

$$E_b = K\phi\omega \tag{2}$$

Where L_a: inductance of armature coil, i_a: armature current, R_a: armature resistance, K: constant related to the design of the machine, ϕ: flux per pole and ω: rotor rotational speed.

2) The equation of the field circuit is:

$$V_{in} = R_f . i_f + L_f . \frac{di_f}{dt} \tag{3}$$

Where L_f: field coil inductance, i_f: field current, V_{in}: terminal voltage, and R_f: field coil resistance.

3) The motion calculation of the motor is:

$$J \frac{d\omega}{dt} = K\phi i_a - T_L \tag{4}$$

$$\phi = K' i_f \tag{5}$$

$$\text{Then } J \frac{d\omega}{dt} = K K' i_f i_a - T_L = K_1 i_f i_a - T_L \tag{6}$$

Where J: motor inertia, and T_L: load mechanical torque.

The suggested motor has the following parameters as specified in Table 1.

Table 1. Parameters of the proposed motor

Parameter	Value
R_a	0.6 Ω
L_a	0.012 H
R_f	600 Ω
L_f	12 H
K_1	1.8
J	0.3 kg.m^2
Rating speed	1220rpm
Rating voltage	240V
Rating power	5hp

2.2. Design of the proposed work drive circuit

In this paper the proposed motor drive circuit consists of H-type bridge with insulated gate bipolar transistor (IGBT) inverter signaled by pulse width modulation (PWM) generator. The PWM technology controls the transfer of energy from any electrical component to another by quickly switching between full power transmission and no power transmission. The PWM generator block productions can be either 1 when the duty cycle is larger than the carrier signal value or 0 otherwise else [21-24]. The duty cycle is the production variable for the PWM carrying information and symbolizing the converter control function. Thus, fluctuating the duty cycle value owing to speed change is the regulator idea in the DC motor. The modulation index can be changed from 0 to 1. The construction voltage of the bridge can be exact by this parameter. The Matlab simulation of the recommended DC shunt motor and drive circuit is given in Figure 2.

The model is tested with applying sudden load of (T_L= *30 Nm*, at *t= 5 sec*). The motor input current and voltage with modulation index (0.6) and carrier frequency (2000 Hz) are given in Figure 3.
The motor speed and torque profiles for existing load condition are displayed in Figure 4. The instant of load applied has influenced the speed profile and dropped it down from the no load speed. The aim of this paper is to design an intelligent speed controller to overcome the speed drop and swinging at different loads and speeds conditions.

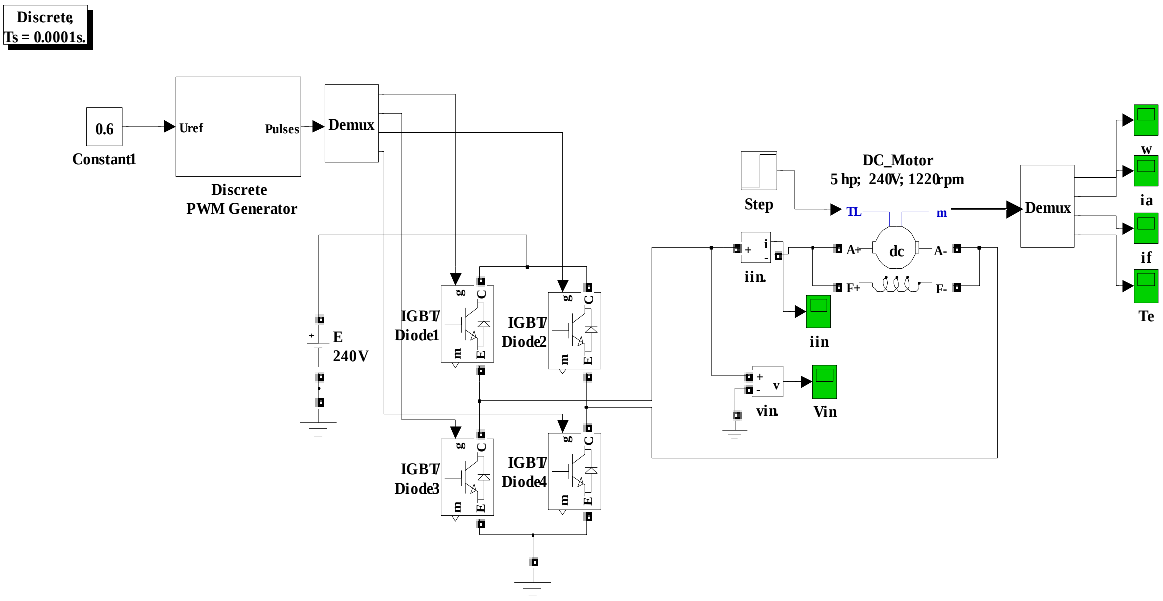
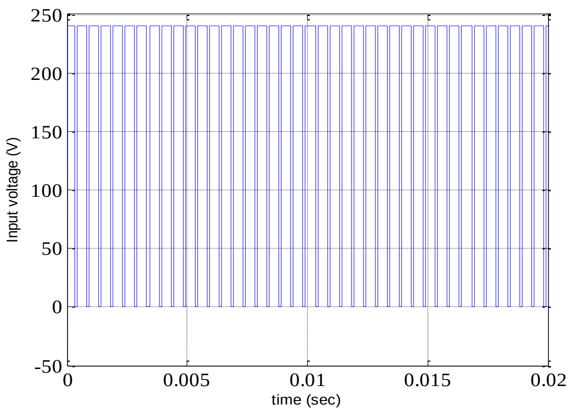
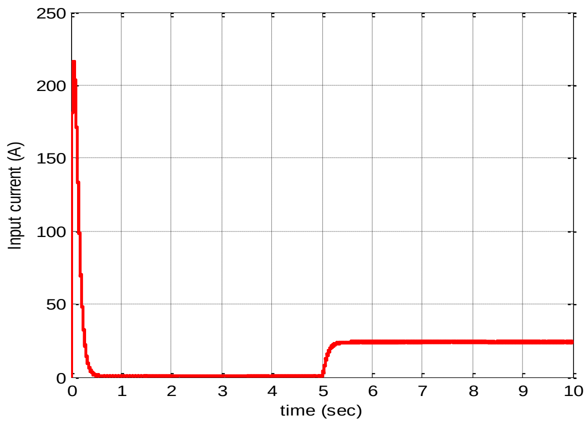


Figure 2. Motor model simulation with the suggested drive circuit

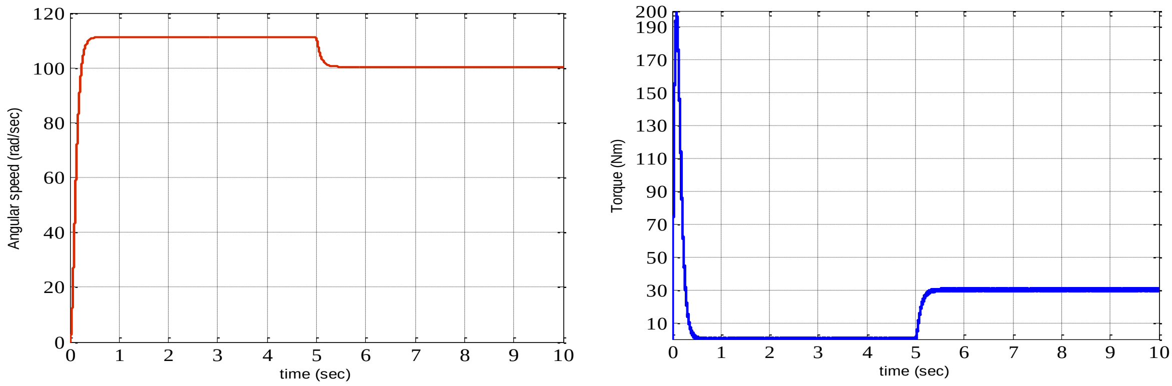


(a) Input voltage



(b) Input current

Figure 3. Motor input voltage and current



(a) Motor angular speed (b) Motor electrical torque

Figure 4. Motor angular speed and electrical torque responses under load condition

2.3. Design and simulation of genetic system

The genetic process is a research finding grounded on Charles Darwin's theory of natural evolution. This process imitates the natural choice process in which the most suitable individuals for imitation are chosen in order to produce descendants of the next generation. The natural selection procedure begins with the choice of the most fit people from the population. They yield an offspring that accede to the fathers features and will be extra to the subsequent group. If parentages have improved appropriateness, their descendants will be enhanced than parentages and they will have a well chance of existence. This process continues to repeat and eventually, a generation with the most fit individuals will be found. This knowledge can be applied to the research problematic. We contemplate a set of explanations to a problem and choose the best group. Five stages are reflected in the genetic algorithm [25-29].

2.3.1. Initial population

The expansion initiates with a group of persons called the population. Everyone is an exposition to the problem that they want to interpret. A separate is considered by a group of variables known as genetic factor. The genes are linked in a chain to form the chromosome (solution). In the genetic algorithm, the group of separate genes is signified using a thread, in alphabetical order. Usually, binary values are used (a series of 1s and 0s). We say that the cipher genes into the chromosome.

2.3.2. Fitness function

The fitness meaning governs the suitability of the separate (the person's ability to compete with other individuals). It gives fitness to everyone. The likelihood that an individual will choose to strain be determined by the degree of his fitness.

2.3.3. Selection

The selection stage idea is to choose the fit characters and allow them to authorization on their genes to the next generation. A couple of individuals (parents) are chosen based on their fitness degrees. People with high fitness have a greater chance of choosing to reproduce.

2.3.4. Crossover

Crossover is the greatest important stage in a genetic process. For both couple of parents to mate, the intersection point is arbitrarily chosen from within the genes.

2.3.5. Mutation

In some newly formed offspring, some of their genes may be exposed to a mutation with a low random probability. This means that some bits in the bit chain can be reversed. The general genetic algorithm stages can be represented in the flow chart as shown in Figure 5. On this flow chart the Matlab model of genetic algorithm system for the proposed work can be established as given in Figure 6.

In this work after selecting the initial population, it is converted to the binary format. The crossover stage is made with two different ways to generate four different children. In the beginning, the crossover takes place at the four least bits of the parents and then it takes place at the five least bits of the parents as shown in Figure 7.

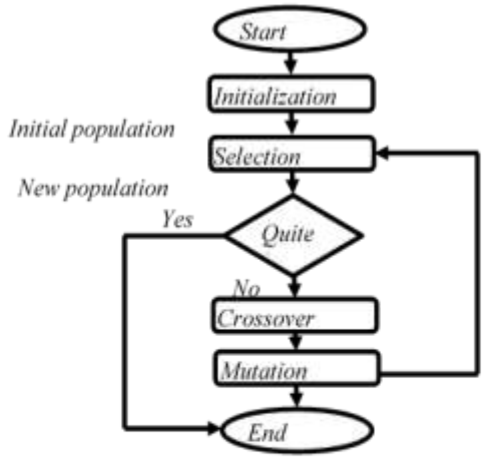


Figure 5. Genetic algorithm flow chart

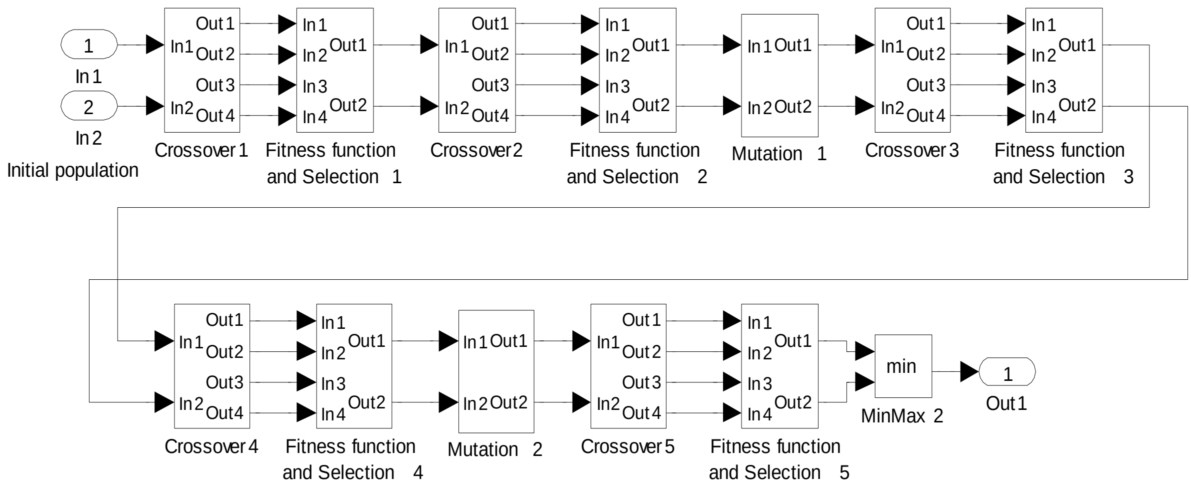


Figure 6. Genetic algorithm system of the proposed work

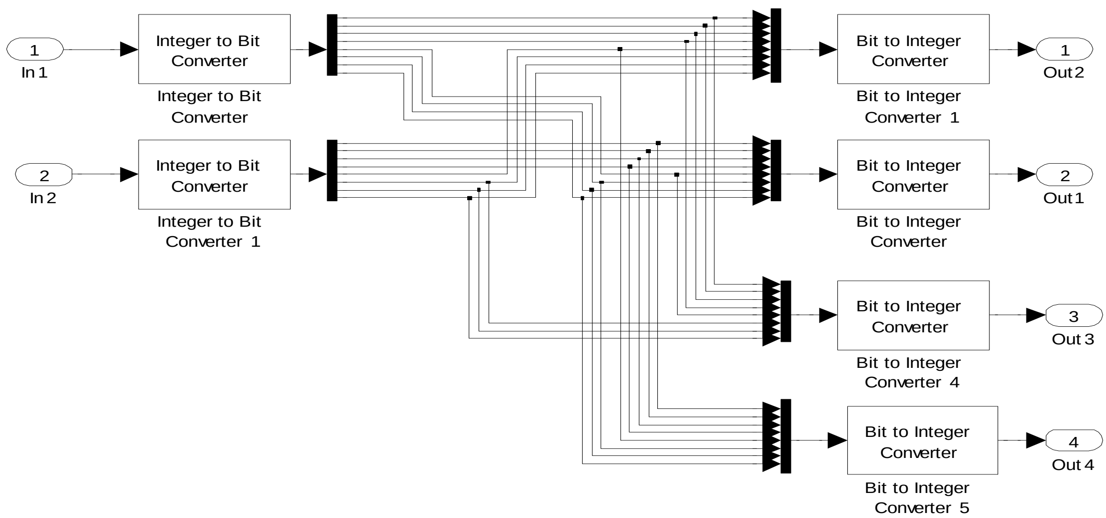


Figure 7. The crossover stage

The fitness task and selection steps are combined in one stage as exposed in Figure 6. In this work the genetic system inputs are error signals (speed error and electric torque error) thus they must be minimized as possible. Therefore, the fitness function is given by [30]:

$$Fitness = \int_0^{t_{sim}} e(t)^2 dt \tag{7}$$

The selection stage is designed to select the children which have less possible values of fitness functions as shown in Figure 8. The mutation stage is made with two different ways (mutation 1 and mutation 2) to produce more generations as shown in Figure 9.

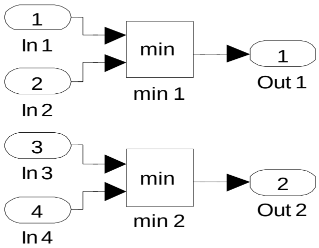
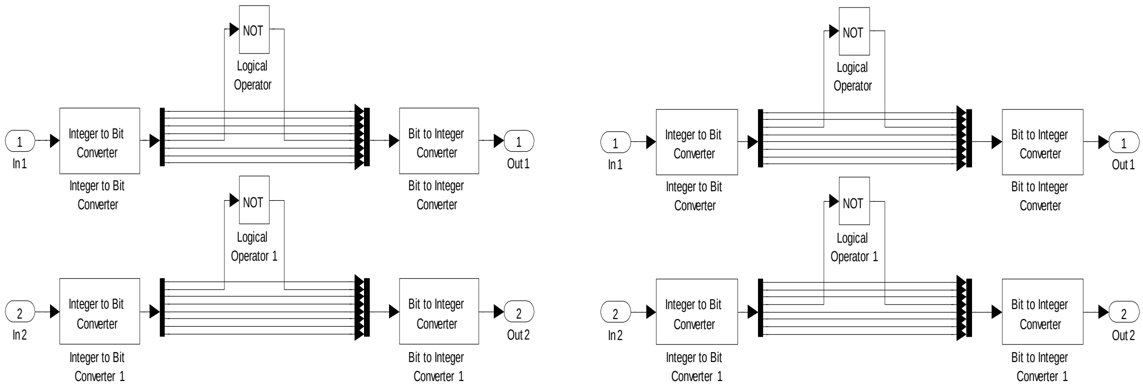


Figure 8. The fitness and selection stage



(a) Mutation 1 (b) Mutation 2

Figure 9. The mutation stage

2.4. Design of the proposed controller

The schematic representation of the proposed controller is given in Figure 10. Obviously, the genetic system enhances the parameters of PID controller in order to satisfy the design criteria.

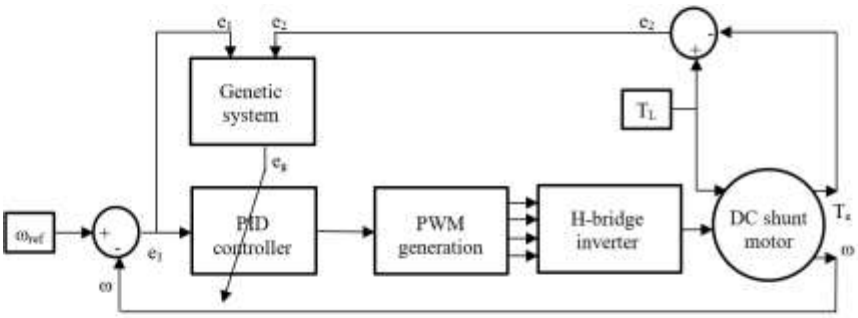


Figure 10. The proposed controller scheme

The PID controller equation weighs the relative term with a factor k_p, the integral term with a factor k_i, and the derived term with a factor of k_d, as given below:

$$u(t) = k_p e(t) + k_i \int_0^t e(\tau)d\tau + k_d \frac{de(t)}{dt} \quad (8)$$

A "control loop" is a feedback mechanism that efforts to correct variances between the measured progression variable and the required set point. In the proposed controller, the genetic system has two inputs; the speed error ($e_1(t)$) and the electrical torque error ($e_2(t)$). The genetic system will produce new genetic children from these errors and the final genetic system output is the genetic error ($e_g(t)$) which is used in the on-line parameters tuning for the PID controller as follows:

$$k_p(t) = k_p\, e_g(t) \quad (9)$$

$$k_i(t) = k_i\, e_g(t) \quad (10)$$

$$k_d(t) = k_d\, e_g(t) \quad (11)$$

As shown in (8) can be modified as follows:

$$u(t) = k_p(t)\, e_1(t) + k_i(t) \int_0^t e_1(\tau)d\tau + k_d(t) \frac{de_1(t)}{dt} \quad (12)$$

The Matlab simulation of the complete system is given in Figure 11. The proposed PID controllerhas the following initial parameters (*k_p = 5, k_i = 0.07, k_d = 0.1*).

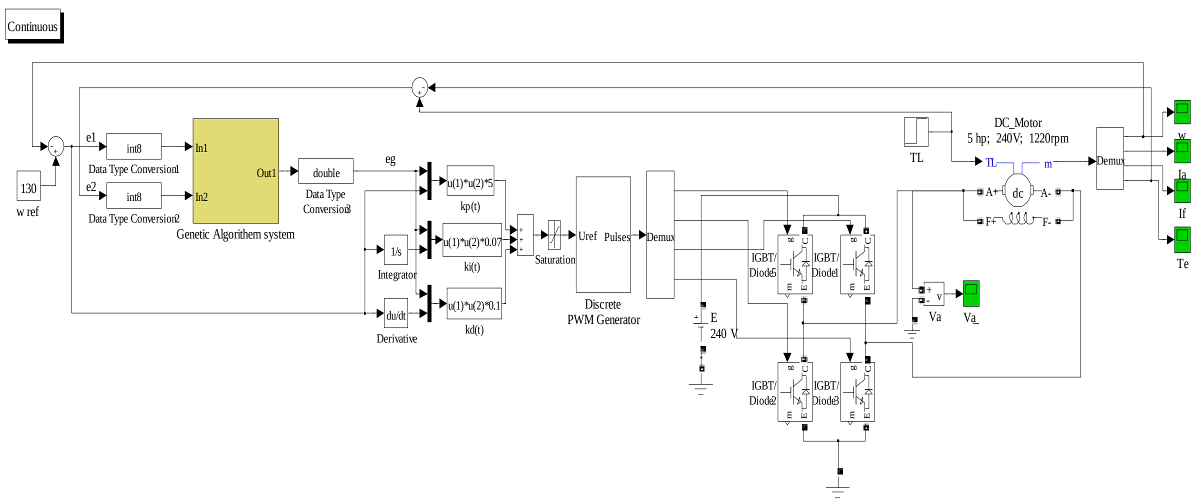


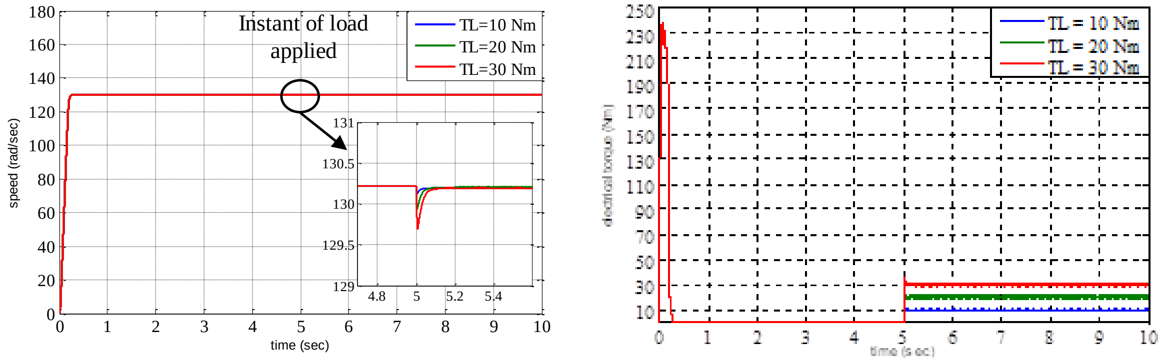
Figure 11. Matlab simulation of complete system model

3. RESULTS AND DISCUSSION

To corroborate the proposed controller ability, the system is tested with different load torques and operating speeds values.

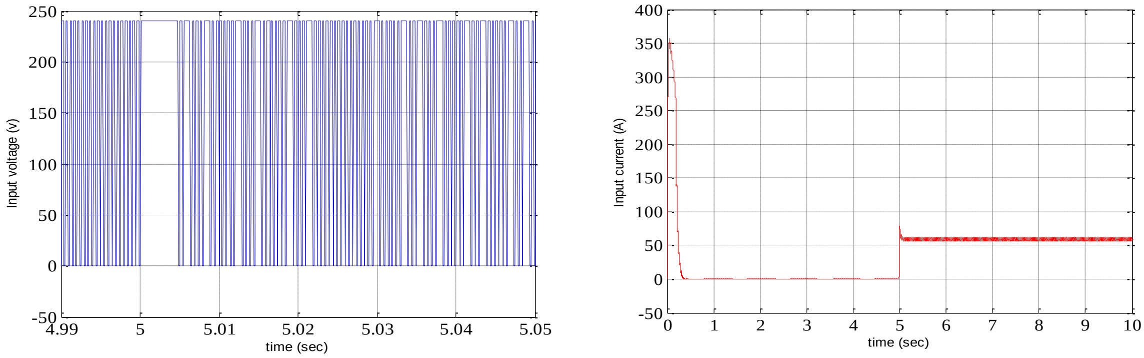
3.1. Different load torque values test

At first, the motor runs at speed (130 rad/sec) and it has been applied three different sudden load torques (10, 20, and 30 Nm) at time instant (t=5 sec). The motor speed and torque profiles under the proposed controller are given in Figure 12. Figure 12(a) evidences the ability of the proposed controller to keep the motor speed constant even when different load values were applied. Furthermore, the motor electrical torque profiles have very fast response to the different sudden loads as shown in Figure 12(b). When the motor is operated with the suggested controller, its input voltage and current with sudden load of (10 Nm) at instant (t=5 sec) are shown in Figure 13.



(a) Motor speed (b) Motor electrical torque

Figure 12. Motor speed and electrical torque profiles under the proposed controller with different sudden load torques (10, 20, and 30 Nm) and (operating speed=130 rad/sec)

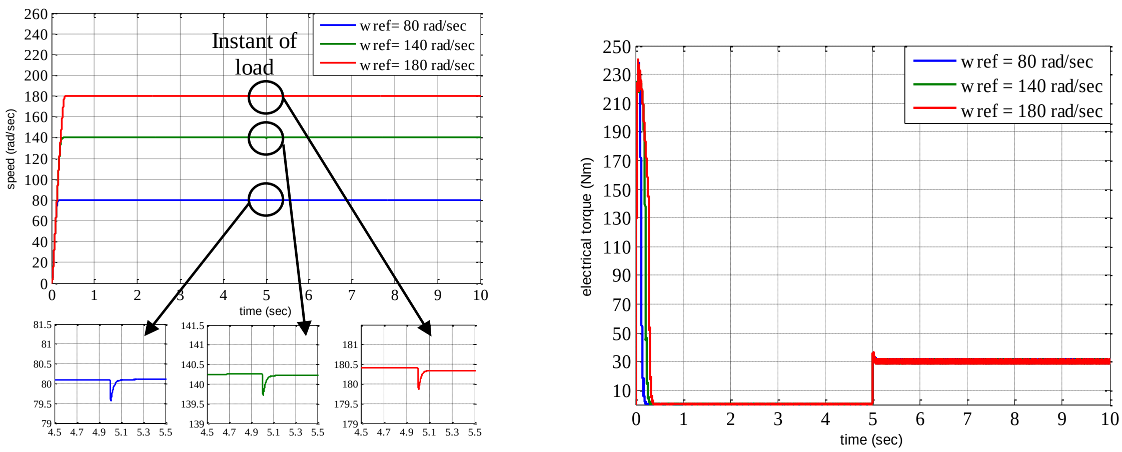


(a) Motor input voltage (b) Motor input current

Figure 13. The motor input voltage by suggested controller

3.2. Different operating speeds test

The main disadvantage of a traditional controller is not working efficiently at different operating conditions. The proposed controller superlatively overcomes this situation as shown in the second test which is prepared by running the motor with different operating speeds (80, 140, and 180 rad/sec) and appliying sudden load of (30 Nm) at time instant (t = 5 sec). The motor speed and torque profiles for these cases are given in Figure 14.



(a) Motor speed (b) Motor electrical torque

Figure 14. The motor speed and electrical torque profiles with different operating speeds (80, 140, and 180 rad/sec) and applying sudden load of (30 Nm) at time instant (t = 5 sec)

From Figure 14(a), it is shown that with the aid of the proposed controller the motor speed profiles stay constant for different operating speeds with sudden load applying. Also the operating speed can easily change in this controller by adjusting the speed reference value (ω_{ref}) only. For the similar operating conditions, the motor torque profiles are given in Figure 14(b) which show the motor electrical torques have very fast response to the sudden load applying.

4. CONCLUSION

This paper presented the design of on-line tuning PID controller strengthened by genetic procedure for speed control of DC shunt motor. The proposed controller is constructed and verified by using Matlab simulation package. The test results show that, the proposed controller has high efficiency to keep the motor speed constant through sudden load applying. Also, when applying different sudden load values, the proposed PID controller has an excellent speed stabilization due to its online parameters tuning by the genetic system. In addition, the motor operating speed can easily change by adjusting the reference speed value in this controller. Unlike the traditional PID controller, the suggested controller has a wide control range even with extensive varying in the motor operating speed.

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