Simulation model of proportional integral controller-PWM DC-DC power converter for DC motor using MATLAB

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ABSTRACT

Smoothly speed range changing, easily speed controlling, and swiftly dynamic response for load torque changing are the main merits which are delivered by direct current (DC) motors. They are also distinguished by their versatility. All these characteristics make the DC motors suitable candidates for various applications. An accurate high-speed control with a good dynamic response, would be of demand for many applications of the DC motors. Controlling the speed of motors using conventional systems is one of the most important method that is adopted and it can be more efficient when used with electronic power devices to control the output voltage. Hence, this paper introduces an efficient proportional integral (PI) speed controller for DC motor fed by direct current-direct current (DC-DC) convertor, which is switched by pulse-width modulation technique. MATLAB/Simulink environment is used to build the whole system. Two operation scenarios have been conducted including constant load with variable speed and variable load with constant speed.

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1. INTRODUCTION

Electric motors are of great importance in many industrial, domestic and military applications. They are used in the process of moving vehicles, including elevator cars, cars, trains, printing and textile machines and other applications. Direct current (DC) motors are considered as one of the most important electric motors because of their advantages including small size, lower cost and light weight. Their maintenance is low, and they feature high torque and a wide range [1]–[3]. Most of the DC motor applications require high performance speed controller. The speed control systems of the DC motor or the so-called control units can be classified into traditional, expert and optimum control systems. Conventional control systems are the most widely used and the simplest to operate. The types of proportional–integral–derivative (PID) controllers are based on the correlation method between the error (i/p) signal and the actuating (o/p) signal. Hence, there are P, I, D, PI and PID controllers. It is worth mentioned that the most common used are PI and PID controllers [4]–[6].

As it has been mentioned above considerable applications of the DC motor would need efficient speed controller with accurate dynamic response. Thereby, controlling of such motors have gained considerable attentions in literatures. PI and PID controllers have been using for motor control application due to uncomplicated structures and intelligible control algorithms. Three methods including Ziegler Nichols, Cohen-coon, and chien-hrones-reswick method (CHR) for tuning the parameters of the PID DC motor controller were compared in [7]. It was stated that the second method had the rapidest setting time and least overshoot compared to other methods.

In order to tackle the tuning problem of PI and PID controllers and obtained optimal performance at different operation speeds, a self-tuning PID DC motor controller was reported in [8]. It was shown that the motor performance can be improved with the self-tuning controller for various speed ranges. PI controller parameter tuning based on particle swarm optimization algorithm was suggested in [9]. The suggested method was compared with the conventional methods. The comparison results showed that the suggested controller possess the advantages of simply implementation, stabilized convergence characteristic, and its computational efficiency was good, over the other methods. A comparison between PI and PID controllers was conducted in [10]. It was concluded that the PID controller offered better performance than the PI controller. Tuning the PI and PID controller by obtained parameters from plant step response was introduced in [11]. It was shown that the specifications of the transient performance could be met, since such method delivered systematic adjustment of the proportional gain.

Using the DC motor in various sectors required an efficient drive system to such motor. Thinks to the development of the power electronic device that enables to have electrical machines drives based on power electronics, which are distinguished by small size and more efficient than the conventional counterparts. Considering the type of the coinventor, the DC motor drive based on power electronics can be classified into two categories. When using one- or three-phase rectifier, i., e., Alternating current-direct current (AC-DC) convertor, the drive is named as rectifier fed. On the other hand, when DC-DC convertor is utilized, the DC motor drive is known as chopper fed drive [12]. Driving the DC motor by AC-DC convertor have been detailed in many literatures [13]–[15]. Nevertheless, manufacturing highly effective semiconductor-switches results in production of high-speed response as well as high operating frequency of the DC-DC convector, which in consequence increases the application of such convertor in DC motor drive. Hence, driving the DC motor using the DC-DC convertor has gained consider attentions in many literatures [16]. Introduced 4th orders mathematical models for DC motor coupled with DC-DC convertor and PI controller to regulate the angular velocity of the motor. Utilizing differential flatness technique, smooth starter for regulation the velocity of A buck DC-DC convertor DC-motor drive system the motor was detailed in [17]. A numerical simulation was utilized to verify the drive system. Additionally, based on the 4th order and differential flatness of DC-DC convertor DC motor drive system an angular velocity path tracking controller was presented in [18]. Moreover, [19] conducted a comparative study based on numerical simulation in order to evaluate three controller systems for DC-DC convertor DC-motor, namely, PI, PI based Fuzzy logic and linear quadratic regulator. It was shown that all the understudying controllers can successfully track the angular velocity trajectory of DC-DC convertor DC motor drive. Similarly, a comparison based on the simulation results between the PI and Backstepping controllers for a combination of DC-DC convertor and DC motor system was introduced in [20]. It was stated that the Backstepping controller offers less setting time than the PI counterpart.

Controlling the switching mode of the DC-DC convertor has been a subject for many literatures, since it is directly effect the performance of the convertor. In fact, many methods have been discussed and each has its merits and demerits. The most popular switching control method is pulse width modulation (PWM) [21]. Seeking a constant operating speed of the DC motor, A microcontroller was used to control the speed of DC motor associated with DC-Dc convertor driven by PWM in [22]. Similarly, based on microcontroller [23]designed a closed loop control for dc motor supplied by PWM. It was stated that the controller could be applied to any motor size with high accuracy. Furthermore, DC motor controller using DC-DC convertor and PWM technique was developed in [24]. It was shown that using the PWM technique provided more flexibility to the motor controller. Mathematic models for DC-DC boost convertor and DC motor and PID controller associated with PWM technique were introduced in [25]. It was found that controlling the DC motor using the closed loop PID controller had better performance compared to driving the motor with open loop and constant DC voltage source.

In this paper PI speed controller for DC motor fed by DC-DC convertor, which is switched by PWM is introduced. MATLAB/SIMULINK environment is utilized to build the whole system, including the motor, the convertor, the PWM and the PI controller. The rest of the paper will be as following: section 2 discusses the DC motor and its dynamic model, section 3 describes the PI controller, while sections 4 and 5 are discussing the PWM technique and the DC-DC convertor, respectively. Moreover, the simulation model is described in section 6, the results are shown and discussed in section 7 and the last section 8 is for the conclusion.

2. DC MOTOR

DC motor has been found for about one century. Actually, DC power was used to design and built the first electrical motor. Although an AC motor is basically utilized in high speed application since it is smaller, less weigh as well as cost and required less maintenances compared to the DC motor, the latter is still used in many industry applications. This is because the DC motor offers wide ranges of speed, adequate speed regulation, simpler control and generally, less cost drive system [26]. According the way of the field winding excitation the DC motor can be classified into separately-excited and self-excited. The later is further classified based on the interconnection between the field and the armature windings into shunt, series and compound motors. Selection of the DC motor type is based on its performance and characteristics. Controlling the speed of the DC motor has been of interesting for many researches [7]–[25]. Generally, there are three methods to control the speed of the DC motor:

a) Controlling the magnetic field of the stator.
b) Controlling the resistance of the armature.
c) Controlling the applied voltage.

The dynamic model of the DC motor can be described by the following (1)-(4).

$$v_a = r_a + l_a \frac{di_a}{dt} + b_{emf} \quad (1)$$

$$\mathrm{T}_m = k_t i_a(t) \quad (2)$$

$$\mathrm{T}_m = J\frac{d^2\omega(t)}{dt^2} + B\frac{d\omega(t)}{dt} \quad (3)$$

$$b_{emf} = b_{emf}(t) = K_b \frac{d\omega(t)}{dt} \quad (4)$$

The transfer function can be found by tacking the $\frac{\omega\,(s)}{v\,(s)}$ ratio in (5),

$$\frac{\omega(s)}{v_a(s)} = \frac{K_b}{[Jl_a s^2 + (r_a J + Bl_a)s + (K_b^2 + r_a)]} \quad (5)$$

where r_a, l_a, i_a and v_a are armature resistance, inductance, current and voltage, respectively. T_m and k_t represent devolved torque by the motor and its constant, respectively. J and B indicate the moment of inertia and friction constant, respectively. $\omega(t)$ is angler speed of the motor. b_{emf} and K_b are back-emf voltage and it constant, respectively [27].

3. PI CONTROLLER

Proportional-integral controller, which is well known as PI controller has gained popularity and it dominate over other controllers in many sectors particularly the industry sector for many decades. This is because such controller possesses the following merits:

a) Uncomplicated construction.
b) Cheap.
c) Easy to design.
d) Delivers good performance in the control system.

The PI controller is used for enhancing system steady state errors response, as the control system is increased by one when using it. On the other hand, such controller does not have the ability to perform very with nonlinear and uncertain systems. However, adding a derivative (D) mode to the PI controller could solve such problem. It must be mentioned that although the incessant advances in the control theory, the PI controller is a powerful candidate for various industry applications, particularly when the fast response is not demanded on the whole control system [28]. Hence, regarding to the advantages of the PI controller, it will be used in this paper. The PI controller adjustment requires two parameters to be determined, i.e., the proportional (P) and the integral (I). the PI transfer function is given by (6).

$$G_c(s) = k_p + k_i \frac{1}{s} \quad (6)$$

4. PWM TECHNIQUE

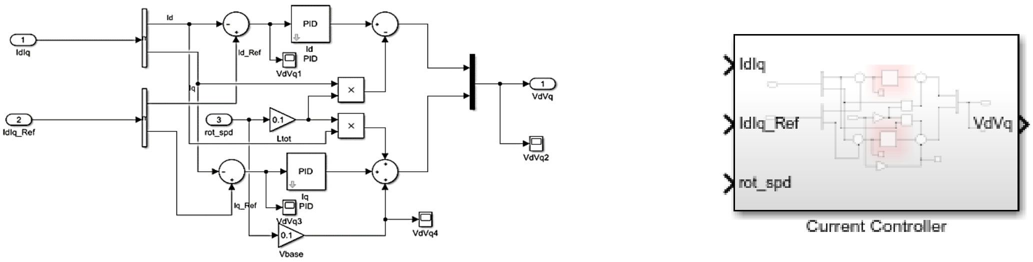
PWM is an efficient mechanism to control an analog circuit by a digital output microcontroller. Such technique has been used in various applications, including communication systems, power control and motor drives. The PWM usually delivers pulses with constant frequency as well as value and difference width. By the advantage of overcoming the week starting problem of the motor, the PWM technique is considered as the most common method to control the speed of the electrical motor. Switching of the power electronic convertor using the PWM delivers the advantages of reduction of the dissipated power, simple structure, no variation in the temperature and suitable with the microprocessor [29].

5. DC-DC POWER CONVERTER

DC-DC convertors are power electronic devises, which convert the DC voltage from the constant values to variable values. Due to the similarity in the behavior of such convertors and the Alternating current (AC) transformers, the DC-DC convertors are usually considered as the DC equivalent of the AC transformers. Since the introductions of the DC-DC convertors, they have been used where ever the DC voltage level need to be changed from one value to another value. This is because they distinguished by rapid response, high efficiency and capable for regeneration operation. Considering the value of the output voltage of the convertors, they can be classified into two types: (a) buck type in which the output voltage is less than the input voltage, (b) boost type where the convertor output voltage is higher than it input voltage. Circuit diagrams of the buck and boost convertors are shown in figure. It should be noted that the switch is a power electronic device and it can be MOSFET, IGBT, BJT, GTO, MCT [30].

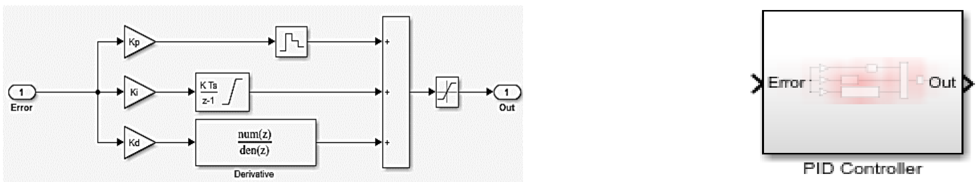
6. SIMULATION MODEL

In this section, a simulation of the entire system will be presented. This system consists of five main parts including, a flow controller simulation model using a PID controller, Figure 1 is current controller using PID controller, consists of Figure 1(a) a flow controller simulation model using a PID controller, and Figure 1(b) a current controller subsystem using a PID controller. Figure 2 is PID controller, consists of Figure 2(a) simulation model of PID controller, and Figure 2(b) subsystem of PID controller speed simulation model using PI controller, Figures 3 is Speed controller by using PI controller, consists of Figure 3(a) Simulation model of Speed controller by using PI controller, and Figure 3(b) subsystem of speed controller by using PI controller and Figure 4 is PI controller, consists of Figure 4(a) simulation model of PI controller, and Figure 4(b) subsystem of PI controller. Simulation model of electrical and mechanical aspects of the motor, Figures 5 and 6. Figures 7 and 8 show the no-load and load-bearing simulation models.



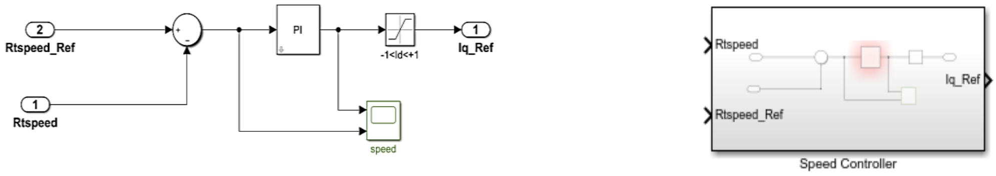
(a) (b)

Figure 1. Current controller using PID controller, (a) simulation model of current controller using PID controller and (b) subsystem of current controller using PID controller



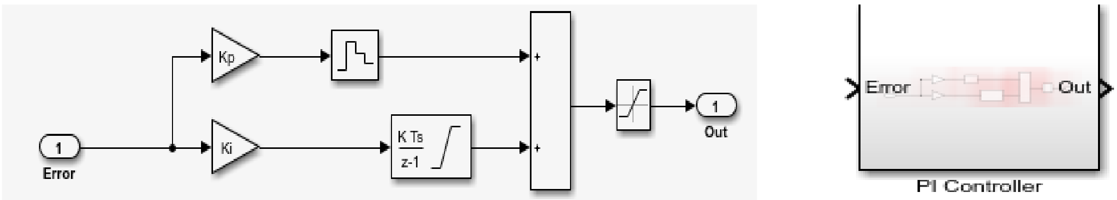
(a) (b)

Figure 2. PID controller, (a) simulation model of PID controller and (b) subsystem of PID controller



(a) (b)

Figure 3. Speed controller by using PI controller (a) simulation model of speed controller by using PI controller and (b) subsystem of speed controller by using PI controller



(a) (b)

Figure 4. PI controller (a) simulation model of PI controller and (b) subsystem of PI controller

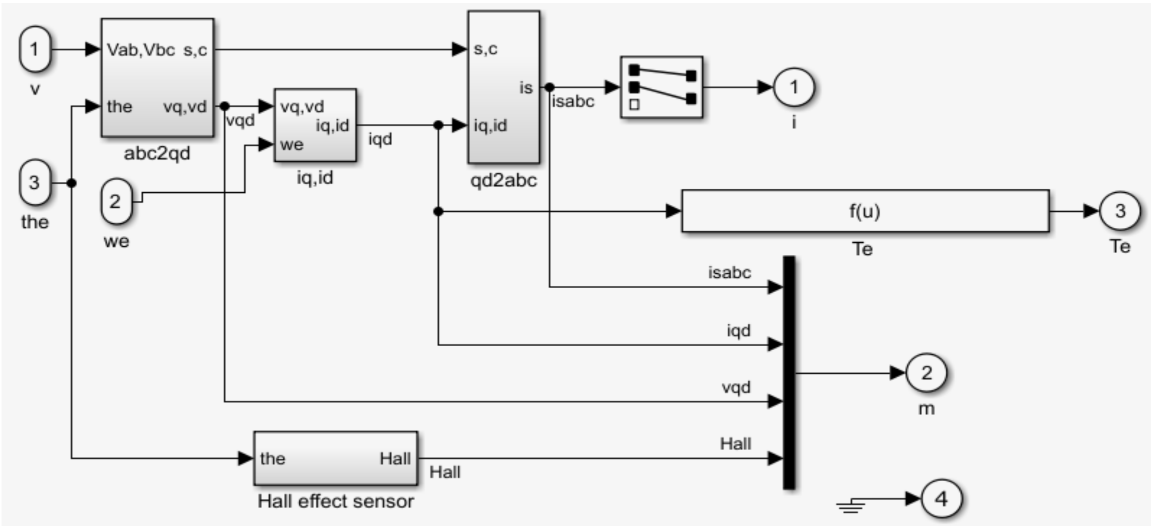


Figure 5. Simulation model of electrical motor

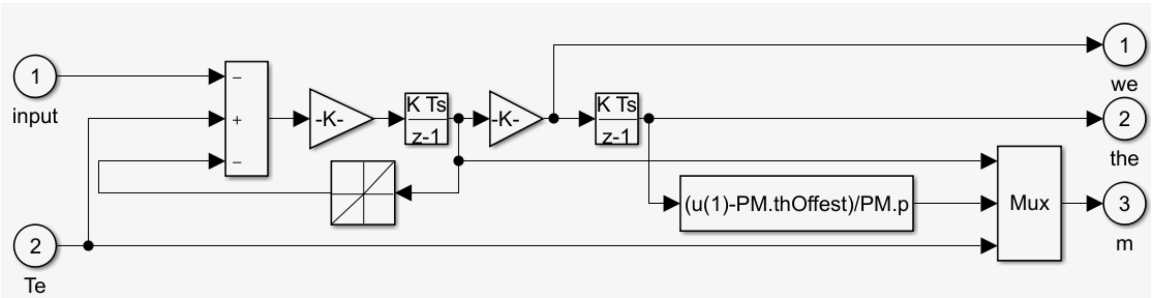


Figure 6. The simulation model of mechanical motor

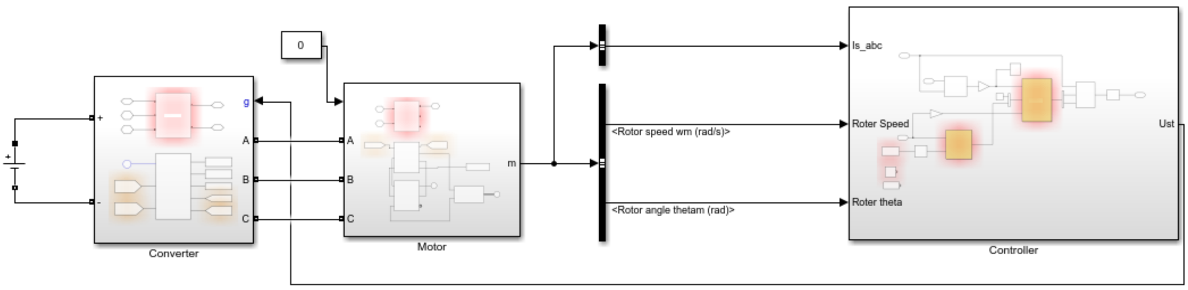


Figure 7. Simulation model with no load

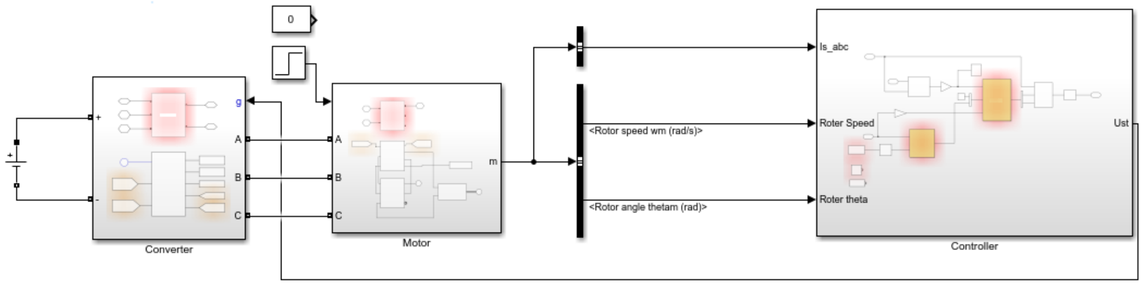
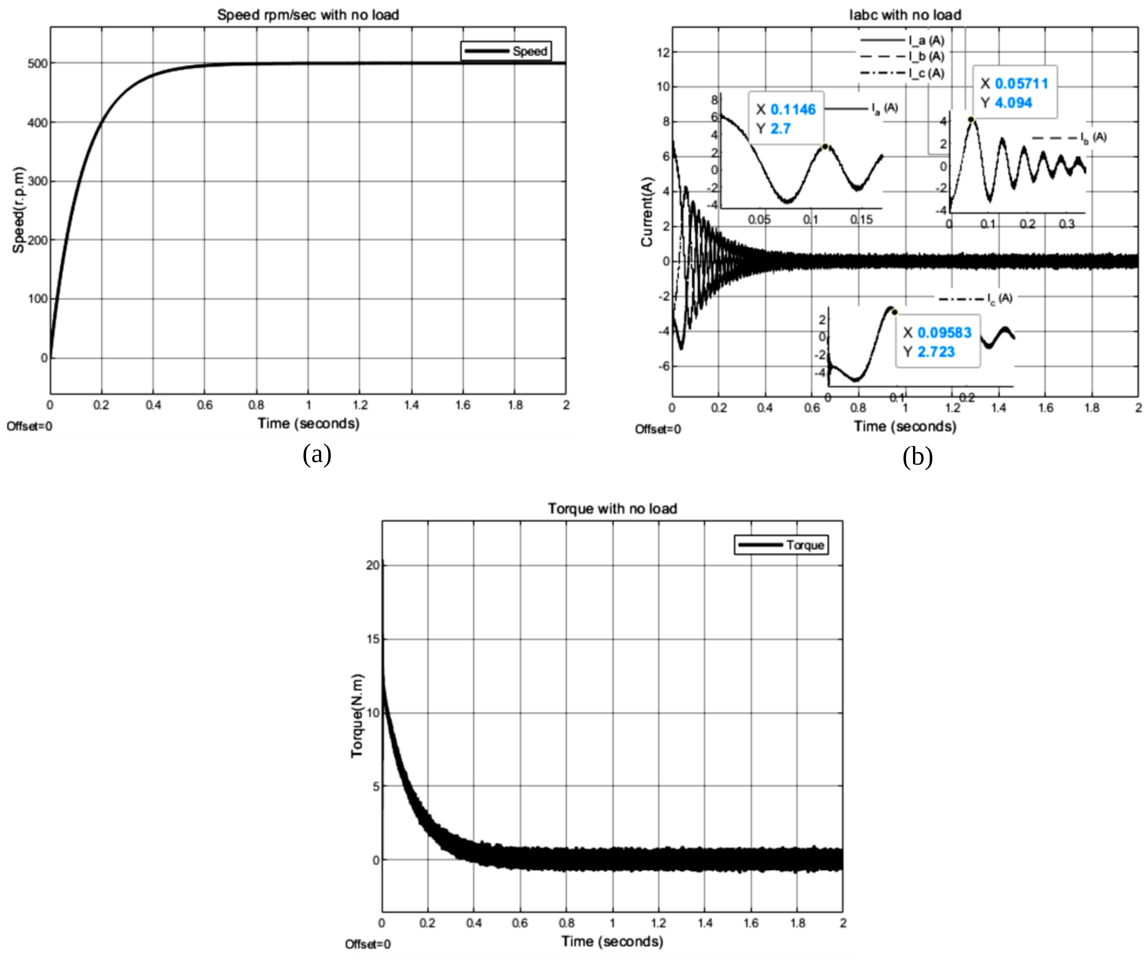


Figure 8. Simulation model with load

7. SIMULATION RESULTS

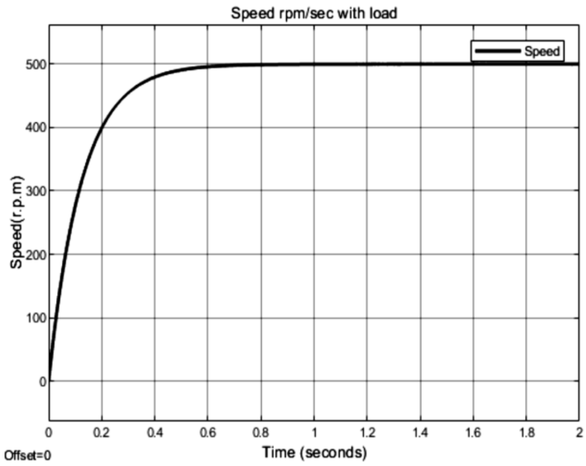
7.1. Constant speed at no-load and load

Two conditions i.e., e., no load and load were investigated for the same speed, i.e. 500 rpm. The speed, current and torque profiles for both speed values are shown in Figures 9 and 10. It can be noted that the simulation time is 2 Seconds. for both cases. Steady state time for both speeds is 0.6 Seconds. Since the no-load current is only required to overcome the internal friction at the rated speed of the motor, the speed as shown in Figures 9(a) and 10(a), is small compared to the load shown in Figures 9(b) and 10(b). The starting torque of the load condition is higher than the no-load condition as shown in Figures 9(c) and 10(c). This is because torque is directly proportional to current.

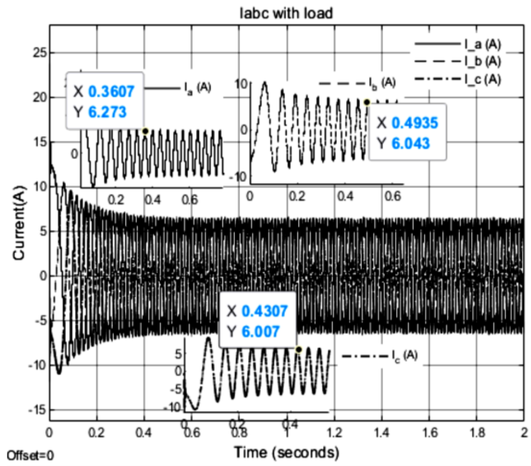


(a) (b) (c)

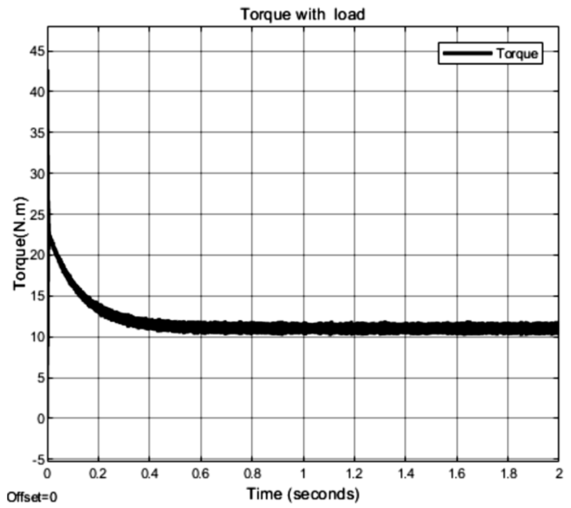
Figure 9. Simulation results of constant speed (500 rpm) at no load (a) speed, (b) current, and (c) torque



(a)



(b)



(c)

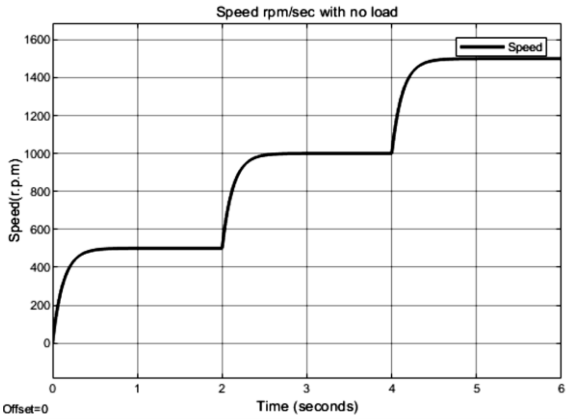
Figure 10. Simulation results of constant speed (500 rpm) at load (a) speed, (b) current, and (c) torque

7.2. Variable speed with no-load and load

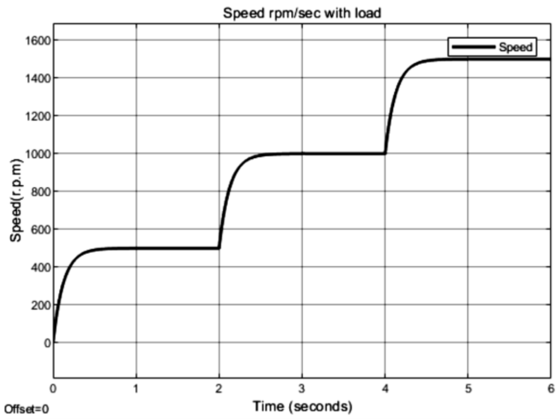
Table 1 summarizes the performances of the speed controller for constant and variable speeds with no-load and load conditions. At no-load and load conditions the increasing of the speed leads to decreasing the current and starting torque. The same mentioned reason above. The simulation has conducted for three different speed values including (500, 100 and 1500) rpm. The profiles of speed, current and torque for both no-load and load conditions have been predicted, as shown in Figures 11 and 12, respectively. The speed as shown in Figures 11(a) and 12(a), is current shown in Figures 11(b) and 12(b). The torque as shown in Figures 11(c) and 12(c). This is because torque is directly proportional to current. It can be noted that the value of starting torque is decreasing with the increasing of the speed for both no-load and load conditions. Due to the fact that the motor speed is inversely proportional to the flux, while the torque is directly proportional to the flux. Hence, increasing the speed means that the flux is decreasing, which consequently desreses the torque.

Table 1. Comparative between constant speed and variable speed

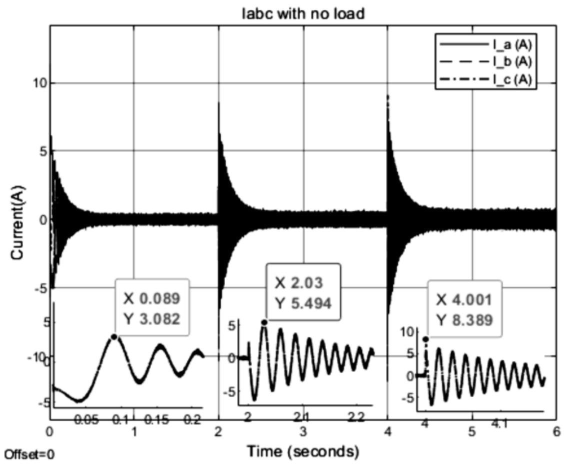
States/Parameter	Speed (rpm)	Current (A)	Staring Torque (N.m)
Constant Speed with no load	500	8	22
Constant Speed with load	500	12	65
Variable Speed with no load	(1500,1000,500)	(5,6.5,8)	(20,20,22)
Variable Speed with load	(1500,1000,500)	(12,23,28)	(42,52,55)



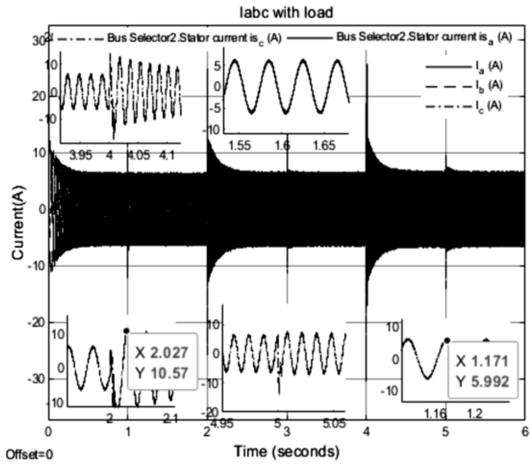
(a)



(a)



(b)



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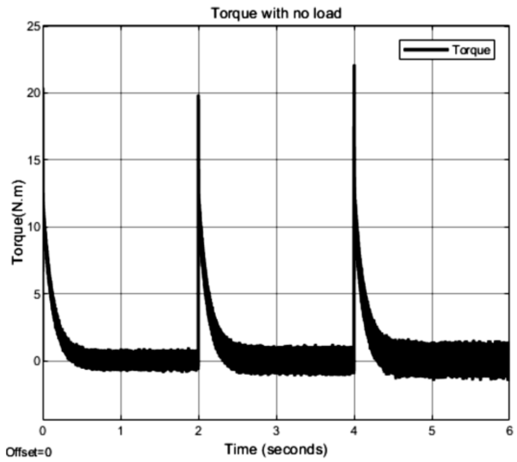
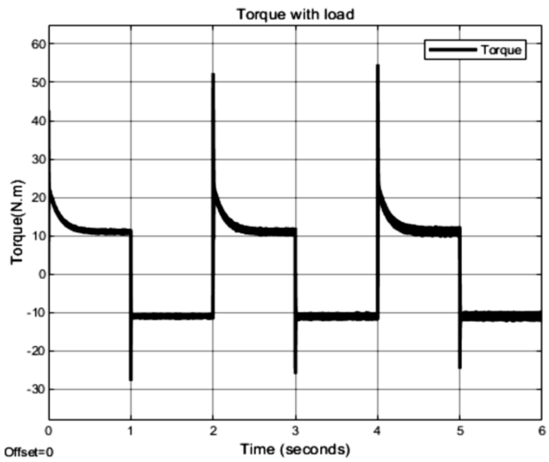


(c)



(c)

Figure 11. Simulation results of variable speed at no load (a) speed, (b) current, and (c) torque

Figure 12. Simulation results of variable speed at load (a) speed, (b) current, and (c) torque

8. CONCLUSION

The use of control systems has proven that it is possible to improve the working performance of the electric motor under the conditions of the working environment that simulates real time. After conducting the simulation, it was noted that it is possible to return to the stable state when the working conditions change for a system that operates using pulse control systems that regulate the work of electronic switches and thus, we get the best performance. After taking the possibilities to change the speed and the state of the load, it can be said that it is possible to improve the performance of the speed controlling by regulate the electric motors using power electronic devices. The performance can be developed and improved through future works, which It can use expert systems such as fuzzy logic and neural network. Also, genetic algorithm and other advanced systems can be used to improve the performance of the work of industrial systems by controlling the speed of the electric motor and the position of the rotor as well.

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