Wireless Speed Control of DC Motor Drive System

Mohamed Y. Hashem, Fawzy A. Osman, Thanaa F. Elshater and Yasser S. Mohamed

Abstract—Application of wireless protocol standard for remote control and monitoring of a separately excited DC Motor drive system is introduced. An appropriate wireless system using ZigBee protocol standard has been developed and implemented. The measurement of armature speed done using an incremental shaft encoder. The simulation of the proposed system is carried out using Matlab/Simulink tools and the simulated results for the armature current and speed are given. Experimental result confirms the validity of this wireless monitoring and control system. The obtained results can be used in design and implementation of such types of wireless systems.

Keywords—DC Motor, Microcontroller, Wireless Communication, Zigbee Network.

I. Introduction

THERE are recently many researches in the use of wireless new technologies to performs a remote monitoring for several applications. These new wireless technologies and devices provide a lot of varieties that full fit for many applications requirements [1]-[3]. Compared to the classical control approaches they provide much more flexibility and reliability. Wireless devices that using standard protocols like ZigBee are widely applied in remote applications because of their lower energy consumption, low maintenance and high data encryption. Wireless monitoring and control are used especially in cases where the monitored or controlled objects are placed in remote area or it's hard to be accessed.

Currently wireless approaches are often applied for remote monitoring and control in many application areas such as robotics, industrial processes, and home automation. Implementations of wireless control in industrial automation for robots and manipulation systems are introduced in [4], [5]. A real-time measurement and monitoring system based on ZigBee and Bluetooth standard technologies are presented in [6], [7]. Most applications that registered recently which are interest to use this technology like home automation applications are introduced in [8]. Other applications are interested in wireless monitoring of electrical drive systems [9]-[11]. This paper presents a modular wireless system for remote monitoring and control of a separately exited DC motor driving system. ZigBee standard used for control signals managements with the power driving circuit.

The simulation is also carried out using Matlab/Simulink tools and the simulated results are presented. The experimental test-rig is carried out and some experimental results are introduced.

II. Separately Excited DC Motor

Figure 1 shows the separately excited DC motor equivalent circuit. The electrical and mechanical modeling equations of the motor are given in equations (1) and (2) [12]-[14].

$$\frac{di_a}{dt} = \frac{-R_a i_a}{L_a} - \frac{k_b \omega}{L_a} + \frac{V_a}{L_a} \quad (1)$$

$$\frac{d\omega}{dt} = \frac{K_t i_a}{J} - \frac{B\omega}{J} \quad (2)$$

Where,

v_a, i_a	Armature voltage and armature current respectively,
e_g	Back EMF,
ω	Angular Velocity of Motor Shaft,
R_a, L_a	Armature Resistance Inductance respectively,
T	Torque Produced by Motor,
J	Moment of Inertia of Motor Shaft,
B	Coefficient of Viscous Friction,
K_T	Torque Constant and
K_b	Back EMF Constant

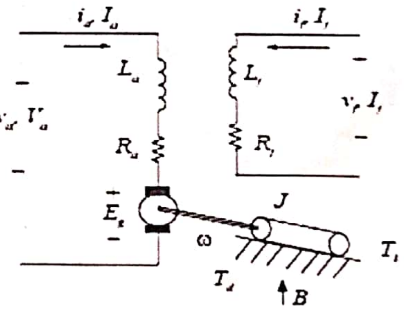

Fig 1 Separately Excited DC Motor

Speed control of a Separately Excited DC Motor shown in Figure 1can achieved through two approaches; Armature voltage control approach and Field flux control approach. The armature voltage control approach has advantage to retain constant torque with linear relation between armature voltage and armature speed while the other approach of field flux control will reduce the torque to ensure constant output power.

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so, the first approach has been chosen [14]-[16]. Also, the second approach has been chosen in [17].

III. Discrete Time PI Controller Design

In the analog control, the PI controller is a widely use in most control systems, in the digital controller can be written in the mathematic Equation as:

$$u(t) = k_p\left[\ e(t) + \frac{1}{T_i}\int_0^t e(t)dt\ \right] \quad (3)$$

Where, e(t) is the error signal, k_p is the proportional gain of the PI controller and T_i is the integral time of the integral part of the PI controller. The z-transform is executed to get the discrete time PI controller equation as follows [18]-[20]:

$$U(z) = Z\{u(t)\} = k_p\left[Z\{\ e(t)\} + \frac{1}{T_i} Z\left\{\int_0^t e(t)dt\ \right\}\right] \quad (4)$$

Then,

$$U\ (z) = k_p\left[\ e(z) + \frac{1}{T_i} \times \frac{T}{2}\frac{1+z^{-1}}{1-z^{-1}} e(z)\right] \quad (5)$$

$$U\ (z) = \left[\left(k_p + \frac{k_pT}{2T_i}\right) + \left(\frac{k_pT}{T_i}\right) e(z)\right] \quad (6)$$

The result of the z-transform,

$$D\ (z) = \frac{U\ (z)}{e(z)} = k_p + \frac{ki}{1-z^{-1}} \quad (7)$$

Where,

$$k_{p1} = k_p + \frac{k_pT}{2T_i} \quad (8)$$

$$k_i = \frac{k_pT}{T_i} \quad (9)$$

The discrete time of PI controller can be rewritten as

$$U_k = k_{p1}e_k + k_i \sum_{i=0}^{k} e_i \quad (10)$$

The equation can be written in the block diagram in Figure 2;

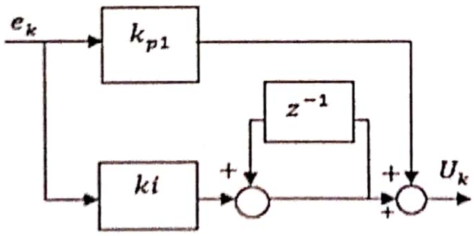

Fig 2 PI Controller

IV. Speed Loop Controller Design

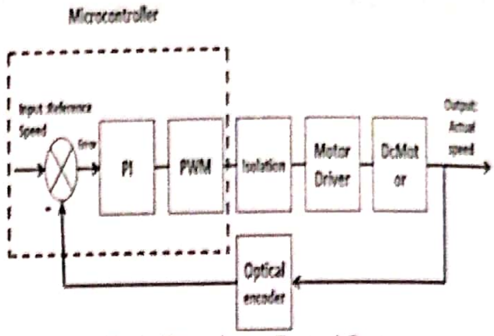

Fig 3: Close Loop Control System

Speed loop as shown in Figure 3 should be designed to have a bandwidth lower than the current loop bandwidth so that the current loop dynamics is too fast to be considered by the speed loop. In this design, the speed loop band width is set to 20Hz. Consequently, the current loop would not need to be taken into consideration in the design as it is too fast to be noticed by the speed loop .Hence, simplify the design process as shown in Figure 4 where the current loop can be replaced by a unity gain.

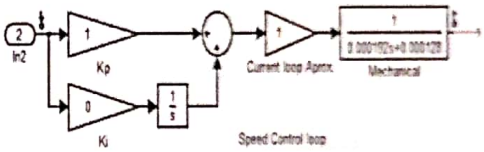

Fig 4 Simplified Model of the Speed Loop

By referring to the pole-zero location shown in Figure 5, the loop has a pole at frequency -0.667 rad/sec to cancel this pole; the zero of the controller can be set at this location. Therefore, $\frac{K_I}{K_P} = 0.667$. preliminarily, by setting $K_i = 1$, gives the value of $K_P = \frac{1}{0.667} = 1.5$. The Bode plot is shown in Figure 6.

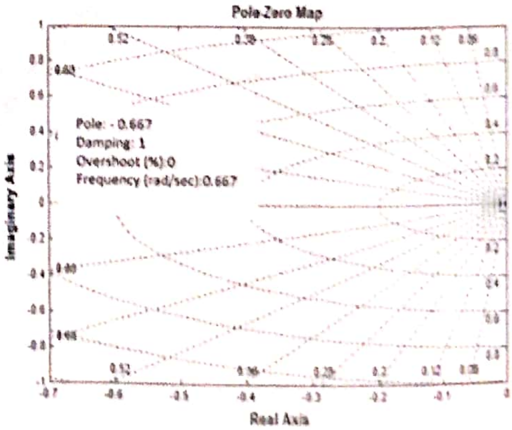

Fig 5.Pole-Zero Location of the Speed Loop

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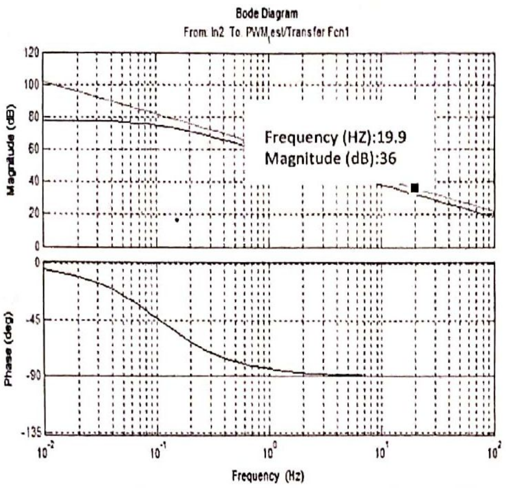

Fig 6 Bode Plot for the Speed Loop at; $K_p = 1, K_i = 0$ $(Blue\ Curves)$; $K_P = \frac{1}{0.667}, K_I = 1$ $(Green\ Curves)$.

The bandwidth of the speed loop is designed lower than. In this design, the bandwidth of the speed loop is fixed at 20Hz. Thus, referring to Figure 6, magnitude of the bode plot at 20Hz is 36 dB. Hence, from calculation shown below, the value of K_P and K_I for the speed controller can be obtained.

$$20\log(K_{\rm i}) = -36dB - 3dB = -39dB \quad (11)$$

$$K_{\rm i} = 10^{\frac{-39}{20}} = 0.01122 \quad (12)$$

$$\frac{K_{\rm i}}{K_{\rm p}} = 0.667 \quad (13)$$

$$K_{\rm p} = \frac{0.01122}{.667} = 0.0168 \quad (14)$$

The speed controller is now completed and the linear model of the loop with the designed value of K_I and K_P is shown in Figure 7.Whereas Figure 8 confirms that the bandwidth of the speed loop is 20Hz when the magnitude is -3.01dB.

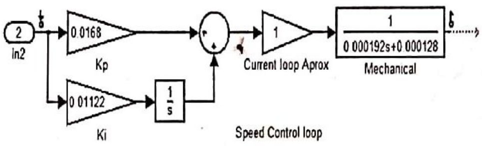

Fig 7 Linear Model of the Speed Loop

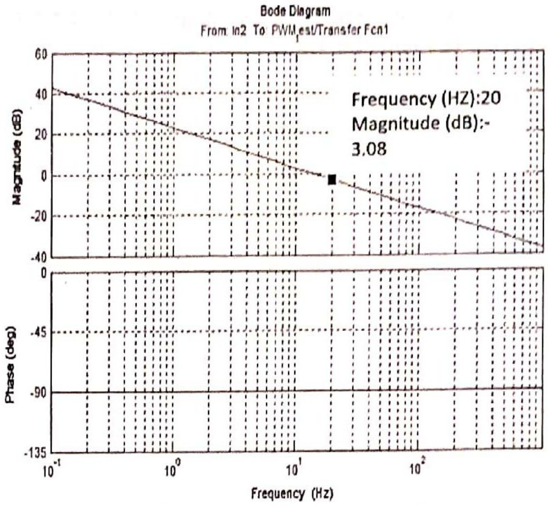

Fig 8 Bode Plot for the Finalized Speed Control.

V. Simulation Results

The Figure 9 shows a step change in the reference speed value, equals the rated speed (2000 rpm) and the corresponding actual motor speed response. Also, Figure 10 shows a motor speed dynamics response by applying a speed change at 0.3 Sec. and the corresponding actual speed is recorded (the motor is un-loaded). It is shown that the speed response is under damped with a minimum over-shoot and fast rising time response.

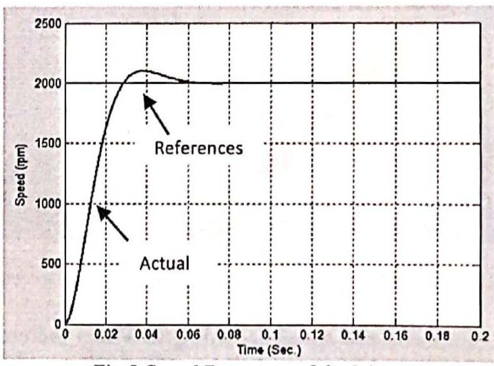

Fig 9 Speed Response of the Motor

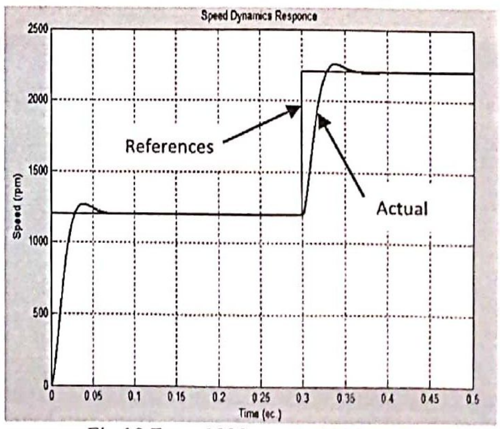

Fig 10 From 1200 rpm to 2200 rpm)

Figure 11 shows the speed response compared to the reference speed in case of multi-step changes.

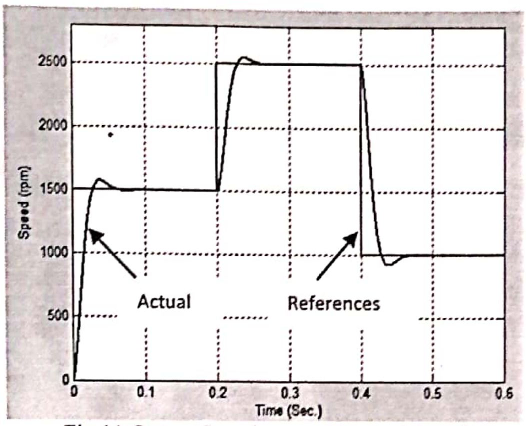

Fig 11 Output Speed versus Demand Speed

VI. Experimental Results

In this section, an experiment is setup to demonstrate the performance of Digital PI controller in Wireless speed control system of DC motor. The controller is tested on different speed tracking performance. The calculated speed from the shaft encoder is shown in Figure 12 when step decrement in the reference speed from 600 RPM to 180 RPM is applied.

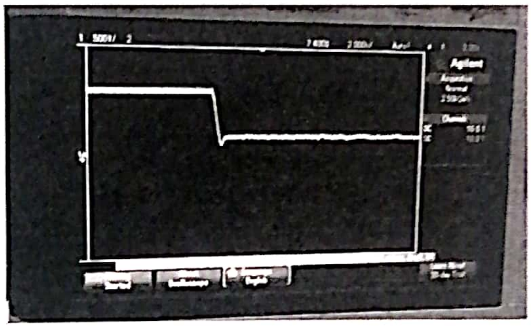

Fig 12 Measured Speed due to Reference Speed Step Decrement.

Also, the measured speed according to a step increment in the reference speed from 180 RPM to 600 RPM was shown in Figure 13.

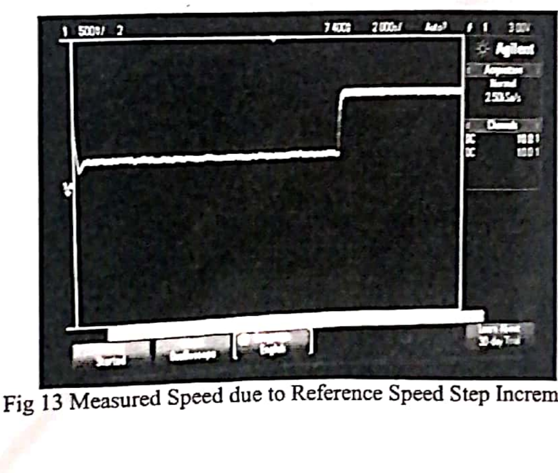

Fig 13 Measured Speed due to Reference Speed Step Increment.

VII. Conclusion

A wireless system for remote monitoring and control of a Separately Excited DC motor has been developed. The introduced system structure is reliable due to the use of wireless standards devices and allows accurate measurement and handshaking for the required parameters and control signals. Experimental results confirm the good performance of the developed wireless system. In the classical control systems directly change in the controller parameters values is very hard due to the change in the designed system parameters; change the values of resistors or change Operational amplifier. In the digital control system, changing the parameter online during operation is easy which can be achieved using the wireless ZigBee technology. The test rig is carried out as well as the experimental results obtained ensure that the developed system can be used in set up of such types of remote monitoring and control systems for various applications.

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