Microcontroller Performance for DC Motor Speed Control System

Y. S. E. Ali, S. B. M. Noor, S. M. Bashi and M. K. Hassan

Abstract--**The electric drive systems used in industrial applications are increasingly required to meet higher performance and reliability requirements. The dc motor is an attractive piece of equipment in many industrial applications requiring variable speed and load characteristics due to its ease of controllability. Microcontrollers provide a suitable means of meeting these needs. Certainly, part of the recent activity on microcontrollers can be ascribed to their newness and challenge. In this paper, implementation of the MC68HC11E9 microcontroller for speed control of dc motor fed by a dc chopper has been investigated. The chopper is driven by a high frequency PWM signal. Controlling the PWM duty cycle is equivalent to controlling the motor terminal voltage, which in turn adjusts directly the motor speed. Experimental results have been obtained that show the employment of microcontroller for speed control and over current protection of a dc motor.**

Keywords--**dc motor drives, Microcontroller, Speed control.**

I. INTRODUCTION

The use of power electronics for the control of electric machines offers not only better performance caused by precise control and fast response, but also maintenance, and ease of implementation. In parallel with the advance in power electronic there have been great advances in microcontroller-based control systems due to the microcontroller flexibility and versatility. This is because all the control algorithms are implemented in the software. [1]

For the continuous control system, the commonly used optimum design approach is usually based on frequency response or zeroes-poles placement [2,3]. However, the relationship between the specifications in the frequency domain and that in the time domain is not straightforward, and sometimes is hard to be predicted.

Adjustable speed drives may be operated over a wide range by controlling armature or field excitation. Speeds below rated by armature voltage control and above rated using field excitation variation, development of various solid state switching devices in the form of diodes, transistor and thyristor along with various analog/digital chips used in firing/controlling circuits, have made dc drives more accessible for control in innumerable areas of applications [3].

A reasonable number of works have been found in the literature, regarding the employment of solid-state devices for the control of dc drives. Ula, et.al [4] utilized the microcomputer to control the speed of a dc motor. The control algorithms are stored and implemented by the microprocessor of the microcomputer. The system employs the use of a Thyristor, which is controlled using the software implemented on the microcomputer.

The use of stand-alone microcontroller for the speed control of dc motor is past gaining ground. Nicolai and Castagnet [5] have shown in their paper how a micro controller can be used for speed control. The operation of the system can be summarized as: the drive form a rectified voltage, it consists of chopper driven by a PWM signal generated from a microcontroller unit (MCU). The motor voltage control is achieved by measuring the rectified mains voltage with the analog to-digital converter present on the microcontroller and adjusting the PWM signal duty cycle accordingly.

Another system that uses a microprocessor is reported in the work of Khoel and Hadidi [6] a brief description of the system is as follows: The microprocessor computes the actual speed of the motor by sensing the terminal voltage and the current, it then compares the actual speed of the motor with the reference speed and generates a suitable control signal which is fed into the triggering unit. This unit drives a H-bridge Power MOSFET amplifier, which in turn supplies a PWM voltage to the dc motor.

The objective of this paper is to explore the approach of designing a microcontroller-based closed loop controller. The interface circuit and the software are all designed to achieve a better performance. The system is designed with a current flow monitor that can protect the dc motor from high currents due to overloading.

The microcontroller system is equipped with an LCD display and a keypad and software was written to monitor the registers on the LCD and read commands from the keypad. Thus, by using the user interface module (UIM) the operator can view and/or change all the control and monitoring variables of the controller program.

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II. HARDWARE DESIGN

Fig. 1 shows the schematic diagram of the complete automatic speed control system of the dc motor.

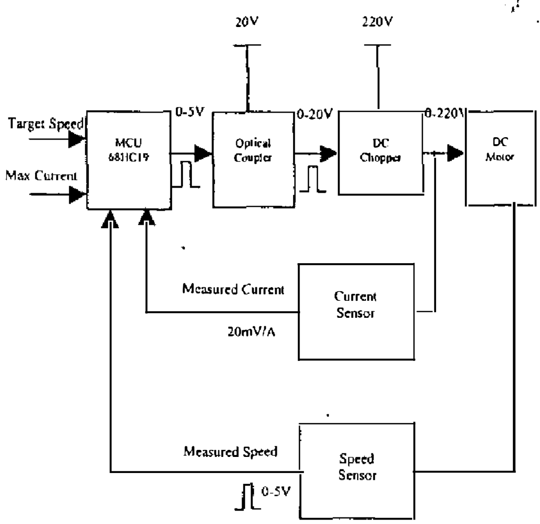


Fig. 1. Block diagram of automatic speed control system.

The 68HC11E9 microcontroller implements the control algorithm by conditioning the speed and current signals and performs the speed regulation according to speed reference fed through the keypad. The software includes a routine to read the motor current and sends emergency shutdown signal to protect the dc motor from over current, also this signal can be activated manually by inserting a designated character by the keypad, which causes a software interrupt and executes the emergency shutdown routine.

The hardware control system includes the dc shunt motor, power circuit, MC68HC11E9 microcontroller, speed sensor (shaft-encoder), and current sensor. The system hardware block diagram is shown in Fig. 2.

The conventional digital proportion MCU technique and the pulse width modulation (PWM) technique are adopted in dc motor control system. An optical encoder was used to measure the speed of the motor. The output of the encoder is a stream of pulses with variable frequency according to the speed of the motor. The resolution of the encoder in this work was 500PPR.

The current sensing was accomplished by using Hall effect current sensor. It senses the current and feeds the current signal to microcontroller. Port PE4 of the microcontroller is dedicated for the current signal and a continuous conversion mode where used to read from the A/D port. The opto-couplers were used to isolate the high voltage circuits from the low voltage controlling signals. The dc motor is the plant that will be controlled. The rating of the motor should be chosen according to the rating of the power circuit switch. For this study a dc shunt motor with ratings 2400RPM, 220V, 2.2A, 0.37kW is used.

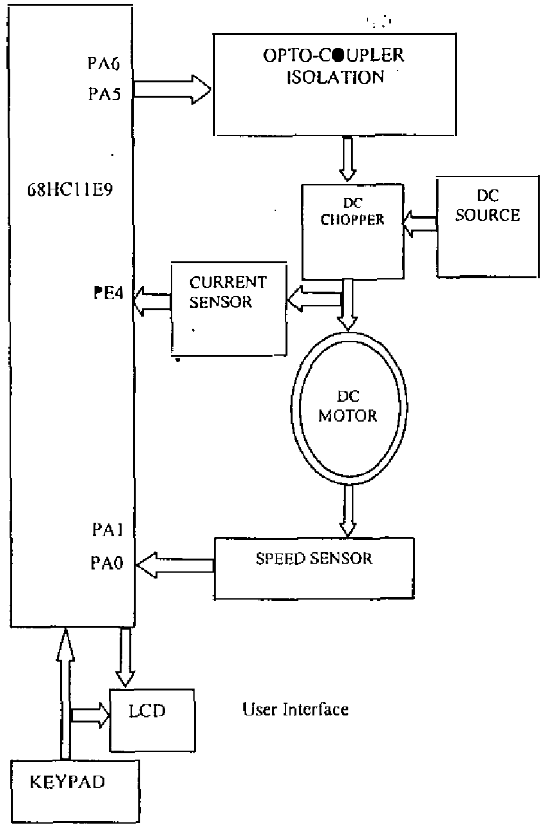


Fig. 2. DC motor control hardware block

The hardware of the microcontroller includes mainly the MC68HC11E9 system with LCD and keypad for user interface. Changing the terminal voltage by means of dc-to-dc chopper (the power circuit) that is controlled by the microcontroller generated PWM signal controls the speed of the motor.

III. SOFTWARE DESIGN

The M68HC11microcontroller (MCU) can control speed of a DC motor accurately with minimum hardware at low cost. The flow chart shown in Fig. 3 describes the main program. The program is written using assembly. It can be divided into three main parts. The initialization is the beginning of the software to initialize timers, I/O Ports.

The second part (I/O scan) is reading the current and speed from the A/D ports and input output capture (IOC) respectively. The microcontroller checks the current and jump to shutdown routine that stops the motor if over load occurs. Otherwise the microcontroller reads the commands from the keypad. From the speed sensor and the speed reference (from keypad) the microcontroller calculates the error and performs the calculation of the control algorithm output and then it calculates the PWM signal width, this is the last part of the program, which called program scan. This part ends by updating the timers and counters to generate the PWM. Then the microcontroller repeats the I/O scan and then the program scan. The motor can be stopped manually by keying a designated character at any time.

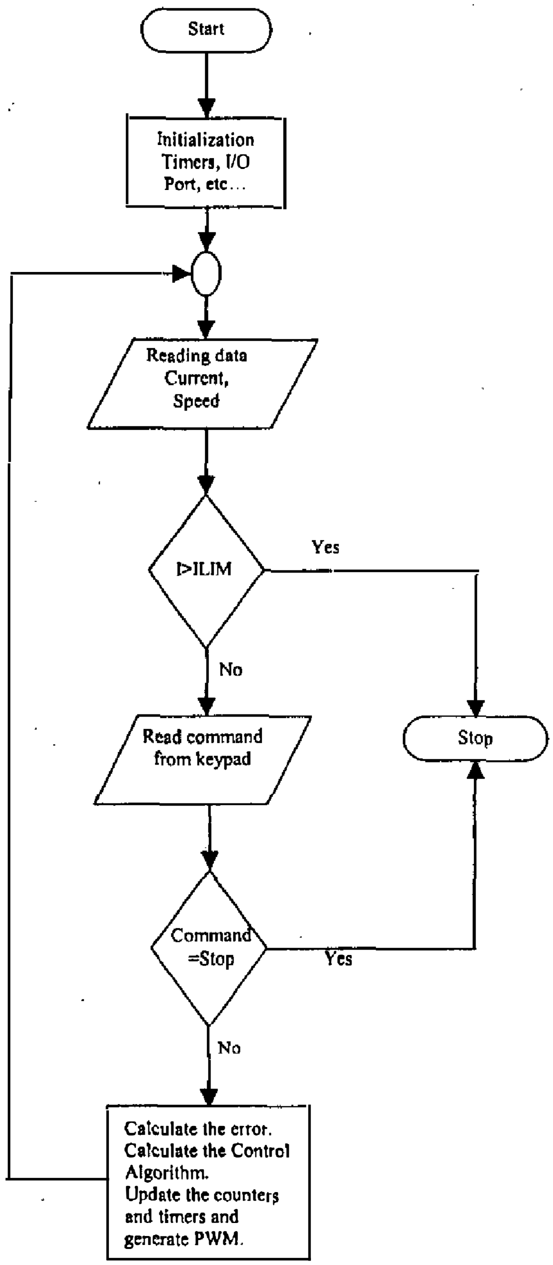


Fig. 3. Main program flowcharts

A. Full Range Frequency Independent Duty Cycle

When designing a PWM unit using the MCU two factors should be considered PWM duty cycle, and PWM frequency. Both are heavily dependent on the operating speed of the MCU.

The PWM frequency, in this work, is kept constant factor. It directly affects the DC motor stability and sensibility to changes in its input voltage. However the frequency can be changed manually within upper and lower limits to make the system flexible and able to operate motors with different ratings and speeds.

The MCU has a built-in timer and counter register "TCNT" which is a 16-bit register that can be incremented at 0.5,2,4, or 8μs by configuring the prescaler unit. 0.5μs is selected for better granularity.

Our objective is how to satisfy the 0% to 100% duty cycle using the MCU. The TCNT is incremented every 0.5μs and will rollover every 32.77ms

When the contents of TCNT equals the contents of OCx register, the control word specified in TCTL1 register will be performed automatically to update the associated pin in port A, the compare flag OCxF set, and an interrupt will be generated if the OCxI interrupt enable is set. In the TCTL1 register one of the following actions can be selected:

- Does not affect OCx pin
- Toggle OCx pin on successful compare
- Clear OCx pin on successful compare
- Set OCx pin on successful compare

In implementing the program the following ports and control words were used:

1. Two-output compare register OC2 and OC3 are used and both use the toggle OCx pin action. Two square waves at the same frequency will be generated on OC2 (PA6) and OC3 (PA5).
2. PA6 and PA5 will be XORed by an external XOR gate to generate the PWM output (PWMOUT).
3. The duty cycle is determined by the phase shift between the outputs at PA6 and PA5. PA6 output is fixed while PA5 is shifted according to the duty cycle.
4. Two interrupt service routines TOC2ISR and TOC3ISR are programmed to handle the interrupts of OC2 and OC3 respectively.

The frequency is configurable within the range 1KHz to 16KHz.The duty cycle can be changed over a full span (from 0% to 100%). Two output compare registers are used in cooperation with an external XOR to generate the output PWMOUT.

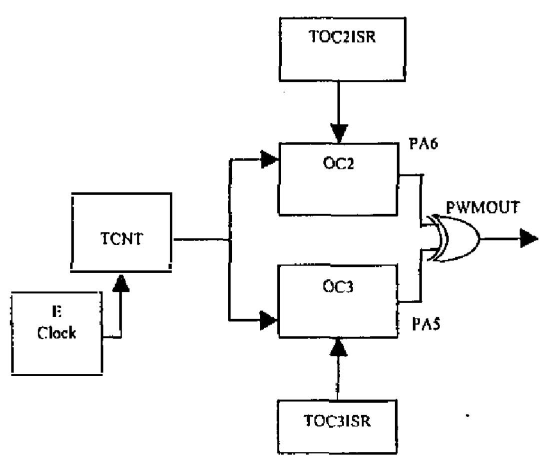


Fig. 4. PWM interrupt service routines.

Fig. 5 shows the isolated PWM block, it accepts two inputs. Duty Cycle that is the output of the speed control algorithm and inputted to this block and Frequency, which is entered through keypad by user and inputted to this block via user interface.

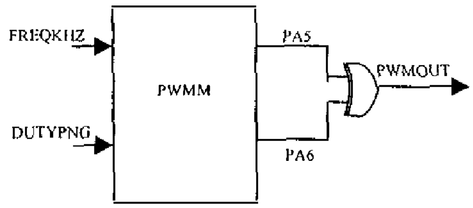


Fig. 5 PWM Block

B. Speed Measurement

Pulse width can be measured by using the input capture register that are available in the 68HC11E9 and can be programmed to capture the positive or negative edge of the input signal. Once the edge is detected the value of TCNT will be copied automatically to the TIC "Timer Input Capture" register and will not be overwritten until the next edge.

Two registers used TIC2 and TIC3. TIC3 is used to capture the positive edge and save the time T1, and TIC2 is used to capture the negative edge and save the time T2. The measured speed (MS) can then be calculated using the equation:

$$MS=(60*2)/((T2-T1)*PPR) \quad (1)$$

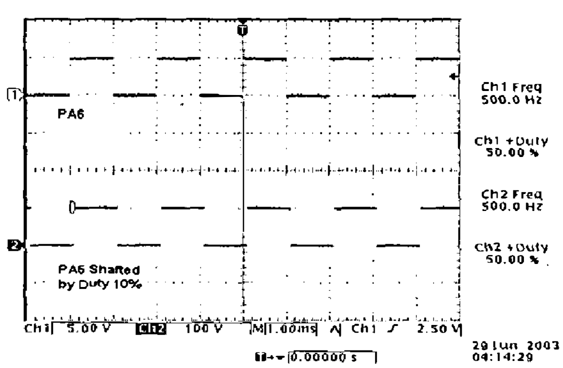
where PPR = pulse pear revolution

IV. RESULTS & DISCUSSION

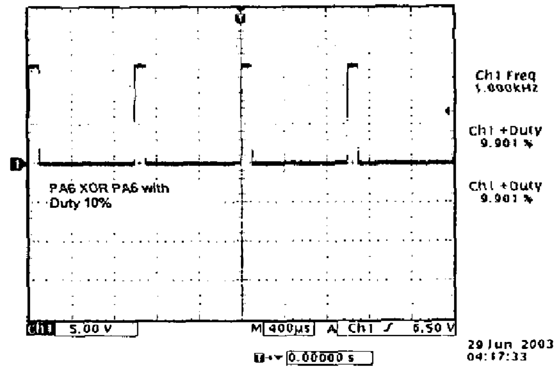
The hardware system has been developed and tested under laboratory conditions. The microcontroller based closed loop control was implemented and applied on a dc shunt motor. The results obtained are as expected which can be discussed as follows.

A. PWM Output

Fig. 6(a) shows the output of microcontroller generated square wave signals at port PA5 and PA6. The signal at PA6 is shifted by a percentage corresponding to the duty cycle. Figure 6(b) shows the corresponding PWM output generated by XORing the signals at PA5 and PA6.



(a)



(b)

Fig. 6. (a) Output at PA5 and PA6 at duty 10%, (b) The corresponding PWM output.

B. Chopper Output

The dc chopper was driven by a high frequency PWM signal obtained from the microcontroller. The voltage supplied to the motor is proportional to the PWM duty cycle generated and fed into the chopper. Figure 7 shows the main output obtained experimentally, which is 201V. The calculated value is $V_{out}=(79.88/100)*254 = 202.89V$.

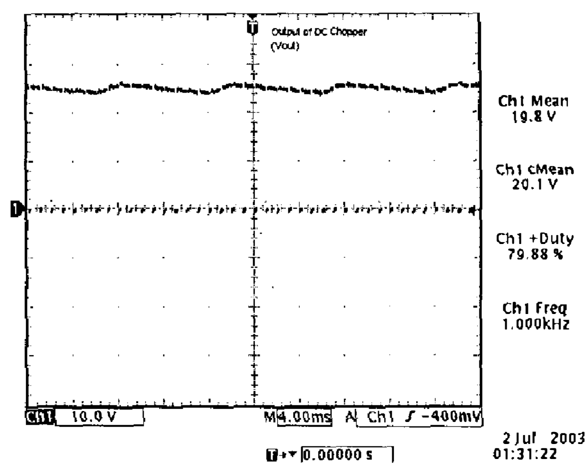


Fig. 7. DC Chopper Output.

The output voltage obtained from chopper is fed into the motor.

C. Speed Output and Motor Response

This shows the output of the motor and its speed response at different conditions. The operator inputs the desired speed through the keypad in the auto-mode. The system will adjust the duty cycle automatically according to the value inputted through the keypad.

Fig. 8 shows the output of motor with speed rising from zero to a predetermined speed command of 1000rpm. It can be seen that a steady rise is achieved with almost small overshoot and then the speed settles to required speed in less than 1.0 sec and almost zero steady state error.

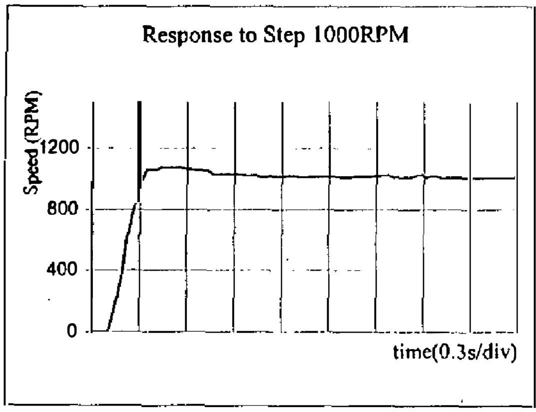


Fig. 8. Speed Response from starting to 1000RPM.

The following graphs show the speed response for desired speed of 1000RPM connected to the load suddenly.

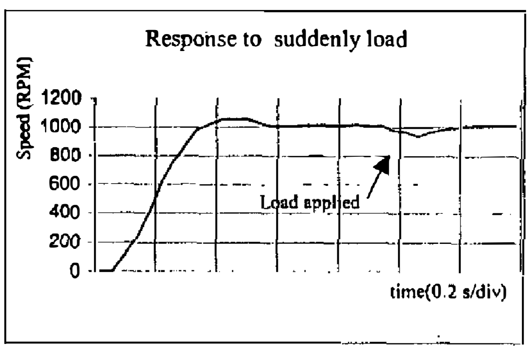


Fig. 9. Speed response from starting to 1000RPM connected to load.

The figure shows a good response with speed reduction at the time of load connecting and then the speed settles to the required speed in about 0.2s.

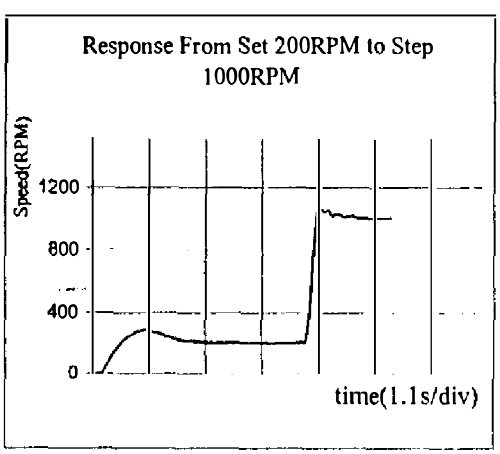


Fig. 10. Sudden raise in speed.

The response of motor to sudden change from a speed of 200rpm to 1000rpm is shown in Fig. 10. Percentage overshoot is much less at high speed.

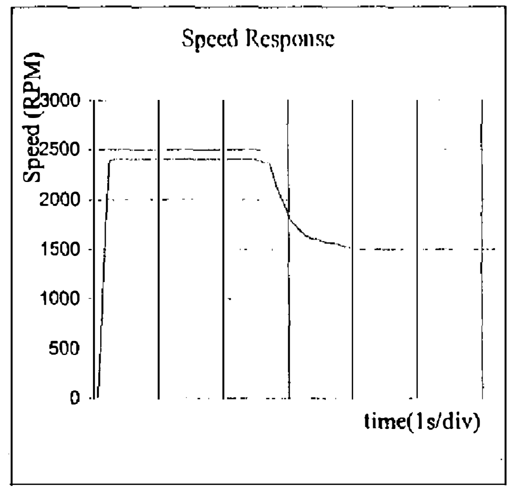


Fig. 11. Decreases in speed.

Fig. 11 shows the motor speed running at 2400rpm; the speed is being reduced to about 1500rpm. The system shows an immediate response with the motor speed exponentially decreasing toward the new speed setting in 1.2s.

Figure 12 shows the testing of motor for response to immediate heavy load. The response shows controller shuts down motor when subjected to over loading.

The graph shows the motor shutting down in less than 0.1sec when subjected to overloads. This insures the adequacy of the system to be employed for protection against overloading.

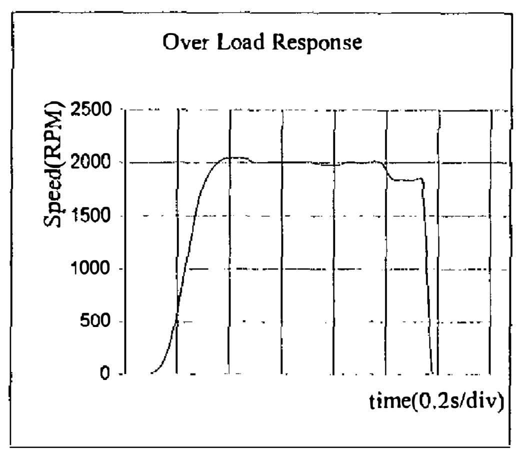


Fig. 12. Responses to loading effect.

Fig. 13 indicates the response of the motor when subjected to an emergency stop, in a situation which may damage or cause harm to equipment or personnel. The figure shows a good response with speed falling.

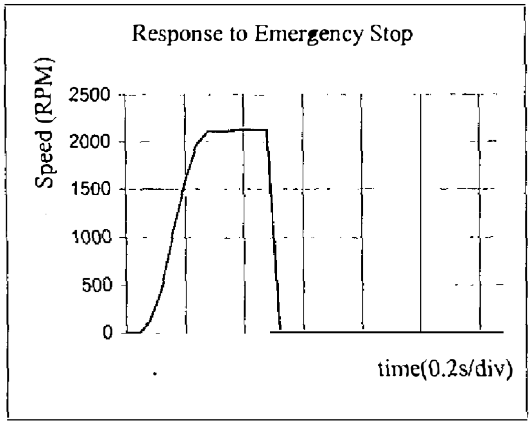


Fig. 13. Emergency shutdown responses.

V. CONCLUSION

The Microcontroller based adjustable closed-loop DC motor speed controller system has been developed. Experimental results have been obtained for the proposed control system with a DC motor as a load.

The results showed that the microcontroller is a reliable instrument to control the motor. This system is applicable to different sizes of motors and capable of controlling the speed of the motors with very high precision. Furthermore the protection and power cut-off system has yielded appreciable response. Thus, it can be concluded that the present system under study is a reliable adjustable drive system for DC motors.

VI. REFERENCES

[1] T. Castabnet and J. Nicolai, "Digital Control for Brush DC Motor," *IEEE Transaction on Industry Applcation*", Vol, 30, No 4, July/Algust 1994.

[2] Krishnan and Thadiappan, "Speed Control of DC Motor Using Thyristor Dual Converter," *IEEE Trans.*, Vol, T-IECI, pp, 391-399, Nov. 1976.

[3] A. H. M. S. Ula and J. W. Steadman, "Design and Demonstrate of a Microcontroller Control for an Industrial Sized DC Motor," *IEEE Transaction on Energy Conversion*, Vol. 3, No. 1, March 1988

[4] A. H. M. Ula and J. W. Steadman, "Design and Demonstration of a Microcomputer for an Industrial Sized DC Motor", *IEEE Transaction on Energy Conversion*, Vol, 3,No.1, March 1988.

[5] J. Nicolai and T. Castagnet, "A Flexible Microcontroller Based Chopper Driving a Permanent Magnet DC Motor," *The European Power Electronics Application*, 1993.

[6] Khoei and Hadidi, "MicroProcessor Based Closed-Loop Speed Control System for DC Motor Using Power Mosfet," *Umia University ICECS 1996*, pp.1247-1250.