Available online at www.sciencedirect.com

ScienceDirect

ELSEVIER

Procedia Technology 10 (2013) 840 – 848

Procedia Technology

1st International Conference on Computational Intelligence: Modeling Techniques and Applications (CIMTA) 2013

Embedded System of DC Motor Closed Loop Speed Control based on 8051 Microcontroller

Reetam Mondal[a],*, Arumay Mukhopadhyay[b], Debdoot Basak[c]

[a] *Assistant Professor, Department of Electrical Engineering, JIS College of Engineering (Autonomous), Block-A, Kalyani, West Bengal, India*
[b,c] *Pursuing B.Tech in Electrical Engineering, JIS College of Engineering (Autonomous), Block-A, Kalyani, West Bengal, India*

Abstract

The objective of the present paper is designing 8051 Microcontroller based Embedded Closed Loop Speed Control System of DC Motor to study the reaction of controlled variable to set-point changes. In this present scheme a tachogenerator has been used as a speed sensor which generates a back emf corresponding to the speed attained by the DC Motor. This instantaneous value of output voltage provided by the tachogenerator is then compared with the desired voltage corresponding to the desired speed. The resulting error is used by the microcontroller to control the firing angle of the SCR for controlling the voltage applied to the DC Motor which in turn adjusts directly the motor speed to attain the desired value. Thus a continuous closed loop speed control system has been achieved. Proportional (P) Control Algorithm has been used in the present scheme. Experimental results have been presented to study the reaction of process speed with respect to set-point changes. The system is of low cost and is suitable for different industrial applications such as subway cars, trolley buses and battery operated vehicles.

Selection and peer-review under responsibility of the University of Kalyani, Department of Computer Science & Engineering

Keywords: Back-emf, DC Motor, Firing angle, Microcontroller, SCR, Set-point change, Speed Control, Tachogenerator.

1. Introduction

The speed of large electrical motors depends on many factors, including supply voltage level, load, and others. A process control loop regulates this speed through direct change of operating voltage or current for a DC Motor. The use of power electronic devices for control of these electric machines not only offers better performance with precise

* Reetam Mondal. Tel.: +919903804772; fax: +913322893944/5323.
E-mail address: reetammondal2008@gmail.com

Selection and peer-review under responsibility of the University of Kalyani, Department of Computer Science & Engineering
doi:10.1016/j.protcy.2013.12.429

control and fast response but also provides quick maintenance and ease of implementation. In parallel with the advancement in power electronics there has been great advances in microcontroller based process control systems as well, due to its flexibility and versatility. Therefore they are widely used in industrial applications because they provide variable speed characteristics. There are many methods of speed control which has been proposed in past couple of years. Thadiappan Krisnan [1] has described and designed SCR based speed control unit for a separately excited DC Motor. In the same year S.A.A.Farag [2] has performed experimental studies on variable speed DC Shunt Motor driven by a single phase full-wave rectified power supply using SCRs. S.J.Jorna and Y.T.Chan [3] designed a Microprocessor based DC Motor drive control using SCRs. Multiple operating modes of thyristor converter has been studied using three phase fully controlled DC Motor motor drive system by Ahms Ula [4]. A software based feed forward control system of DC Motor has been considered to calculate the load torque by Tsuyoshi Hanamoto [5]. R.Abdolllah Khoei [6] has presented a closed loop speed control system using a Power MOSFET and a microprocessor as its controller. Y.S.E Noor Ali, Samsal Bahari Mohd and S.M Bashi Hassan [7] has investigated the MC68HC11E9 Microcontroller performance for DC Motor Speed control fed by DC chopper. Speed Control of DC Motor using DC Chopper has been investigated by Y.S.E Noor Ali, Samsal Bahari Mohd, S.M Bashi Hassan[8]. Abu Zahrin Ahamad [9] has proposed a method to estimate the motor current to control the PWM Voltage to maintain a constant speed of the DC Motor. H.Chin Choi [10] has presented experimental results of solving speed and position control problems by using embedded controllers. A simplified approach of Programmable Logic Controller (PLC) based speed control of DC Motor has been proposed by A.S.Z El Din [11]. Huan Guo-Shing Shing [12] has proposed a LABVIEW aided PID designed controller to monitor and control DC Motor Speed. Hu Lingyan, Xueqiang Chan and Wu Helei [13] designed a closed loop system of motor speed control where they adopted the algorithm of PWM to control the armature voltage and motor speed. A motorized golf bag has been designed by Zhu Haishui [14] which has high efficiency and used a low cost DC Motor controller. Sliding Mode Control (SMC) Technique was used by R.K Munje, M.R.Roda, E Kushare and Bansidhar [15] to control the Speed of DC Motor. A conventional cascade speed control system has been realized by Liu Zhijun [16]. Radu Duma [17] implemented a real time control algorithm for digital motor control using stellaris LM3S8962 microcontroller. Different speed control techniques of DC Motor has been studied and compared by Rohit Gupta, Ruchika Lamba and Subhransu Padhee [18]. Ziegler-Nichols tuning formula has been implemented for speed demand applications of DC Motor by P.M.Meshram [19].

In the present investigation attempts have been made to design and develop AT89c51 Microcontroller based embedded closed loop speed control system of DC Motor where Proportional (P) Control algorithm has been implemented to control the firing angle of the SCR for controlling the voltage applied to the DC Motor. In this design of Speed control system tachogenarator has been used as a speed sensor. The tachogenerator output voltage after conversion into suitable form by the signal conditioning circuit designed is fed to the microcontroller which then using suitable control software compares this measured speed signals with the reference or desired signal given and generates an error. This error is used by the controller to trigger the SCR at an angle measured from the reference provided by the Zero Crossing Detector (ZCD) circuit to achieve the required voltage across the Motor terminals which maintains the process speed at desired value.

2. Methodology and Block Diagram

In the proposed design shown in **Fig.1.** a DC motor of 12 Volt, 1000 rpm, Zero Crossing Detector (ZCD) for zero reference and a Tachogenerator as a Speed sensor has been used. This system describes the design and implementation of the AT89c51 Microcontroller based closed loop DC Motor Speed Control System that controls the speed of a DC motor through Optically Coupled Half Controlled SCR bridge rectifier used as a Motor Driver circuit. The tachogenerator used gives a back emf in the range of 0 - 10 Volt corresponding to the speed attained by the DC Motor. This output voltage of the tachogenerator is then given as input to the signal conditioning circuit which converts the output voltage from 0-10Volt to 0 – 5 Volt. This analog value of voltage obtained after signal conditioning is fed to ADC converter which gives the corresponding digital values. The controller unit will sense this digital data of output voltage of the tachogenerator and will compare with the desired level of voltage corresponding to the set-point speed. The error obtained is reduced by Proportional (P) Control Algorithm during which the controller continuously sends triggering pulses through the opto-coupler circuit to the SCRs of the Motor

Driver Circuit which controls the voltage applied and hence the speed of the DC motor. Then the error signal is updated and the cycle is thus repeated. Thus the desired speed is attained.

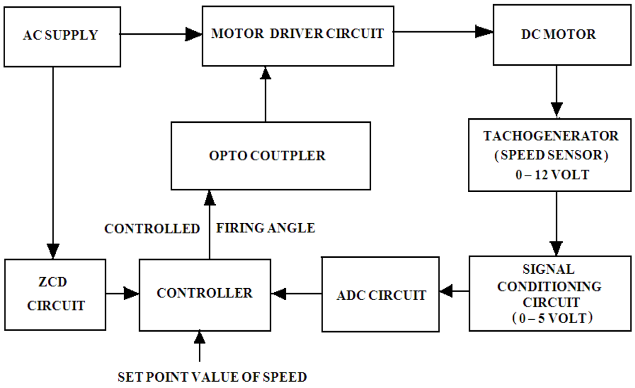

Fig.1.Block Diagram of Closed Loop DC Motor Speed Control System

3. Hardware Implementation and Discussions

The detailed hardware circuit of Closed Loop Speed Control system described above consists of Speed Measurement and Monitoring circuit using tachogenerator as a speed sensor, Analog Signal Conditioning Circuit, Analog-to-Digital (ADC) converter, Zero Crossing Detector (ZCD) circuit, optically coupled Motor Driver circuit using MCT-2E and interfacing of AT89c51 Microcontroller with the hardware circuit.

3.1. Regulated Power Supply Circuit Designed

Most of the electrical domestic appliances feature microcontroller unit, mechanical relay, or solid state SCR switches and several loads such as single phase motors, lamps, valves, etc. They are either powered directly via a regulated power supply or a switch mode power supply (SMPS). A regulated power supply is one that controls the output voltage or current to a specific value. The controlled value of voltage is held nearly constant despite variations in either load current or the voltage supplied by the power supply's energy source. They are more efficient, consume less power and are more compact and weigh less.

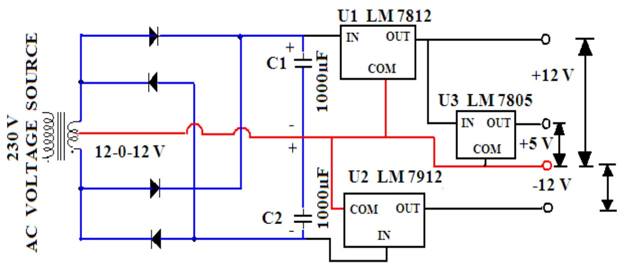

Fig.2.Circuit Diagram for Power supply designed Using voltage regulators

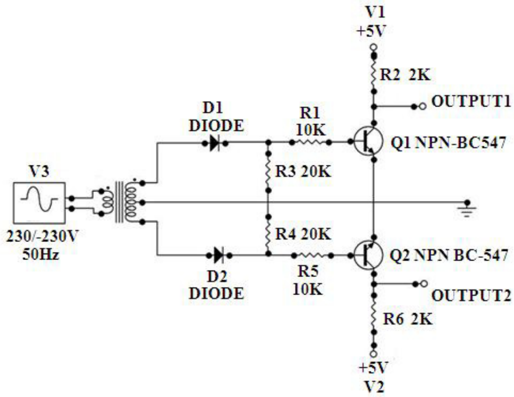

Fig.3. Modified 50/60 Hz Zero Crossing Detector Circuit Designed

Therefore, in the present investigation a regulated power supply shown in **Fig.2.** has been designed using full-wave centre tap rectifier circuit with 12-0-12V, 500mA centre-tap step-down transformer, diodes, 1000μF, 63V electrolytic capacitor and LM 7812, LM 7805 and LM 7912 voltage regulators from where output voltages of +12V,+5V and -12V respectively are distributed to various units of the system components as required for their respective operations.

3.2. Modified Zero Crossing Detector (ZCD) Circuit Designed

A Zero Crossing Detector (ZCD) literally detects the transition of the a.c signal waveform from positive to negative and vice-versa, ideally providing a narrow pulse that coincides exactly with the zero voltage condition. This will be required by the microcontroller to generate a triggering pulse to the SCRs with some delay from the zero crossing of the a.c signal. In this present work as shown in **Fig.3.** a 4.5-0-4.5 Volt, 500mA centre-tap transformer is used with two diodes and two n-p-n transistors with suitable resistors are used to obtain the outputs of the ZCD circuit from the collector terminals which are connected to +5V supply. Outputs are obtained from output terminal 1 and output terminal 2 respectively of the modified Zero Crossing Detector (ZCD) circuit designed.

3.3. DC Motor

Essentially, a DC motor consists of a stator, a rotor and commutator. The stator is the housing of the motor and contains magnets and the rotor is the rotating part of the motor, which is called the armature, contains conductors placed in the armature slots through which current flows. The control of speed of these DC Motors can be achieved by variation of the applied voltage amplitude. This can be achieved by SCR bridge circuit. By variation of the SCRs' firing angle the amplitude of the DC voltage and current of the armature conductors, and hence the speed can be varied.

3.4. DC Tachogenerator (Speed Sensor)

Tachogenarator is a transducer that converts speed of rotation directly into an electrical signal. They are commonly used for speed control of rotating equipments. The tachogenerator is coupled with the DC motor. Tachogenerator gives an output voltage according to the speed attained by the DC motor. The amount of output voltage (e_0) generated by the tachogenerator is given by,

$$e_0=[\ n_p n_c \varphi\omega \times 10^{-8} / (60 n_{pp})\ ]\ \text{Volt} \tag{1}$$

where, n_p= Number of poles,n_c= Number of Conductors in the armature, φ_p=flux per pole, n_{pp}=parallel brush between positive and negative brushes, ω=rpm to be measured.

3.5. Sensor Analog Signal Conditioning Circuit Designed

For successful process control, the parameter to be controlled should be sensed by a suitable sensor, converted into a signal which will truly represent the parameter and present it to the controller for further action. Signal conditioning using passive circuits are extensively used for many years. As microcontroller can not recognize voltage beyond 5 Volt, so it is necessary to convert the voltage signal into 0-5Volt range. In this present research work we have designed a Sensor analog signal conditioning circuit shown in **Fig.4.** that converts 0-12Volt output signal of the tachogenerator into 0-5Volt for each variation in the process variable (speed of the DC Motor).

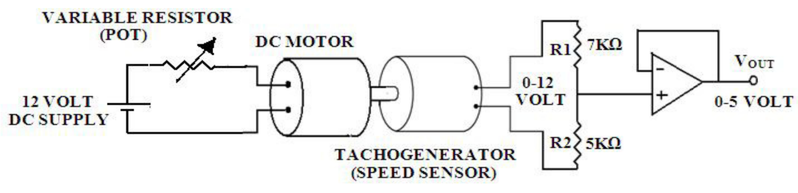

Fig.4. Sensor Signal Conditioning Circuit Designed

3.6. Optically Coupled Motor Driver Circuit interfaced with 8051 Microcontroller

An opto-isolator, also called an opto-coupler or a photo coupler, is an electronic device designed to transfer electrical signals by utilizing light waves to provide coupling with electrical isolation between its input and output. The main purpose of an opto-isolator is to prevent high voltages or rapidly changing voltages on one side of the circuit from damaging components or distorting transmissions on the other side or low voltage side. In this investigation opto-coupler MCT-2E has been used which protects the microcontroller which requires low voltage from over voltage damaging and also prevents the motor to run in the reverse direction.

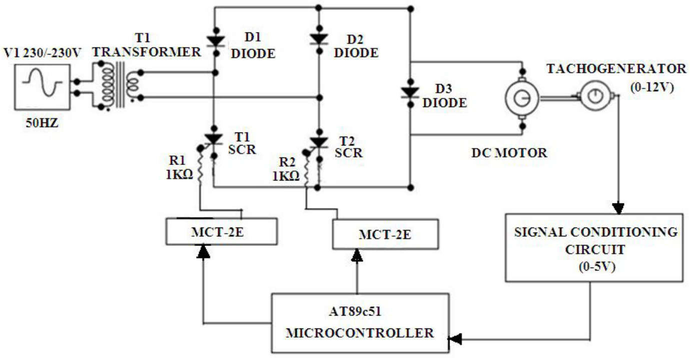

Fig.5.Interfacing between 8051 microcontroller and DC Motor Driver Circuit

As shown in **Fig.5.** Half controlled bridge rectifier DC Motor driver circuit with a flywheel diode D3 has been used. Flywheel diode (D3) is used to eliminate negative spikes in the output voltage and prevent reversal of load voltage, improves power factor angle and better load performance. Here we have used ***phase controlled technique***, the basic principle of which is to control the point of time at which the SCRs are allowed to conduct during each cycle. That is at the instant SCR starts conducting, at that particular point of time control action should start. So at the point of control SCRs are to be turned ON. This can be achieved by application of Gate signal through the Opto-coupler MCT-2E with the help of the Microcontroller at any angle α with respect to the applied voltage. This angle is called ***the firing angle or delay angle***. It should be ensured though the SCR is forward biased it should not be allowed to conduct until it is triggered.

4. Software Implementation of the Control Unit

According to the general design requirement, hardware circuit, principle of the system, the character of the hardware connection, each module chip, the function requirement, as well as the improvement of program readability, transferability and convenient debugging the software design shown in **Fig.6.** has been modularized. In this design of closed loop speed control system KEIL µVision 4 Software has been used as the C Compiler. The KEIL µVision Debugger accurately simulates on-chip peripherals of the 8051 microcontroller.

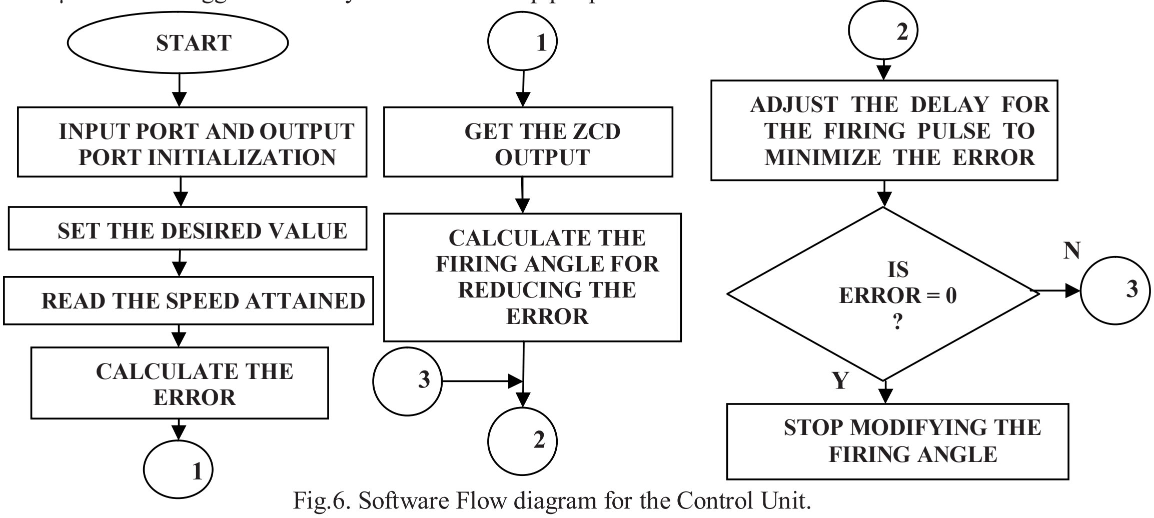

Fig.6. Software Flow diagram for the Control Unit.

5. Experimental Results and Discussions

In the first step of experimentation, calibration of the DC Motor with and without speed sensor has been done by varying the voltage across the Motor terminals by varying resistance of potentiometer and recording the process speed.

5.1. Open Loop Speed Variation of DC Motor with input Voltage (without Speed Sensor)

The input voltage of the DC Motor was varied from 0 – 12 Volt by using a 10KΩ multi-turn Potentiometer(POT) for which an open loop speed variation from 150 rpm to 800rpm has been obtained. The open loop variation of Speed with applied voltage without speed sensor has been shown in **Fig.7.** This variation of Speed with the applied voltage will be required later for firing of the SCRs with the microcontroller. The SCRs will be fired at this voltage levels instead of using a potentiometer to get the required Speed.

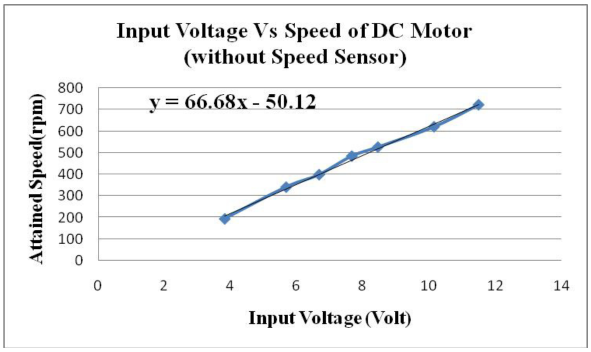

Fig.7. Open Loop Speed Variation with applied voltage without Speed Sensor

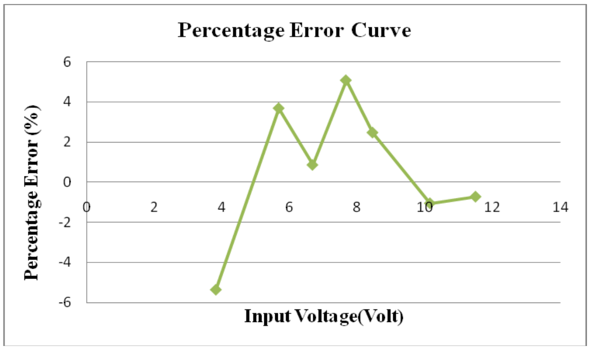

Fig.8. Percentage Error Curve

By examining the curve of **Fig.7.** it is observed that it is almost linear. This leads to the development of linear approximation of speed attained with applied input voltage by plotting a linear trend line equation and comparing it with the curve obtained. Thus linear calculated values or true values of motor speed are obtained. The error percentage is calculated from the measured value and the true values of speed. From the percentage error curve in **Fig.8.** it is observed that the percentage error lies between **±6%.**

5.2. Open Loop Speed Variation of DC Motor with input Voltage (with Speed Sensor)

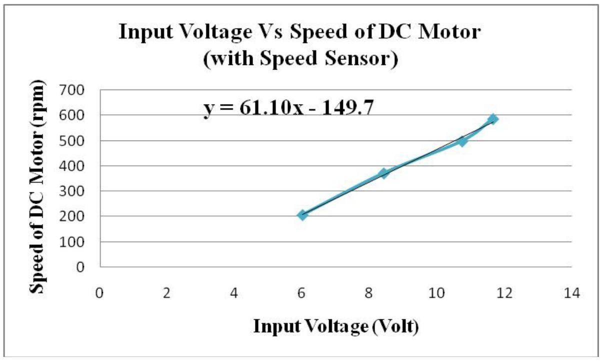

Fig.9. Open Loop Speed Variation with applied voltage (with Speed Sensor)

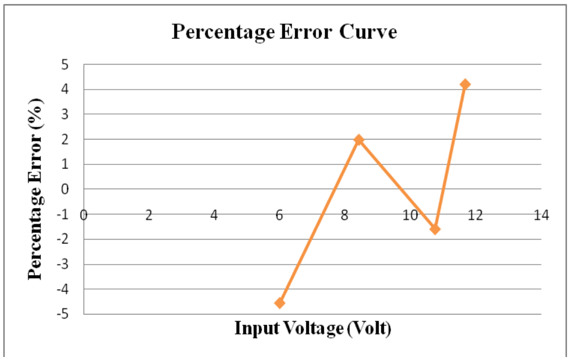

Fig.10. Percentage Error Curve

Fig.9. represents variation of DC Motor Speed with applied voltage with speed sensor. Here the tachogenerator used as a Speed Sensor is coupled as a load with the shaft of the DC Motor whose speed is to be controlled. While performing the previous experimentation of open loop speed variation without speed sensor, we have observed that

there were large fluctuations of Speed with the variation of applied voltage without the load. But here the deviation of the curve from the trendline equation is very small which means variation of measured value of motor speed compared with the calculated true value is also almost linear. The error percentage is calculated from the measured value and true value of attained Speed. From the percentage error curve in **Fig.10.** it is observed that the percentage error lies between ±5%.

5.3. Variation of Tachogenerator (Speed Sensor) Output Voltage with Speed attained by DC Motor

Fig.11. represents variation of DC Motor Speed with the tachogenerator (Speed Sensor) output voltage. The speed variation was obtained from 200 rpm to 600 rpm. The tachogenerator generates a back emf in the range of 0-10 volt corresponding to each speed attained by the DC Motor. This analog value of voltage is fed to the signal conditioning circuit which converts it in the range of 0-5 Volt to be fed to the Microcontroller unit.

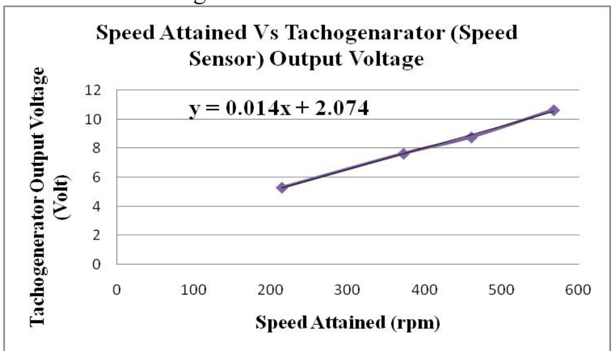

Fig.11.Variation Tachogenerator Output Voltage with Speed Attained by DC Motor

It is observed from **Fig.11.** that the variation of the tachogenerator (Speed Sensor) output voltage with the Speed of the DC Motor compared with the linear trendline equation is almost linear.

5.4. Variation of Signal Conditioning Output with Tachogenerator (Speed Sensor) Output Voltage

The input given to the 8051 Microcontroller should vary with in 0 to 5 volts. The AT89c51 Microcontroller used cannot recognize analog voltage beyond 5Volt. Therefore, the tachogenerator output voltage is given as input to the Signal Conditioning circuit designed as shown in **Fig.4.** which converts the output voltage of the tachogenerator from 0-10Volt to 0-5 Volt.

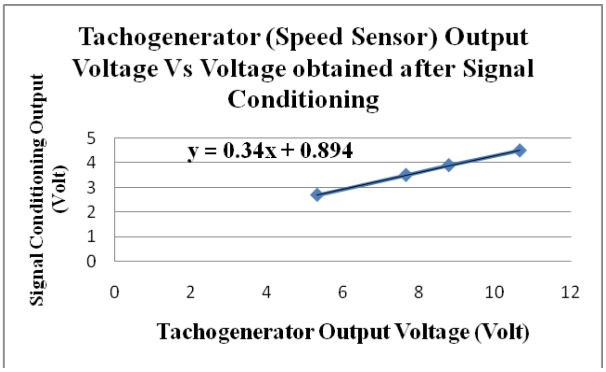

Fig.12. Variation of Signal conditioning output with Tachogenerator Output Voltage

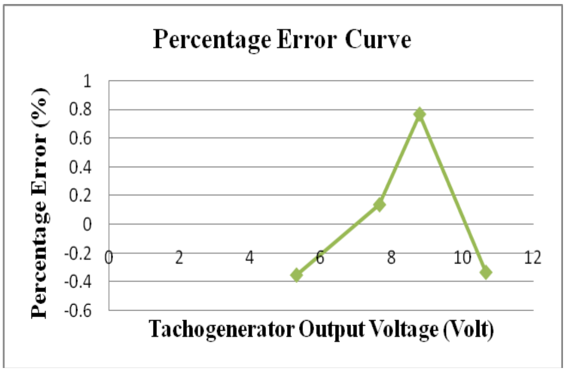

Fig.13. Percentage Error Curve

The variation of the output voltage after signal conditioning with respect to the change in tachogenerator output voltage is shown in **Fig.12.** The percentage error curve in **Fig.13.** shows that the percentage error calculated after comparing the measured values with the true values obtained from linear trendline equation, lies between -0.4% to -0.8%.

5.5. Digital Signal Conditioning using Analog to Digital Converter (ADC)

The signal conditioning circuit output which is an analog voltage is now converted to its equivalent digital form using ADC as shown in **Table.1.** This digital output is given as input to the microcontroller unit used.

Table.1. ADC Digital Output corresponding to the Output of the Signal conditioning circuit

Signal Conditioning Output (Volt)	ADC Digital Output
2.69	01110001
3.54	10010001
3.97	10100011
4.56	10111100

Table.2. Open Loop Voltage and Speed Variation with change in firing angle

Input Binary Combination		Delay	Firing angle (Degree)	Voltage from Driver Circuit (Volt)	Speed Attained (rpm)
0	0	0x1E	40.75°	11.25	588
0	1	0x3E	82.01°	9.76	496
1	0	0x5E	126.16°	7.68	382
1	1	0x7E	174.90°	6.62	224

5.6. Variation of Open Loop Voltage with Firing Angle

Table.2. represents the Open Loop Voltage and Speed Variation with change in firing angle of the SCRs from 40.75º to 174.90°. This variation has been achieved through C program using AT89C51 Microcontroller. For different binary combinations of input given to the Microcontroller, the Microcontroller triggers the SCRs with different delays given in the look-up table written in the C program. It is observed that with the decrease in the firing angle, the open loop voltage across the load in the driver circuit increases and vice-versa. Thus, Speed of the DC Motor also increases.

5.7. Closed Loop Speed Control of DC Motor

Table.3. shows that with the increase in set-point Speed in Closed Loop Speed Control System the Speed Attained by the DC Motor increases proportionally by multiplying the error between the set point and the Speed attained, with a proportional constant repeatedly until the error is reduced to zero. Thus, Proportional(P) Control of Speed is obtained with some offset error.

Table.3. Speed attained for a given Set-point Speed

Set-point speed (RPM)	Speed attained (RPM)	Percentage Error (%)
372	390	1.980902
460	484	-2.71335
567	603	1.071955

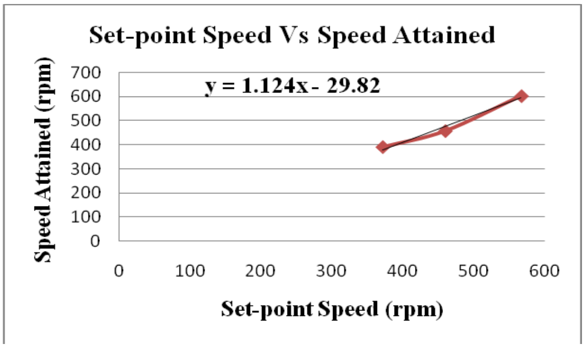

Fig.14. Set-point Speed Vs Speed Attained Curve

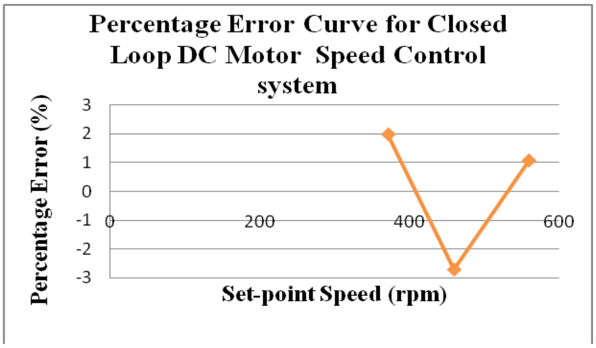

Fig.15. Percentage Error Curve

It is observed from **Fig.14.** that the variation of Process Speed attained with Set-point Speed is almost linear. The error percentage is calculated from the measured value and the true value of process Speed attained. It is observed from **Fig.15.** that the error percentage calculated from linearity of closed loop speed control system using 8051 Microcontroller is reduced nearly to **± 2 %** compared to **±6%** of open loop speed control system achieved previously using potentiometer by varying its resistance and thus the DC Motor terminal voltage.

6. Conclusion

A method of designing a Single phase half-controlled SCR based bridge rectifier circuit used as a DC Motor driver has been presented with which the speed of DC motor has been successfully controlled by using 8051 microcontroller. Other processors such as 8085 and 8086 Microprocessors could also be used but the system designer has to add peripherals such as Memory, I/O ports and timers externally to make them functional compared to 8051 Microcontrollers. Thus 8051 Microcontrollers are ideal for these embedded control applications in which cost and space are critical. Speed of high rating 220V,8A,1400 rpm DC Motors can also be controlled using rheostats of 500Ω,2A instead of using potentiometer (POT) by varying the armature voltage as it has been done here for 12 Volt,1000 rpm DC Motor. But it is observed that speed control using Microcontrollers as digital controller is more accurate and versatile than any other analog controllers. Both the circuit design and the control algorithm of the continuous digital controller have been studied. The effectiveness of the design method has been well verified by experimental results. The percentage error of closed loop speed control system lies approximately between ± 2% which has been reduced from ± 6% obtained in open loop speed control system. Thus, the result shows that the Microcontroller is a reliable and highly flexible instrument to control the DC Motor with more accuracy and precision. An offset error has been obtained in the present work which can be eliminated by using PI control algorithm which provides the future scope of work. The controller implemented has reduced the total hardware complexity and thus is more convenient and easy to implement.

References

[1] Thadiappan Krisnan, "A *Fast-Response DC Motor Speed Control System*",IEEE Transactions on Industry Applications, Vol-IA-10, Issue-5, 1974, pp.643-651.
[2] S.A.A Farag, "*Studies on an SCR Controlled Variable Speed DC Shunt Motor*", IEEE Transactions on Power Apparatus and Systems, Vol-PAS-93, Issue-3,1974, pp.785-792.
[3] S.J Jorna, Y.T. Chan, "*Microprocessor Control of Position or Speed of an SCR DC Motor Drive*", IEEE Transactions on Industrial Electronics and Control Instrumentation, Vol.27, Issue-3, 1980, pp.228-234.
[4] AHMS Ula, "*Design and demonstration of a microcomputer controller for an industrial sized DC motor*", IEEE Transactions on Energy Conversion, Vol.3, Issue-1, 1988, pp.102-110.
[5] Tsuyoshi Hanamoto, "*Speed Control Method of DC Drive System with Speed Observer*", International Conference on Industrial Electronics, Control and Instrumentation, IECON 1991, Vol.1, pp. 613-618.
[6] R. Abdolllah Khoei, "*Microprocessor based closed-loop speed control system for DC motor using power MOSFET*", Proceedings of the Third IEEE International Conference on Electronics, Circuits, and Systems, ICECS 1996, Vol.2,1996,pp.1247-1250.
[7] Y.S.E Noor Ali, Samsal Bahari Mohd, S.M Bashi Hassan, "*Microcontroller performance for DC motor speed control system*", Power Engineering Conference, PECon 2003, pp.104-109.
[8] S.B.M Moor, M.Senan.Bashi, M.K Hasan, "*Microcontroller based adjustable closed-loop dc motor speed control*", Proceedings of Student Conference on Research and Development, SCORED 2003, pp. 59-63.
[9] Abu Zaharin, "*A study on the DC motor speed control by using back-EMF voltage*", Asian Conference on Sensors, 2003, pp.359-364.
[10] H Chiu Choi, "*Applications of embedded controllers in speed and position controls*", International Conference on Industrial Electronics and Control Applications,ICIECA 2005, pp. 6-7.
[11] A.S.Z El Din, "*PLC-Based Speed Control of DC Motor*", CES/IEEE 5th International Power Electronics and Motion Control Conference, IPEMC 2006, Vol.2, pp.1-6.
[12] Huan Guo-Shing Shing,"*PC-based PID speed control in DC motor*", International Conference on Audio, Language and Image Processing, ICALIP 2008 , pp.400-407.
[13] Hu Lingyan, Xueqiang Chan, Wu Helei, "*Embedded System of DC Motor Speed Control based on ARM*", IEEE International Colloquium on Computing, Communication, Control and Management, ISECS 2008, pp.123-126.
[14] Zhu Haishui, "*Design on a DC Motor Speed Control*", International Conference Intelligent Computation Technology and Automation (ICICTA), 2010, Vol.2, pp.59-63.
[15] R.K Munje, M.R.Roda, E Kushare & Bansidhar, "*Speed control of DC motor using PI and SMC*", Conference Proceedings (IPEC), 2010, pp. 943-950.
[16] Liu Zhijun, "*PWM speed control system of DC motor*", International Conference Electronic and Mechanical Engineering and Information Technology (EMEIT),2011,Vol-3, pp.1301-1303.
[17] Radu Duma, "*Embedded control of electrical motors*", 16th International Conference System Theory, Control and Computing (ICSTCC), 2012 , pp.1-6.
[18] Rohit Gupta, Ruchika Lamba, Subhransu Padhee," *Thyristor Based Speed Control Technique of DC Motor: A Compatitive Study*", International Journal of Scientific and Research Publication, Vol-2, Isssue-6, June 2006, pp.1-6.
[19] P.M. Meshram, "*Tuning of PID controller using Ziegler-Nichols method for speed control of DC motor*", International Conference on Advances in Engineering Science and Management ICAESM 2012, pp.117-122.
[20] Muhammad H. Rashid, ''*Power Electronics Circuits, Devices and Applications*," Prentice Hall, 3rd Edition.