International Journal of Advance Research in Science and Engineering
Vol. No.5, Issue No. 02, February 2016
www.ijarse.com
IJARSE
ISSN 2319 - 8354

DSP BASED CASCADE SPEED CONTROL OF DC MOTOR USING DUAL CONVERTER

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ABSTRACT

Cascade control can provide better stability and faster control operation in the presence of disturbances and variations in load. It has numerous applications in DC drive systems which are an integral part of renewable energy systems based on wind source. In this paper we present, cascade control of PMDC motor using DSP processor(DSPIC30F6012A) to control the speed of DC motor in both directions using dual converter. Experimental results using cascade control show that the response of systemis improved as compared to the system without current control as inner loop.Speed of Motor is tracked with an accuracy of 99.28% and better time response with cascade controller as compared to single controller which has an accuracy of 98.42%.

Keywords: DSP, Cascade, Dual- Converter, DC Motor.

I. INTRODUCTION

Permanent magnet DC Motors and their control drives are playing very importantrole in industrial applications such as electrical vehicles, steel rolling mills, electric crane, robotic manipulators and also for commercial applications like home appliances, washers, driers and compressors. Apart from these, DC motors are also used in wind energy which is most important source of renewable energy. For all the above applications, speed control of dc motor is required with respect to change in load and disturbances[1].With the advent of power electronics, converter based motor control systems have become popular. In [2], different Speed control techniques of DC motor have been described along with comparative study of different converter based Speed control techniques. Cascade control involving inner current control loop and outer speed control loop has been proved to be effective in improving the response of control system. There is abundant literature available on cascade control, In [3] Author has proposed a speed control strategy for thyristor driven DC Motor subjected to parameter variation.A dual mode adaptive inner current loop is cascaded with a model referenced adaptive speed control loop. In [4] authors have presented MATLAB aided Cascade designed controller to control and monitor DC Motor speed using microcontroller PIC16F877A which is operated by PWM signal. In [5]Author presented a new speed control strategy of BLDCM motor, to reduce the low precision of speed feedback of a brushless DC motor where a cascade DC-DC with full-bridge circuit is introduced and motor closed loop speed control is achieved, In[6] Authors presented the implementation of real time control algorithm for digital motor control.The steps required for The implementation of the control algorithm on an embedded computing system are described in detail and a cascade control topology is proposed in order to control the speed of the DC motor, In[7] Author Proposed three-level cascade structure for robust velocity-tracking control of electrical motor drive is presented.They showed that with a cascade control structure, adaption of controller of different motors can be easily accomplished and the robustness problems can be solved with the most suitable technique at each control level. In[8] a novel scheme for the speed position control of PMDC drives is presented. A cascade-control scheme,based on multiple instances of a second-order sliding mode control algorithm is suggested,which provides accurate tracking performances under large uncertainty about the motor and load parameters. All the above methods either demonstrate simulation results or real time implementation using microcontrollers for unidirectional DC drives. As DSP provides easy implementation of complex control with greater accuracy and speed of response, it is becoming popular in industrial drive systems. In [9]a DSP based PID controller has been developed to control speed of PMDC motor. It is found to improve accuracy of the speed control system to a great extent. To implement bidirectional speed control, Dual converter has been used. In this paper, we have modified the existing system in [9], by implementing cascade control to furtherimprove the system response and precision. For a permanent magnet DC motor the differential equations describing the operation of electrical circuit are given as

$$V_a(t) = Ri_a(t) + L\frac{di_a}{dt} + E_a \quad \text{\_\_\_\_\_\_\_\_\_(1)}$$

R- Armature Resistance in Ω and

L-Armature Inductance in H

$V_a(t)$ – Armature terminal voltage

E_a – Armature back emf

$i_a(t)$ – Armature current

and for mechanical circuit are

$$T_e = B\omega(t) + J\frac{d\omega}{dt} \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_(2)}$$

T_e - Electromagnetic Torque in N-m

B-Friction Coefficient of motor and load

J-Moment of Inertial of motor and load

The electrical time constant (L/R) for armature circuit is much smaller (i.e. faster) than the mechanical one J/B.Hence we can break the system into two smaller and separated subsystems, i.e. the electrical and the mechanical part and use two PID controllers. The changes in the load torque have a direct effect on the armature current and hence if the current is controlled, then the transient response of the speed control system can be improved as compared to a single PID controller. This technique is called as Cascade control. It is one of the most popular complex control structuresimplemented to improve the disturbance rejection properties of a controlled system. In cascade structure,each loop has associated its corresponding PID controller. The controller of the inner loop is called secondary controller whereas controller of outer loop as the primary controller. The structure is shown in Fig. 1.

Usually, conventional cascaded speed and current controllers are designed to ensure a definite separation of speed and current loop in frequency domain. The separation in turn allows independent design of speed and current controllers and minimum interaction among these loops. However there are number of practical cases, where the conventional configuration cannot deal adequately with robustness issues.

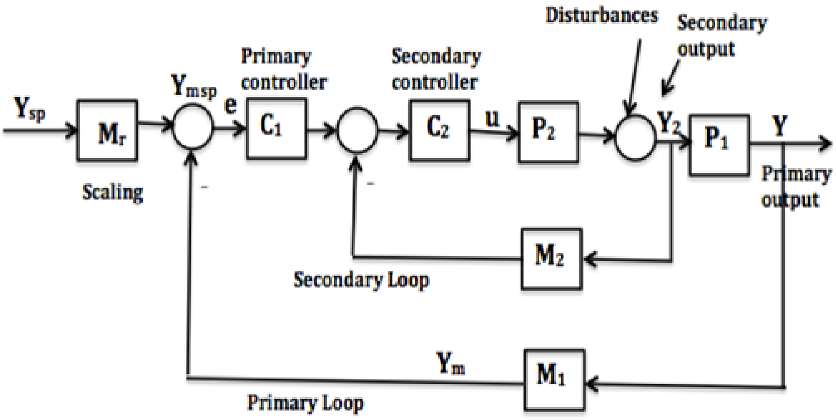

Fig 1: Cascade Control System

In particular, when current loop is subjected to parameter variations, the conventional cascade control does not guarantee for maintaining the outer loop in an acceptable performance [10]. To overcome this difficulty, we are using one PID controller soft coded inside the DSP processor for speed control and other PI controller as hardware for current control.

II. BLOCK DIAGRAM

The block diagram of the speed control system is as shown in Fig 2, [11]. Speed of motor is controlled below its base speed using armature voltage control method. A Dual converter is used to provide variable voltage to the motor in forward and reverse direction. Firing pulses for dual converter is generated using a single conditioning unit. Optical encoder placed on the motor shaft gives real time information of speed of the motor. Current measurement is done by Hall-effect current sensor.Hall-effect sensor produces a voltage proportional to the measured current [12]. Output of optical encoder is compared with the voltage corresponding to preset reference speed and the resultant error voltage is given to the PID controller.

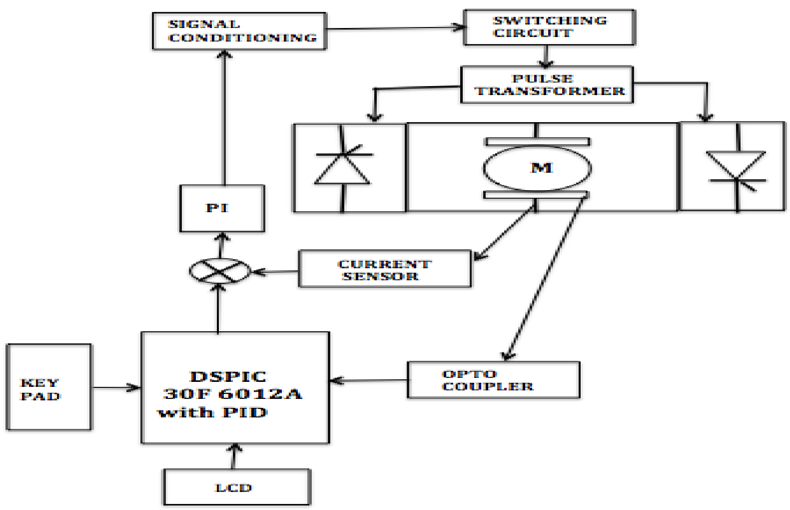

Fig 2:Block Diagram of DSP based Cascade Control

Output of this PID controller is given to current PI controller as a set point, which is compared with the current sensor voltage. PI controller output voltage is given to signal conditioning unit which will generate triggering pulses for the dual converterand thus control the speed of motor.

III. HARDWARE IMPLEMENTATION

PID controller for speed is implemented using DSP.The equation for PID controller in discrete form is given below

$$u_k = \bar{u} + K_c e_k + K_I \sum_{i=0}^{k} e_i + K_d \left(\frac{e_k - e_{k-1}}{T}\right) \quad \text{---(3)}$$

Where, K_c is the Proportional gain, $K_I = \frac{K_c}{T_i}$ is the integral gain and $K_d = K_c \times T_d$ derivative gain and T is Sampling time.

e_k − error at current instant

e_{k-1} − error at previous instant

In this project value of PID control parameters are selected by using trial and error method. The values of PID controller parametersare given below

$K_c = 1$

$K_d = 0.01\sec$

$K_i = 0.1/\sec$

T= 0.001sec

$F_{sampling}$=1 KH_z

PI controller for current is implemented as shown in Fig3. Control parameters are selected as

$K_p = \frac{R_{f_2}}{R_{in}} = 1$ (From fig. 3)

$K_i = \frac{X_c}{R_{in}}$ =0.03/sec where $X_c = \frac{1}{2\pi fC}$

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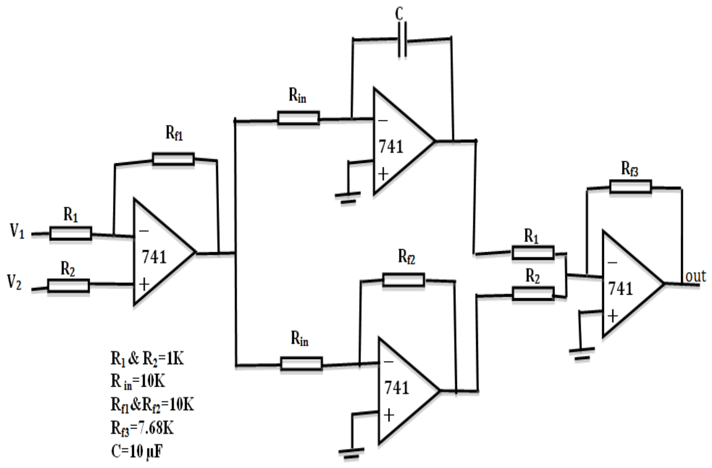

Fig 3: PI controller circuit

Motor Specifications

Motor is ¼ hp 1500rpm, 12VPMDC motor with armature current rating of 2.1amp.

3.1 Speed Sensor

Optical encoder consists of a rotating and stationary member.The rotor is a plastic disc mounted on the motor shaft. The disc has a kind of optical pattern that uses opaque and transparent segments which is electronically decoded to generate position information.In this disc contains 30 strips, so encoder will generate 30 pulses in one rotation. The stator is a module (MOC7811)consisting of an infrared emitting diode facing a photo detector in a molded plastic housing.Output pulse of Optical encoder is converted into voltage and is given to DSP processor.Output of DSP processor will go to PI controller as a set point.

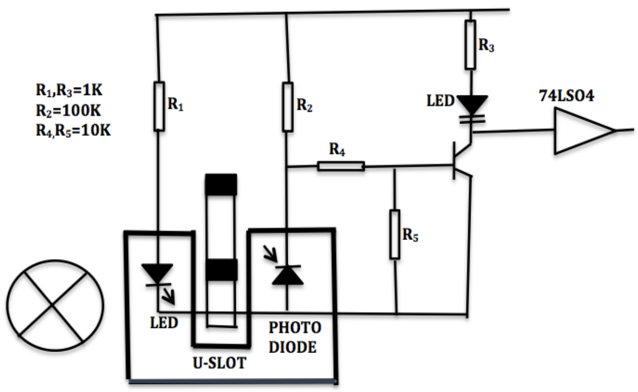

Fig 4: Speed Sensor with Signal Conditioning

3.2 Current Sensor

Current sensor is the secondary variable of feedback used.Output of current sensor is given to PI controller as variable input and set point of PI controller is signal generated by DSP.Current is sensed using Hall- effect sensor ACS712. When applied current flows through this current sensor a magnetic field is produced which is sensed by the integrated Hall IC and is converted into proportional voltage. Output of PI Controller is given to signal conditioning unit. This signal is amplified and given to ramp generator circuit; output of this circuit is

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IJARSE
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saw tooth wave which is given to 555timer in monostable mode which produces series of pulses, which is given to Dual Converter to trigger the SCR. The frequency of triggering pulses will change according to increase or decrease in error voltage and accordingly firing angle will change.

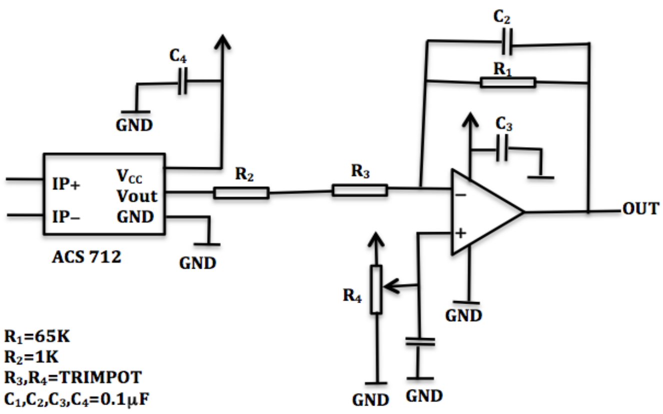


Fig 5: Current Sensor with Amplifier

3.3 Dual Converter

Thyristors used In Dual converter is 25TT S12 with max voltage 25V.In this one converter acts as a rectifier and other converter acts inverter. In Dual converter both the voltage and current can be reversed at dc terminal. In this work we have used the non-circulating current control mode, which eliminates use of bulky reactor for limiting circulating current. In this mode of operation, only one converter acts at a time. The complete hardware implementation is given in Fig. 6.

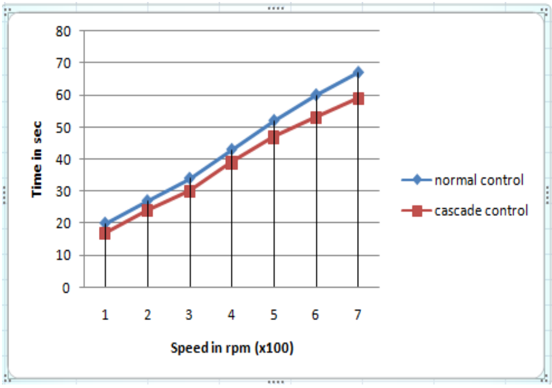
Fig 6: Actual Implementation

IV. RESULTS

Experiments were carried out by changing the speed set-points using the keypad provided in the set-up. The time required by the two controllers namely, single loop and cascade was observed and compared. During these experiments motor is not loaded. The results are presented in Table 1.

Set Speed in rpm (rpm_1)	**Time(in sec) required to achieve the given speed**	
	Single Controller	**Cascade Controller**
100	20	17
200	27	24
300	34	30
400	43	39
500	52	47
600	60	53
700	67	60
800	75	67
900	84	76
1000	91	83

Table1: Response of controllers



Graph1: Response Time for Controllers

From above graph we observe that response of system with cascade control showed better performance than system without cascade control.We also observed that at higher speed cascade system is reaching the given speed in less time than it is for the system at lower speed.So we can observe system performance with cascade is increasing at higher speed.The controller performance can be compared by calculating error as follows:

$$\%error = [(rpm1 - rpm2)/rpm1] \times 100\% \quad (4)$$

Set Speed (rpm_1)	Motor Speed (rpm_2)		%error	
	g Controlle	r controlle	Single Controller	Cascade controller
100	98	98	2	2
200	194	199	3	0.5
300	294	301	2	0.33
400	395	398	1.25	0.5
500	493	501	1.4	0.2
600	596	599	0.66	0.2
700	688	694	1.71	0.85
800	792	793	1	0.87
900	890	895	1.25	0.55
1000	985	988	1.5	1.2

Table 2: Controller Performance

Experimental results show that in cascade control system time required to achieve the given speed is less compared to the time required without cascade and it has better set point tracking with an accuracy of 99.28% as compared to single controller which has an accuracy of 98.42% as we can see in Table 2

V. CONCLUSION

The cascade speed control system is implemented for speed control of PMDC motor. Control is implemented using DSPIC30F6012A processor and current control is implemented with separate analog control block. We also observed that current sensor performance is better at higher speeds, possibly due to lesser effect of disturbances. Future work includes analysis with load on a higher rated motor and also implementing circulating current control to improve the speed of operation further.

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