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Design and Simulation of Closed Loop Speed Control of DC Drives by Using Dual Converter

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Abstract— This paper presents the speed control scheme of DC motor and provides a firing angle based speed control technique of the separately exited dc motor. The best control characteristics of DC motor have used in industries for different range of loading condition. A dual converter comprised of two single phase AC-DC thyristor converter is proposed. Speed of DC motor is controlled by controlling the armature voltage. Armature voltage is controlled using controlling the firing angle of thyristor. The circulating operation of dual converter, in which rectifier 1 will be rectifying ($0<\alpha_1<90°$) and rectifier 2 will be inverting ($90°<\alpha_2<180°$). By using the closed loop system controlled the speed of dc motor with different loading condition using inner current and speed control loop. The linear & non-linear regions are clearly visible in control characteristics. Firing control scheme improve armature voltage & also reduce ripple content & possibility of discontinuous conduction in circuit. The controlled performance exhibited is superior & also firing angle smoothly controlled with fast response.

Keywords- AC-DC converter, separately exited DC motor drive, dual converter, MATLAB

I. INTRODUCTION

DC motors are widely used in industry because of its low cost, less complex control structure and wide range of speed and torque. There are many methods of speed control of separately exited dc motor drive namely field control, armature voltage control and armature resistance control methods. DC motor provided high starting torque which is required for traction application. In DC motor control over a large speed range, both below and above the rated speed can be achieved quite easily. DC motor have their inherent disadvantages that it needs regular maintenance and it is bulky in size, so it is very difficult to replace them[4]. Armature voltage control method is widely used in industries to control the speed of dc motor below base speed.

By the development in advance power semiconductor switches such as thyristor, MOSFET, BJT, diode, IGBT etc. there are an increased usage of SMPS or any other power electronics circuit within the modern commercial and industrial environment particularly in application for AC-DC conversion. And the other things is that, there are power supply system is AC in nature and mainly traditional DC drives are used in operation so that easy in speed control requiring some forward and reverse operation. The output of one ac/dc converter normally has substantial ripple content due to thyristor switching. Furthermore, the current becomes discontinuous when its average value falls below a certain threshold because the current cannot reverse in a thyristor. Current discontinuity has an important effect on the converter transfer characteristics and subsequent drive performance[12]. Ideally, the armature current should follow the desired reference current with minimum delay, preferably within one sampling period. Optimum response is achieved when the output follows the input after one period with no overshoot at any operating point in continuous or discontinuous current conduction[11].For achieve effective control on speed direction and AC-DC conversion, a simple controllable dual converter is used. The reversal current and speed through the dc motor is virtually provided by dual converter. For obtaining the operation of dc drive in four quadrant operation mainly two types of converter is used[9][10].

A. Class-E Chopper

B. Dual Converter

Now a day's mainly using the dual converter in dc drives operation for achieving four quadrant operations. By using the class-E converter mainly using MOSFET or IGBT as switching devises and the frequency of that is very high. By using the thyristor as a switch in Class-E chopper but need an extra commutation circuit for turn off the thyristor while in dual converter it is naturally commutated so; dual converter is mainly preferred for this application.

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A combination of two single phase full wave thyristor fed controlled rectifier with their output terminals connected in anti-parallel allows operation in four quadrant as shown in fig.1.where ever a single converter offers only two quadrant operation because of the unidirectional current of AC-DC converter if the bridge rectifier.

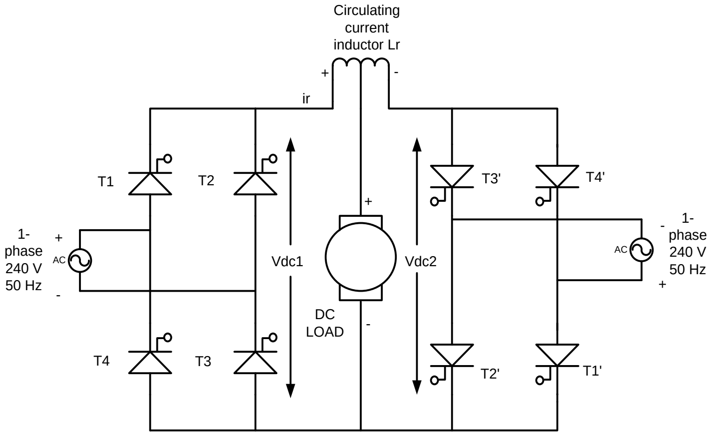

Figure 1. single phase dual converter with circulating current mode

Therefore, for these firing angles converter 1 is working as a rectifier while the other, converter 2 is working as a line commutated inverter.

The average output voltages of converter 1(V_{dc1}) and converter 2(V_{dc2}) are shown below.

$$V_{dc1} = 2V_m/\pi \cos \alpha_1 \qquad (1)$$
$$V_{dc2} = 2V_m/\pi \cos \alpha_2 \qquad (2)$$

Here one converter is rectifying and the other one is inverting so that,

$$V_{dc1} = - V_{dc2} \text{so,}$$
$$\cos\alpha_1 = -\cos\alpha_2 = \cos(\pi-\alpha_1)$$

Therefore,

$$\alpha_2 = \pi-\alpha_1 \qquad (3)$$

Because the instantaneous output voltage of the two converters are out of phase, there can be instantaneous voltage difference and this can result in circulating current between the two converter, this circulating current cannot flow through the load and is normally limited by a circulating current reactor L_r.

The circulating current i_r is given by,

$$i_r = \frac{1}{\omega l r} \int_{\pi-\alpha 1}^{\omega t} Vr \, d(\omega t) \qquad (4)$$

$$= \frac{2Vm}{\omega Lr}(\cos\alpha_1 - \cos\omega t) \qquad (5)$$

$$ir > 0 \text{ for } 0 \le \alpha_1 \le \frac{\pi}{2}$$
$$ir < 0 \text{ for } \frac{\pi}{2} \le \alpha_2 \le \pi$$

In case of operation without circulating current, only one converter operates at a time and carries the load current and the other converter is completely blocked by inhibiting gate pulses[10].

Thus, with circulatory current mode, both the converters are in conducting state, one operates as rectifier producing a given average voltage at its d.c terminals and the other operates as an inverter producing the same average counter-voltage[9].

II. BLOCK DIAGRAM

The schematic diagram of the dc drive system is shown in Fig.3 the power circuit consists of a single phase fully antiparallel connected controlled bridge converter that drives a separately excited dc motor[1]. The thyristor bridge converter gets its ac supply through a single phase transformer and fast acting ac contactors.

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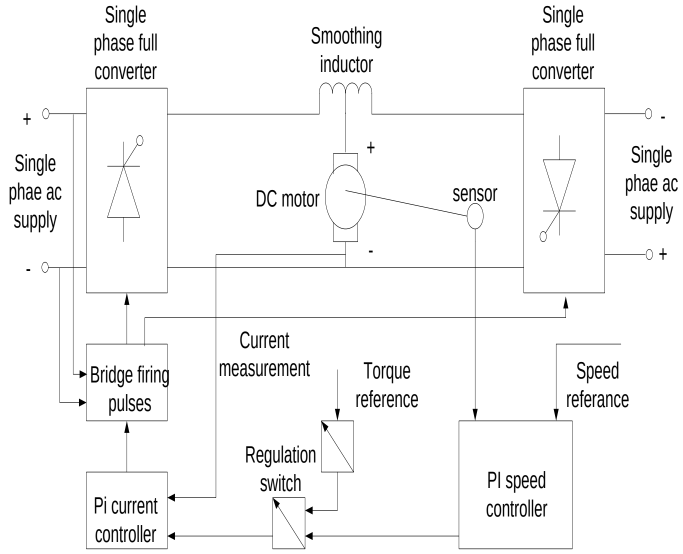

Figure 2. Schematic block diagram of closed loop dual converter

The dc output is fed to the armature of the dc motor. The output of the current controller is the control voltage for the converter firing circuit. The firing pulses for the SCRs are generated with a delay angle, by cosine wave crossing method. The speed and current controllers is PI controller[5]. Output of the tacho generator is filtered to remove the ripples to provide the signal of speed. The speed command and reference signal is compared to the speed signal to produce a speed error signal. This signal is processed through a proportional plus integrator speed (PI) controlled to determine the torque command. The torque command is limited, to keep it within the safe current limits, and the current command is obtained by proper scaling.

The armature current command is compared to the actual armature current to have a zero current error. In case there is an error, a PI current controller processes it to alter the control signal. The control signal accordingly modifies the triggering angle α to be sent to the converter for implementation. The inner current loop assures a fast current response and hence also limits the current to a safe level. This inner current loop makes the converter linear current amplifiers. The outer speed loop ensures that the actual speed is always equal to the commanded speed and that any transient is overcome within the shortest feasible time without exciding the motor and converter capability[5].

The inner current loop will maintain the current at level permitted by its commanded value, producing a corresponding torque. As the motor starts running, the torque and current maintained at their maximum level, the accelerating the motor rapidly. When the rotor attains the commanded value, the torque command will settle down to a value equal to the sum of load torque and other motor losses to keep the motor in steady state.

III. MATLAB SIMULATION CIRCUIT

The speed control of separately excited DC [SEDC] motors by PI and PID controller is widely used in industry application. This chapter describes the designing of a closed loop model of the SEDC drive for controlling speed below the rated speed. The modeling of closed loop speed control of SEDC motor using single phase fully controlled rectifier using dual converter is done in MATLAB. The speed of separately excited DC [SEDC] motor can be controlled below the rated speed by using controlled rectifier as a converter.

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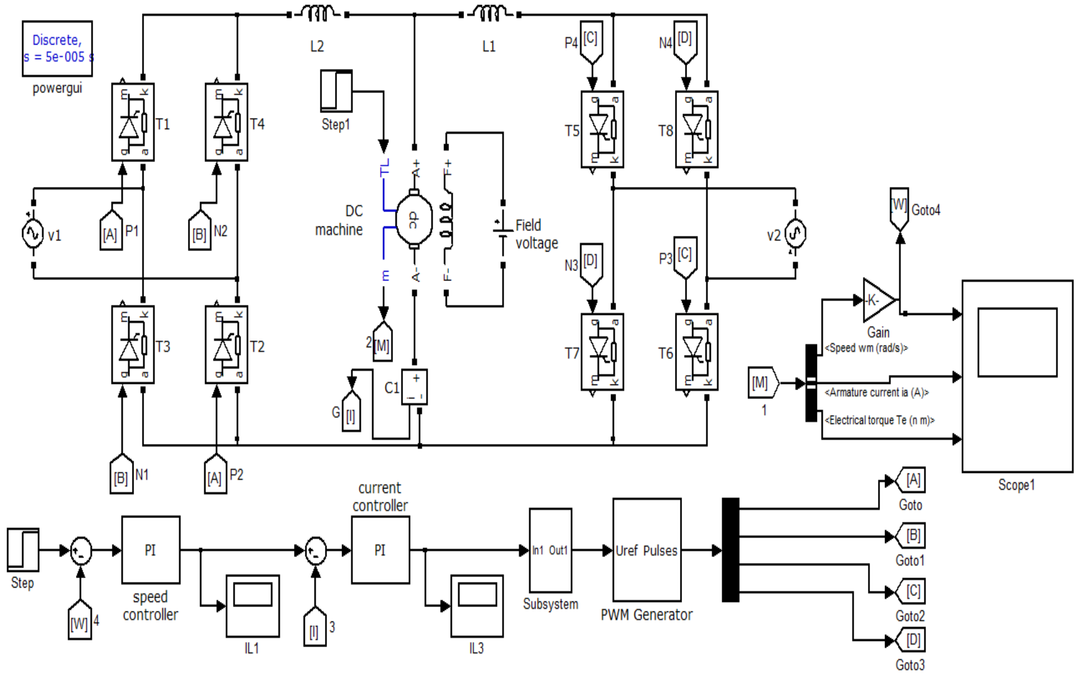

Figure 3.Closed loop Simulink model of Dual Converter

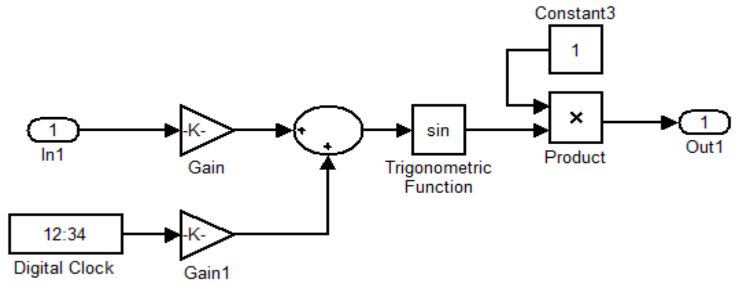

Figure 4.Subsystem model

The controlled rectifier firing circuit receives signals from the controllers and then controlled rectifier gives variable voltage to the armature of the dc motor for achieve required speed. There are two control loops, first one for controlling current and another one for control of speed. Proportional-Integral [PI] type controllers are used, which removes the delay and provides fast control. The results are obtained for reference speed which is rated or below the rated speed of motor. The speed of the motor is obtained at pre-set value [ref. Speed]. When the load is increase, speed of the motor is decrease. But by closed loop control of motor, the speed of the motor is settled at reference speed.

IV. SIMULATION WAVEFORM

When we set the reference speed of the dc motor at 900 RPM (forward motoring in 1st quadrant) and -900 RPM (reverse motoring in 3rd quadrant) with maximum rated torque and on no load condition waveform of the actual getting speed, speed error, o/p of PI speed controller, o/p of PI current controller and armature current is shown below.

4.1 W*= 900 with different loading torque

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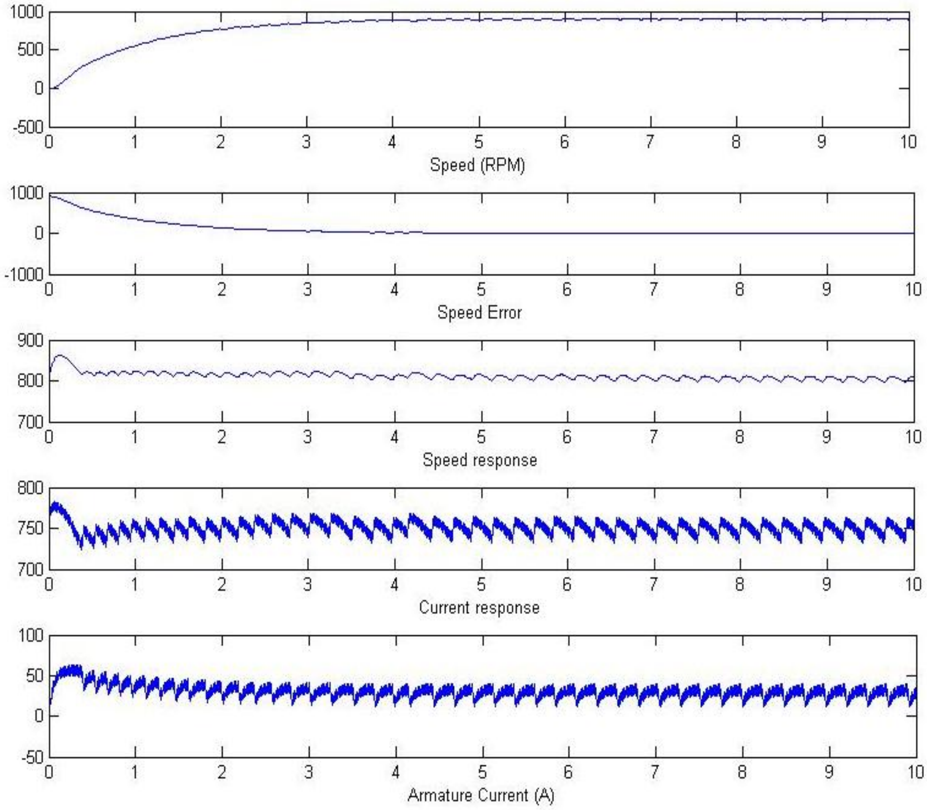

Figure 5. W=900 RPM at T=7.5 N.m Speed, system response and armature current*

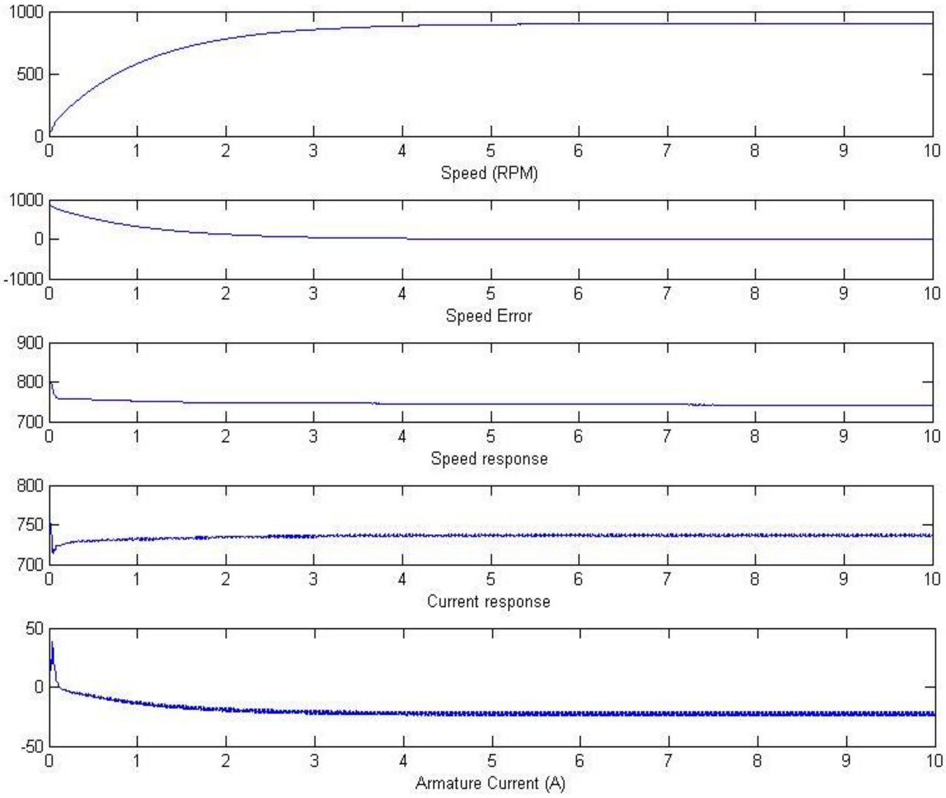

Figure 6. W=900 RPM at T= -7.5 N.m Speed, system response and armature current*

4.2 W*= -900 with different loading torque

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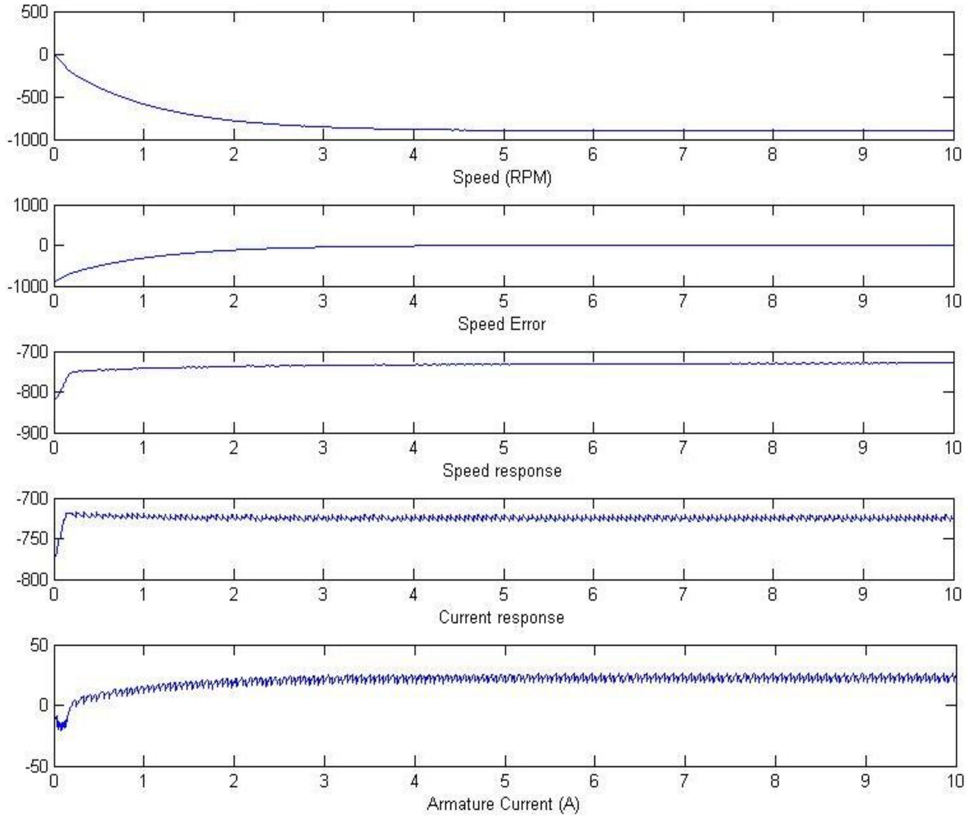

Figure 7. W=-900 RPM at T=7.5n.m condition Speed, system response and armature current*

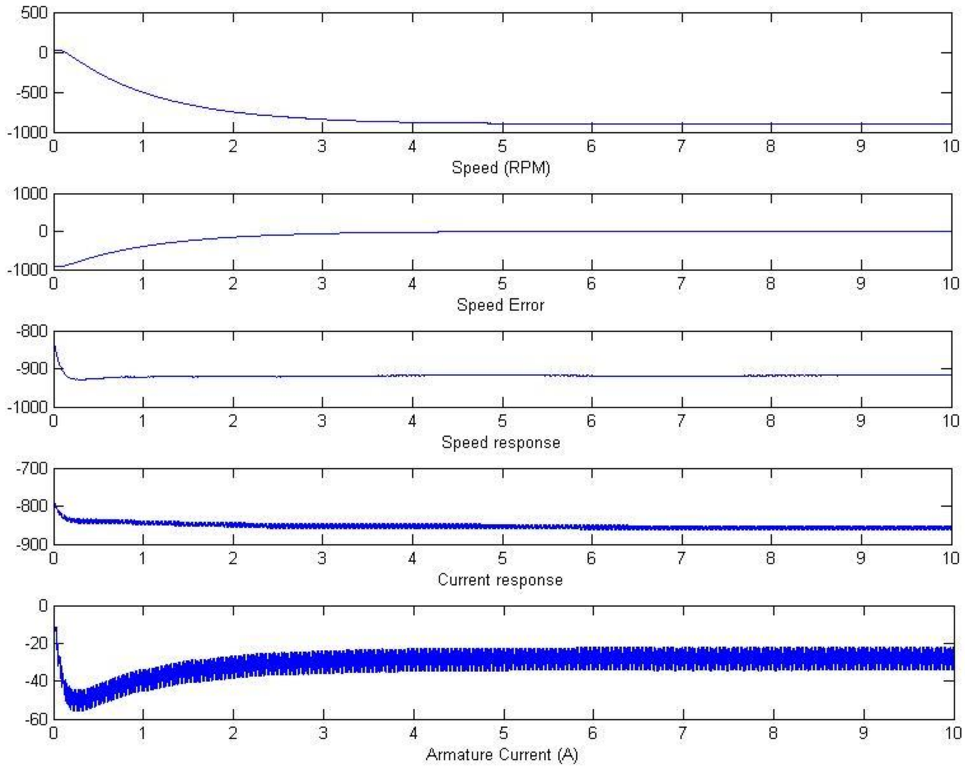

Figure 8. W=-900 RPM at T=-7.5n.m condition Speed, system response and armature current*

4.3 Modulating signal and generating pulses at the speed 900 RPM

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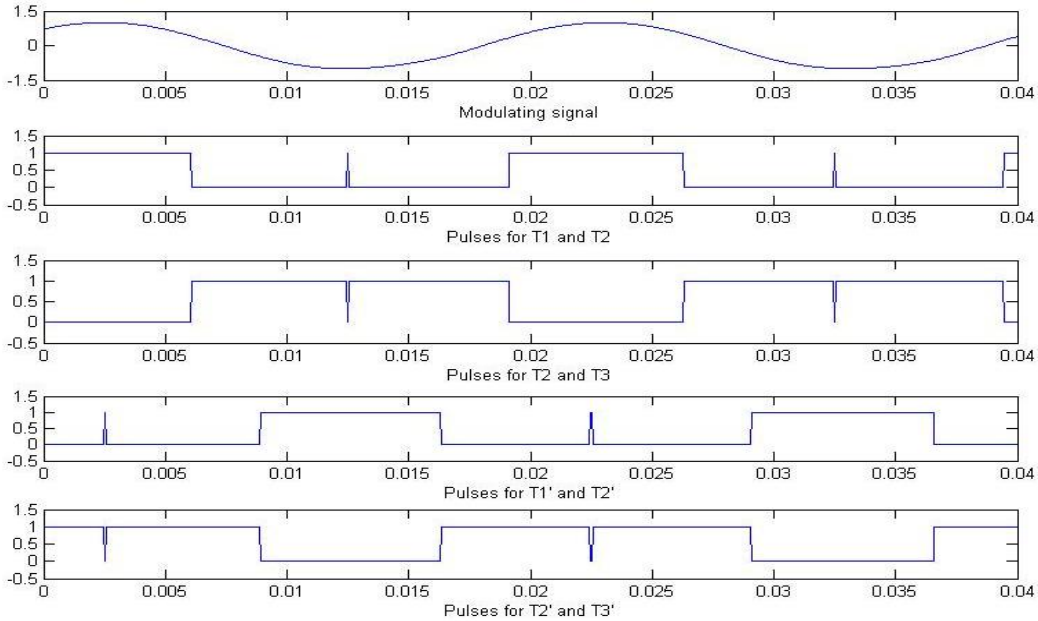

Figure 9 Modulated signal and generated pulses

4.4 Ratings of the DC motor

Table 1. Ratings of the DC motor

SR NO.	CONTENTS	RATINGS
1	Rated Power (P)	1 HP
2	Rated supply Voltage	110V
3	Armature Resistance Ra	0.9Ω
4	Armature Inductance La	0.046H
5	Field Resistance Rf	86.95Ω
6	Field Inductance Lf	15.93H
7	Rated Speed	950RPM
8	Rated Field Voltage	50V (DC)
9	Rated Torque	7.49 n.m

V. SIMULATION RESULT

Table 2. Simulation result comparison with open loop and closed loop

CLOSED LOOP RESULT						OPEN LOOP RESULT
Sr no	Reference speed(rpm)	Load torque(N.m)	Armature Current(A)	Actual speed(rpm)	Steady state time (s)	Actual speed(rpm)
1	900	7.5	24.3	900	4.5	770
2		5	10.15		4	815
3		No load	1.3		3.9	900
4		-5	-11.78		4	1020
5		-7.5	-23.86		5.1	1070
6	-900	7.5	23.65	-900	4.5	-1070
7		5	11		4.5	-1020
8		No load	1.4		4	-900
9		-5	-10.3		4.6	-815
10		-7.5	-22.1		4.7	-770

VI. CONCLUSION

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For stable operation of SEDC motor, the designing of speed controller is done by using the inner current controller or outer speed controller. By this approach system becomes stable. From the simulation result we observed that the speed of SEDC motor is constant at the reference speed which is rated or below the rated speed of motor and also observed that the speed error is set to be zero. The system's response shows the fast rise time, fast setting time.

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