International Journal of Advance Research in Science and Engineering
Vol. No.5, Issue No. 05 , May 2016
www.ijarse.com
IJARSE
ISSN 2319 - 8354

SPEED CONTROLLING OF ELECTRIC VEHICLE USING THYRISTOR: A COMPARATIVE ANALYSIS

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ABSTRACT

The vivid control mechanism of electric motor have contributed in the extended use of electric motor in the electric vehicle industry. With the increasing contribution of power electronics units, the speed controlling of DC/AC electric motor is rapidly getting more sophisticated and accurate. Armature field voltage controlled speed variation of DC motors is one of the widely used techniques. Various power semi conductor devices like Thyristor and IGBT are used to control Armature voltage using different single phase AC/DC converter. There are various thyristor based circuits like Half converter, full converter, dual converter and semi converter are are used for controlling the speed of DC motor, which are making future of electric vehicles and hybrid vehicles more promising . This paper comprises various motor speed control techniques using thyristor and presents a comparative performance analysis of IGBT and thyristor.

Key Terms: Speed Control, DC Motor, Thyristor, IGBT, Converter Circuits.

I. INTRODUCTION

DC motors are used widely in controllable-speed drives and various applications of position control [1].Speed of motors below the base speed can be controlled by controlling the armature-voltage . Speeds above the base speed are achieved by controlling the field-flux [2]. As speed control mechanism for DC motors are less expensive and simpler than those methods for its rival the AC motors, DC motors are generally preferred where wide range of speed control is needed. DC choppers circuit provides variable dc output voltage from a fixed value of dc input voltage [3].The Chopper circuit can operate in all the four quadrants of the Voltage - Current plane. The output magnitude and direction of output voltage and current can easily be controlled. The complete four -quadrant chopper is extensively used in reversible dc motor drives. The promising part is that, by applying chopper it is feasible to implement dynamic braking and regeneration for dc motors.

DC motors are very popular in electric vehicle industry because of its simplified control structure, wide range of speed torque variation and low cost. In most of the cases DC motors are customized during assembling according to the requirement of application, thats why DC motors leads in the competition. For controlling the armature voltage for the sake of speed control a DC arrangement is popularly used which consist of chopper or controlled rectifier designed with the help of power electronic circuit elements like thyrisotr or IGBT, and because of the nonlinear nature of semiconductor power electronic devices a nonlinear torque speed relationship

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ISSN 2319 - 8354

is observed [4]. In recent past various researcher proposed different types of DC motor control circuits of various industrial requirements [5,6] basically based on thyristors.

The Silicon controlled rectifiers and thyristors, are generally opted as the power electronic semiconductor switching circuit elements for the power stage on the criterion of their well verified ruggedness and affordable cost. For the sake of controllers cost reduction number of power stage components reduction and bus commutated circuit topology can be opted [7]. Paper consist of mathematical modelling of DC motor[8], Thyristor controller circuits[9] and controlling mechanism using IGBT[10], rest of the paper is arranged in following sections; Section II covers mathematical equivalent model for DC motors, Section III and Section IV comprises various control mechanism using thyristor and IGBT respectively, Section V covers simulation results and discussion, that presents comparative analysis of thyristor and IGBT and final section, section VI concludes the paper.

II. MATHEMATICAL EQUIVALENT OF DC MOTOR

For the better understanding of the behaviour of DC motor , a dynamic and steady-state model of separately excited DC motor is considered. The equivalent mathematical model is very helpful in analysis of speed-torque characteristics of DC machine. The electrical equivalent circuit for separately excited DC motor is shown in figure-1 in which 'Ea' is end terminal voltage applied across the motor, L1 and R1 are the armature inductance and resistance respectively. r2 and L2 are the field resistance and inductance. Eb is the back emf generated by the armature bindings and Ʈm is the developed electromagnetic torque of motor. Ia and If are armature and field current respectively and Ef is field emf.

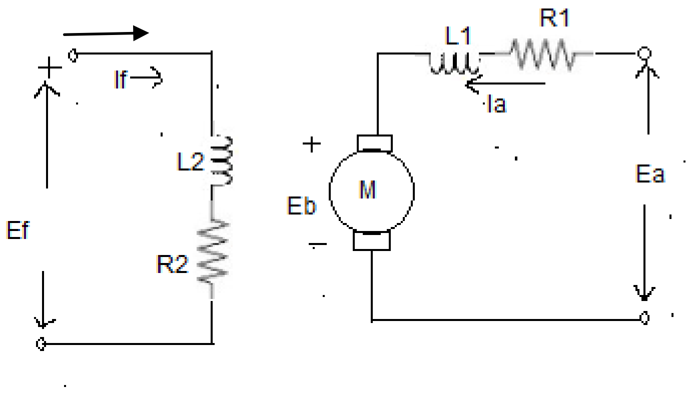

Figure 1 Electrical equivalent of separately excited DC motor

Now applying KVL at input side

$$Ea = R_1 I_a + L_1 \frac{dI_a}{dt} + E_b \qquad (1)$$

Due interaction between field flux and armature current the resultant torque can be expressed, as in equation 2

$$Ʈm = K\upsilon\varphi Ia \qquad (2)$$

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ISSN 2319 - 8354

Here Ku is a constant depending on motor geometrical structure and windings and φ is the flux per pole due to the field winding. The direction of armature current 'Ia' decides direction of generated torque. But as per Faraday's principle when a coil will rotate in magnetic field, an emf will get generated with direction opposite to source voltage, which is termed as back emf Eb. Back emf is dependent on linking flux and can be expressed as in equation (3)

$$Eb = Ku\varphi\omega \qquad (3)$$

Further steady state condition can be depicted for evaluating the speed of DC motor. Steady state equation is given in equation (4)

$$Ea = IaR1+Eb \qquad (4)$$

From equation (2) and (3) , equation (4) can be rewritten as;

$$Ea= (Tm/Ku\varphi)\ R1 + Ku\varphi\omega \qquad (5)$$

Expression for speed can be deduced as;

$$\omega= (Ea/Ku\varphi) - Tm/(Ku\varphi)^2R1 \qquad (6)$$

Certain conclusions can be drawn from equivalent mathematical model of DC motor presented in equation (6); the speed of separately excited DC motor can be controlled by three key parameters, Armature voltage (Ea) controlled, Armature resistance (R1 or Ra) Controlled and Field Flux (φ) controlled. Armature voltage control method is preferred when required speed is higher than base speed and flux control technique is preferred when desired speed range is below base speed.

On the basis of equation (6) an ideal speed torque characteristic of separately excited DC motor can be plotted figure (2) , following graph is for armature voltage controlled method , where Ea is changing keeping field voltage constant.

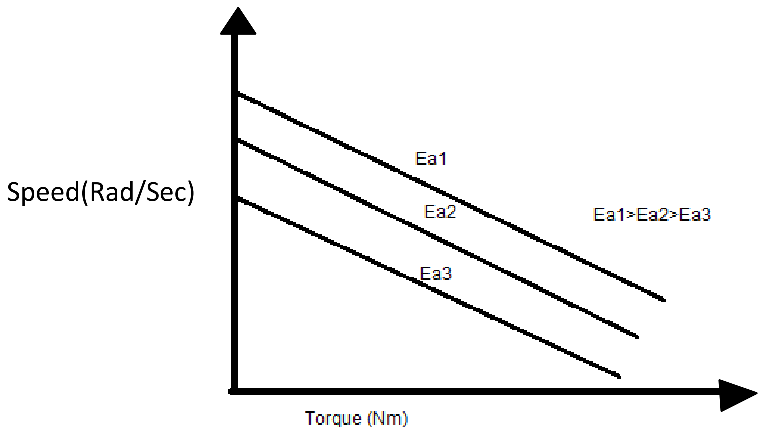


Figure 2 Ideal Speed Torque Characteristics

III. IGBT FOR MOTOR SPEED CONTROL

IGBT is insulated gate bipolar transistor, which is a three terminal device and act a an electronic switch for specific applications where high speed and accurate switching is needed. IGBT is used in many applications where electric power switching is needed, like electric vehicles, air conditioners, frequency drives, stereo systems etc. IGBT simply combines gate driven characteristics of MOSFET with the low value of saturation voltage and high current. Isolated gate field effect transistor used for control input and the bipolar power electronic transistor act as a switch. During on state it has very low voltage drop because of superiority in state current density and conductivity modulation.

It is possible to built controlling circuit over smaller chip area and at lower cost. The power consumption of IGBT is very low and due to specific structure at MOS gate the device response is easily controllable as compared to SCRs. IGBT have good forward blocking and reverse blocking capability. A inductive load circuit for IGBT is shown in figure (3).

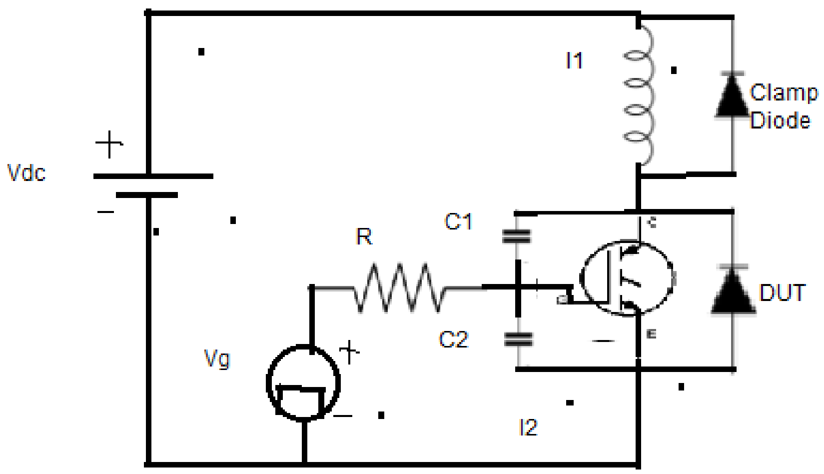


Figure 3 Inductive Load Circuit

Since the nature of the most loads are inductive, which subjects devices to higher stresses, the turn-on ,turn-off transients of the IGBT are achieved with an inductive load test as circuit shown in above figure. The load inductance is considered to be high enough so as to handle the load current constant during switching actions. The freewheeling clamp diode is required to maintain the flow of current in inductive load when the IGBT under test (DUT) is turned to off.

IV. MOTOR SPEED CONTROL MECHANISMS USING THYRISTOR

A separately excited DC motor is fed through single phase half wave Converter using thyristor. That offers single quadrant drive.

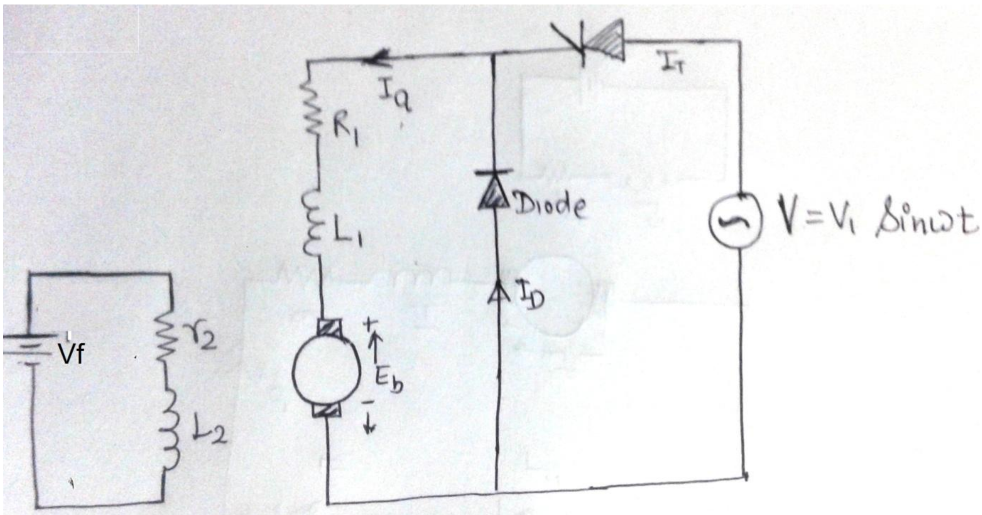


Figure 4 Separately Excited Motor with Single Phase Half Wave Converter

The average output voltage of a single phase converter can be evaluated as;

$$Vo = \frac{V1}{2\pi}(1 + Cos\delta)\text{ , for } 0<\delta<\pi \qquad (7)$$

But the introduction of Half wave converter in field circuit promotes the magnetic loss and it delivers only in one quadrant. Single phase converter can be designed in two other way for speed control; single phase semi converter and single phase full converter, corresponding circuits are given in figure 5 and 6. In both the cases the output voltage depends upon firing angle and the magnitude will be V1/π of single phase semi converter and 2V1/π for single phase full wave converter.

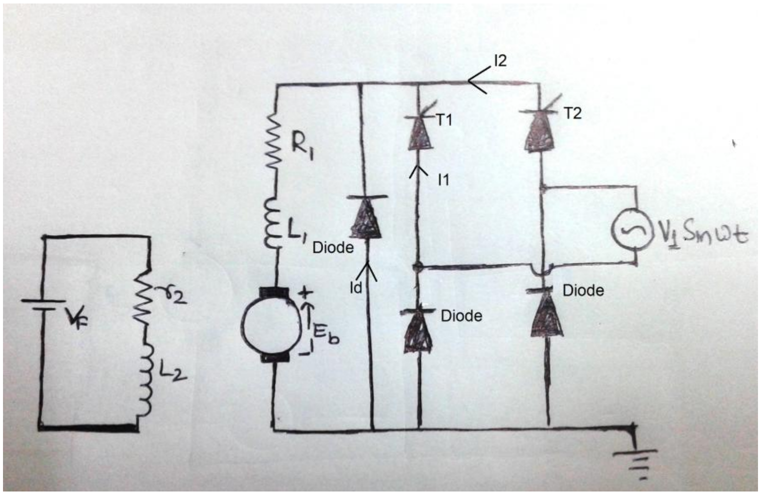


Figure 5 Single phase semi converter

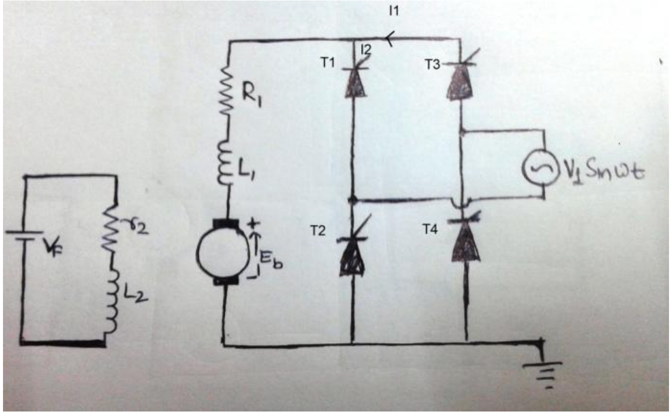


Figure 6 Single Phase Full wave converter

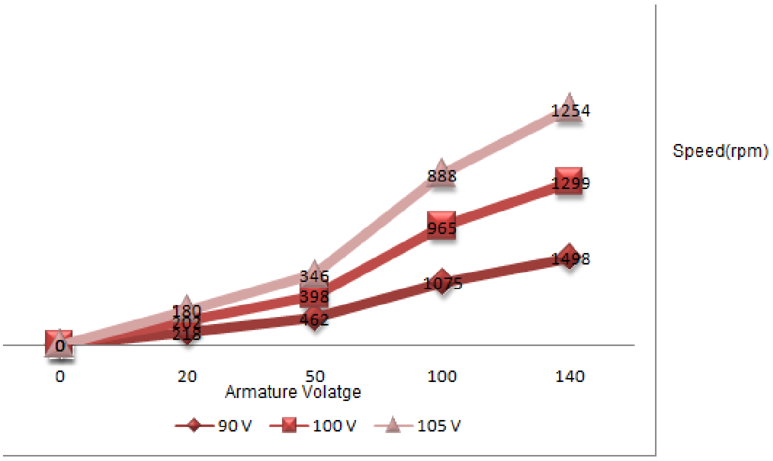
V. SIMULATION AND RESULTS

To get the better understanding of addressed subject separately excited DC motor is considered and a graph has been plotted between armature voltage and speed ad various values of filed voltage. Obtained date is presented in table 1 and graph in figure 7.

Table 1 Armature voltage Vs speed for different field voltage

S.No	Armature Volatge (V)	Speed in rpm (filed voltage Vf)		
		90 V	100 V	105 V
1	0	0	0	0
2	20	218	202	180
3	50	462	398	346
4	100	1075	965	888
5	140	1498	1299	1254

Obtained graphical analysis suggests that the speed and armature voltage variation changes for change in value of filed voltage, which advocates that applying a control mechanism over filed voltage the speed of DC motor can be controlled in a sophisticated manner.



Secondly a separately excited DC motor speed variation is evaluated with respect to armature voltage for speed control mechanisms using IGBT and thyristor, a comparative analysis is given in table 2 and result shown in figure 8.

Table: 2 Armature voltage vs speed analysis using IGBT and SCR

S.No	Armature Voltage (V)	Speed (rpm)	
		Thyristor	IGBT
1	0	0	0
2	50	425	362
3	75	625	545
4	100	865	741
5	120	1068	906
6	150	1330	1128
7	200	1589	1486

Figure 8 depicts the comparative behaviour of thyristor and IGBT, the slop of IGBT is smaller than thyristor, which suggests that required speed change from base speed can be obtained at lower armature voltage if thyristor is used for controlling. Thyristor can be opted as an alternate power electronic controller for managing the speed of DC motor.

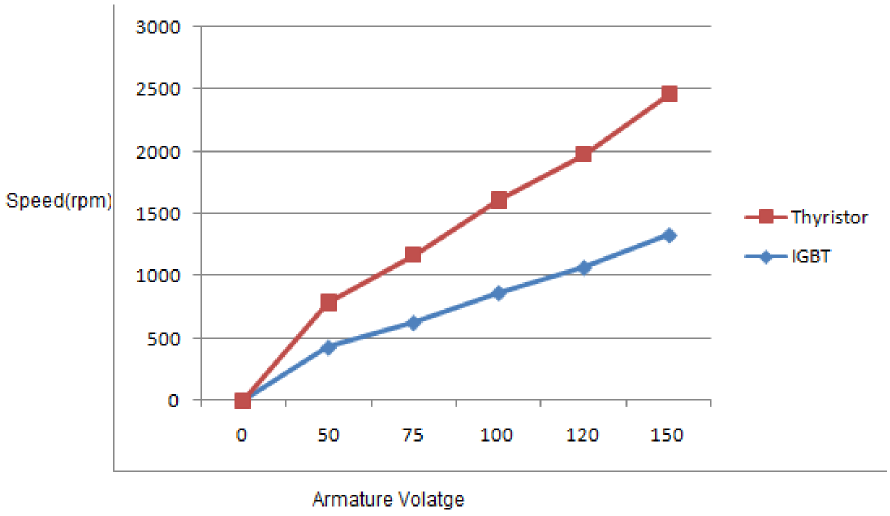


Figure 8 Speed Vs Armature voltage for IGBT and thyristor control

VI. CONCLUSION

In this work various DC motor speed control mechanism using thyristor as a power semiconductor alternate are discussed. An analytical view is presented over variation in speed with change in armature voltage for various values of filed voltage. The comparative performance analysis of IGBT and thyristor for separately excited DC motor suggests that, the required speed variation can be obtained by smaller change in armature voltage in case of thyristor than IGBT. But as far as controlling is concerned IGBT control is 18-20% higher than thyristor.

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