Design of MOSFET Based Speed Control of DC Motor.

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Abstract- DC motors are used in industries and as such their speed control becomes of immense importance. It has been found that many of these applications perform with a greater efficiency when the motors are fed from a source of variable DC power. In this report we analyze the separately excited dc motor using, MATLAB (Simulink), for speeds above and below the rated speed using a chopper circuit. The chopper circuit receives a signal from the firing circuit and then gives a signal to the armature voltage controller of the separately excited DC motor and the speed is accordingly increased or decreased. There after the simulations of the system have been carried out and analyzed under varying circumstances of speed and load torque.

I. INTRODUCTION

Industries are the backbone of the modern era and so it is of utmost importance that they always run with the highest possible efficiency. And for this reason many industrial applications require dc voltage sources, some by force and some by choice. However many of them perform better when they are fed from a variable dc source as compared to fixed voltage sources. These include battery operated vehicles, subway cars, battery charging etc. The conversion of fixed dc voltage to variable dc can be obtained by using semiconductor devices. Earlier this used to be achieved by AC link chopper but were costly, bulky and less efficient. This is the place where the dc chopper comes into play. Being a single stage conversion device the dc chopper has altogether heralded a new era in rapid transit systems. As most of the traction systems in India still operate via dc motors this project aims to simulate and analyze a model of dc chopper using power MOSFET and study the speed control characteristics and the advantages and limitations of using a power MOSFET.

Here current limit control method is used for dc chopper. The previous set value of the load current is used to operate {on/off} the chopper circuit. The minimum and maximum values of load current are set. The load current goes below the limit. Then the dc chopper is switched on. Whenever the load current gets the maximum limit current then dc chopper is switched off. At the same time by setting the value of current {maximum/minimum} it is possible to control the frequency of chopper. In general on the basis of dc motor excitation the dc motor are classified into two types. They are separately excited and self excited dc motor. In this project we used separately excited dc motor. Hence its field winding and armature are excited from two different sources. The fundamental of electric drives, power electronic circuits, devices and application are explained in detail [1-3].

II. WORKING PRINCIPLE OF DC CHOPPER

Chopper is basically a very high speed on/off switching device. Its basic job is to connect and disconnect the load from source at a great speed. In this way the constant dc voltage is chopped and we obtain a variable dc voltage. There are basically two time periods in chopper operation, one is the "on" time denoted as TON and other is the "off" time denoted as TOFF. During TON we get the constant source voltage VS across the load and during TOFF we get zero voltage across the load. The chopper plays the role of providing this pattern of providing alternate zero and VS. In this way we obtain a chopped dc voltage in the load terminals.

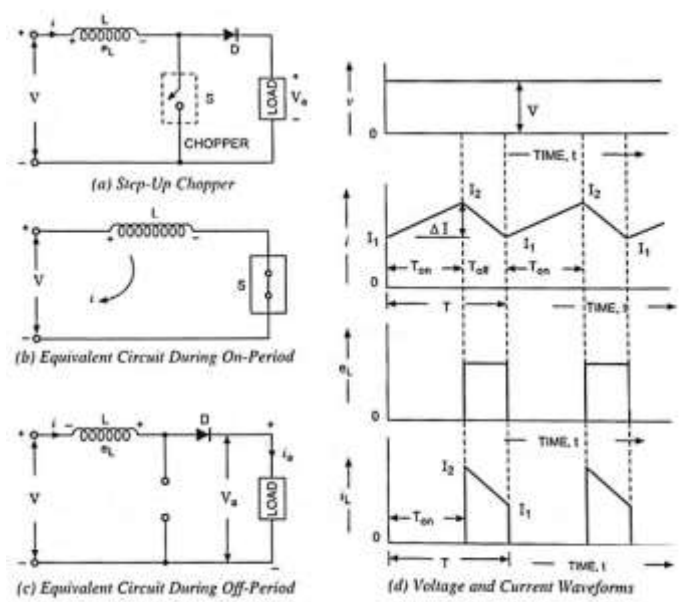

Figure 1: Basic Chopper circuit and its Waveforms

III. CONTROL STRATEGIES

We observed that the average output voltage can be controlled by varying the duty cycle of the chopper circuit. So the task in front of ourselves is basically to vary the duty cycle so as to get the required voltage output.

Two modes exist which can help us in varying the duty cycle of the system in order to get the required output voltage.
The two control strategies existent are:
- Time Ratio Control (TRC)
- Current Limit Control (CLC)

Time ratio control- In this method we vary the time ratio. This can done in two ways:
- Constant frequency system
- Variable frequency system

Constant frequency system- in this method we vary the on time of the system but as a whole the chopping frequency or we can say the time period is kept constant. Basically in this method we are varying the width of the pulse and as such this method is also known as PULSE WIDTH MODULATION. Variable frequency system- In this method we are varying the chopping frequency, that is, we are varying the time period of the system but in doing so we are keeping either the TON or TOFF constant.

Current Limit Control- in this method of control the turn on and off times of the chopper circuit is determined by the former value of load current. The previous maxima and minima of the load current act as set values and decide the on and off time of the chopper circuit. When the current in through the load crosses the maxima the device is switched off and when it falls below the minima the device is switched on. However this method is very tedious and complicated as it involves the feedback loops and hence the triggering circuit for this mode of operation becomes very complex and as such PWM method is generally the preferred mode of operation.

As the name presents, in the case of a separately excited DC motor, the main supply is given separately to the armature and field windings. The major distinguishing fact in these forms of DC motor is that the armature current does not move across the field windings as the field winding is powered from a separate external supply of DC. From the torque equation of motors, we know that:

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So, the torque, in this case, can be changed by modifying the field flux (φ), independent of the current of the armature (Ia). The figure below presents the separately excited DC motor.

$$T_g = K_a \phi I_a$$

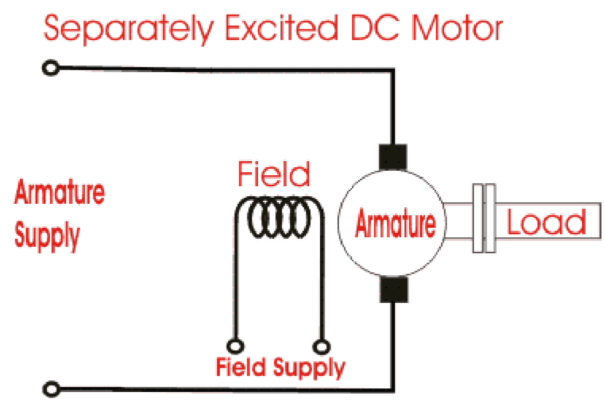

Figure 2 : Separately excited DC Motor

Here, the field coil is powered from a separate DC voltage supply, and the armature coil is also powered from another source. Armature voltage supply may be variable but, an independent fixed DC voltage is applied to induce the field coil. Therefore, those coils are electrically separated from each other, and this junction is the main feature of this type of motors.

Figure 3 : DC Motor

This is because of their excellent performance features and control properties; the only essential drawback is the mechanical commutator which reduces the speed and power of the motor, maximizes the inertia and the axial length, and needs too periodic maintenance than the other types. The commutator is removed with alternating current motors, supplied by variable frequency static power converters, but the cost can be increased because of their complexity.

V. MATHEMATICAL EQUATIONS OF SEPERATELY EXCITED DC MOTOR

$$V_a = E_g + I_a R_a + L_a \left\{ \frac{dI_a}{dt} \right\}$$

Armature resistance in ohms {Ra} Armature inductance in Henry {La} Armature voltage in volts {Va} Armature current in amps {Ia} Motor back emf in volts {Eb}.

Torque Equation:

$$T_d = J\frac{d\omega}{dt} + B\omega + T_L$$ **…Equation (1)**

Load torque in Newton-Meter {TL} Friction co-efficient of the motor {B} Moment of inertia in Kg/m2 {J} Torque developed in Newton-Meter {Td} Angular velocity in rad/sec {w} Assume {B=0}

New Torque Equation:

$$T_d = J\frac{d\omega}{dt} + T_L$$ **…Equation (2)**

Taking field flux as phi, Back emf constant {KV} as K Back emf of motor equation:

$$E_g = K\phi\omega$$

$$T_d = K\phi I_a$$ **…Equation (3)**

After taking Laplace transformation on both side {Basic motor armature equation}

$$I_a\{s\} = \frac{\{V_a - E_g\}}{R_a + L_a s}$$ **…Equation (4)**

$$I_a\{s\} = \frac{\{V_a - K\phi\omega\}}{R_a\left\{1 + \frac{L_a s}{R_a}\right\}}$$ **…Equation (5)**

$$\omega\{s\} = \frac{\{T_d - T_L\}}{Js} = \frac{\{K\phi I_a - T_L)}{Js}$$ **…Equation (6)**

VI. CIRCUIT DIAGRAM

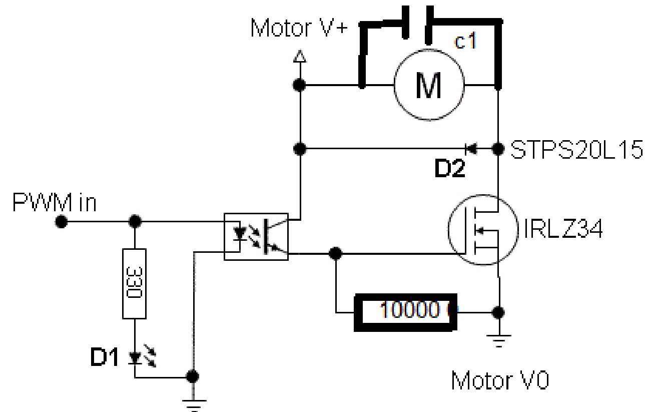

Figure 4: Circuit for Speed Control Using MOSFET

The easiest and most popular way to drive a DC motor using a H-bridge is by using pulse width modulation (PWM). Here the MOSFETs are switched at a constant frequency with a control signal having variable duty cycle. This allows the average voltage across the motor to vary and thus control the rotor angular velocity.

The MOSFETs in a H-bridge can be switched in different sequences to provide the desired voltage polarity. There are two common modes: bipolar and unipolar.

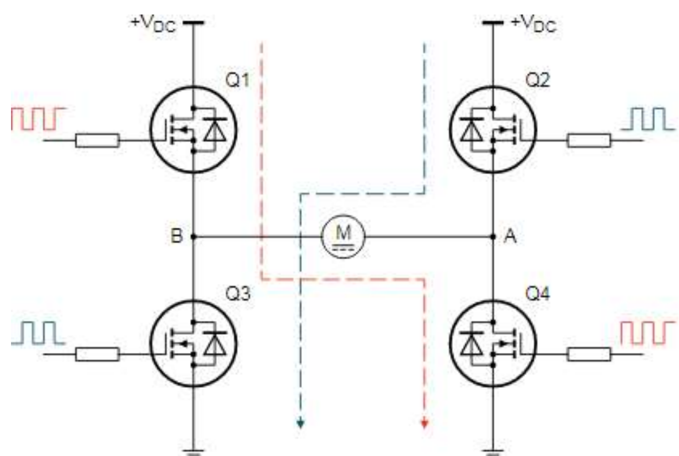

Figure 5: Bipolar drive H-bridge switching

The bipolar drive allows two MOSFETs to be switched ON at a time. For example for positive current (from node A to node B) both Q2 and Q3 are turned ON. Whereas, for negative current, Q1 and Q4 are turned ON. The direction of the current is chosen by activating one or the other couple of FETs while applying a voltage across the motor that varies between V_{DC} and $-V_{DC}$, with an average value that depends on the duty cycle (δ).

A time delay, known as dead-time, must be set between the turning OFF of one pair and the turning ON of the other pair, in order to avoid cross-conduction (or shoot through), that is shorting the supply.

Due to the magnetic field build up in the motor, during the delay phase some current will continue to flow, even though all the devices are turned OFF, by recirculating through the MOSFETs body diodes.

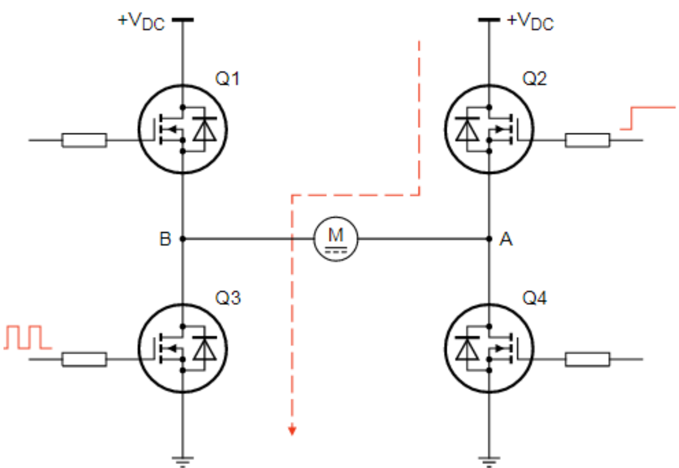

Figure 6: Unipolar drive H-bridge switching

The unipolar drive scheme, instead, allows for the current to be regulated by keeping ON one right side MOSFET (Q2 or Q4) while switching only one left side MOSFET(Q3 or Q1). In its simplest form it allows for the elimination of the dead time which reduces the complexity of the driver circuit. For the same reason described in the bipolar drive some current will be forced to flow through one of the MOSFETs body diode when the switching MOSFET is turned OFF.

If we assume Q3 switching and Q2 turned ON, then when the former is switched OFF the current will flow through Q1 body diode. In order to decrease the loss caused by the diode voltage drop, Q1 can be switched ON while Q3 is OFF. In this case a proper dead-time constraint must be respected.

One of the major difference with the bipolar drive scheme is the fact that the voltage across the motor will have an amplitude of only V_{DC}. As a consequence the peak of the ripple current through the motor ends up being half of the one found for the bipolar case, thus leading for lower losses in the motor itself.

VII. RESULTS & DISCUSSION

Here see that the speed of a dc motor can be successfully controlled by employing a chopper circuit. Here we initially study the basic output characteristics of a MOSFET based chopper and study the output variables for various load characteristics and then we move on towards the simulation of the closed loop model of the dc system involving the chopper and then study it for various change in load torque, rated voltage value and other input parameters. The loops involved are carefully optimized using various mathematical approaches and finally the circuit is simulated and the various plots obtained under various conditions are carefully studied.

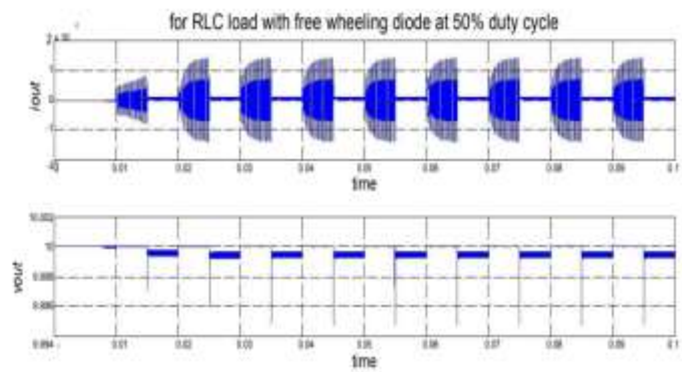

Figure 7: Output Waveform

VIII. FUTURE SCOPE

The above described model has been run and tested successfully in MATLAB simulation, so there lies the opportunity to implement the above described model in hardware and study the impact of the approach taken in this report. Moreover in this report we have analyzed only the impact of the approach on separately excited dc motor so there lies the scope to extend the study to various other kinds of motors. Also here we have done the speed control below the
rated speed so analysis can also be extended to study the dynamics for above the rated speed using field flux control.

IX. REFERENCES

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