Analysis & Design of Dc Motor Drive Speed Controller Using Closed Loop Based Converter

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Abstract- *DC Motors are widely used in industrial applications because of their excellent control of speed for acceleration and deceleration. The main problem in DC Motor drive is the high starting current. Due to this high starting current insulation of the motor may damage and also efficiency will decrease. In a traditional dc motor system a resistor starter is used to monitor the armature current of the motor. This project proposes a model to run a separately excited direct current (DC) motor using a single phase alternating current (AC) source by converting the AC source into variable DC source using a buck-boost converter. A MOSFET based soft starter is used to limit the starting current and also a PI controller is used to control the speed of the DC Motor. This controller calculates the reference current based on the reference speed of the motor and feeds it into the soft starter. In this separately excited dc motor runs on a single phase AC source with better control. The main advantage is that the motor becomes independent of the input voltage level as it can be adjusted. The speed of the DC Motor can also be controlled. The circuit becomes small with less switching and copper losses and the armature current can also be controlled because of the soft starter. This project also proposes a closed loop control of buck-boost converter without using soft starter for the speed control and initial current control of a DC Motor in which losses and cost can be reduced when compared with the former one.*

Keywords:- DC, AC, MOSFET, PI

I. INTRODUCTION

Now a days, Developments of high performance motor drives are mostly important for industrial applications. In this it must have good load regulating response and dynamic speed command tracking .DC motors are including excellent control of speed for deceleration and acceleration. For accurate voltage control, the power supply is directly connected to the field of the motor. Their simplicity, ease of application, reliability and reasonable cost has long been strength of industrial applications in DC drives.

The main problem of dc motor is, it draws high armature current at the starting condition. Because of absence of the back emf in the motor. Speed of the motor depends upon the back emf. The high amount of armature current can cause insulation failure as well as damage of motor as well as decrease the motor life. The conventional solution is to use a resistance initially to limit the current. Once the current stabilizes, it removes the resistance slowly. This method has the disadvantage of energy waste at each start-up maneuver although there will be a control over the armature current. Also the limit of the armature current will depend on the net resistance of the armature circuit and source voltage.

Power electronics circuitry can be used in order to get rid of the above problems here. A circuit of chopper is used in which hysteresis control is provided. Hysteresis controller maintains the current b/w the two pre-set threshold values. The speed of the dc motor is proportional to the back emf which is proportional to the armature current of the motor. Based on this fact if the armature current is controlled then the dc motor speed can also be controlled. The reference voltage is converted into reference current by using a PI controller this reference current is given to the soft starter to limit the armature current safely. First the ac-dc buck-boost converter is designed and its performance is analyzed. Later on, the voltage control method and PWM method were designed and developed. Based on literature survey, to control inrush current during the starting period, the soft starter for the dc motor is designed. The soft starter is a MOSFET based hysteresis current control system to dc motor drive for low power application. Depending on the performance of the soft starter the speed controller is designed. It is seen that the entire system uses only two switching devices. So that the installation cost and energy loss is less compared to the conventional method. By using two converters power loss and cost also increased. So that here we are using a closed loop based buck-boost converter. In this proposed concept there is no need of a soft-starter, only the buck-boost converter controls the initial armature current and also speed. The objective of this project is to propose an alternative control topology for speed control of dc motor and also to limit the starting current of the dc motor by using the closed loop based buck-boost converter. The closed loop based buck-boost converter is more suitable for speed control and initial current control of a dc motor under below rated speed. This proposed topology reduce the power loss and cost by using the single converter for the controlling of speed and initial current of dc motor. PWM controlled rectifiers can efficiently and economically be employed in low and medium power applications of dc drives. Due to the high dc voltage, the ac-dc buck-boost converter is especially suited as a front-end power source in variable speed drive systems to convert the utility supply voltage into a variable dc link voltage. There are three possible conventional means may usually be used to control or monitor the level of the armature current when starting a dc motor. The possible means are Use of a gradually decreasing tapped resistance between the supply voltage and the armature circuit, Use of a chopper circuit between the supply voltage and the armature circuit, Use of a variable dc voltage source. the performance study of a separately excited dc motor whose speed is controlled by armature voltage variation is presented. Both the open loop and closed loop steady state and transient characteristics are reported. The speed controllers considered in the closed loop mode are the proportional and proportional plus integral types. To each of these two control arrangements is added an inner current controller loop.

II. CIRCUIT DISCRIPTION AND PRINCIPLE OF OPERATION

The basic block diagram of the entire model of DC Motor drive with ac-dc buck boost converter as shown in below figure. The block diagram comprises a bridge rectifier. It used to regulate the sinusoidal signal into unidirectional signal. The bridge rectifier consists of four diodes, two diodes are connected in series and other two diodes are connected in series & that are connected in parallel. The rectifier produces unidirectional signal and the filter capacitor is connected to the output in order to remove the voltage ripples. Hence it converts the pulsating dc into a pure dc. This pure dc signal is applied to the input of the buck boost converter .It produces the constant dc signal into variable dc signal which is essential for the speed control of dc motor drive. The converter consists of a switching device (here an IGBT is used), an inductor, a capacitor and a diode.

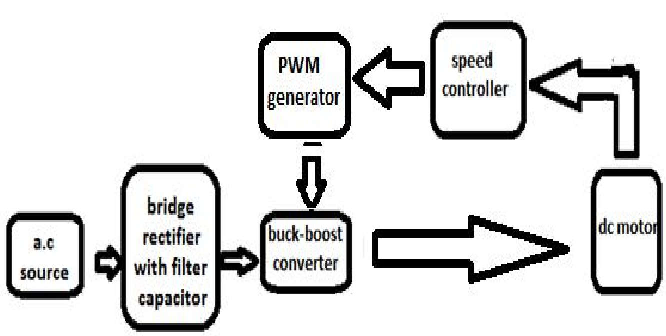

Figure1. Block diagram of the proposed model

For the gate of the switch in the buck-boost converter, the PWM signal is given to that. Therefore the magnitude of the output voltage can be controlled. When the switch is in closed position, the inductor act as an energy storing device and acts as a source to the motor when the switch is in open position. Here the capacitor acts as a filter to remove ripples in the output waveform. The diode, allows the current to flow from the motor to the inductor and not vice versa, thus maintaining the unidirectional rotation of the motor. Based on the input voltage which is rectified & reference voltage of converter, the gate pulse is generated. The input voltage acts as a soft starter, once the variable dc voltage is produced. The soft starter is mainly a switch (GTO) based starter .for controlling the armature current it uses hysteresis control. This controller mainly contains relay which gives zero or one. It is based on the contrast between the threshold value & the input value of the controller. The armature current is compared with the reference current in this starter. The switch turns off only when the difference between armature current & reference current is more than the higher limit of the hysteresis controller. If the difference is lesser than the lower limit of the hysteresis controller the switch turns on, thus closing the circuit. In series to the switch, a smoothing inductor is connected. The inductor does not allow sudden change of armature current when the switch turns on and off. In order to prevent any currents flowing in the reverse direction, a diode is connected in parallel to the motor. To control the speed of the motor to a preferred level a speed controller is used. A PI (Proportional-Integral) controller is used which takes the input as motor speed & produces a output that can be taken as reference current. To limit the current to the desired level, this reference current acts as reference for the soft starter. The Proportional and integral are connected parallel to each other .the sum of both the proportional P and integral I is taken as the output. The speed can be varied from zero to the motor speed which is achieved not including the controller at that terminal voltage. Thus, the rated voltage of the motor is taken as the reference or desired output voltage of the buck-boost converter.

III. SPEED CONTROLLER BASED CLOSED LOOP BUCK-BOOST CONVERTER

Normally an ac source is converted into a dc source using a bridge rectifier and a large filter capacitor used to remove the ripples. This method has having some disadvantage such as harmonic currents and invariable dc voltage levels. There are other methods such as the controlled bridge rectifiers used for dc motor drive which requires number of switching circuits. To remove these short comings Pulse Width Modulation based switching devices are used. Here a buck-boost converter with a single switching device is used to produce variable voltage levels. This makes the converter circuit compact and simple. Based on the duty cycle ratio formula a system can be developed which gives pulses to the switching device based on the reference output voltage.

It is also known that when a dc motor is started the initial armature current is very high. This is because of the absence of the back emf in the motor. The back emf is directly proportional to the speed of the motor. Such high armature current can cause insulation failure as well as motor damage as well as reduce the life of the motor. The traditional solution would be to use a resistance initially to limit the current and once the current is stabilizes remove the resistance slowly. This method has the disadvantage of energy waste at each start-up maneuver although there will be a control over the armature current.

Also the limit of the armature current will depend on the source voltage and the net resistance of the armature circuit. To overcome these problems power electronics circuitry can be used here. A buck-boost converter based on closed loop control is used. The speed of the dc motor is proportional to the back emf which is proportional to the armature current of the motor. Based on this knowledge if the armature current is controlled then the speed of the dc motor can be also controlled.

Using a PI controller the reference voltage is converted into reference current which is taken as reference signal and compared to the given saw-tooth wave to produce pulses using PWM technique. First the ac-dc buck-boost converter is designed and its performance is analyzed. Later, the PWM method and the voltage control method were designed and developed. The input and output characteristic are discussed in details as follows as section in this paper. The speed controller is then designed. It is seen that the entire system uses only one switching devices and the installation cost and energy loss is less compared to the traditional method. The PWM signal given to the gate of the switch in the buck-boost -boost converter, controls the amplitude of the output voltage. The inductor act as an energy storing device when the switch is closed and acts as a source to the motor when the switch is open. The capacitor here acts as a filter to remove ripples in the output waveform. The diode used, allows the current to flow from the motor to the inductor and not vice versa, thus maintaining the unidirectional rotation of the motor. Once the variable dc voltage is generated, that voltage acts as input to the motor. The speed of the motor is given to the speed controller. In this speed controller the speed of the motor is compared to the reference speed then the difference is given to the PI (Proportional-Integral) controller.

A speed controller is also used to control the speed of the motor to a desired level. A PI(Proportional-Integral) controller is used which takes the motor speed as the input and gives a reference current as the output .

This reference current is given to saturation block and here we applying some limits. And this saturated signal acts as a reference signal and it is compared with a saw tooth wave form to generate the pulses by using pulse width modulation.

This pulses are used as gate signals of the buck-boost converter switch by using this gate pulses we can control the initial current and get the variable voltage and therefore control the speed also.

It is to be noted that the speed can be controlled from zero to the motor speed which is achieved without the controller at that terminal voltage. Thus, the rated voltage of the motor is taken as the reference or desired output voltage of the buck-boost converter.

For a uniform pulse width modulation technique, a saw tooth waveform vc having a constant switching frequency fs , is compared with a constant waveform vr, which acts as a dc reference signal with variable waveform. The width of the pulse changes based on the amplitude of vr. In other words the amplitude of vr decides the Ton (on time) and Toff(off time) of the switch of the buck boost converter. Here when vr is greater than vc the gate pulse is high, and when vr is lesser than vc, gate pulse is low.

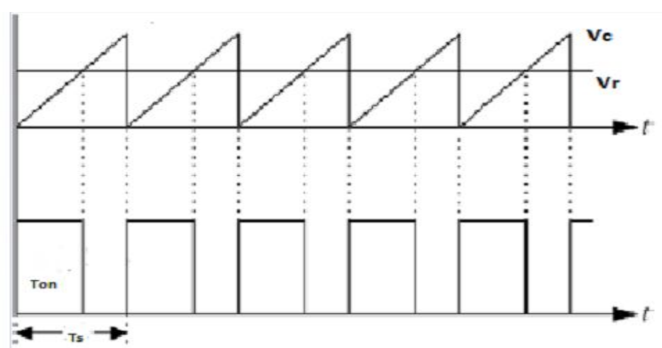

Figure2. Pulse Generation

A modification can be done such that the user can directly give the reference voltage without calculating the duty cycle and knowing the relationship between the duty cycle ratio and output voltage and input voltage. The relationship and modifications are discussed in the section of steady state analysis of buck-boost converter. As the duty ratio of the PWM wave changes, its instantaneous value also changes, so long as the switching frequency is much greater than that of the modulation frequency. The reference wave varies like a sine wave the average of the PWM wave will also vary like a sine wave. The average of the PWM wave never goes all the way to 1, which would be a continuous high pulse, nor does it ever go all the way to zero, which would be a continuous low pulse. This means that the depth of modulation is never reaching 100%, which is good. The Modulation depth is the ratio of the current signal to the case when saturation is just starting.

IV. SIMULINK MODEL

(a) Resistive Starter

The below figure shows the Matlab/Simulink model of DC Motor with Resistive Starter. In this work ,speed of the dc motor and initial current of the motor are controlled by using soft-starter based buck-boost converter and closed loop based buck-boost converter.

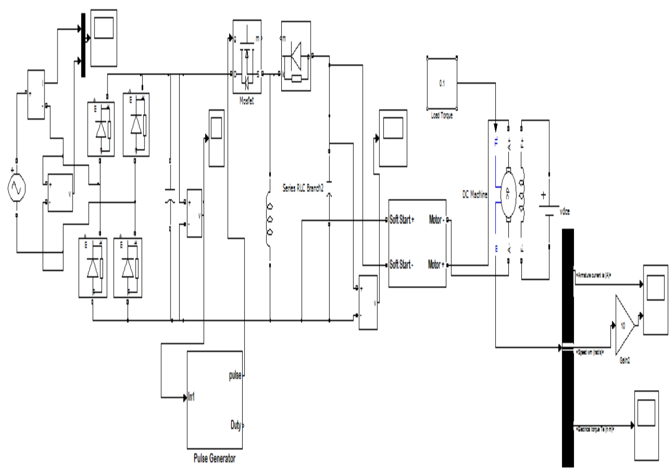

Figure 3.Matlab/ Simulink model of DC motor with resistive starter

(b) Soft Starter

The below figure shows the Matlab/Simulink model of DC Motor with Soft Starter using Matlab/Simulink platform. In this section, the initial current is controlled by using the soft-starter and speed is controlled by the buck-boost converter.

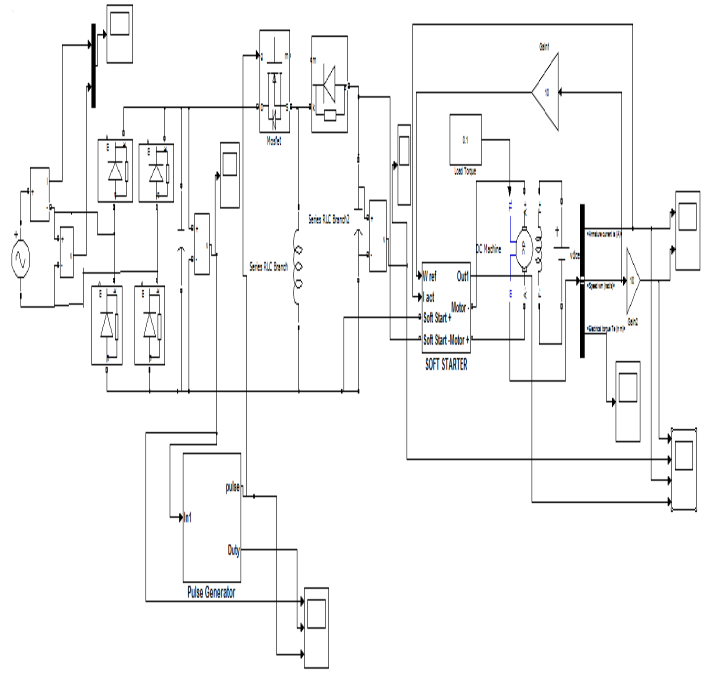

Figure 4.Matlab/ Simulink model of DC motor with soft starter

(c) Closed Loop Drive System

The below figure shows the Matlab/Simulink model of DC Motor with Starter Operating under Closed Loop Drive System using Matlab/Simulink platform.

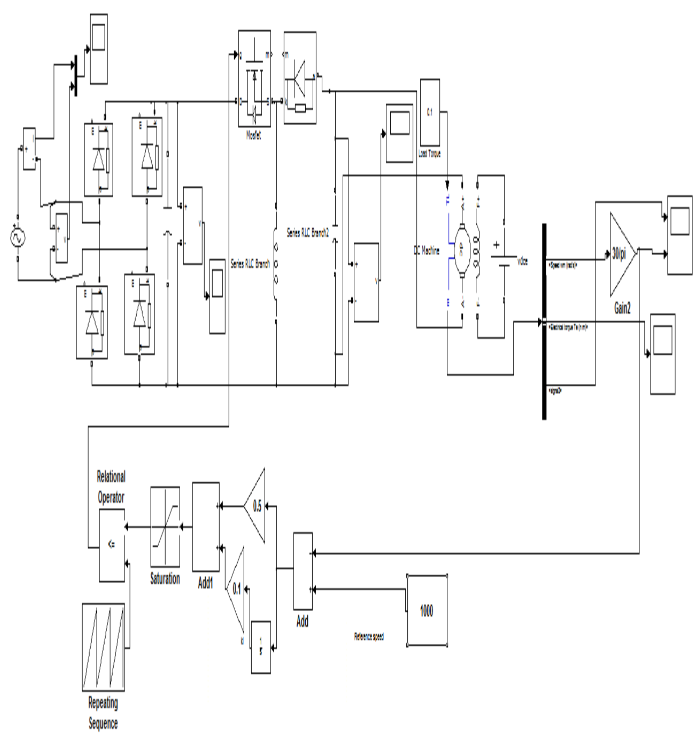

Figure 5. Matlab/ Simulink model of DC motor with starter Operating Under Closed Loop Drive System

Buck-Boost Converter Parameters

1.Ideal switch	
R_{on}	0.1ohm
R_s	10^5ohm
2.Inductor,L	10 Mh
3.Diode	
R_{on}	0.001ohm
V_f	0.8V
R_s	500V
C_s	250nF
4.Capacitor,C	3000µF

Table 1

Speed Controller parameters

W_{Ref}	100 rad/sec
K_p	1.6
K_i	50

Table 2

V. SIMULATION RESULTS

(a) Starting Currents of the Motor

In resistive starter method initial current of the motor can be controlled below the rated value as shown in figure 6. But the disadvantage here is wastage of energy occurs due to the energy drop across the resisters. In soft-starter control method, current can be controlled to the required value as shown in figure 7. There is no need of external resistors so that the energy wastage is reduced and copper losses are also reduced. Coming to closed loop based buck-boost converter method, the system will limit the initial current as below the rated value based on the given motor as shown in figure 8. The main advantage is that it reduces the cost and switching losses because there is no need of soft starter to control the initial current.

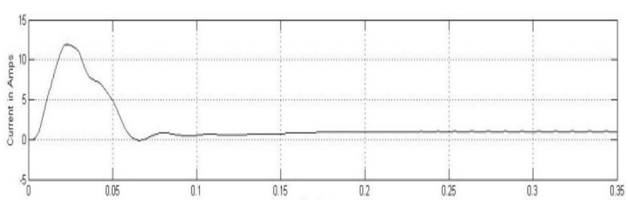

Figure 6. Initial current of DC motor with resistive starter

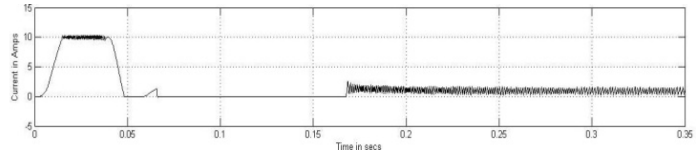

Figure 7. Initial current of DC motor with soft starter

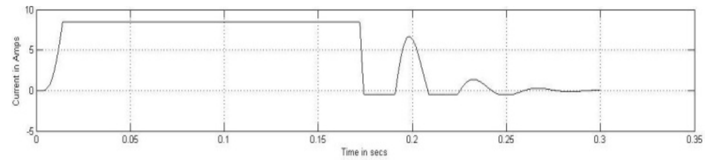

Figure 8. Initial current of DC motor with Closed Loop Buck-Boost Converter

(b) Speed of the Motor

In resistive starter there is no effect on the speed of the motor it only controls the initial current is shown in figure 9. It is the main disadvantage. In soft- starter speed can be controlled is shown in figure 10. But this is done using two converters i.e., soft-starter and buck-boost converter. Coming to closed loop based buck-boost converter method, speed of the motor is controlled similar to the soft-starter as shown in figure 11 using a single converter that is buck-boost converter so that switching losses and cost are reduced.

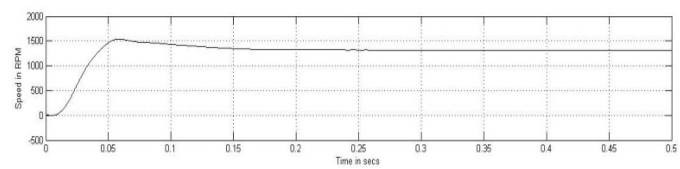

Figure 9. Speed of DC motor with resistive starter

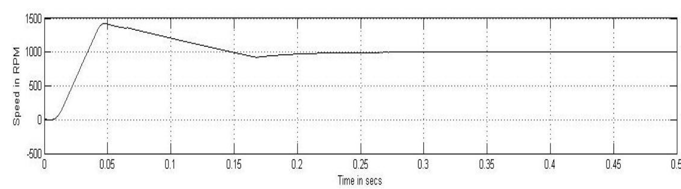

Figure 10. Speed of DC motor with soft starter

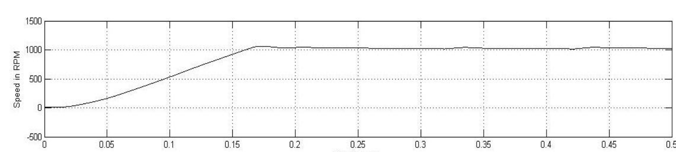

Figure 11. Speed of the DC motor with closed loop buck-boost converter

VI. CONCLUSION

In this project a closed loop based buck-boost converter circuit is implemented. This type of combination is used for controlling of speed and the initial current of the dc motor. Both soft-starter based buck-boost converter and closed loop based buck-boost converter results are compared. By using this closed loop based buck-boost converter. The speed is controlled accurately and the initial current is reduced. The entire system uses only one switching device so that the installation cost and energy loss is less compared to the traditional method.

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