Implementation of High Power Dc-Dc Converter and Speed Control of Dc Motor Using DSP

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Abstract
This paper describes the design and implementation of high power DC-DC step- up converter using analog control circuits and speed control of DC motor using TMS320F240 DSP. In this technique a 24V DC input supply is converted into 135V DC by two-stage conversion. The full bridge topology is proposed for step up the DC voltage. The output of step-up converter is provided to the capacitive accumulator circuit which consists of 1.2F capacitor bank in it. The capacitive accumulator is mainly used to compensate peak power demand of the load for a transient period when sudden changes occur at load side and to store the energy under regenerative braking condition of DC motor. The capacitive accumulator circuit provides a constant voltage to the DC chopper under normal working condition. The closed loop speed control of DC motor is achieved using TMS320F240. The current and speed feedback are compared with their references respectively to achieve the speed control of DC motor which is used in military application.

Keywords: Capacitive accumulator, DC Chopper, DC-DC step up converter, DSP, Two stage conversion

I.Introduction

Speed control of DC motor could be achieved using conventional or electrical techniques. In the past, speed controls of dc drives are mostly mechanical, requiring large size hardware to implement. Advances in the area of power electronics have brought a total revolution in the speed control of dc drives. This development has launched these drives back to a position of formidable relevance, which were hitherto predicted to give way to ac drives. These drives have now dominated the area of variable speed because of their low cost, reliability and simple controlled drives are widely used in applications requiring adjustable speed, good speed regulation and frequent starting, braking and reversing. Some important applications are: rolling mills, paper mills mine winders, hoists, machine tools, traction, printing presses, textile mills, excavators and cranes. Fractional horsepower dc drives are widely employed -as servo means for positioning and tracking. Adjustable speed drives may be operated over a wide range by controlling armature or field excitation. Speeds below rated by armature voltage control and above rated using field excitation variation, development of various solid sates switching devices in the form of diodes, transistor and thyristor along with various analog/digital chips used in firing/controlling circuits, have made dc Drives more accessible for control in innumerable areas of applications.

The solid-state powers electronic switching devices can be broadly grouped into:

(i) Those supplied from AC source; Thyristor bridge rectifiers (converters)

(ii) Those employing dc supply namely Choppers and inverter.

DC chopper has many advantages over the other means of speed control applications, these advantages arc:

a. Fast dynamic response.
b. High energy efficiency
c. Flexibility in control
d. Fewer ripples in the armature current.
e. Ability to control at low speeds
f. Reduction in overall system size and cost.
g. Light weight and compact control.

Owing to these obvious facts, chopper control has been chosen for the purpose of experiments in this paper.

DC-DC step-up converters have widely been used in computer hardware and industrial applications such as (Smedley, K.M., and Cuk 1995) computer auxiliary power supplies, car auxiliary power supplies and servo-motor drives. In recent years, the DC-DC. conversion technique has developed very quickly. The main objective is to reach a high efficiency, high power density and cheap topology in simple structure. For example, the Cuk-converter was invented only a few years ago.The DC drive used as servo for tracking in military application requires a very high voltage for driving. But the supply voltage available in the system is very less. High efficiency, low volume, lightweight and less loss are some basic requirements of such application.

The two-stage dc-dc full bridge converter is proposed in this paper to achieve the required specification .A two-stage dc-dc full bridge step-up converter used to converts the DC source voltage of 24 volts into a constant output voltage of 135V. The full bridge configuration operates with the minimum voltage and current stress of the transistors, and it is very popular for high power applications.

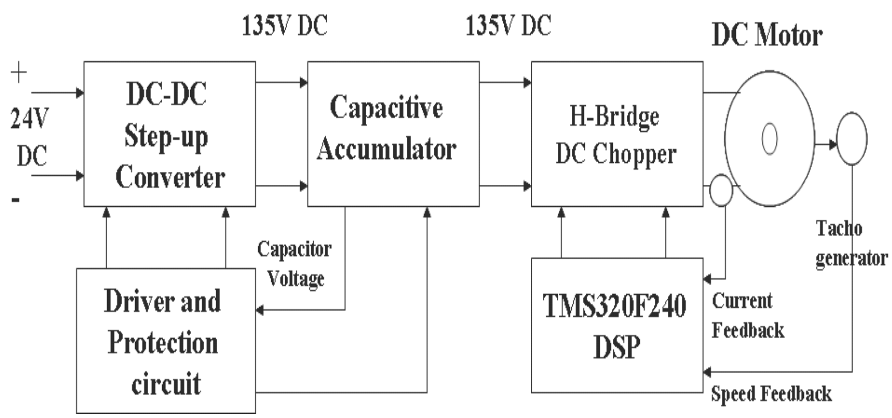


Fig.1. Complete Block diagram

Fig. 1, shows the block diagram of the proposed high power DC-DC converter and speed control of dc motor. Analog circuits with associated protection circuits control the DC-DC converter, which converts 24V DC to 135V DC, and the closed loop speed control is achieved by controlling the output of the H-Bridge DC chopper using TMS320F240 DSP.

2. Two Stage Dc-Dc Step Up Converter Analysis And Operation

Conversion of 24V DC to 135V DC is not possible with direct DC-DC conversion because direct DC-DC conversion is not capable of stepping up to such a high voltage. Therefore the conversion is done with two stages. The two- stage DC-DC step up converter is shown in Fig.2. The 24V DC from source is given to the capacitor for getting the constant DC supply, then the constant DC is given to the full bridge topology.

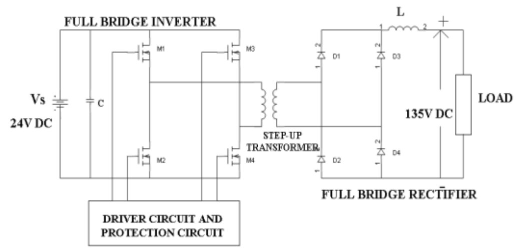


Fig.2. Two stage DC-DC step-up converter

MOSFET is mainly employed in full bridge topology because MOSFETs are preferred to for lower voltage rating and higher switching frequency. Using copper sheet bus bars instead of wires for connections can reduce the wire inductances and high voltage spikes. The driver circuit that employed with IC UC1846 gives the gate pulses required for MOSFETs. The full bridge topology overcomes the drawbacks of the push-pull topology i.e. in push-pull topology the peak inverse voltage is twice that of the supply voltage. The constant DC output of the capacitor is converter into 24V AC using full bridge topology. Then the 24V AC is stepped up to 135V AC using step-up transformer. The ferrite core step-up transformer is used which makes the size of transformer as more compact and capable of operating at high switching frequency.

The output of the transformer is given to the uncontrolled full-bridge rectifier whose output is 135V DC. In order to smoothen the output current of the uncontrolled full-bridge rectifier the inductance of minimum value is used. The induction values is calculated by determine the current flow during both ON time and OFF time individually using

V_L=L(di/dt) (1)
ΔI= ($V_{L/}$ /L)* ΔT (2)

2.1 Capacitive Accumrulator

Capacitive accumulator is a series combination of capacitor cells that acts as a load to the two stage step-up converter. The final output of the two-stage converter is stored in the capacitive accumulator and also used to store the voltage during regenerative braking. The capacitive accumulator has been designed for the following specifications.

Operating Voltage=145volts.
Minimum voltage=135volts.

The value of capacitive accumulator is calculated by using,

(1/2) CV^2 = Energy (3)
(1/2) C*[$V_{op}{}^2$ - $Vmin^2$] = [(peak power required- Converter output) * Acceleration time] (4)

The discharge circuit is included in parallel to the capacitive accumulator. The capacitive accumulator with discharge circuit is shown in Fig.3. Both the manual and automatic discharging circuit are connected with the capacitive accumulator. The manual discharging is provided in order to discharge the voltage across the capacitance when the automatic discharging is not possible because of power failure in the converter circuit. The automatic discharge has been done with an IGBT switch in series with discharge resistor, which is connected as shown in Fig.3. The IGBT receives pulse from the protection circuit when over voltage occurs and the capacitor discharge through the resistor in series with it.

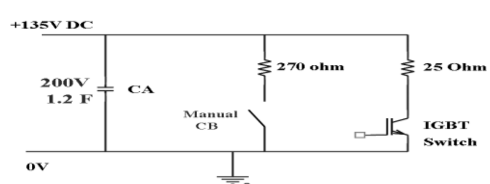


Fig.3. Capacitive Accumulator with Automatic and Manual Discharge Circuit

2.2 Over Voltage Protection Circuit

The capacitive bank in the capacitive accumulator is rated for 200 volts. Any voltage greater than 155 volts across the capacitive accumulator is considered to be over voltage in our circuits. The over voltage protection circuit will provide protection in over voltage situations. The output voltage in the capacitor is sensed and scaled down using resistor combination. The sensed level is compared with a reference value corresponding to 155 volts in a comparator. During normal operating conditions the reference value is greater than the sensed value, hence –ve reference is given to the comparator and the output of the comparator is –ve. Thus there will be no change in operation.

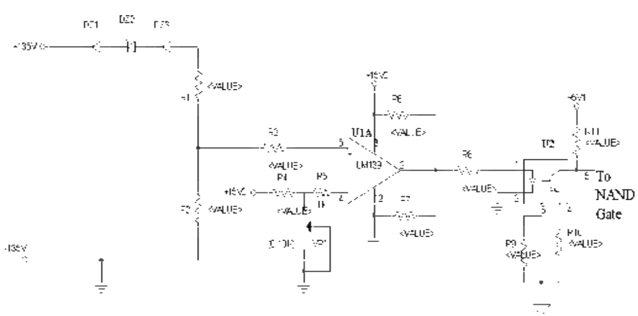


Fig.4. Over voltage protection circuit

During the fault condition i.e., during over voltage across the capacitor (i.e. 155 Volts) the sensed value is greater than the reference value, hence +ve reference is given to the comparator, whose output is +ve which in turn enables the optocoupler, the output of the optocoupler is high since the output is taken from the collector terminal. The output taken out from the optocoupler is applied as input to the NAND gate. Now one of the inputs for the NAND gate is over voltage signal and the other input is an output of another protection circuit. Here the second input to the NAND gate is power ground short circuit signal. When anyone of the input to the NAND gate is high then the output is high. When anyone of the fault occurs i.e. either over voltage or the power ground short circuit then output of the NAND gate enables the control circuit to withdrawn the gate pulses to the full bridge topology, bringing the converter to OFF condition. IGBT in the discharge circuit is enabled and the discharge of the voltage across the capacitive accumulator takes place. The over voltage output is processed together with the power ground signal to ensure permanent tripping of the converter and also discharge the capacitor voltage.

3. Two Stage Dc-Dc Step Up Converter Analysis And Operation

A H-Bridge DC Chopper is connected between a fixed-voltage DC source and a DC motor as shown in Fig.5. to vary the armature voltage.

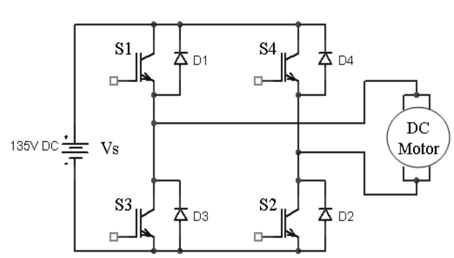


Fig.5. H-Bridge DC Chopper

In addition to armature voltage control, a DC chopper can provide generative braking of the motors and can return energy back to the supply. This energy-saving feature is particularly attractive to transportation systems with frequent stops such as" mass rapid transit (MRT)".chopper drivers are also used in "battery electric vehicles (BEVs)". A DC motor can be operated in one of the four quadrants by controlling the armature and/or field voltage (or currents). It is often required to reverse the armature or field terminals in order to operate the motor in the desired quadrant. In this project the motor is operated at both the direction and frequent braking are also required (Rashid, M.H 1993).The chopper is controlled by PWM pulses which are generated by the TMS320F240 DSP. Motor is operated at both the direction by varying the armature voltage and the current reversal is taken place by the pulses applied to the chopper switches. The pulse patterns of H-Bridge chopper switches are shown in Fig.6. Pair of switches are operated at the same time and the current flows through the motor.

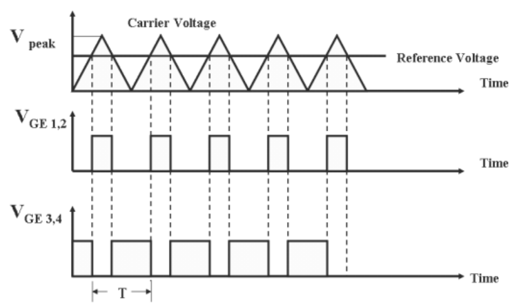


Fig.6. PWM pulses of DC Chopper

3.1 Closed loop speed control of DC Motor

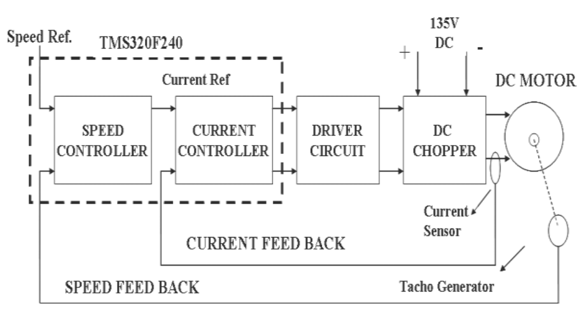


Fig.7. Block Diagram of Closed Loop Control of DC Motor

Fig.7, Shows the block diagram of closed loop control of DC Motor using TMS320F240 DSP.The H-Bridge chopper is used for providing supply to the DC motor, which is to be controlled. Various speed of motor can be obtained by varying the pulse width of chopper switches. The tacho generator connected with the DC motor converts the speed of motor into equivalent voltage. The speed feedback taken out is comparing with a speed reference at speed controller and the output of the speed controller is given as a reference current to the current controller. The input current of DC motor is taken as the current feedback and given to the current controller. The current controller compares the reference current and feedback current and generates error signal. The error signal is applied to the driver circuit of the DC chopper. The pulse width of the chopper switches varies depends on the error signal and thus the motor runs at the constant speed.

4. Experimental Results

The hardware system has been developed and tested under laboratory conditions. The High power DC-DC converter for 24V DC to 135V DC has been designed and tested. Similarly the DSP based closed loop control was implemented and applied on a 135V DC motor. The testing on DC-DC converter and DC motor Speed control and carried out individually. Finally the entire system has been implemented i.e. the output of DC-DC converter has been applied to the DC chopper and has been tested under various conditions.

4.1 DC-DC Step Up Converter

The MOSFET switches used at full bridge topology are FB180SA10.The pulses are provided to the switches by IR 2110.

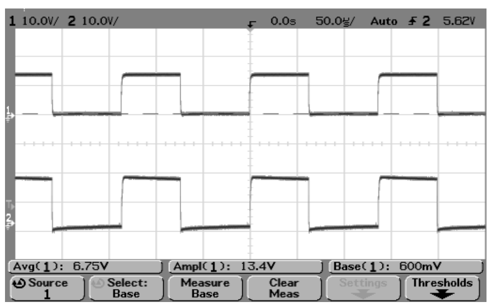


Fig.8. Pulse Generated by IR2110

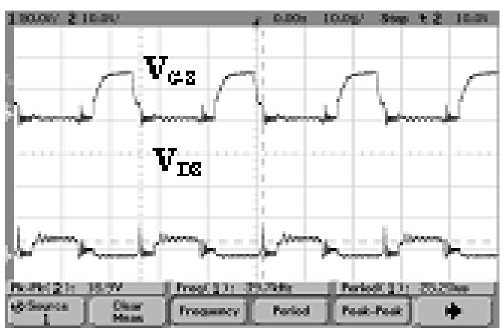
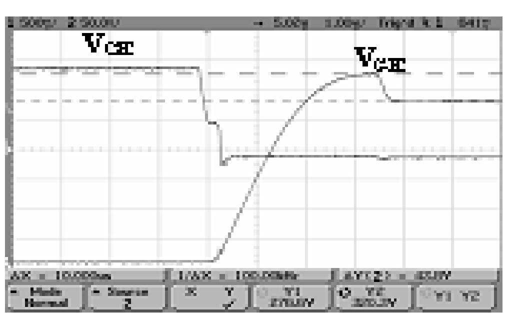


Fig.9. V_{GS} and V_{DS} of MOSFET

The pluses generated by IR 2110 are shown in Fig.8.The output pulses across Gate to Source and Drain-to-Source of MOSFET are shown Fig.9.The transformer has been designed with ETD59 core and material used for winding is ferrite materiel. The Collector to Emitter voltage and Gate to Emitter voltage of IGBT used in capacitive accumulator during both ON time and OFF time are Shown in Fig.10.



ISSN 2222-1719 (Paper) ISSN 2222-2863 (Online)
Vol 2, No.4, 2011

Fig.10. Pulses across IGBT during Turn-OFF

The IGBT switches of 600V are used in H-Bridge DC Chopper. The allowable dead time is applied between two switches, which are in same leg to avoid short circuit.The gate pulses of IGBTs are generated by DSP TMS320F240 and have been applied to the switches after bootstrapping using IC IR2110.

4.2 DC Motor Control

The IGBT switches of 600V are used in H-Bridge DC Chopper. The allowable dead time is applied between two switches, which are in same leg to avoid short circuit. The gate pulses of IGBTs are generated by DSP TMS320F240 and have been applied to the switches after bootstrapping using IC IR2110.The gate pulses for different duty cycle are follows.

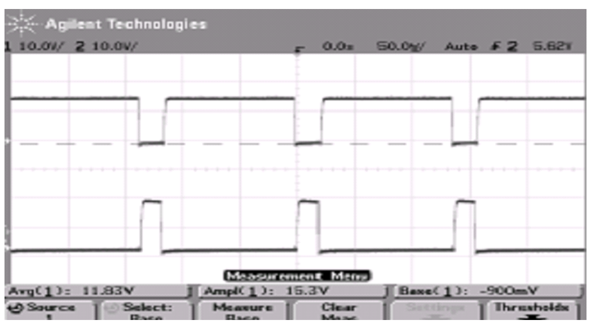


Fig.11. Pulses with longer ON time for S1, S2 & shorter ON time for S3, S4

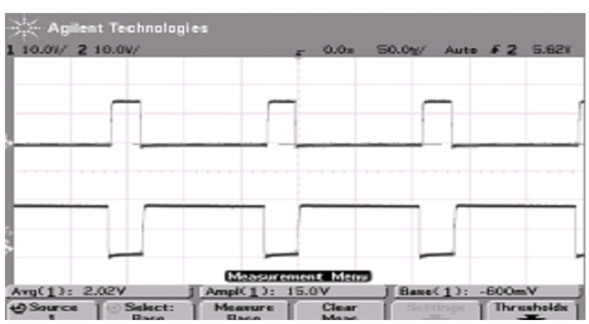


Fig.12. Pulses with longer ON time for S3, S4 & shorter ON time for S1, S2

Fig. 12, Pulses with shorter ON time for S1, S2 longer ON time for S3, S4 The direction of rotation and speed of the motor depends on the pulse applied to the switches of IGBT. When the width of pulse applied to all the four switches is equal the motor will not run. The H-Bridge having two pair of switches, one pair is S1, S2 and another pair is S3, S4. When the pulse width of pair of switches high and the pulse width of another pair of switches is low then the motor runs at particular speed in one direction.Fig.11 shows the pulses applied to the chopper switches, where pulses to the switches S1, S2 are high and pulses to the switches S3, S4 low. At this condition the motor runs at clockwise direction at constant speed. When pulses applied to the switches are as shown in fig.12, then the motor runs at anticlockwise direction at constant speed. The "Gate-Emitter (V_{GE})" and "Collector-Emitter Voltage (V_{CE})" across the switches S1, S2 and S3, S4 respectively. Under this condition the motor is idle. The motor speed can vary by varying the pulse width of switches, which is generated by TMS320F240 DSP. Whenever the new speed command is applied that processed in DSP, generate new pulse depends on the speed requirement and applied to switches to achieve new speed, the motor finally reaches the constant speed and closed loop speed control is achieved.

5. Conclusion

The Two Stage DC-DC step-up converter and the H-Bridge DC Chopper circuit have been developed and the experimental results are observed for both the systems. All the circuits are designed and simulated using OrCAD Pspice before implementation .The closed loop speed control system is experimented and results were obtained by connecting DC motor as a load to the H-Bridge Chopper which is controlled by TMS320F240 DSP.The coding of TMS320F240 for DC motor speed control were generated and experimented using CODE COMPOSER 2000. This system is highly adoptable because of its reprogrammablility, execution speed and precise control. The efficiency of system also improved.

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