Abstract— The speed of separately excited DC motor can be controlled from 0 to rated speed using chopper. The chopper firing circuit receives signal from controller and the chopper responds by providing variable voltage to the armature of the motor for achieving desired speed. There are two control loops, one for controlling current and another for speed. The controller used is Proportional-Integral type which ceases the delay and provides fast control. In this way, the Modelling of separately excited DC motor is done. After obtaining the complete model of the system, it is simulated using MATLAB (Simulink) in open loop. The simulation of DC motor drive is done and analysed under various speeds and load torque conditions. The above simulated model will be implemented as done and analysed under various speeds and load torque (Simulink) in open loop. The simulation of DC motor drive is complete model of the system, it is simulated using MATLAB (Simulink) in open loop. The simulation of DC motor drive is complete model of the system, it is simulated using MATLAB (Simulink) in open loop.

Keywords— Hybrid Electric Vehicles, I.C. Engines, Chopper

I. INTRODUCTION

The DC-DC converters find wide applications in switched mode power supplies. The input voltage of the converter varies in a wide range especially the source is derived from a renewable resource. Therefore, the input to these converters is unregulated with the output voltage expected to have ripples and harmonic free. From the energy point of view, output voltage regulations in the DC-DC converters is achieved by continuously adjusting the amount of the energy absorbed from the source and that injected in the load which is in turn can be achieved by controlling the time intervals of energy absorption and energy injection in the circuit as in [1]. These two basic processes of energy absorption and injection constitute a switching cycle presented as duty cycle of operation D. There are two operation modes known as Current Continuous Mode (CCM) and Current Discontinuous Mode (DCM). Several methods and techniques were applied aiming at regulating the Duty cycle D of the chopper with purpose to reduce the voltage ripples and to maintain the output voltage at minimized switching losses of the chopper. Pulse Width Modulated (PWM) converters are required to operate with high frequency due to demand for high power density with reduced switching losses by using so called soft switching techniques. Realizing this aim can be achieved by applying Zero-Voltage Switching (ZVS) in the main switching circuit with an active auxiliary circuit that is activated just before the main switch is to be turned on and is deactivated sometime afterward. The auxiliary circuit consists of an active switch (IGBT) and passive elements such as inductances and capacitances that have lower ratings than those in the main power circuit as the auxiliary circuit is activated for only a fraction of a switching cycle.

P.W. converters with such circuits are referred to Zero Voltage Transitions (ZVT) PWM in the literature [6]. The auxiliary circuits can either be non-resonant circuit with a switch with a hard turn-off as or a resonant circuit with LC resonant components that allow the switch to have a soft turn-off but at the expense of increasing the circulating current.

II. DC CHOPPER

A Chopper is a static switch used to convert fixed dc to variable dc. It can be viewed as a DC equivalent of a transformer. The power semiconductor device used for a chopper circuit can be forced commutated thyristor, power BJT power MOSFET, GTO or IGBT as in [4].

A chopper is high speed on/off semiconductor device which connects the load and disconnects the load from source at very high speeds. In this a manner a chopped DC is obtained from a constant source as in [4].

There are five types of dc choppers, Class A, Class B, Class C, Class D and Class E based on the V-I plane. The five different choppers are classified according to their output (Io, Vo) capabilities as follows:

(a) First quadrant - I (Class A chopper) +Vo, +Io.
(b) Second quadrant - II (Class B chopper) +Vo, -Io.
(c) Two quadrant - I and II (Class C chopper) +Vo, ±Io.
(d) Two quadrant - I and IV (Class D chopper) ±Vo, +Io.
The first-quadrant chopper (Class A) operates in the first quadrant of V-I plane with power flowing from source to the load as both V and I are positive. Hence the dc motor runs in the forward direction and the speed of the motor can be varied by the varying the duty cycle (D) of the chopper.

The second-quadrant chopper (Class B) operates in the second quadrant of V-I plane. The power flows from load to the source as I is negative in this quadrant. The chopper operation is possible only if the load is with an active element.

The two-quadrant chopper (Class C) operates in the first and second quadrant of V-I plane. Therefore, power flow is bidirectional. With a dc motor as a load, the chopper operates the motor in forward motoring mode in first quadrant and forward regenerative mode in the second quadrant as in [4].

The two quadrant chopper (Class D) operates in the first and forth quadrant of V-I plane. Again the power is bidirectional with dc motor (load) operated in forward motoring and reverse regenerative mode. The operation of the Class A, Class B, Class C and Class D choppers are discussed in the literature [4].

The four quadrant chopper (Class E) operates in all the four quadrants of V-I plane. The operation of the four quadrant chopper is illustrated in the next section.

III. CLASS-E CHOPPER OPERATION

Operation of a four quadrant chopper (Class E), is illustrated with a dc motor as load as shown in Fig. 2. The circuit diagram is as shown in Fig. 1.

From Fig. 1, for the load to operate in first quadrant (forward motoring), the switches T1 and T4 are operated. Here, the switch T1 is switched whereas switch T4 is kept on. Therefore, both the voltage and current across and through the load are positive rotating the motor in forward direction. Now, the speed of the motor can be varied by varying the duty cycle of the switch T1. As the duty cycle varies, the voltage across the armature of motor varies proportionally thereby varying the motor speed as the N is proportion to armature voltage.

Now to apply brake to the motor electrically, the chopper is to be operated in second quadrant. This can be done by operating switch T2. When the switch T2 is on, the inertial energy of the motor is stored in the armature inductance, the voltage across the inductor increases. Once the switch is turned off, the voltage across inductor adds with the back EMF of the motor feeding the inertial energy back to the source through freewheeling diodes D1 and D4. For the energy to be fed back to the source, the combined voltage of inductor and back EMF should be more than source voltage (Vs). If the inertial energy of the motor is feed back to source, it is called regenerative braking and if dissipated in a resistor, it is called electrical braking. In the quadrant, the motor is in forward regenerative mode as in [4].

To operate the chopper in the third quadrant, switches T3 and T2 are to be operated. Here, switch T3 is switched and switch T2 is kept on. Now the voltage and current across and through the load are negative driving the motor in reverse direction. Also the speed of the motor can be varied by varying the duty cycle (D) of the switch T3. In this quadrant, the motor is in reverse motoring mode as in [4].

Now to operate the motor in fourth quadrant, only switch T4 is operated. With the switch T4 turned on, the voltage across the armature inductance increases. When the switch T4 is turned off, voltage across the inductor adds to the back EMF. If the combined voltage is more than source voltage, the inertial energy is fed back to the supply as in [4].
In this proposed simulation, a separately excited DC motor is made to run in all the four quadrants. For this purpose, four IGBTs are chosen for the H-bridge configuration. The motor circuit acts like a buck converter in motoring operation and as boost converter in braking operation. A distinct logical sequence is implemented in this simulation to present the four quadrant operation in a single time line.

In motoring mode, when the switch 1 is in OFF state, the motor’s inductive energy should be allowed through a free wheeling diode. In case of reverse motoring, the same free wheeling diode diverts the motor and creates a dead short circuit across the supply. Hence, the above said logic sequence is utilized to reverse the connections of the free wheeling diode. The reversible diode arrangement and its sub-circuit are shown in the Fig. 4.

The simulation time line is allotted for 4 seconds in which 2 seconds for forward and 2 seconds for reverse operations. A pulse generator is configured with period 4 seconds and pulse width 50%. This mark time (ON time) of the pulse operates the motor in forward mode and the space time (OFF time) operates the motor in reverse mode.

Another pulse generator (transition triggering) is configured with a period of 2 seconds and pulse width 50%. The mark time is for motoring and the space time is for braking. As the period of this pulse (Trans) is half of the time line pulse, this trans pulse creates two motoring and two braking modes of operations. For triggering the IGBTs, the general pulse generators are configured with 1 KHz switching frequency and its duty ratio can be adjustable. The logic connections of the pulse generators are shown in the Fig. 5.

In forward motoring mode, the switch 4 continuously conducts and the switch 1 will be operated with PWM1. After 1 second, the transition (trans) pulse goes OFF (braking mode) and this makes the changeover switch (x1) to connect to zero (OFF). Simultaneously, the changeover switch (x2) shifts to PWM2. During this braking mode, when switch 2 is ON, the moment of inertia makes the motor to operate as generator and charges the current.

V. SIMULATION

The armature voltage, regeneration voltage and the speed for all the four quadrants are shown in the Fig. 6.
The motor is loaded with 1N-m, when the braking sequence is initiated, the speed gradually drops and the regeneration voltage starts rising. The negative speed indicates the motor is in reverse operation mode.

Fig. 8. Regenerative power at different duty cycles.

In Fig. 8, a comparison is presented among the braking periods with respect to the duty ratios. At 50% duty cycle, the braking time is almost $1/4$ of time line period. But at 90% duty cycle, the time dropped to almost $1/2$ of the 50% duty cycle case. The more the ON time, more the inductance charges and it increase the regenerating power and also the braking torque.

Fig. 9. Braking effect for different load torques (approx zero, 1 N-m and 10 N-m torque).

The regenerating power is around 125W for 50% duty ratio and 290W at 90% duty ratio. The response of braking for different load torques is shown in the Fig. 9.

The braking time for zero load torque is equal to the allotted quadrant operation period. For 1 N-m torque, the braking period drops to 50% and for 10 N-m, braking period is around $1/4$ of zero torque condition. Here, more the load torque, less the application of braking. Combining the above two results, the motor can be properly controlled by changing the duty ratio for a specified load torque.

VI. HARDWARE IMPLEMENTATION

The A 200v, 5A DC motor is used for hardware implementation. The IGBTs used are CT60. A 15w lamp is used as a load to absorb the regenerating power. The switching pulses are generated from analog ICs. XR2206 is used to generate a triangular wave whose frequency can be adjusted between zero to 100KHz in this circuit. That triangular signal is compared with a DC value (POT connected across a 12V DC supply) and thus produces the triggering pulses. The transitions form motoring mode to braking mode are achieved using 555 timers configures in bi-stable mode. The AC voltage is rectified using two separate 5A bridges and they are filtered with two 1000 µF/450V DC. One is used to for excitation and the other is for armature.

The switch over between quadrants is designed using 4PDT relays which are triggered by 555 timers in mono-stable mode.

VII. RESULTS

The four quadrant operation of the dc drive is successfully implemented and the output voltage in the regenerative mode is boosted more than the supply voltage. This boost in voltage is compared in terms of the intensity of light of the regenerative load (bulb). The model shows good results in an applied voltage range of 100-150V.

Fig. 10. Hardware implementation

VIII. FUTURE SCOPE

By designing the snubbers more accurately, the whole drive can be made more sophisticated. Also by using micro controller the control circuit becomes simpler and the switching circuitry reduces. The inertia of the motor is not sufficient to overcome the magnetic locking of the motor under regenerative mode, so inertia of the motor is to be increased for better run.

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