Battery Powered Electric Vehicle Employing Permanent Magnet DC Motor

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***Abstract*—This paper presents the speed control of a permanent magnet dc (PMDC) motor for an electric vehicle (EV). The motor is operated in forward motoring and forward braking regions. The performance of the drive is simulated using MATLAB® Simulink.**

Keywords— Battery powered electric vehicle (BEV), DC-DC converter, PMDC motor, MATLAB®Simulink.

I. INTRODUCTION

Battery powered vehicles are popularly known as electric vehicles. Although several batteries and fuel cells have been developed, only available at affordable price is the lead acid battery. Therefore, electric vehicles are generally powered by lead acid batteries [1].Series and separately excited dc motors, permanent magnet dc motor, brushless dc motor and induction motor have been used in electric vehicle.

Many researches are done in designing high performance motor drives as industries are demanding more robust and high performance drives. A drive should maintain dynamic speed response. Among all the motors DC motor provides excellent control of speed for acceleration. Main advantage of using DC motor in drive application is that the power supply is directly fed to the field of motor which allows a precision voltage control which is useful in speed and torque control application [2].

Although AC motors are mainly used in industry but DC motors are still used in several applications such as EV propulsion, textile industries and in public transport TRAM(trolley) and metro. The control of DC motor is usually made of power electronic devices. DC motor drive is classified according to the type of the converter which is utilized in order to control the speed and torque of the DC motor. When a DC to DC converter is used the motor is called chopper fed DC motor drive [3].DC drives are widely used in industrial applications. It is considered as single input and single output system having speed torque characteristics well suited with most mechanical loads. Controlled rectifier provides a variable dc voltage from a fixed dc voltage. Due to their ability to supply a continuously variable dc voltage, controlled rectifier and dc chopper made a revolution in modern industrial equipment and variable speed drives [4].

Chopper is a static power electronic device that converts fixed DC input voltage to variable DC output voltage. Chopper systems are characterized by high efficiency, and fast response. Choppers are now being used all over the world for rapid transit system. It has replaced controlled rectifier converter in many applications due to high efficiency, fast response.

A. Principle of Buck-Boost Converter:

The basic switched mode converter is the buck-boost converter [5]. The output of the buck-boost converter can be either higher or lower than the input voltage.
When the switch is turned-ON, the input voltage source supplies current to the inductor, and the capacitor supplies current to the resistor (output load).When the switch is turned-OFF opened, the inductor supplies current to the load via the diode D as shown in Fig. 2.

B. DC Drive with chopper control for EV:

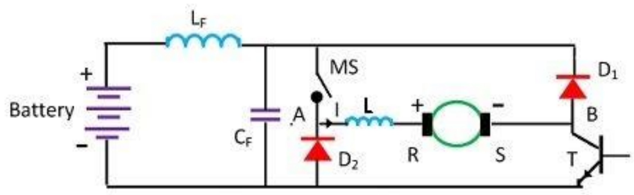

Fig. 3. DC Drive with chopper for EV

Voltage employed have typical values of 6 V, 12 V, 24V, 48V and 110 V. Higher voltage yields a motor with less weight, volume and cost, but then battery cost becomes high.

Regenerative braking is usually employed. It increases the range of vehicle by 7-15%. The regenerative braking does not have any braking torque at zero and close to zero speed. Therefore, mechanical brakes have to be employed with regenerative braking. The braking system should be designed to provide coordination between regenerative braking and mechanical brakes.

A permanent magnet dc motor drive for a battery powered vehicle is shown in fig .3. The drive employs chopper with regenerative braking facility. L_f and C_f filter is employed to filter filter out chopper control with regenerative facility. L_f and C_f filter is employed to filter out the harmonics generated by the chopper. MS is a manual switch and RS a reversing switch. Inductance L is provided to assist regeneration and keep the ripple in motor current low.

Motoring operation:- In motoring mode, the machine works as a motor and converts the electrical energy into mechanical energy, supporting its motion.

For motoring operation MS is kept closed[6]. Transistors switch T is operated at a constant frequency with variable on time to obtain variable dc voltage for starting and speed control. When T is on, the current flows through the source, L_f, MS, L, R, armature, S and T. when T is off, the armature current freewheels through S, D_1, MS, L and R.

Regenerative braking operation: for regenerative braking operation MS is kept open and motor armature is reversed with the help of the reversing switch RS making B positive with respect to A. when T is on, the armature current builds up through the path consisting of T, D_2 and L. when T is off, the armature current flows against the battery voltage through the path consisting of D_1, L_f, battery, D_2 and L and the energy feedback is utilized to charge the battery.

The drive is operated at the closed loop torque control. As the torque is directly proportional to the current, this gives closed-loop torque control. By approximately controlling the torque the driver sets the vehicle speed at a desired value.

C. Drive System Equations

During Motoring operation:

$$\frac{di_a}{dt} = \frac{\left(TV_c - i_a R_a - K\omega_n\right)}{\left(L_a + L\right)}$$

$$\frac{d\omega_n}{dt} = \frac{\left(Ki_a - T_l - B\omega_n\right)}{J}$$

$$\frac{dV_c}{dt} = \frac{\left(i - i_{in}\right)}{C_f}$$

$$\frac{di}{dt} = \frac{\left(V - V_c\right)}{L_f}$$

$$i_{in} = -\left(i_a T\right)$$

During Breaking Operation:

$$\frac{dia}{dt} = \frac{\left(\left(1-T\right)V_c - i_a R_a - \left(2MS - 1\right)K\omega_n\right)}{\left(L_a + L\right)}$$

$$\frac{d\omega_n}{dt} = \frac{\left(Ki_a - T_l - B\omega_n\right)}{J}$$

$$\frac{dV_c}{dt} = \frac{\left(i + i_{in}\right)}{C_f}$$

$$\frac{di}{dt} = \frac{\left(V - V_c\right)}{L_f}$$

$$i_{in} = \left(i_a T\right)$$

Where, V: applied voltage (V)
i_a : motor current (A)
i_{in} : Load current (A)
i : Supply current (A)
V_c : Capacitor Voltage (V)
L_a : Armature Inductor (H)
L : Series Inductor (H)
L_f : Source Inductor (H)
C_f : Capacitor voltage (F)
R_a : Armature Resistance (Ω)
ω_n : Motor output speed (rps)
T_l : Load torque (Nm)
K: Back e.m.f constant (V-Sec/Rad)
B:Viscosity coefficient
J: Moment of inertia (Kg-m^2)
T and MS: Semiconductor Switches

II. MATLAB/SIMULINK SIMULATION RESULTS

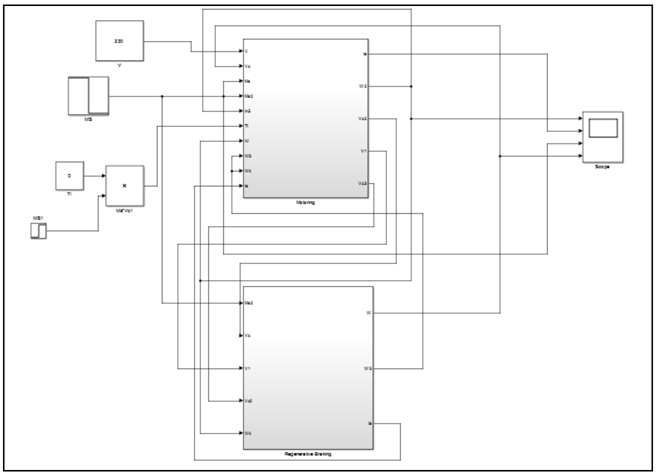

Fig. 4. MATLAB® Simulink model of DC motor

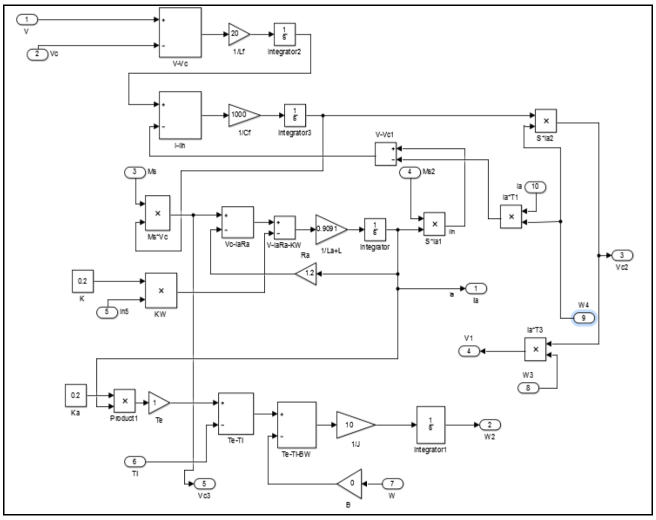

Fig. 5. MATLAB® Simulink model of Motoring Action.

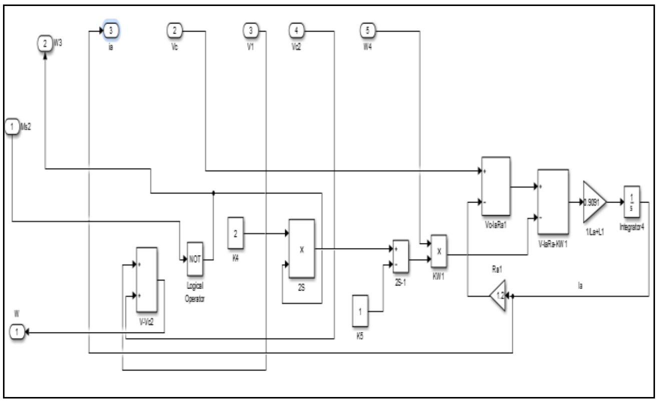

Fig. 6. MATLAB® Simulink model of Regenerative Braking

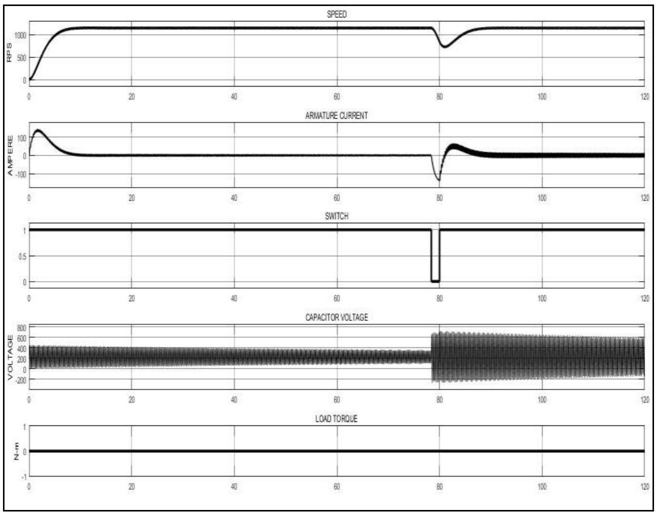

Fig. 7. Motoring and Regenerative Braking operation with T_l=0 N-m is shown in the above figure.

Referring to Fig.7 In trace 2, initially the back EMF is zero, current reaches to peak value of 140 A .When the back EMF increases considerably armature current drops to zero. During regenerative braking the current direction reverses.
In trace 1, speed gradually increases and reaches to steady state value of 1165 rps. During regenerative braking speed decreases.
Trace 3, while in motoring operation the capacitor voltage decreases, during braking motor acts as generator and charges the capacitor.

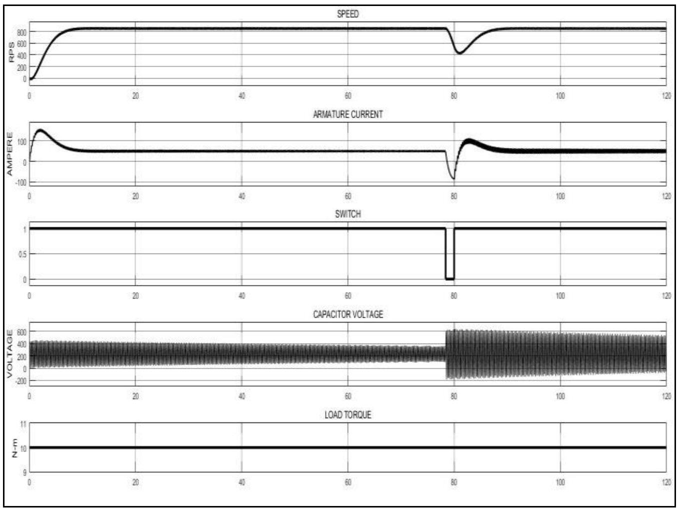

Fig. 8. Motoring and Regenerative Braking with the load of 10 N-m.

Referring to Fig.8 In trace 2, when T_l=10 N-m, current reaches to peak value of 148 A and then drops to 50 A. During regenerative braking the current direction reverses with magnitude of 87.71 A.
In trace 1, speed gradually increases and reaches to steady state value of 855 rps. During braking speed decreases.

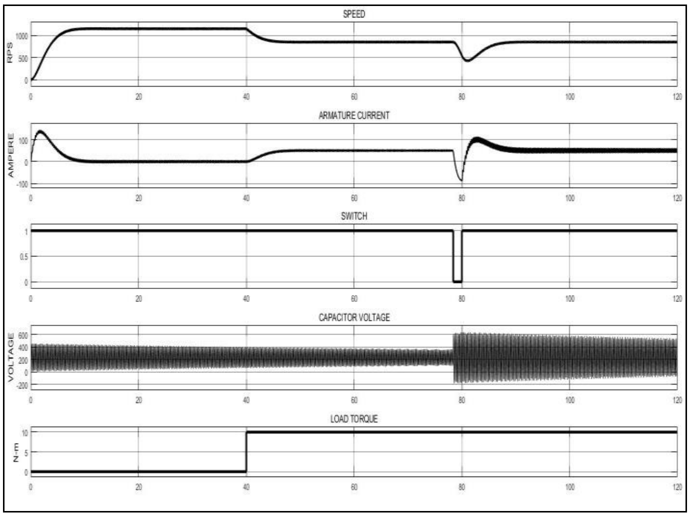

Fig. 9. Motoring and Regenerative Braking with the load of 10 N-m applied at 40^{th} sec.

Referring to Fig.9 In trace 2, current reaches to peak value of 140 A and drops to zero. When load is applied at t=40s, current increases by 53 A. During regenerative braking the current direction reverses with magnitude of 87.7 A.
In trace 1, speed gradually increases and reaches to steady state value of 1165 rps. During braking speed decreases to 421 rps.
Trace 3, while in motoring operation the capacitor voltage decreases, during braking motor acts as generator and charges the capacitor.

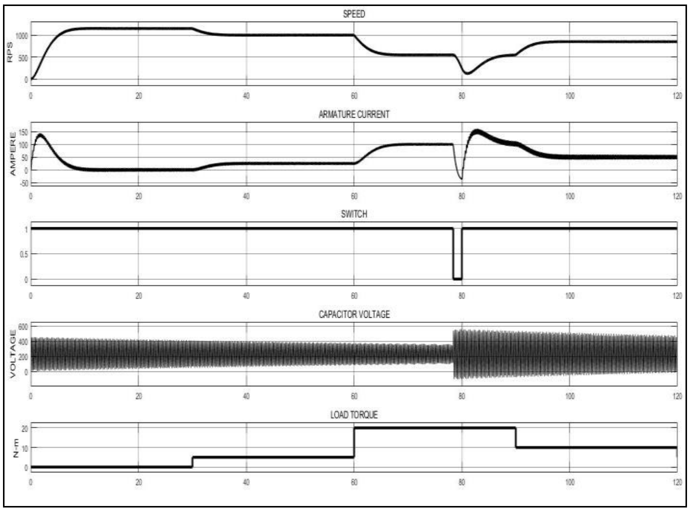

Fig. 10. Motoring and Regenerative Braking with the different load conditions.

Referring to Fig. 10. Initially current reaches to peak value of 140 A. For different load conditions during motoring and braking the variations in speed and current values are shown in Appendix II.
The variations of applied load torque is as shown in trace 4.

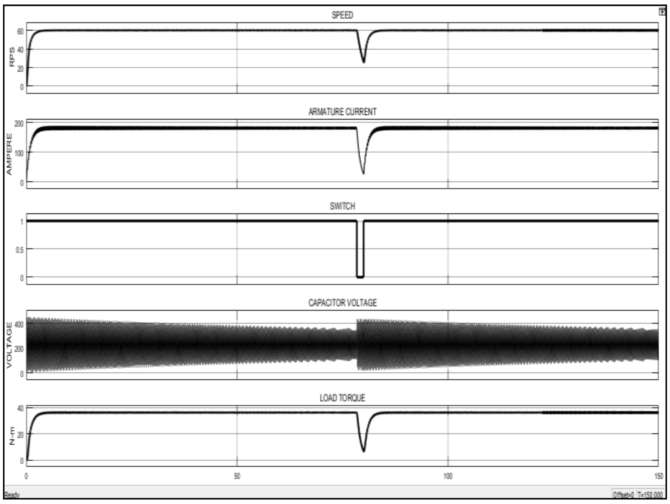

Fig. 11. Closed loop current controlled motoring and braking.

Referring to trace 2, Taking armature current as reference, we are limiting the current which in turn sets the desired vehicle speed.

III. CONCLUSION

We have considered a BEV employing PMDC motor for our study. PMDC drive has been simulated to demonstrate its operation during forward motoring as well as during braking operation. The control circuit of this drive limits the current or the developed torque during motoring as well as during braking operation. The current limit control command will be set by the vehicle driver to set the vehicle speed according to road and loading conditions. The drive performance is demonstrated through the transient simulation using MATLAB® Simulink. It can be seen from the results that PMDC motors can be successfully employed for an EV application.

IV. REFERENCES

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APPENDIX

I.PMDC MOTOR SPECIFICATIONS

Notation	Values
J	0.1 kgm^2
B	0.1 Nm/rad/sec
K	0.2 V-s/rad
R	1.2 Ω
L	555 mH
L_f	14.28 mH
L_a	555 mH
V	230 V
C_f	1 mF

II. MOTORING AND BRAKING VALUES WITH VARIABLE LOAD TORQUE

Load Torque (N-m)	Speed (rps)	Peak Current (A)
0	1149	138
5	979	25.26
20	545	98.90
10	855	54
20	111	-35