Simulation of Energy Recycling Technique for an Electric Scooter Using MATLAB/SIMULINK Environment

K Naresh[1], P Bharat Kumar[2], Dr K S R Anjaneyulu[3]

[1] PG Student, Department of EEE, JNTUA College of Engineering, Ananthapuramu, Andhra Pradesh, India
[2]Adhoc Lecturer, Department of EEE, JNTUA College of Engineering, Ananthapuramu, Andhra Pradesh, India
[3]Professor, Department of EEE, JNTUA College of Engineering, Ananthapuramu, Andhra Pradesh, India

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Abstract –***Nowadays Electric Vehicles are widely used for the urban transportation because of their sustainability, High torque, low volume, zero emission and energy saving. Electric scooter can go certain limit of distance based on the battery capacity it consists. This paper presents the model construction of an energy regenerative electric scooter via MATLAB/SIMULINK so that one can evaluate the performance of the energy recycling technique for an electric scooter. The present model distance/charge is limited based on the battery packs. The proposed method offers longer distance/charge.***

Key Words: *Electric Vehicle (EV), Model Construction, MATLAB SIMULINK, Energy Regeneration, Distance/charge, etc.*

1. INTRODUCTION

The automotive industry is targeting sustainable transportation in near future. Electric motor plays a major role in Electric Vehicles. Internal combustion engines are relatively less efficient in converting the on-board fuel energy to propulsion as most of the energy is wasted as heat. Whereas electric motors are efficient in converting the stored energy in driving a vehicle, and electric drive vehicles do not consume power while coasting. Some of the energy loss in braking is captured and reused by regenerative braking[2].

With help of regenerative braking one fifth of the energy loss can be regenerated. Typically petrol engine effectively use only 15% of its fuel content to move the vehicle. Whereas an electric drive vehicle has an on-board efficiency of about 80%. But due to reason such as cost, inability to reach higher speeds electric drive vehicles failed to capture markets. Contrary to this petrol vehicles can cover longer distances with higher speed but it cannot cover shorter distance with slow speed (say in traffic) in an official way.

By increasing the range of electric vehicles they could easily capture the automobile industry. Hybrid technology [1] is the most promising technology that could be implemented for increasing the EV range as current electric vehicle industries are switching towards this concept for increasing the vehicle range. In this paper, the concept of energy recycling technique for an electric scooter is incorporated.

The brushless DC (BLDC) motor is fixed into the Hub of rear wheel and DC motor is mounted to front wheel. The block diagram of system is as shown in Fig -1.

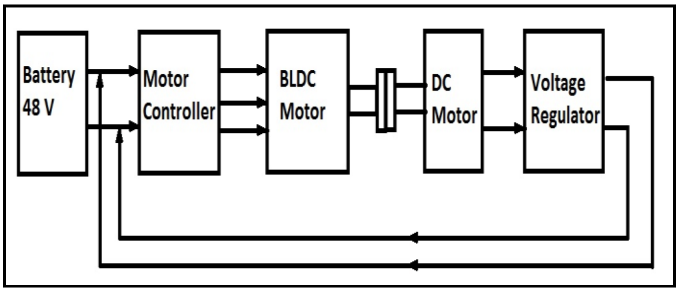

Fig -1: Block Diagram of BLDC-DC Coupling System

To model a BLDC motor drive system, it is must to have the motor model a precise value of torque which equals to current and back-EMF. Several simulation models have been presented to analyze performance of BLDC motor [3-6]. Various modeling techniques according to the applications of BLDC motor have been used. Hence in this paper 3 phases, 23 no. of pole pairs, trapezoidal back-EMF of BLDC motor for automotive industry application is modeled and simulated in MATLAB/SIMULINK.

There are two types of BLDC according to back-EMF signal of motor; sinusoidal and trapezoidal. There are also two types of BLDC with respect to have sensors for detecting rotor position or not. Normally Hall Effect sensors are used for low cost, low resolution applications and the optical encoder is for high resolution applications [7]. These Sensed signals are used to adjust PWM sequence of 3-phase bridge inverter. In sensor less control strategies, back-EMF integration, flux linkage-based, freewheeling diode conduction and speed independent position function techniques are used for electronic commutation. In this system, Hall Effect signals are produced according to rotor position for commutation. Also a 3-phase inverter of MOSFETs is used as voltage source. Different control strategies can be applied to the system. As shown in fig -2.

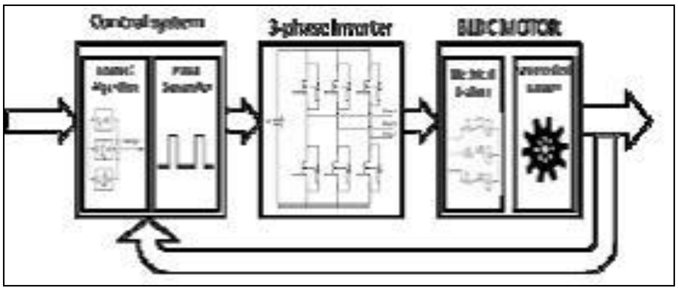

Fig -2: schematic system of BLDC motor drive

2. MATHEMATICAL MODELLING

In this paper a 3 phase, 23 no. of pole pair's trapezoidal back-EMF type Brush Less DC is modeled. Therefore abc phase variable system is more applicable than d-q axis. For the purpose of simplifying equations and overall model, some assumptions were made such as magnetic circuit saturation is ignored, stator resistance and self and mutual inductances are equal and constant, and all semiconductor switches are ideal.

The electrical and mechanical mathematical equations of BLDC are:

$$V_a = Ri_a + (L-M)\frac{di_a}{dt} + E_a \quad (1)$$

$$V_b = Ri_b + (L-M)\frac{di_b}{dt} + E_b \quad (2)$$

$$V_c = Ri_c + (L-M)\frac{di_c}{dt} + E_c \quad (3)$$

$$\begin{cases} E_a = K_e\omega_m F(\theta_e) \\ E_b = K_e\omega_m F(\theta_e - \frac{2\pi}{3}) \\ E_c = K_e\omega_m F(\theta_e + \frac{2\pi}{3}) \end{cases} \quad (4)$$

$$\begin{cases} T_a = K_t i_a F(\theta_e) \\ T_b = K_t i_b F(\theta_e - \frac{2\pi}{3}) \\ T_c = K_t i_c F(\theta_e + \frac{2\pi}{3}) \end{cases} \quad (5)$$

$$T_e = T_a + T_b + T_c \quad (6)$$

$$T_e - T_l = J\frac{d^2\theta_m}{dt^2} + \beta\frac{d\theta_m}{dt} \quad (7)$$

$$\theta_e = \frac{P}{2}\theta_m \quad (8)$$

$$\omega_m = \frac{d\theta_m}{dt} \quad (9)$$

Where k = a, b, c

V_k is kth Phase voltage applied from inverter to BLDC,

I_k is k th phase current, R is resistance of each phase of BLDC,

L is inductance of each phase BLDC,

M is Mutual inductance,

E_k is k th phase back-EMF,

$T_k$is electric torque produced by k th phase,

$T_e$is electric torque produced by BLDC,

$K_e$is back – EMF constant,

K_t is torque constant,

ω_m is angular speed of rotor,

θ_m is mechanical angle of rotor,

θ_c is electrical angle of rotor

$F(\theta_e)$ is back-EMF reference as function of rotor position.

3. SIMULINK MODEL

The simulation model consists of four parts as shown in Fig. 1, each part is simulated separately and integrated in overall simulation model. The overall model of system is as shown in Fig -3. Initially the battery was charged fully, from the battery the power flows to the BLDC motor through the controller. After Electric scooter starts rotates due to the motor power, the Permanent Magnet DC Generator which is at front wheel will starts rotation, the DC Generator will generates a DC power this unregulated DC power is regulated through a Voltage regulator to recharge the batteries. The re generated power is connected across the terminals of Batteries parallel through the diodes to make DC motor as Generator.

The BLDC motor which is fed by battery through an motor controller, which can controller the power supplied to the BLDC by based on the Hall Effect signals of rotor position as shown in Fig -4.

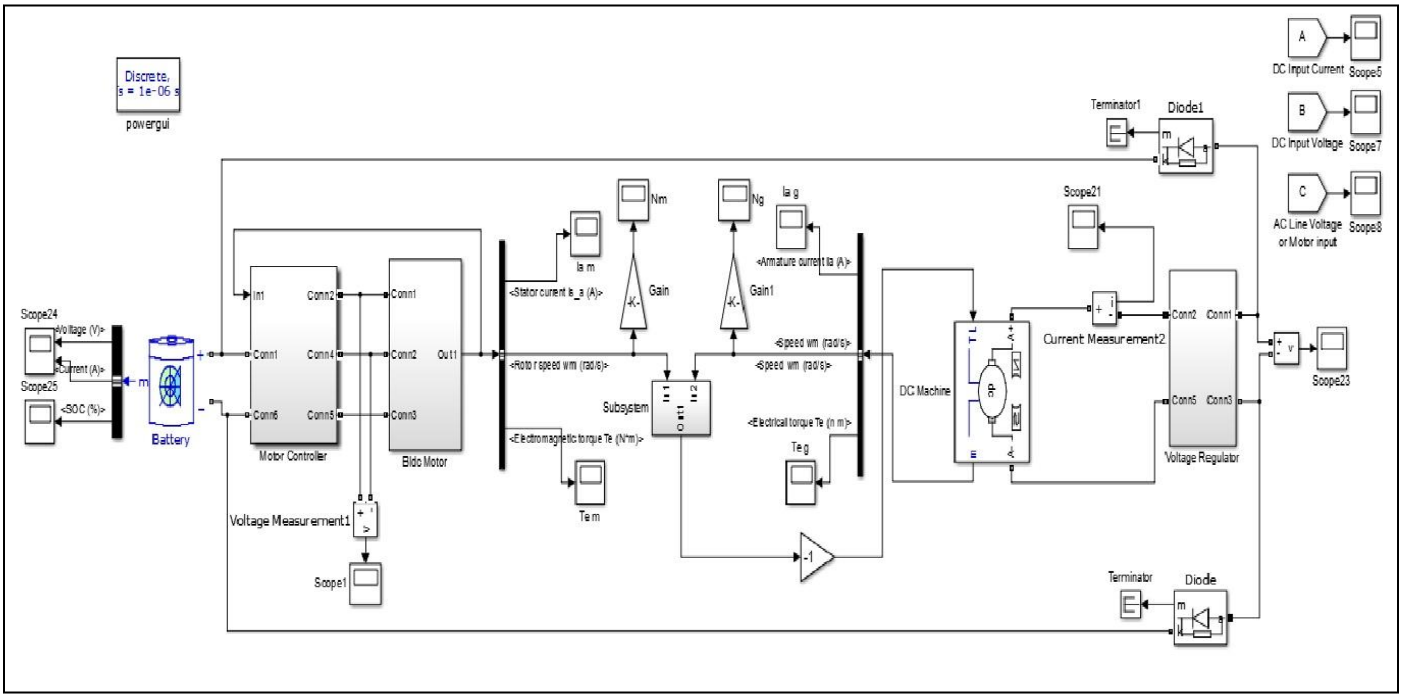

Fig -3: Overall model of the system

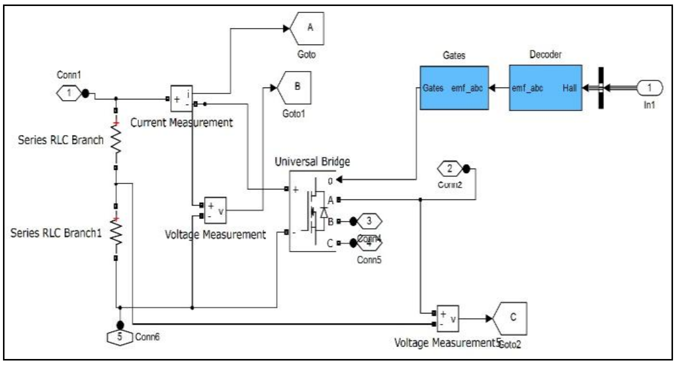

Fig -4: BLDC Motor Controller

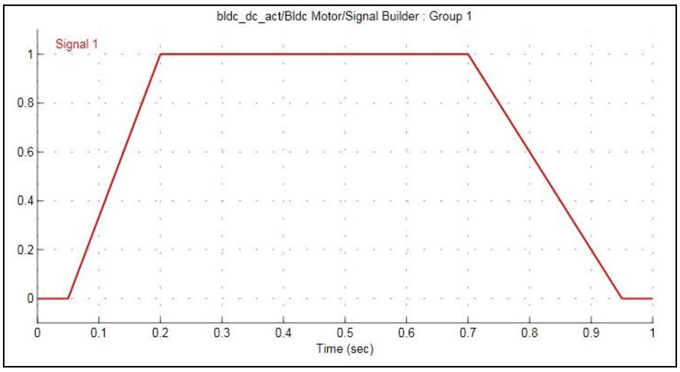

Fig -5: Torque Input Signal

For designing self-excitation drive system it is necessary for the model to give precise value of torque related to back-EMF and torque. The torque input signal given to the motor is as shown in Fig -5.

The stator winding is energized in sequence to rotate the rotor and commutation is done electronically, such that the knowledge of rotor position is necessary to energize the stator winding in correct sequence.

4. SIMULATION RESULTS

The BLDC Motor and DC Generator Parameters are as shown in Table 1[1] and Table 2

Table -1: BLDC Motor Parameters

Parameter	**Value**
Rated Torque (Nm)	34
Number of Phases	3
Number of pole pairs	23
Frequency (Hz)	161
Number of slots	51
Outer diameter (mm)	223
Stack length (mm)	50
Air-gap length (mm)	1
Air –gap flux density (T)	0.843
Phase resistance (Ω)	0.059563
Rated current(A)	24.78
Total losses(W)	190.82
Power factor (%)	80.19
Efficiency (%)	87.27
Active part mass(kg)	6.25
Power/mass ratio(W/kg)	240

Table -2: DC Generator Parameters

Parameter	**Value**
Armature resistance (Ω)	0.4382
Armature inductance (H)	0.006763
Torque constant (N.m/A)	1.8
Total Inertia J (kg.m^2)	0.2053
Viscous friction coefficient Bm (N.m.s)	0.007032

The battery levels of the system are as shown in the Fig -6, the battery discharging levels of voltage and current are obtained. The DC input voltage and DC input current given to the system is obtained from the Fig -7, 8 & 9. It is clear that when the load is connected to batteries there is distortion inboth the battery voltage and battery current levels because of zero resistance among the battery terminals. This can be eliminated by the limiting resistors as shown in the Fig -4. After the motor controller we can get trapezoidal waveform as shown in Fig -10.

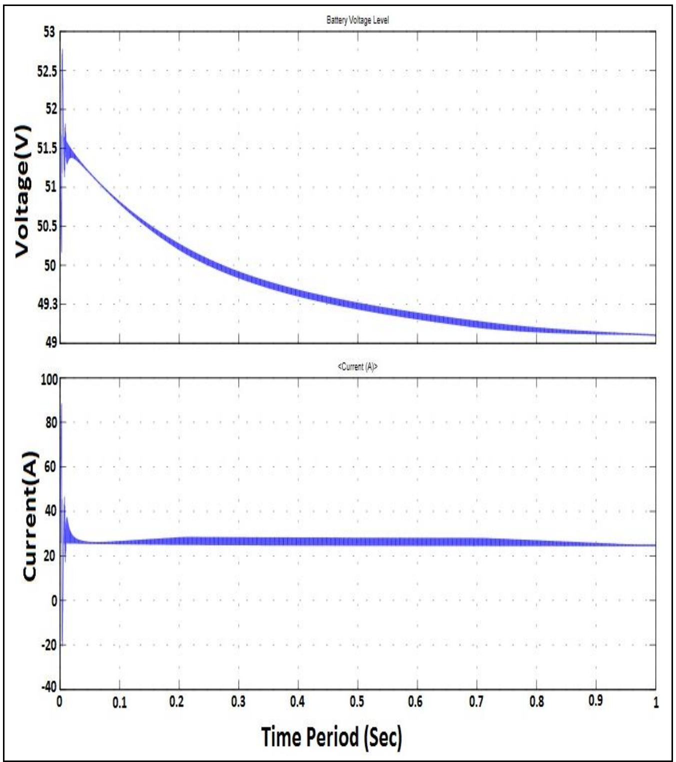

Fig -6: battery Levels

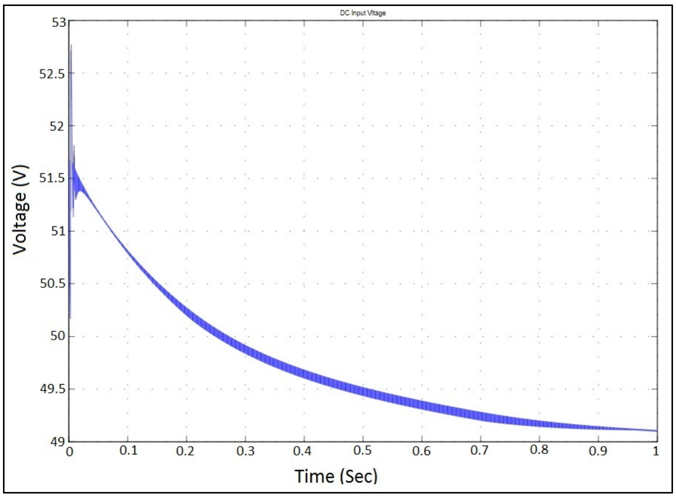

Fig -7: DC Input Voltage Level

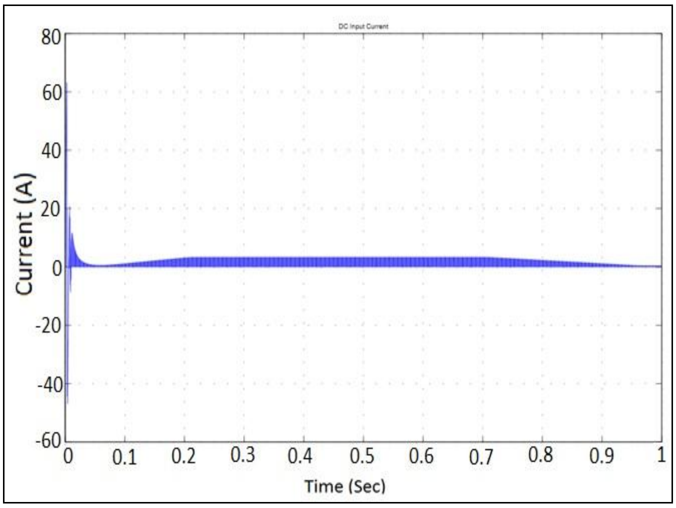

Fig -8: DC Input Current

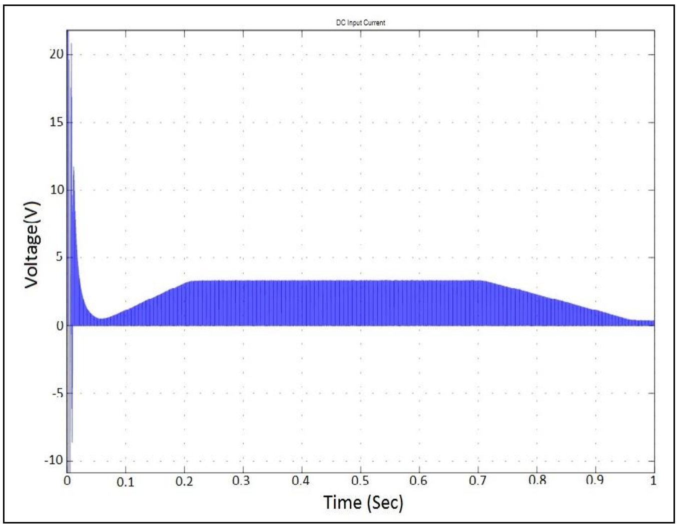

Fig -9: DC Input Current Zoom

When the EV runs then the DC Generator will produce some energy and this power is fed through a voltage regulator to feed back to the input. The output voltage and DC output current levels are shown in Fig -10 & Fig -11.

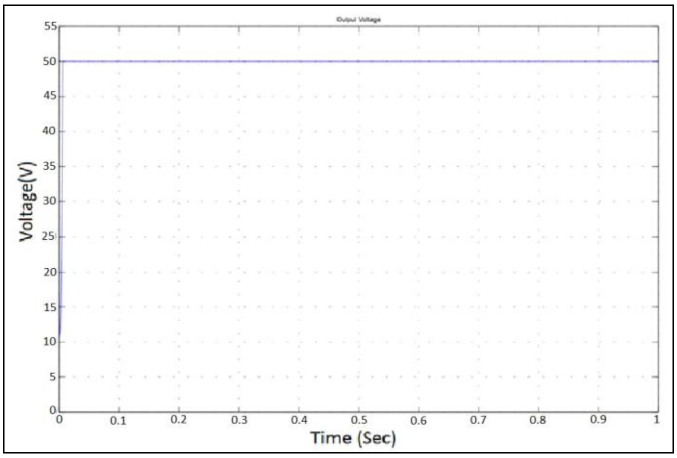

Fig -10: DC output voltage

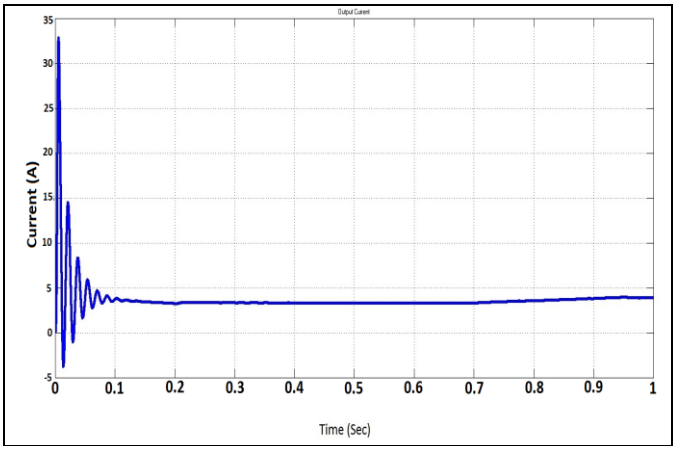

Fig -11: DC Output current

From the above graphs the following data is obtained

Parameter	Giving at Input side	Getting at Output side
Voltage	49V	50V
Current	3.5A	3A
Power	171.5W	150W

Efficiency of the system: output power regenerated/ input power given to the system

Efficiency = 87.56%

For eg: **if scooter runs 60km/charge** then by using this technique

(60*87.56/100)= 52.536km

Of power is regenerated

Within this 52.536km time again

(52.536*87.56/100) = 46km

Of power regenerated

Within this 46 km time again

(46*87.56/100) = 40.27km

Of power generated

Similarly at final the electric vehicle can go **above 450 km/charge.**

5. CONCLUSIONS

The modeling of self-excited technique in an electric vehicle is presented in this paper. The feedback signal and commutation mechanism utilizes speed, position of the rotor and stator current. The simulation results show that with this technique the no. of km/charge is increased and one of the major drawbacks of the EV is eliminated.

6. REFERENCES

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BIOGRAPHIES

K Naresh is an M.Tech Scholar in JNTUA College of Engineering, Anantapur. He is IEEE student Member. He has done his Bachelor of Technology from Seshachala Institute of Technology, Puttur.

P Bharat Kumar is Lecturer in Department of Electrical and Electronics Engineering, JNTUA College of Engineering, Anantapur. His areas of interests are Control Systems.

Prof K S R Anjaneyulu is professor in Department of Electrical and Electronics Engineering, JNTUA College of Engineering, Anantapur. He has 32 years of teaching experience in JNTUACEA. His areas of interests are Electrical Power Systems and Control Systems.