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E-bike With Sustainable Energy Recovery System

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Abstract **- An electric bicycle, also known as an e-bike, is a bicycle with an integrated electric motor used to assist propulsion. Many kinds of e-bikes are available worldwide, but they generally fall into two broad categories: bikes that assist the rider's pedal-power and bikes that add a throttle, integrating moped-style functionality. As per our research, we found out that the e-bike manufacturers in India do not provide the feature of energy recovery in the cycles. In this research, we have tried to modify the e-bike into having an energy recovery feature with the help of hub motors, batteries and the related circuitry. The Hub motor is placed on the rear axle and the battery with its related circuitry is encased in the frame of the cycle. With the help of the Matlab simulation, we have tried to find the peak voltage delivered by the BLDC hub motor. We have also used a supercapacitor that will help reduce the load on the batteries and in turn increase the battery life. The supercapacitor will drain first when the motor starts from a rest position and then the power will be supplied by the battery. The simulation results are satisfactory with the motor generating 36V peak-peak which is enough to charge the batteries.**

Keywords **- E-bikes, energy recovery, BLDC motor, supercapacitor, sustainability, electric vehicles**

I. INTRODUCTION

E-bikes use rechargeable batteries and typically travel up to 25 to 32 km/h (16 to 20 mph). Most of the e-bikes available today need to be charged from an external source for them to be used in pedal-assist mode or motor-driven mode. There are not enough charging stations available for the bikes to get charged. A solution for this was to replace the drained out battery with charged ones that can be kept with the rider or made available at a particular charging spot. The drained out battery will then be charged and kept for use by another rider. But this also has some practical difficulties.

Our research is on implementing the feature of energy recovery in these e-bikes. The energy required for the electric bike to work can be generated by the electric bike itself. It makes use of a motor that can also function as a generator. The electric energy generated is stored in the battery, which is then consumed when the E-bike requires a pedal-assist or motor drive. It also has a supercapacitor that gets charged first before the battery starts charging. This supercapacitor will help in providing the initial high voltage for the motor to start. This reduces the load on the battery and increases the number of cycles.

In this research paper, we will use simulation to find out the peak voltage generated by the motor. The general battery specification for the e-bikes is 30-36V. If we can generate this voltage using the motor, then we can charge the batteries and use them to run the motor.

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II. BRIEF DESCRIPTION OF THE PROJECT

A lot of research has been done in the field of Regenerative Braking. This can be achieved using a Mechanical system or an Electric system. In the Mechanical system, a free-spinning flywheel is used to store the energy while riding and this energy from the flywheel is used for pedal-assisted working of the cycle. In the Electrical system, this is performed with the help of motors and batteries, to store the energy.

The E-Bikes discussed in this project has a Regenerative Braking System which helps the E-Bike to create the energy required for its functioning on its own. This is achieved with the help of a Brushless DC (BLDC) motor, a Supercapacitor, batteries and its associated circuitry.

The energy that is spent for riding the E-Bike, will be converted into electrical energy and stored in the Supercapacitor and the batteries. This stored electric energy can be used to run the motor that is attached to the rear wheel and make it self-driven. This process is achieved in two ways:

1. Electrical energy is generated due to the BLDC motor and this generated electrical energy is stored in the Supercapacitor and the battery with the help of converters.
2. The Electrical energy that is stored in the Supercapacitor and the battery is consumed by the BLDC motor to assist in pedaling by providing a boost of power or a complete motor drive.

III. PROPOSED SOLUTION

1. Hardware Modification

The design of the proposed setup for Regenerative Braking will be explained in this section. The basic layout of the design will include the BLDC motor attached to the Rear hub axle, the Battery pack attached to the frame of the cycle, a converter circuit with the Supercapacitor and batteries encased and attached to the bicycle and the Switch mechanism attached to the brake handles.

1.1 Rear Wheel Motor attachments

The BLDC motor has to be secured to a rigid location on the body of the cycle and at the same time, it has to rotate in sync with the wheel. So we have attached the BLDC motor on the axle of the rear wheel. The gear connected to the cycle's chain is attached to the shaft of the BLDC motor. When the rider pedals the cycle, the drive is passed through the chain to the gear that is attached to the BLDC motor. This ensures that the Wheel and BLDC motor are always in sync.

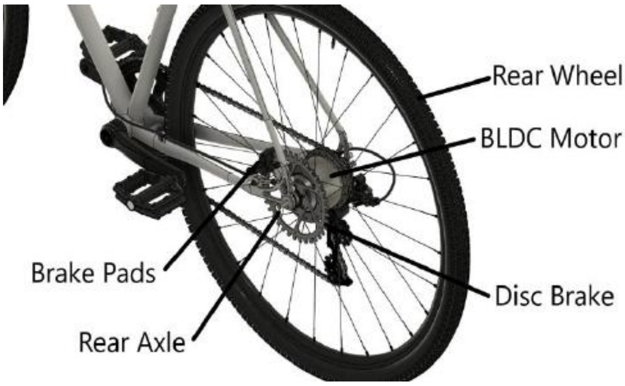

Fig.1. CAD model of the rear wheel

1.2 Battery Pack

The Battery pack refers to the pack of cells connected together in series connection, parallel connection or in combined series and parallel connection. Lead-acid and gel batteries are not used as energy storage due to their significant weight and dimensions. The Nickel-Cadmium cells have very low capacity and low continuous discharging current for this kind of application. For the project, it requires a large capacity, high discharge current and high operating temperature which can be obtained from the Lithium-ion and Lithium-polymer cells. In this project, we are using lithium-ion cells as it is cost-effective compared to lithium-polymer cells. The parameters of a single cell are given below -

Table I: Battery Parameters

PARAMETER	**VALUE**
Nominal Capacity	2500 mAh
Maximum voltage	4.2 V
Nominal voltage	3.6 V
Minimum voltage	2.0 V
Charging voltage	4.2 V
Maximum charging voltage	4.25 V
Charging current	2.5 A
Maximum charging current	4.0 A
Maximum continuous discharging current	10 A
Safe discharging current	10 A
Weight	44.3 g
Charging Temperature	0 --- 45 ℃
Discharge Temperature	-20 --- 60 ℃

Fig.2. CAD model of the Battery Casing

1.3 Switch Mechanism

The Auto-switch is a push-button, which is part of the Electronic control circuit. When the push button is pressed, it completes the Electronic control circuit and the electric charge gets converted from DC to AC and passed to the BLDC motor. When the Auto-switch is not activated, the electric charge developed in the BLDC motor is stored in the Supercapacitor and then in the battery.

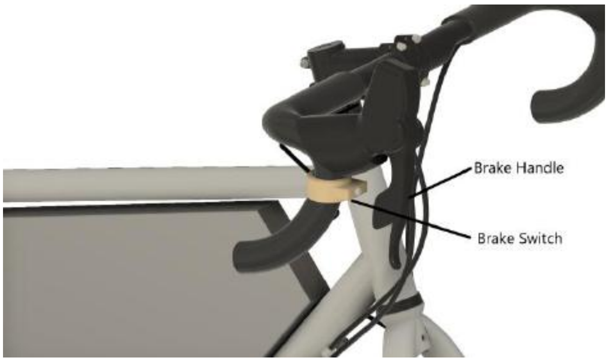

Fig.3. CAD model of the Auto-switch

2. Electronics

***2.1 BLDC motor* -** Permanent magnet brushless DC motors are controlled using a polyphase semiconductor bridge network. BLDC motors are a type of synchronous motor i.e. the magnetic field generated by the stator and the magnetic field generated by the rotor rotates at the same speed. BLDC motors do not experience the 'slip' that normally occurs in induction motors, here we will assume that

1) The motor is not saturated

2) Stator resistance for all winding is constant

3)Power semiconductor devices for motor control are ideal

4) Self and mutual induction of stator coil is constant

5) Iron loss is negligible.

2.2 Electronic control circuit - The electronic control unit consists of the battery management system, BLDC drive unit, battery current control, switching circuitry.

Battery management system - A battery management system (BMS) is an electronic system that manages a rechargeable battery (cell or battery pack), such as by protecting the battery from operating outside its safe operating area, monitoring its state, calculating secondary data, reporting that data, controlling its environment, authenticating it and/or balancing it.

2.3 Supercapacitor - A battery (SC), also called an ultracapacitor, is a high-capacity capacitor with a capacitance value much higher than other capacitors, but with lower voltage limits, that bridges the gap between electrolytic capacitors and rechargeable batteries. It typically stores 10 to 100 times more energy per unit volume or mass than electrolytic capacitors, can accept and deliver charge much faster than batteries, and tolerates many more charge and discharge cycles than rechargeable batteries.

IV. CALCULATIONS

1. BLDC motor considered

For the following project, we have considered a BLDC hub motor with the following specification -

Fig.4. E-bike hub motor

Rated Voltage: 36V

Rated Current: 8A

Rated Speed: 328 rpm

Rated Power: 240W

No-load current: 0.75A

Rated Torque: 6N

Weight: 2.28kg

1.1 Torque power relation

The torque and the power can be given by the following equation

$$T_e = \frac{e_a.i_a + e_b.i_b + e_c.i_c}{\omega_m} \quad (1)$$

Where,

Te = Torque

e_a ,e_b , e_c = back emf components

i_a,i_b, i_c = current through the winding

Then, $(e_a.i_a + e_b.i_b + e_c.i_c)$ is the electrical power which is converted to mechanical power there for let

$$P_e = \sum_{all\ winding} e_{winding}.i_{winding}$$

(2)

Therefore

$$T_e = \frac{P_e}{\omega_m}$$

(3)

The equation of the power can be written as

$$P_e = T_e.\omega_m$$

(4)

From the above equation, it is clear that the power generated by BLDC is directly proportional to the torque and the angular velocity of the motor.

1.2 BLDC generator Modeling

With the above assumption, the phase back-emf equation of the BLDC motor can be expressed as follows

$$\begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \times \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L_s - M & 0 & 0 \\ 0 & L_s - M & 0 \\ 0 & 0 & L_s - M \end{bmatrix} \times \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

(5)

Where,

e_x = phase back - EMF voltage

v_x = terminal voltage,

i_x = phase current,

R_s = phase resistance,

L_s = phase self-inductance,

M = mutual inductance, respectively.

The BLDC motor produces three-phase back-EMFs and has a trapezoidal shape, as shown in the figure

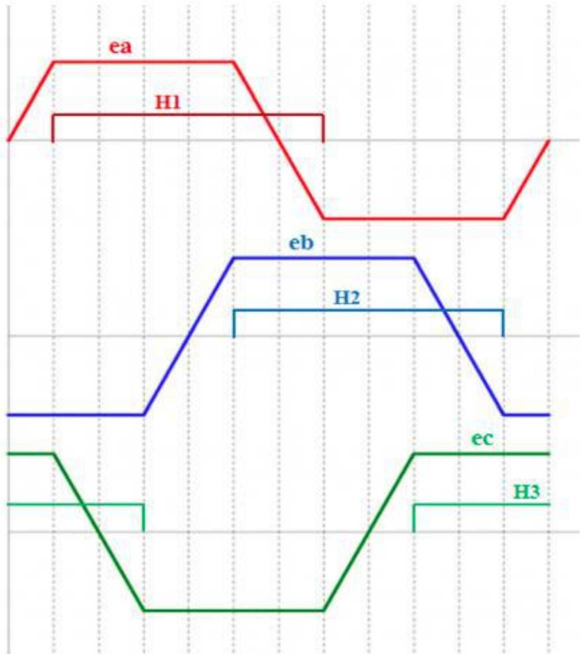

Fig.5. Trapezoidal back-EMF

The phase current shape of the BLDC generator depends on the power conversion connected to the motor and employed rectification strategy.

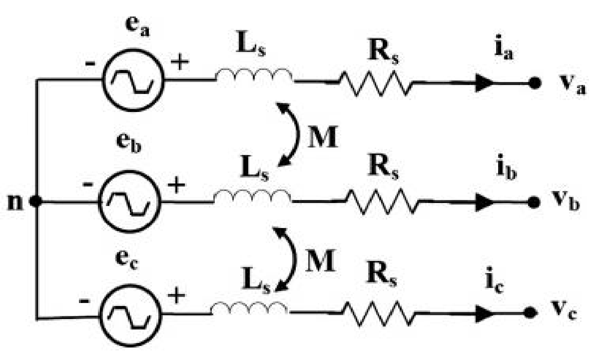

Fig.6. BLDC Equivalent circuit

The air gap power is composed of three components:

1) output power

$$P_{airgap} = \frac{3}{T}\int_0^T e_a(t).i_a(t)dt$$

(6)

2) Stator copper loss

$$P_{loss} = 3R_s.i_{a,rms}^2 \quad (7)$$

3) Stator inductance loss, this part is zero

Because the copper losses are a constant value in certain RMS current and the average power of the inductive component is null, so for optimal utilization of output power maximization strategy can be used on-air gap power components.

$$\begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} = k_e.\omega_m.\begin{bmatrix} F(\Theta_e) \\ F(\Theta_e - \frac{2\pi}{3}) \\ F(\Theta_e + \frac{2\pi}{3}) \end{bmatrix}$$

(8)

Where e_a, e_b, $e_c$are back emf for each winding, $K_e$is the back emf constant and $F(\theta_e)$ is a function representing the trapezoidal waveform and $\theta_e$is the rotor position.

The back-EMF voltage of the BLDC motor in generator action is trapezoidal and to maximize the air gap power, a trapezoidal phase current waveform should be injected. To maximize the power for the Permanent Magnet Synchronous Generator, a sinusoidal voltage is induced in the stator winding. We will be using the same technique to maximize the output power in this situation. Therefore, the reference current waveform generator is used for comparison.

The trapezoidal shape phase currents are produced by BLDC motors using the hysteresis controllers. Since the voltage and current have identical shapes, all harmonic components involve producing the power.

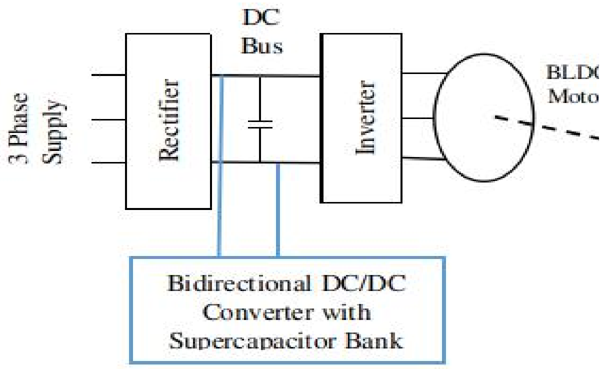

Fig.7. Block Diagram for the regenerative braking system

V. RESULTS

For the simulation purpose, we have paced the BLDC rotor at contrast angular velocity and measured the output voltage at the terminal. The motor had 3 poles and the three winding with trapezoidal back emf, stator inductance of the motor was kept at 8.5mH and stator resistance of 0.4 Ohms

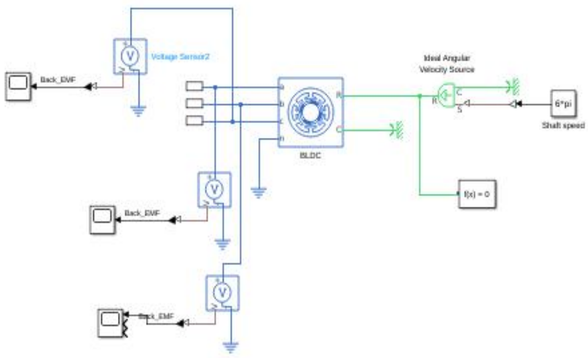

Fig.8. Simulink Simulation BLDC as a generator

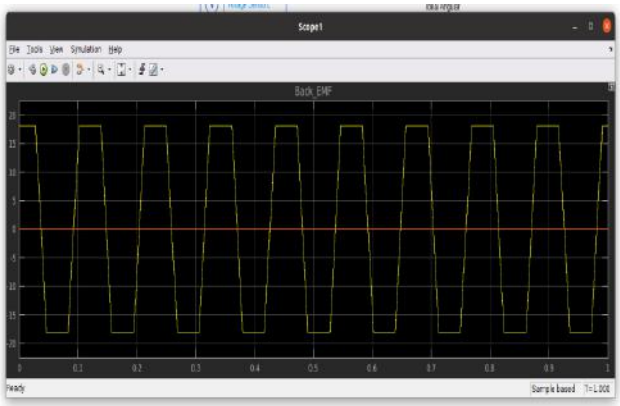

Fig.9. Coil A - Back Emf generated by BLDC in generator action

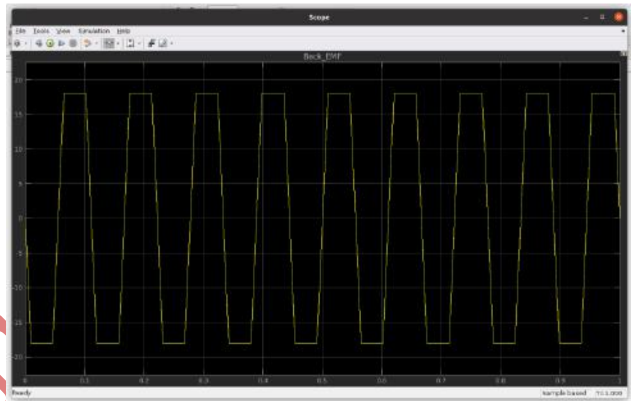

Fig.10. Coil B - Back EMF generator by BLDC in generation action

From the above graph, we can see that during the free-running phase of the BLDC motor acting as the generator, it generates approximately 36 Peak to Peak. By changing the switching sequence, by which the inverter used to drive BLDC will act as a single switch boost converter circuit. The DC-link switches to the supercapacitor bank and the supercapacitor starts charging. After the supercapacitor is charged completely, the DC link switches back to the battery and starts storing the power in the battery.

The efficiency of generated electrical energy is dependent on the combined operation of the electrical machine and the power electronics. If the supercapacitor is fully charged the regenerated energy can be stored in the battery back.

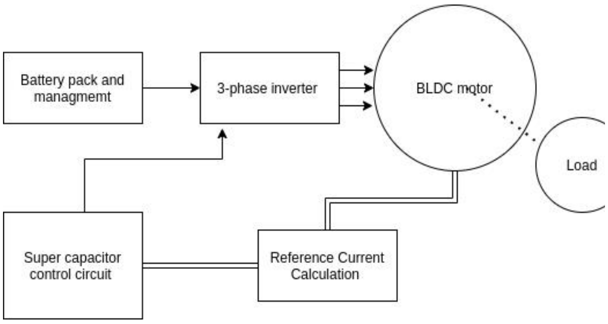

Fig.11. Block diagram for the proposed system

VI. Conclusion

The E-bikes manufactured in India do not include the system required for energy recovery. The reason being, the amount of current generated due to regenerative braking is very low and does not serve the purpose considering the added weight of the additional electronic and mechanical components. Our idea of using a Supercapacitor and battery in the circuit thus helps to provide a solution to this problem. The battery gets charged with the electricity generated in the BLDC motor. But when the motor requires to start, it needs a quick and high initial supply of charge which cannot be provided by the batteries. So we have also added a Supercapacitor that can provide this high initial supply of charge. This will prevent the batteries from getting drained quickly and also reduce the load on them. This will improve the battery life significantly.

Our aim was to generate enough voltage to charge the batteries used. The batteries of the e-bikes available in the market are in the range of 30-36V. From the above simulations, we can see that the BLDC motor generates approximately $36V_{peak\ to\ peak}$ which is required for charging the battery and the Supercapacitor. This validates that the above-explained circuitry and components can be used in the e-bike for energy recovery.

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