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Performance Analysis of Brushless Direct Current Motors and Swappable Lithium Iron Phosphate (LiFePo4) Batteries for Electric Rickshaws

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ABSTRACT:
The advent of fossil-fuel use in vehicles has caused environmental hazards over time and as such a need for environmentally friendly alternatives arose. Harnessing the energy from the sun and converting it to electricity to drive vehicles became the most viable option. The use of this solar-powered technology brought about the need for vehicles that can make use of the energy. One of such vehicles is the Electric Rickshaw (E-Rickshaw) which offers a promising solution for reducing carbon emissions and promoting clean mobility. The goal of this study is to assess the performance analysis of an Electric Rickshaw powered by a Brushless Direct Current (BLDC) motor and swappable Lithium Iron Phosphate (LiFePO4) batteries for the purpose of enhancing the efficiency and range of the vehicle. The study involves the development and simulation of a model of an electric rickshaw, as well as the determination drive cycle for the vehicle.
Keywords: fossil-fuel, new energy vehicle, solar-powered technology, Electric Rickshaws, Performance Analysis, Swappable, Simulation, Drive Cycle.

I. INTRODUCTION

The world is rapidly changing, and so are our transportation needs. As we move towards a more sustainable future, electric vehicles (EVs) are becoming an increasingly popular alternative to traditional gasoline-powered vehicles. EVs are propelled by one or more electric motors that are powered by a battery pack. The battery pack can be charged by plugging the vehicle into an electrical outlet or by using regenerative braking, which converts some of the vehicle's kinetic energy into electrical energy and stores it in the battery pack. EVs offer numerous advantages over traditional vehicles, including lower operating costs, reduced greenhouse gas emissions, and quieter operation.

There are several different types of EVs, including battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and hybrid electric vehicles (HEVs). BEVs are powered solely by electricity and have no internal combustion engine. PHEVs have both an electric motor and an internal combustion engine, and can be charged using an external power source. HEVs also have both an electric motor and an internal combustion engine, but they cannot be charged using an external power source and instead rely on regenerative braking and the internal combustion engine to recharge the battery pack.

The advancement of electric vehicle technology has opened up new avenues for sustainable and efficient transportation solutions. In recent years, electric rickshaws, also known as e-rickshaws, have emerged as a popular mode of transportation in many urban areas, offering an environmentally friendly alternative to conventional fuel-powered vehicles. E-rickshaws contribute to reducing carbon emissions and improving air quality, thereby addressing the challenges of urban pollution and climate change.

The performance and efficiency of an e-rickshaw are greatly impacted by the choice of a suitable motor and battery. Due to their great efficiency, need for little upkeep, and long lifespan, BLDC (Brushless Direct Current) motors are the most popular type of motor used in electric vehicles. LiFePO4 (Lithium Iron Phosphate) batteries are additionally preferred over other battery types because of their high energy density, lengthy cycle life, and excellent thermal stability.

In this project, we aim to analyze the sizing and performance of a BLDC motor and swappable LiFePO4 batteries for an e-rickshaw. The project involves the development and simulation model of an e-rickshaw, as well as the determination of the appropriate drive cycle for the vehicle. This study will provide valuable insights into the design and optimization of e-rickshaws for efficient and sustainable transportation.

II. METHODOLOGY, DESIGN AND IMPLEMENTATION

For the purpose of realizing the objectives of this paper, a series of tasks were carried out. They include:

1. Selection of Rickshaw model:

For the purpose of this project, the rickshaw model chosen was the TVS King Deluxe Rickshaw. The TVS King Deluxe Rickshaw was selected based on its popularity and wide use in the Nigerian market. The rickshaw model is also known for its durability, low maintenance cost, and ease of use.

The TVS King Deluxe Rickshaw has a weight of 347 kg and is designed to accommodate up to 5 passengers, each weighing an average of 80 kg. The rickshaw has a 199.26cc engine with a maximum power output of 6.7 kW (8.98 hp) and a top speed of 60 km/h.

The TVS King Deluxe Rickshaw also has a manual transmission system and a 165 mm ground clearance, making it suitable for the Nigerian terrain. In addition, the rickshaw comes with a telescopic front suspension and hydraulic rear suspension, providing a comfortable ride for passengers.

The selection of the TVS King Deluxe Rickshaw was made with consideration of its compatibility with the BLDC motor and LifePo4 batteries selected for the project. The rickshaw model is suitable for the installation of the BLDC motor and motor controller, and can accommodate the LifePo4 batteries without compromising the structural integrity of the rickshaw.

1. Sizing of BLDC motor and LiFeP04 battery:

To determine the BLDC motor rating required to drive the motor, calculations were made which involved forces that would be acting on the vehicle and the necessary energy to overcome them. The Specifications of the exact vehicle (as stated above) were also incorporated into the calculations so as to get a value for the motor in watts that would be able to move the vehicle.

Also to determine the battery capacity, the motor wattage was used. This aided in determining the Amp hour capacity of the battery (single battery).

1. Data collection and Drive cycle determination:

Drive cycle analysis is the process of measuring the energy and power requirements of a vehicle or a set of vehicles while driving over a predetermined route. The drive cycle is determined and modeled after the Indian Drive Cycle (IDC) for electric rickshaws.

The IDC test cycle includes four driving modes - Low Speed, Medium Speed, High Speed, and Extra High Speed. Each mode has a different speed range and acceleration rate, and the test cycle simulates stop-and-go traffic conditions with various degrees of acceleration and deceleration.

The Indian Drive Cycle (IDC) is a set of driving conditions that simulates the typical driving patterns. It consists of four phases - start, drive, idle, and stop. The drive cycle is repeated until the total distance is covered.

Other values were also taken into account while determining the drive cycle of the rickshaw included:

i. Number of stops the vehicle makes on its route.
ii. Time taken at each stop.
iii. Weight of rickshaw.
iv. Number of passengers.
v. Average weight of passengers.
vi. Battery charging infrastructure.
vii. Average speed of the vehicle.
viii. Total distance per trip.
ix. Number of trips.

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x. Driving conditions:
a. Topography
b. Traffic condition
c. Speed limit
ii. Battery capacity.
iii. Motor Rating.

After the motor, battery and drive cycle have all been accurately determined, the next process is modelling to check the system.

1. Modelling and simulation:

Modelling and simulation of an electric rickshaw is a useful tool in understanding the performance characteristics of the vehicle. In this project, we made use of MATLAB's Simulink software to build a simulation model of the electric rickshaw. The simulation model will include all the necessary components required to drive the vehicle, and we analyzed the simulation results to gain insights into the vehicle's performance

The following is a block diagram of the electric rickshaw model:

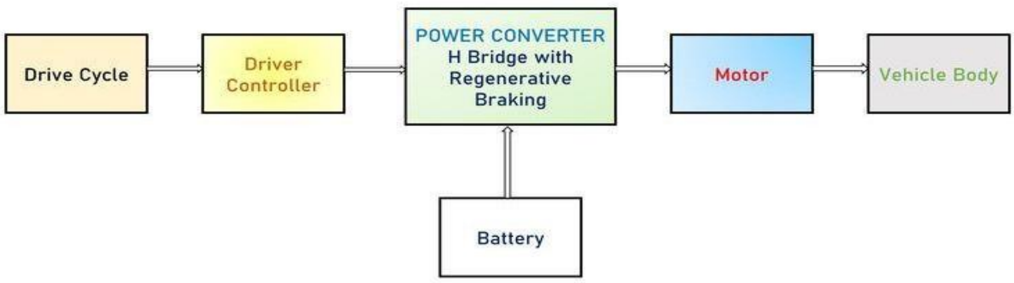

Figure 1. Block Diagram of Electric Rickshaw

As shown in the diagram, the electric rickshaw model consists of several main components:

1. **Battery:** This is the power source for the electric rickshaw. It is modeled as a voltage source with a specified capacity.
2. **Motor Controller:** The motor controller takes input from the accelerator pedal and regulates the amount of power delivered to the motor.
3. **Motor**: The motor is responsible for driving the electric rickshaw. It receives power from the motor controller and converts it into rotational motion.
4. **Vehicle Body:** Vehicle body is simply the frame of the vehicle which includes components such as wheels, chassis, transmission system, axles etc. Simulink readily has a "Vehicle body" block under simscape library where we can feed parameters such as mass of the vehicle, Drag , Pitch etc. The actual vehicle body also includes wheels which is also available in the simscape library as "Tires(Magic Formula)". Other than these components, we can also include simple gear block to simulate the transmission system.
5. **Power Converter:** The brain or processing center of an electric vehicle can be thought of as the power converter. Basically, it is made up of power electronics. It is the one that makes electric vehicle control possible. Because the battery's voltage is a constant DC, if it were applied directly to the motor let's say a BLDC it would always run at a constant speed, making it impossible to change the motor's speed. The power converter, which is made up of inverter or chopper topologies depending on the type of motor used, uses a variety of

methods to manage the motor's speed, including Vector Field manage, PWM, and others, to solve this problem.

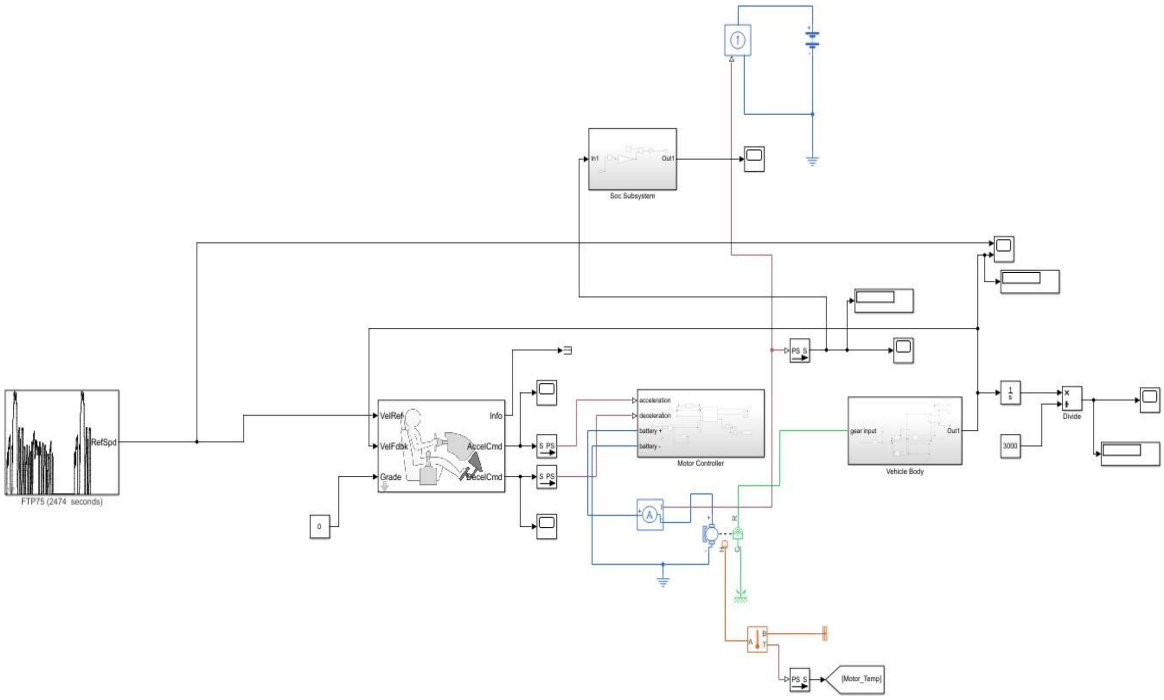

Figure 2. Simulink Model of an Electric Rickshaw.

The rickshaw Simulink model as shown above includes the following subsystems:

1. Vehicle body
2. Motor Controller
3. SOC/Battery subsystem
4. Longitudinal driver
5. The Input (Drive cycle input)

All components within each subsection can be found in the simscape library on MATLAB simulink.

- Vehicle Body Subsystem

The "Vehicle body" block, "Tires (Magic Formula)" blocks, and a "Simple Gear" block are the components of the vehicle body subsystem in Simscape. The axles are connected within the front tire and the rear tire, and the tires are connected to a common hub from the vehicle body. The front and rear tires get the usual forward force and the normal reverse force, respectively. With the aid of physical constants, the wind speed and vehicle inclination are determined. Here, a straightforward gear block represents the vehicle's transmission system.

- Motor Controller Subsystem:

The "Controlled Voltage Source" block, "Controlled PWM Voltage" block, "H-Bridge" block, and a solver configuration make up the motor controller subsystem. The longitudinal driver block provides the acceleration and deceleration commands in this case, and the "Controlled PWM voltage" block generates pulses of varied width that are supplied into the H bridge. The battery is then given a voltage by the H-bridge that matches the pulse. The DC motor's speed is in turn controlled by the battery's changeable voltage. The temperature measuring connection can also be used to monitor the controller's temperature while it is in use.

Note: For the battery to get energy feedback and for the vehicle to operate in accordance with the drive cycle, the regenerative braking option in the H bridge block should always be turned on.

- SOC Subsystem:

The SOC subsystem is employed to obtain the percentage drain in the battery of the simulated vehicle.

- DC Motor:

For simulation purpuses, a DC motor from the simscape library is used (instead of the previously mentioned BLDC motor). As per our calculations, the peak power and torque values are input in the system. Considering this and also the temperature limitations, the parameters of the DC motor are experimented to get the optimum value.

- Longitudinal Driver:

It is a parametric longitudinal speed tracking controller for generating normalized acceleration and braking commands based on reference and feedback velocities. From the simulink model, we could see that the vehicle output speed is fed back and compared with the reference speed (drive cycle) in order to obtain the acceleration command and the deceleration command.

- Battery **:**

The battery is required to power the controller and motor. The controller uses the battery power according to produce the input given by the motor to obtain maximum speed. The battery is also used to power every electrical component in the vehicle.

III. SIMULATION RESULT

The model developed in Figure.2 above was simulated using a preset drive cycle in the simulink drive cycle component. The drive cycle used Is the FTP75 drive cycle which is shown below in graphical form.

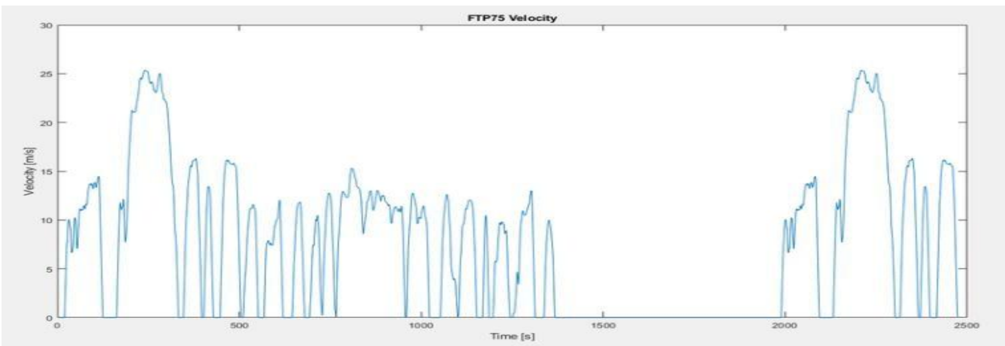

Figure 3. FTP75

The simulation of the model is to yield three outputs:

1. The Rickshaw Speed: The speed the rickshaw would need to move at so as to cover a certain distance in a certain time frame.
2. Motor and Controller temperature: This indicates a gradual increase in temperature of component parts while the vehicle is in use.
3. Battery/SOC: This shows the decline of the battery in percentage while the vehicle is in use. The graphs for all three outputs are shown below.

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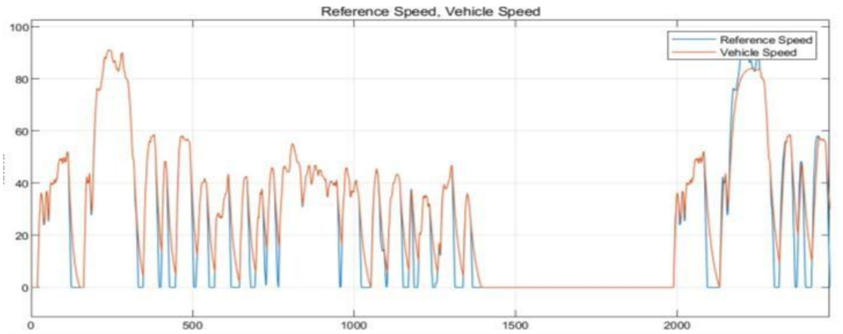

Figure 4, Electric Rickshaw Speed

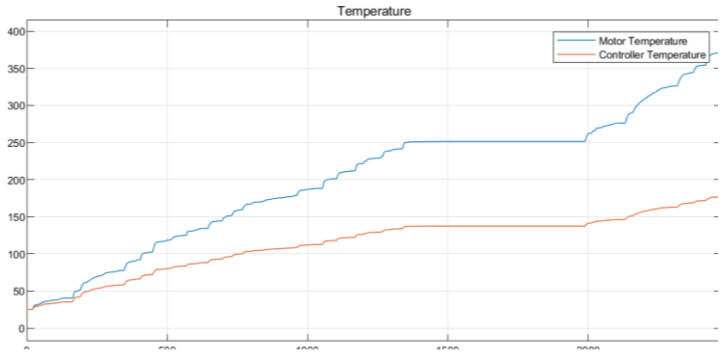

Figure 5. Motor & Controller Temperature

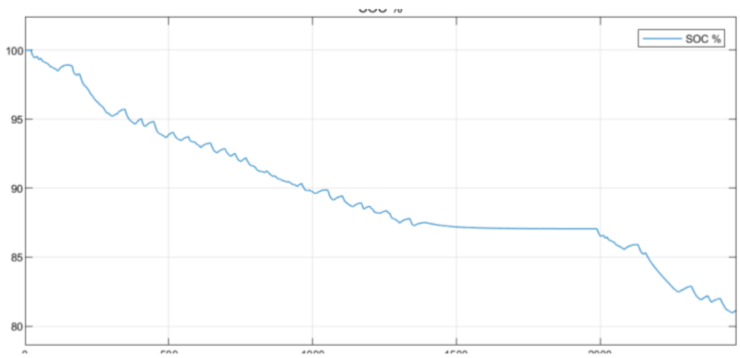

Figure 6. Battery SOC in Percentage

Observation from simulation:

1. The actual path of the speed is approximately followed 90% of reference Drive cycle (i.e. FTP75).
2. The SOC % of the battery is reduced to ≈ 83%.
3. The Temperature of Motor is increased to ≈ 370 C
4. The Temperature of Controller is ≈ 180 C

The simulation results above show changes in temperature, state of charge (SOC) and speed based on the drive cycle data input. More accurate and practical results can be obtained by giving more accurate parameters. Additionally, it's possible that the simulation's use of a DC motor differs from the motor's actual characteristics. This explains why the motor temps were a little higher than anticipated. In the real-time application, air cooling is used to regulate the temperature of the motor, battery, and controller. As a result, the temperature of these components does not rise as much.

IV. CONCLUSION

In this paper, the performance analysis of BLDC motors and swappable LiFePO4 batteries for Electric Rickshaws was presented. Based on the analysis, it is seen that the combination of both components for use in Electric Rickshaws yields optimal results. They offer the best performance, reliability, long life span among a host of other advantages. The use of the BLDC Motors and swappable LiFePO4 batteries in Electric Rickshaws is a promising way to reduce pollution and improve the environment. Further research into this area to will aid in optimizing the existing system and as such make better models which will in turn help secure safer and more affordable options of transportation.

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