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Simulation-Based Framework Analysis of Electric Vehicle System and Retrofitting of Electric Motorcycle

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Abstract: *The simulation-based analysis of a brushless DC (BLDC) motor system for electric vehicle applications is presented in this paper. With MATLAB Simulink and Simscape Electrical as models, the paper focuses more on software and design elements. A 72V battery pack, a three-phase inverter that powers the BLDC motor, and a buck converter for voltage control are all integrated into the system.A cascade control architecture with proportional-integral (PI) controllers regulates speed and voltage, targeting precise operation. Rotor speed analysis. The battery state of charge (SOC) exhibits a non-linear decrease, reflecting voltage-based estimation limitations compared to ideal linear discharge. Power electronics design for the charger is supported by EASYEDA PCB Design software. The study underscores the need for optimized PI tuning and advanced SOC estimation to enhance system reliability*

Keywords: DC (BLDC)

I. INTRODUCTION

Due to a startling increase in the number of vehicles, there is currently excessive pollution, and methods to lower it are being researched. Because of their high pollutant content and quick rate of depletion, conventional fossil fuels like gasoline, diesel, and so on are unreliable. To increase efficiency and reduce emissions in such a scenario, new fuel combustion techniques, a hybrid fuel mix, and upgraded equipment are required. Electric vehicles are among the most important alternatives that have been adopted in this day and age.[1].

Retrofitting electric vehicles (EVs) is becoming a key solution in the shift to environmentally friendly urban transportation. By 2032, the global EV retrofitting market is expected to have grown from its 2023 valuation of USD 65.94 billion to USD 125.37 billion.[2] According to financial analysis, buying a comparable new electric two-wheeler could cost up to INR 1.5 lakh, while retrofitting an ICE two-wheeler could cost between INR 50,000 and INR 1 lakh. Fuel savings from retrofitting can be significant, ranging from INR 50,000 to 60,000 per year for a gasoline two-wheeler. On the other hand, charging an electric two-wheeler would probably cost no more than INR 10,000 per year.[2].

With a particular emphasis on electric two-wheelers (E2Ws), the Indonesian government has been aggressive in developing legislative frameworks and implementing tax incentives to encourage the adoption of EVs. Travel Cost per Km Comparison (in ₹) for the New ICE 2W and the Retrofitted E2W is ₹ 1.66 and 1.245, respectively, according to the data in GGGI's Technical Report on Retrofitting.[2].

The retrofitting of conventional two-wheelers into electric vehicles (EVs) in India is gaining momentum as a pragmatic solution to accelerate decarbonization, supported by diverse regional policies and technological innovation.[3] Retrofitting enables existing vehicles to be exempt from the scrappage policy and extends their useful lives by eight to ten years. [3][4].

In this paper retrofitting of the ICE bike to electric bike is explained and the simulation of the battery and motor using MATLAB also included.

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II. SPECTFICATION CRITERIA

The specification criteria for electric bike retrofitting are foundational to ensuring safety, efficiency, durability, and regulatory compliance. Research underscores that improper component selection can lead to catastrophic failures, such as thermal runaway in batteries or motor overheating in hilly terrains.[5]

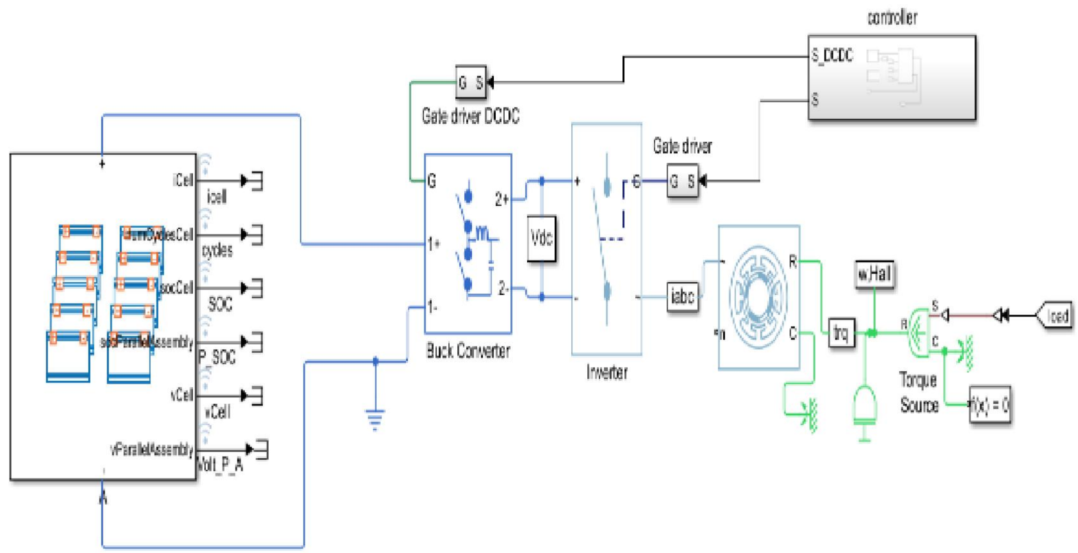

Fig .1 Simplified Electric vehicle simulation

Electric Motor

Electric vehicles are designed using a variety of electric motor types. These motors include three phase AC induction motors, DC series motors, BLDC motors, and Permanent Magnet Synchronous Motors (PMSM) [6][7]. Permanent Magnet Assisted Synchronous Reluctance Motor (PMAssi-SynRM), Synchronous Reluctance Motor (SynRM)[7].

The BLDC motor's efficiency characteristic yields an output of 88.28%. The efficiency of PMSM motors is 92.51%. More ripple is present in SynRM, and the efficiency under running conditions is 87.12%. [7]The overall PMAssi-SynRM characteristic on load yields an efficiency result of 90.20 percent. A PMSM motor achieves maximum efficiency at the same load parameter value by differentiating the performance of each motor. The overall performance of the drive implementation is indicated by the motor's efficiency when operating.

Because power is transferred to the wheels via an external transmission system in in-runner configuration motors, they weigh less than BLDC hub motors. Additionally, manufacturers of low- and medium-performance scooters use BLDC motors for propulsion[6].

Specification of Motor

- Type: BLDC (Brushless DC) Hub Motor.
- Power Rating-2KW, 30Amp,72 volt

Battery

The importance of the battery in the motorcycle design is very crucial. The design consists of choosing the right Battery Chemistry associated with affordability. The

Range of the Vehicle depends on the amount of fuel storage in the fuel tank. In the case of the electric vehicle, the Battery has to store electrical energy and provide it as the vehicle demands it. Therefore, the design of the battery and selection of the cells are very important[8][9].

Specifications of Battery

- Type of cell: $LiFePO_4$ Lithium Fherro phosphate
- Capacity: 2.1 Kwh,30 Amphr,72 Volt

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III. SIMULATION

Motor simulation

The simulation starts with a speed reference from the RPMReq subsystem, discretized by a Zero-Order Hold (ZOH). The speed error, calculated by comparing the reference and measured speed, is processed by the Speed Controller[10]. This signal, along with a voltage reference, feeds into the Voltage Controller, which adjusts the voltage error. A PWM block generates signals for the S_DCDC subsystem, a DC-DC converter, adjusting the voltage to the Commutation subsystem.[10] This subsystem, using hall sensor inputs, drives the motor, with measured speed and voltage fed back to close the loops.

The ideal rotor speed for BLDC motors is typically the rated speed, optimized for efficiency and longevity, with application-specific adjustments for high-speed or low-speed operation.[11] The ideal back EMF depends on the motor's design, with sinusoidal back EMF preferred for smooth torque and low ripple in advanced applications, while trapezoidal back EMF is common for simpler, cost-effective systems[12].

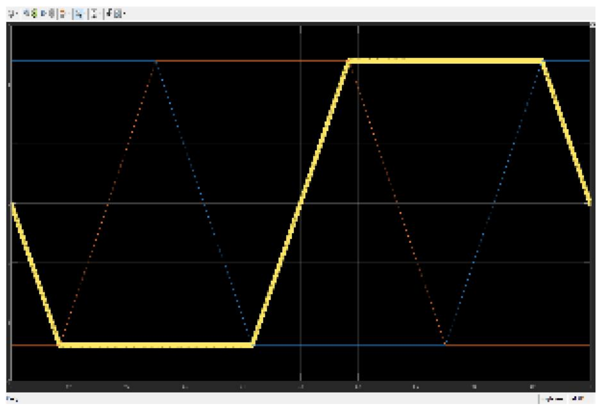

Fig 2: BLDC Back emf simulation

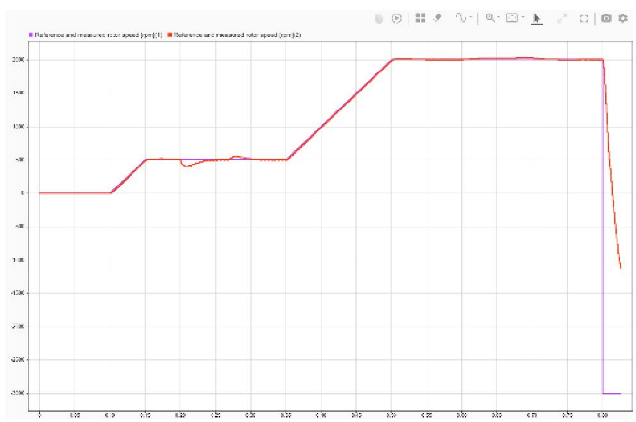

Fig 3: BLDC rotor speed

The rotor speed waveform shows good overall performance, with smooth ramp-up and ramp-down phases and a relatively stable plateau, but deviates from the ideal BLDC motor rotor speed waveform in terms of minor ripples and a small steady-state error during steady-state operation. These deviations are typical in real-world systems and are likely due to torque ripples from commutation, control system limitations, and friction or load effects. From a technical perspective, while the current performance is suitable for general applications, optimization through better control

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tuning, advanced algorithms like FOC, and improved motor design could align it closer to the ideal, particularly for high-precision applications[13].

2. Battery Simulation

The cell is modelled using an equivalent circuit with a voltage source, resistance, and dynamic elements, all adjustable based on charge and temperature. This ensures the pack's design reflects real-world performance, including heat transfer and safety under various conditions [14]. The modelling approach in Battery Builder emphasizes the equivalent circuit model, where the cell's electrical behaviour is represented by:

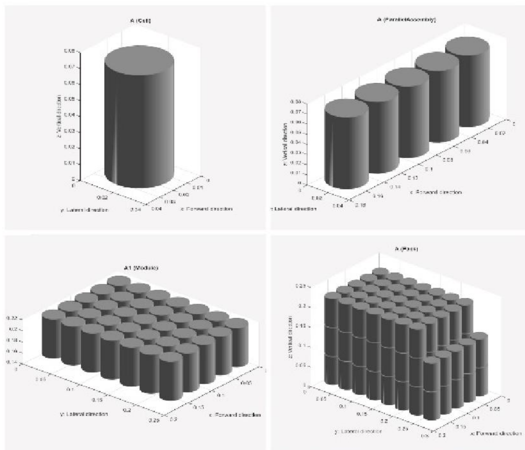

Fig 4: MATLAB Battery pack design

A voltage source for OCV, tabulated as a function of SOC and temperature, capturing the nonlinear voltage-SOC relationship[14][15].

A series resistance model for ohmic losses, which affects efficiency and heat generation[14].

One or more RC pairs to model the dynamic response, such as charge transfer and diffusion effects, with time constants determined by the battery chemistry[14].

The generated Simscape model can be thermally coupled with blocks from the Thermal Management System library, enabling simulations of cooling efficiency and cell-to-cell temperature variations, essential for designing safe and efficient battery systems.

Fig 5: Battery SOC waveform

The given SOC waveform shows a non-linear decrease, typical for real-world battery systems where SOC is estimated from voltage, which has a non-linear relationship with true SOC. An ideal SOC waveform for a 72V 30Ah battery under constant current discharge (e.g., 30A) should be a straight line, decreasing linearly from 100% to 0% over 1 hour. The discrepancy stems from voltage-based SOC estimation [14][15]

Advanced battery models in MATLAB can incorporate degradation effects over time, such as capacity fade and

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Fig 6: PCB Design 2D and 3D view

increased internal resistance due to aging. This capability is crucial when designing battery management systems (BMS) that must ensure reliability and longevity[16].

TABLE 1: Steps to design a battery pack

OBJECT TYPE	ELECTRICAL PARAMETERS	THERMAL MODELING	IMPACT ON PACK DESIGN
Cell	OCV vs. SOC, internal resistance, RC pairs	Thermal ports, heat generation, temperature dependence	Basis for capacity and voltage
Parallel Assembly	Number of parallel cells, total capacity	Inherits cell thermal properties	Increases current handling, maintains voltage
Module	Number of series assemblies, total voltage	Inter-assembly gaps, thermal paths	Boosts voltage, affects heat distribution
Module Assembly	Number of modules, inter-module gaps	Thermal interactions between modules	Scales up for larger systems
Pack	Overall configuration, cooling plate placement	Ambient and coolant thermal paths, cooling blocks	Final system, critical for thermal management

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IV. PCB DESIGNING

TABLE 2 Steps to design PCB

STEP	ACTION	CONSIDERATIONS
Choose Mode	Select Online/Desktop	Online: internet; Desktop: complex OK
New Project	Create schematic	Organize for large designs
Place Components	Add from library, verify	Check datasheets, ratings
Join Components	Wire, label nets	Consistent naming, hierarchy
Convert to PCB	Generate netlist	Verify connectivity
PCB Layout	Place, route, set layers	Trace width, impedance, ground planes
DRC	Run DRC, fix errors	Meet manufacturer specs
Gerber Files	Export for fabrication	Include all layers, verify
BOM	List components	Include values, footprints
Order PCB	Use EASYEDA or upload	Check manufacturer requirements

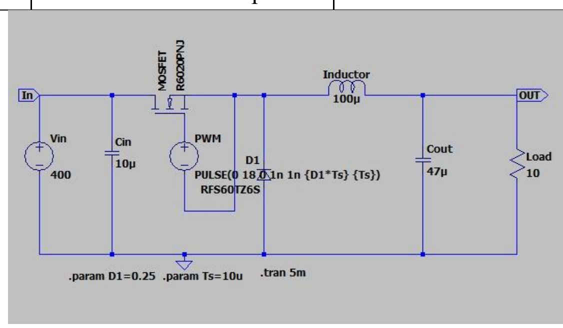

Fig 7 schematic of intermediate buck converter

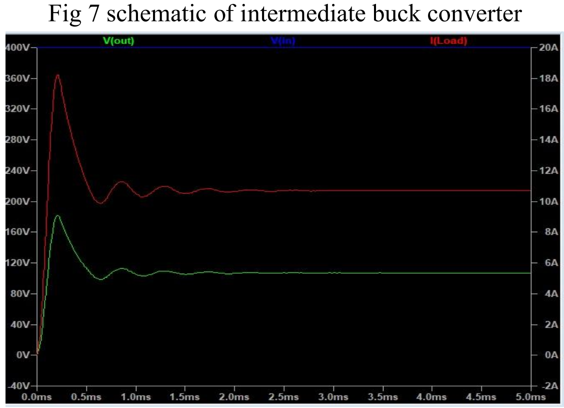

Fig 8: Simulation Result Of intermediate Buck converter

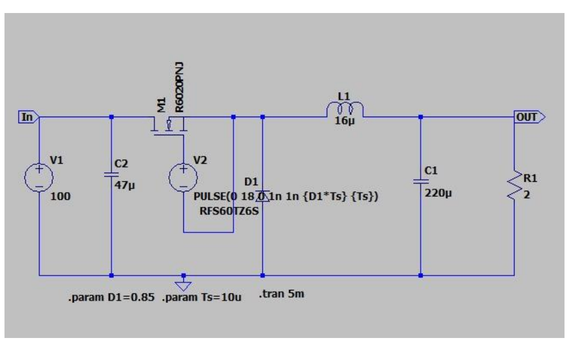

Fig 9: Schematic of charging stage buck converter

Fig 10: Simulation Result of Charging stage Buck converter

The buck converter circuit is a standard design for stepping down voltage, with components including an input voltage source, MOSFET, inductor, diode, output capacitor, and load resistor.[17] The simulation waveforms confirm its operation, showing the expected switching behaviour and stable output with minimal ripple[17][18] Fig.7 shows the LTspice schematic of intermediate buck converter of 400V to 100V and the result of the simulation of an intermediate 400V to 100V buck conve rter are shown in fig.8. Buck converter showing stable 100V output voltage with <1% ripple. Fig.9 shows the LTspice schematic of charging stage buck converter of 100V to 48V and the simulation Result of Charging stage 100V to 84V Buck converter is shown in fig.10 the result shows stable 84V output voltage with <1% ripple.

V DESIGN CONCEPT AND RETROFITTING

Designing an electric bike that could go 100 kilometres on a single battery charge was the main goal. The TVS Victor, a fuel-powered motorcycle, served as the model for the basic design. An electric motor and batteries were installed in place of the motorcycle's motor transmission, combustion engine system, fuel tank, and exhaust system. [19] The TVS Victor motorcycle is seen in Fig. 11 prior to the fuel engine and other components being removed. The bike is shown in Fig. 12 after the controller, motor, and battery have been mounted. To improve the bike's balancing system, a BLDC hub motor is mounted on the back wheel, and the battery is positioned where the engine would be on an ICE bike. Because the majority of the connections to the mechanical part are no longer in use and because an open connection could result in a short circuit, the original wiring is removed. The meter, brake lamp, horn, signal lamp, tail lamp, and headlamp are all kept in their original positions. After retrofitting, the entire motorcycle is displayed in Fig 13.[20][21]

Fig 11: TVS Victor before retrofitting

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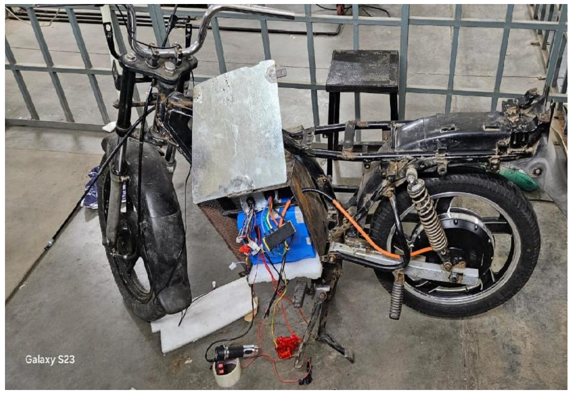

Fig 12: Arrangement of Battery, Motor and controller

Fig 13: Complete retrofit motorbike

VI. CONCLUSION

This study successfully simulated a 2kw Brushless DC (BLDC) hub motor system for electric vehicle applications using MATLAB Simulink and Simscape Electrical, integrating a 72V battery pack, a buck converter for voltage regulation, and a three-phase inverter. Controlled by a cascade PI architecture, the system achieved precise speed and voltage regulation, though rotor speed analysis revealed minor oscillations indicating commutation inaccuracies. The battery's state of charge (SOC) exhibited a non-linear decrease, highlighting limitations in voltage-based estimation compared to ideal linear models. EASYEDA facilitated the charger's power electronics design, ensuring manufacturability. These findings underscore the need for optimized control strategies, such as field-oriented control, and advanced SOC estimation techniques to enhance system reliability and efficiency. Future research should explore these advancements to further improve BLDC motor systems for electric vehicles.

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