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Simulated and Experimental Analysis of Different Batteries for Light Weight Electric Vehicle

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Abstract: *The increasing demand of efficient solution for automobile sector due to rise in petroleum prices, its harmful effects on environment, The Electric mobility contributing to greater extent to balance the energy and power demands, energy storage units as well as environment safety. Electric vehicle has major efficient features of zero combustion, longer charging and discharging cycle which plays a vital role to replace the ongoing increase in price of petroleum fuels and its harmful effect son environment with their degrading store. Many non-conventional energy sources like solar, tidal, wind etc. Can be used to generate energy and store it in suitable types of batteries to run these vehicles. The Different types of batteries like lead acid, lithium ion, nickel bromide is used as an energy storage device for these electric vehicles. But with many advantages these batteries have some structural and thermal issues if not designed or connected properly. These issues are capacity loss, cell balancing, thermal runaway, reduction in battery life etc. Therefore, much focus needs to give on proper battery connections, selection of battery for specific application considering its working parameters. Possible types of connections for batteries are active, passive and semi active as per their connections in series and parallel type. For series combinations apposite terminals of batteries are connected to each other, in which current remains constant and battery voltage is summed up to increase for maintaining the same capacity or ampere hour (Ah) rating of batteries. Whereas in parallel connections same terminals of the batteries are connected to each other in which voltage remained constant and battery current is summed up to rise. This is needed when we need to double the battery capacity or ampere hours (Ah) rating according to your system needs while maintain the same level of voltages. The present work focused on Virtual modelling and design optimization of electric vehicle selecting suitable load (BLDC motor) using simulation in MATLAB/ Simulink with different types of batteries to know the variation of battery parameters like SOC, current, temperature and voltage etc. as per time, evaluating the displacement covered and velocity. Then its validation through experimental set up by analyzing the battery behavior of light weight vehicle.*

Keywords: Self Charging Electric Cycle, Simulink, Paddling, Lithium-ion Batteries, Lead Acid Batteries, etc.

I. INTRODUCTION

Problem Definition

- Many batteries are used in electric vehicle application but selection of it on basis of road conditions and suitable application is major task considering its working parameters like SOC, current and voltage. More importantly its cost and life cycle. This project mainly focuses on comparative experimental and simulated analysis of various batteries considering suitable light weight vehicle (most probably e-cycle)
- Mechanical energy can be converted into electrical energy by means of paddling of cycle and storing the

energy in suitable storage unit and further it will be used for basic operations like mobile charging, lighting the headlight or in certain case running e-cycle using stored electrical energy for a short distance. This will help in two ways, first for exercise of the person while paddling and second the converted energy which may be lost to environment will be used to charge the battery which will be helpful to run the bicycle for a short distance travelling.

- To reduce the stresses on battery and in order to increase in life of it second energy storage system in terms of battery or any other device is proposed here.

Objective

- To Evaluate of work done earlier through related literatures and research work to finalize the proposed idea for light electric vehicle.
- To Evaluate of energy conversion mechanism parameters and applied components to get maximum energy to be stored for battery charging through paddling of bicycle.
- To Design of proposed set up using MATLAB / Simulink to simulate the results of battery performance.
- Comparative analysis of different battery types using the same Simulink circuit for finalizing the effective types of battery to be useful for the proposed work.
- Experimental analysis on suitable EV set up to validate the simulated results.

Scope

- The designed bicycle can be used to travel certain number of short distances and due to its optimized weight, it would be easy to carry the bicycle from one location to other location. Also, the comparison of both the batteries would give the difference in costs and working of the bicycle with the use of respective battery. It would be a good mode of transport for shorter distances as it would save excessive use of fossil fuels used which will help in conserving our environment.

Methodology

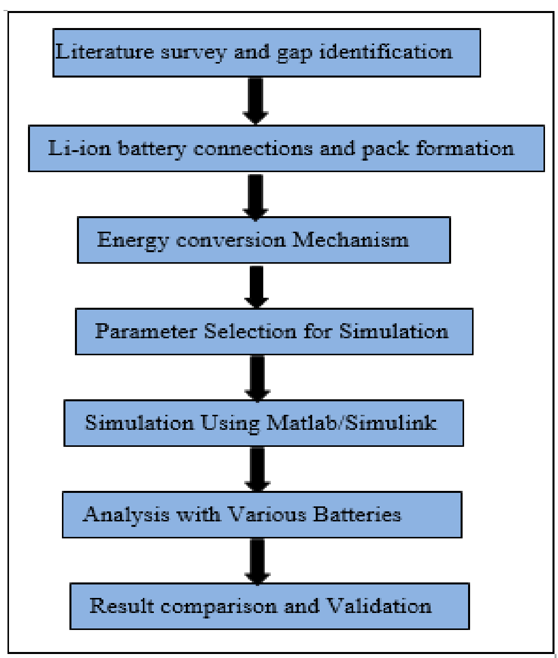

Figure 1: Summarized Literature survey

II. LITERATURE SURVEY

Table 1: Summary of Literatures

Sr	Name of Author and year of publication	Work Done	Future Scope
1	Hampus Ekblad, et.al. 2016	literature of how different parameters are associated with bicycle planning	Evolution in implemented factors for Bicycle design
2	Gicky Jose,et.al. 2015	Design and Development in bicycle	Adjustment of gears as per trials and increase in safety of rider
3	Akshay N. hakole, et.al. 2019	Generation of electricity using Dynamo	Use of Renewable sources for electricity generation
4	Rajesh Kannan, et.al. 2012	Generation of power with the help of bicycle paddling	Alternate resource for nonrenewable source of energy
5	Chien-Cheng et.al. 2017	Development And optimization of frames of bicycles	Points to decrease the self- No weight of vehicle and implement in transportation
6	Rupesh H. et.al., 2019	Development in fabrication for E-Bicycle	Implementation in bicycle using electric as well as solar energy
7	TinaNielsen et.al. 2020	Recreation conflict focused on emerging E-Bike technology	Restrictions, limits and regulation for sustainability of E- Bike trials
8	Hardik Keshan, et.al. 2016	Comparison of Lithium- ion and Lead-Acid batteries	Helpful for classification and selection of batteries for various purposes such as E-vehicles
9	C Iclodean1, et.al. 2017	Comparison of various batteries for E-Bicycle	Comparison of Lithium-ion and Lead-Acid batteries and studying its advantages for future use
10	S Manish Yadav, et.al. 2018	Importance of human powers and alternative energy source is investigated	Replacement to non-renewable energy resources
11	MD. Rezwanul Kabir, et.al. 2011	Pedal powered generator used for power generation	Modification in vehicle design for smooth working of vehicle
12	B.Sneha, et. al. 2015	Easy way of generating power at small levels	Use of Renewable sources for electricity generation
13	M. Jawahar, et.al. 2014	Design and construction of pedal operated water pump	Combination of storage of energy which can increase the machine efficiency
14	Markus Lutz et. al. 2011	Design and development of electric vehicle and its advantages	next work in force in electrical mobility and electrical vehicle
15	Mitesh Dodiya, et.al. 2016	Self-rechargeable electric folding bicycle which can be used of propulsion	The design of folding bicycle can be modified taking self-weight into consideration
16	R.S Jadoun et. al. 2020	Explore the acceleration and speed of electric powered bicycles	Work on increasing the efficiency of the system
17	MD Saquib Gadkari, 2014	Method of generating power by ceiling fan and storage of energy in battery	The combination can be used in other applications

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III. STRUCTURAL ANALYSIS OF THE PROPOSED SYSTEM

Figure 2: Possible configurations for electric vehicle design

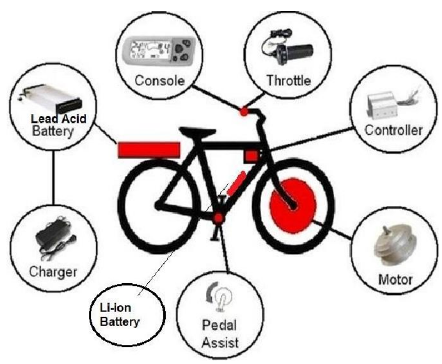

Figure 3: Structural Configuration for the proposed set up

Calculation for the real range of your e-bike:

Volts x Amp-Hours = Watt-Hours (20 Watt-Hours = 1 mile of travel) 36 V x 10 Ah=360 WH x ((1 mile)/ (20 WH)) =18 mile range

Overall cost to charge = Electricity Cost (5.36□/kWh) x Battery Size (kWh)

□5.36/kWh x 0.5 kWh battery=□2.68per charge

Structural Configuration for the proposed set up

Table 2: The comparisons of the different DC Motors available.

Types	Advantages	Disadvantages	Applications	Drives
Stepper DC	Precision positioning Stepper DC High holding torque	Slow speed Requires a controller	Positioning in printers and floppy drives	Multiphase DC
Brushless DC electric motor	Long lifespan Low maintenance High efficiency	High initial cost Requires a controller	Hard drives CD/DVD players Electric vehicles	Multiphase DC
Brushed DC electric motor	Low initial cost Simple speed control	High maintenance (brushes) Limited lifespan	Treadmill exercisers Automotive starters Toys	Direct (PWM)

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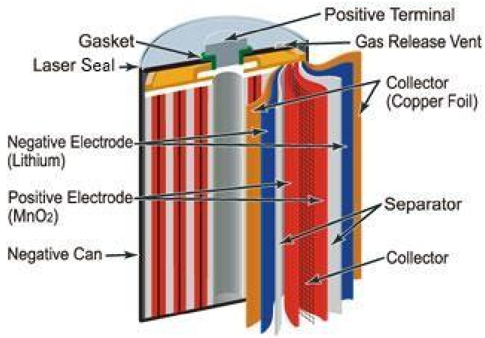


Figure 4: Structure Lithium Ion Battery

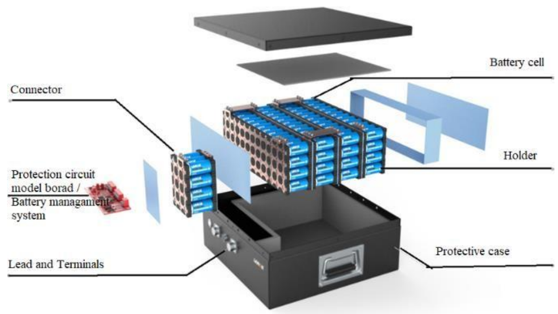
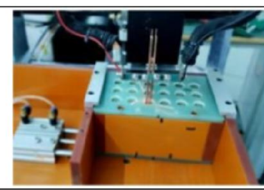
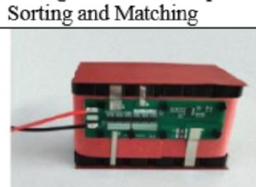
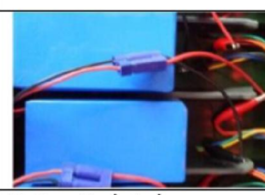
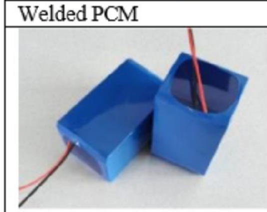
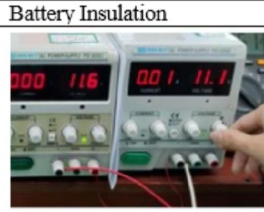
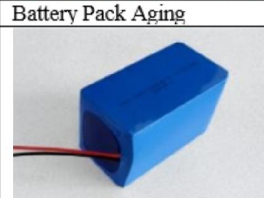


Figure 5: Structural configuration of Lithium-ion battery pack

Table 3: Steps involved in li-ion battery pack formation

		
Cell Capacity Grading	Voltage Internal Impedance Sorting and Matching	Cell Spot Welding
		
Welded PCM	Battery Insulation	Battery Pack Aging
		
PVC Shrink Film	Finished Product Performance Test	Battery Code-spurting

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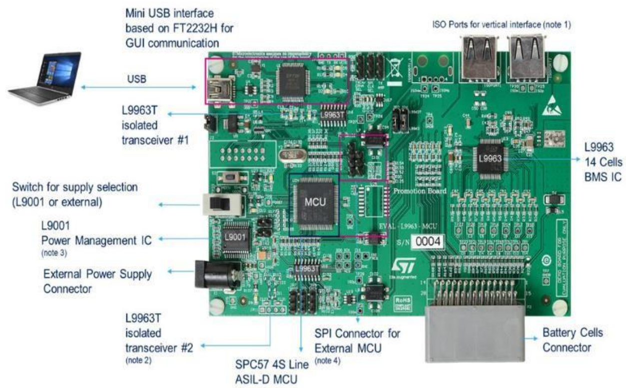

Figure 6: Battery management system

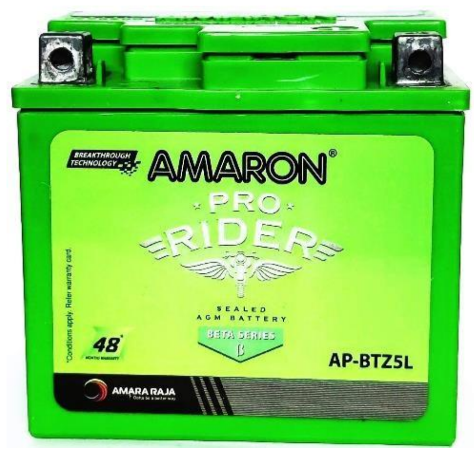

Figure 7: Lead acid battery of 12 V 24 A

Table 4: Battery types and its selection

Battery Type	Advantages	Disadvantages
Lead-Acid (sealed)	• Inexpensive and simple to manufacture • Mature, reliable and well-known technology • Low self-discharge—the self-discharge rate is among the lowest in rechargeable batteries. • Capable of high discharge rates. • Low self-discharge—the self-discharge rate is among the lowest in rechargeable batteries. • Capable of high discharge rates.	• Not to be stored in a discharged condition • Low energy density—poor weight-to energy density • Environmentally unfriendly • The electrolyte and the lead Content can cause environmental damage.
Lithium-Ion	• Highest energy density to weight ratio • Eliminates need for periodic care for a long life • Has no memory effect • Achieves a better cost-performance ratio for battery packs in series than for single cell • Is arguably better for the environment, from a raw materials viewpoint, to other options. • Li-ion-Cobalt is the most developed Li-ion technology, with flexible shape options	• All lithium-ion technologies require a protection circuit to prevent overheating. • All lithium-ion technologies require a protection circuit to prevent overheating. • Can damage easily by over charge or discharge

NiCD	• Fast and simple charge—even after prolonged storage. • High number of charge and discharge cycles—if properly maintained. • Good load performance—the NiCD allows recharging at low temperatures • Long shelf life in any state-of-charge • Forgiving if abused—the NiCD is one of the most rugged rechargeable batteries. • Economically priced — the NiCD is the lowest cost battery in terms of cost per cycle. • Available in a wide range of sizes and performance options	• Relatively low energy density when compared with newer systems • Memory effect—the NiCD must periodically be exercised to prevent memory • Environmentally unfriendly—the NiCD contains toxic metals • Some countries are limiting the use of the NiCD battery • Has relatively high self-discharge—needs recharging after storage
NiMH	• 30%-40% higher capacity over a standard NiCD. • The NiMH has potential for yet higher energy densities. • Less prone to memory than the NiCD. Periodic exercise cycles are required less often. • Environmentally friendly—contains only mild toxins; profitable for recycling. • NiMH generates more heat during charge and requires a longer charge time than the NiCD • About 20% more expensive than NiCD	• Limited-service life—shallow rather than deep discharge cycles preferred. • Repeated discharges with high load currents reduce the battery's cycle life. • High self-discharge—NiMH has about 50% less stored shelf life than NiCD. • Performance degrades if stored at elevated temperatures • High maintenance—requires regular full discharge to prevent crystalline formation

Charging Protocols:

Charging an electric vehicle is not as simple as refuelling an IC engine vehicle. Compatibility between the electric vehicle supply equipment (EVSE) and the electric vehicle on various parameters has to be established before the charging can begin. Voltage, current, frequency, communication medium, billing and fast charging compatibility are among the various factors that decide whether a charging station will be able to charge a specific EV. Since there are various EV and EV charging unit manufacturers, standardization is indispensable. The different EV charging protocols offer this much needed standardization among the EVs charging system and EVSE. Protocols are like a code, and both parties hold the same code to establish contact.

Going back to the phone, it represents the power management ICs integrated inside the phone and charger, respectively, when the phone and charger are connected via the data cable. When the two ICs are connected, they will coordinate with each other for the most suitable voltage and current, and the fast charging will only be activated after mutual authentication and "handshake". When activated, the power management IC also adjusts the output and input voltages and currents according to the protocol, which is the charging protocol. The roles, different charging protocols, the control strategy for the charging process, all have some differences.

- **EVSE:** 'Electric Vehicle Supply Equipment' refers to the charging equipment that safely connects an electric vehicle to a mains electrical supply. EVSEs may also offer authentication, metering, payment services, and remote monitoring. Bureau of India Standards (BIS) has published standard IS: 17017 that covers general requirements and safety norms for EVSEs.
- **Charging Protocol:** Charging Protocols define the type of Connector that goes into vehicle inlet, max power and voltage for the connection, communication protocols, and type of the communication link.
- **CMS (Central Management System):** A cloud-based backend system managed by the company operating the charging station. The EVSE communicates with the CMS to manage user authorization, billing and rate of charging. The CMS will also enable user-facing apps to help end-users findnearest charging stations, reserve a charging slot and pay.

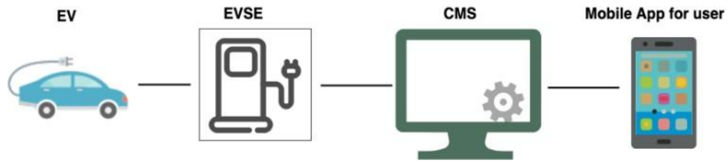

Figure 8: EV charging mechanism

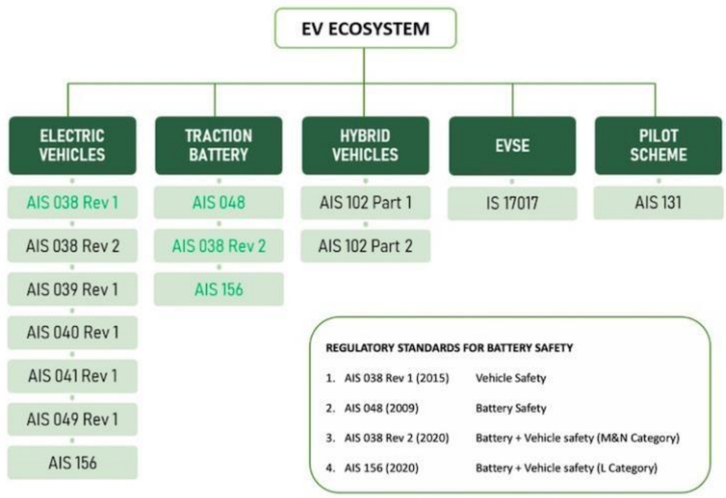

Figure 9: Classification of EV standards used for project work

Design Calculations for Energy recovery mechanism:

Assuming, Weight of bicycle = 20 Kg and Weight of person sitting on bicycle =80 Kg So,

- Total weight =100 Kg
- Wheel size of bicycle = 622mm=0.622m i.e., radius = 0.311m
- Length of bicycle = 6 ft. =1828mm= 1.828m
- Rolling friction = 0.01 and Coefficient of drag= 0.88 Assuming expected speed of our bicycle = 25Km/hr. Width of bicycle = 2 ft. = 609mm =0.609 m
- Area = length of bicycle × width = 1.828 × 0.609 = 1.1132 mm^2
- Speed = 25 Km/hr.

Considering approximately paddling of 2 hours.

- Velocity = 25000/3600 =6.94 m/s
- Total Power required = [mass × acceleration due to gravity× velocity× rolling friction] + [air density× coefficient of drag× area× $velocity^3$] = [100×9.8× 6.94× 0.01] + [0.6465× 0.88× 1.113× 6.94^3] = 68.012 + 211.66 =279.672 W.

Calculation of battery required for EV e.g., Lithium-ion battery

- Calculations of battery pack for generating approx. 100-watt energy for approx. 2 hours.
- Single battery with 3.7 V and 2500mAh capacity.
- Using formulae (assuming 80% efficiency of the battery)
- Therefore, we need 24 cells of batteries with a pack of three (3.7 x 3 = 11.1) pairs in parallel and eight (2500mAh x 8 = 20Ah) in series combination.
- Similar calculations will be performed for other types of EV batteries for experimental analysis.

Table 5: Characteristics of different energy storage devices.

Type	Energy Efficiency (%)	Energy Density (Wh/kg)	Power Density(W/kg)	Cycle Life (Cycles)	Self-Discharge Rate
Lead-Acid	70-80	20-35	25	200-2000	Low
Ni-Cd	60-90	40-60	14-180	500-2000	Low
Ni-MH	50-80	60-80	220	<3000	High
Li-ion	70-85	100-200	360	500-2000	Medium
Li-polymer	70	200	250-1000	>1200	Medium
Flywheel	95	May-30	1000	>20000	Very High
Flywheel	95	>50	5000	>20000	Very High

Table 6: Battery Parameters Comparison

Sr. No.	Parameters	Lithium-ion battery	Lead Acid Battery
1	Weight	Lightweight	3times weight of
2	Resilience/discharge	Less vulnerable to high discharge and climate change	Damages through excessive discharge and extreme temperature
3	Life	Excellent	Good
4	Efficiency	High	Low
5	Replacement	6-7years	1.5-2years
6	Cost	Very High	Average
7	Power density	125W/Kg	40W/kg
8	Usable Energy	80%	50%
9	Voltage per cell	3.2V	2V
10	Maintenance	Basic annual Maintenance	Regular Maintenance every 3months

Simulation of Battery Connection Circuit

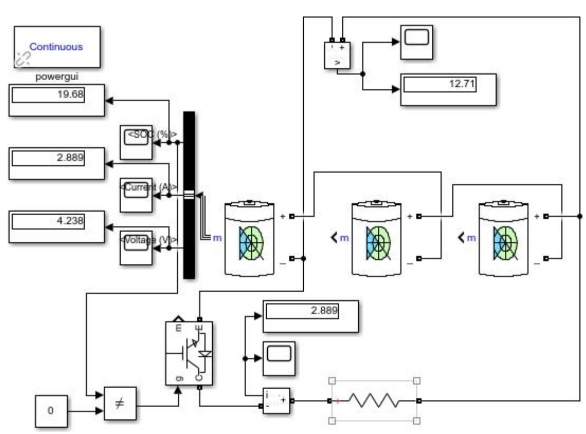

Figure 10: Simulation model Lithium-Ion batteries connected in series

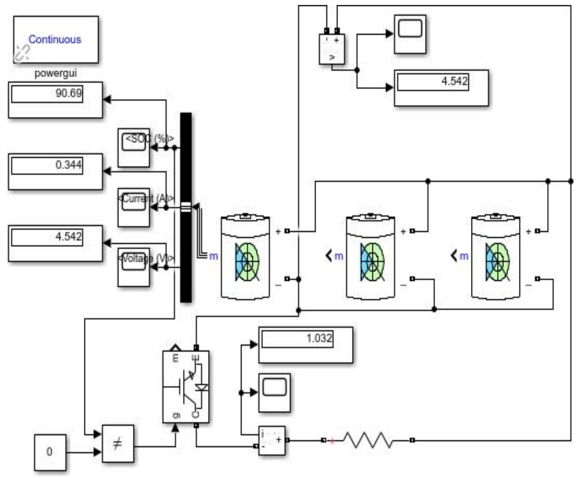

Figure 11: Simulation model Lithium-Ion batteries connected in Parallel

Observations Results

Table 7: Comparative simulation results of battery connections in series and parallel

Sr. No.	Battery Parameters	Series connection	Parallel connection
1	State of Charge	19.68	90.69
2	Voltage	12.71	4.542
3	Current	2.889	0.344

Simulation of Charging and Discharging Circuit of Battery

DC Voltage 12V, Nominal Voltage 11.1V, Rated Capacity 20Ah, Initial SOC 0, Time of Simulation 30 Minutes (1800 seconds).

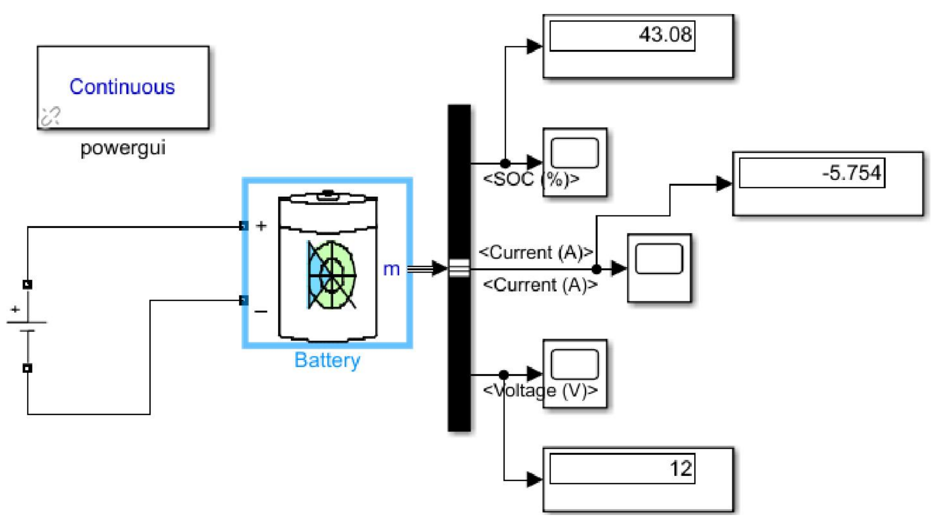

Figure 12: Charging Circuit for Lithium-ion Battery in MATLAB / Simulink

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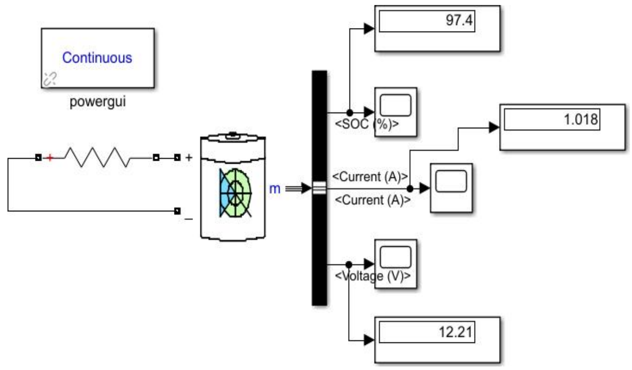

Figure 13: Discharging Circuit for Lithium-ion Battery in MATLAB / Simulink

Discharging Circuit of Battery

Simulations of Balancing circuit of the battery

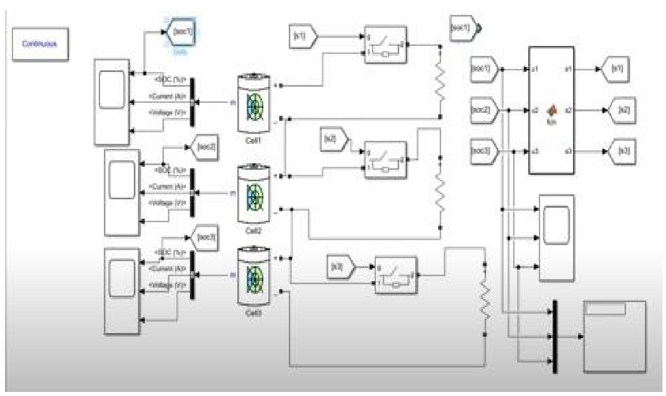

Figure 14: Simulink circuit for passive cell balancing

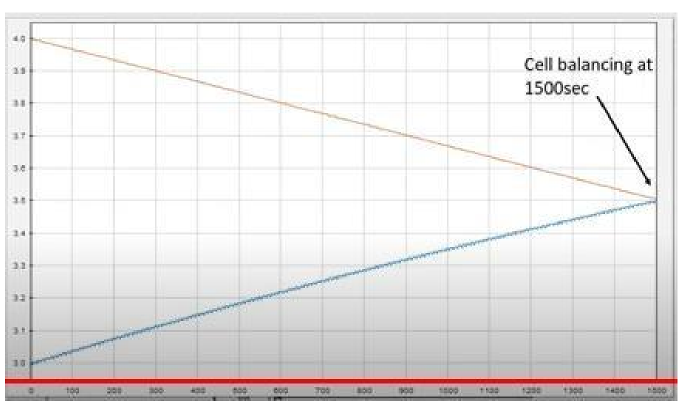

Figure 15: Results for passive cell balancing

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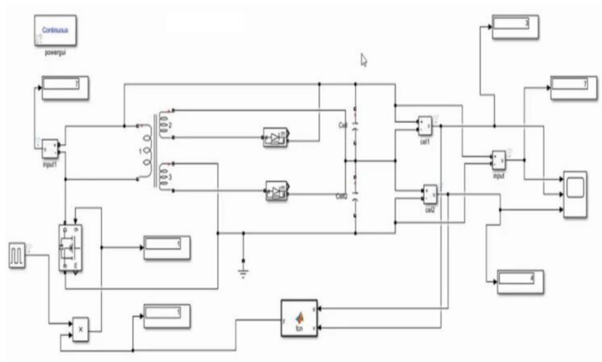

Figure 16: Simulink circuit for active cell balancing

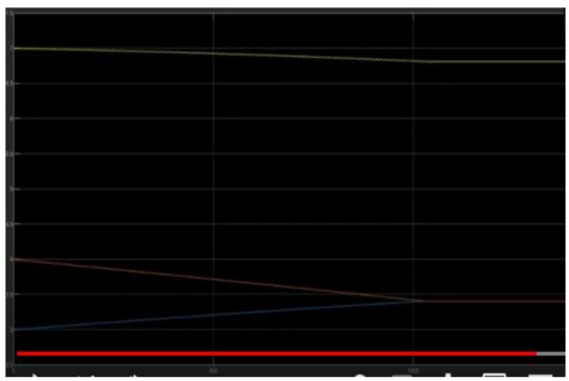

Figure 17: results for active cell balancing

Application based simulation – battery swapping (time of simulation 2474 s with step size of 100s)

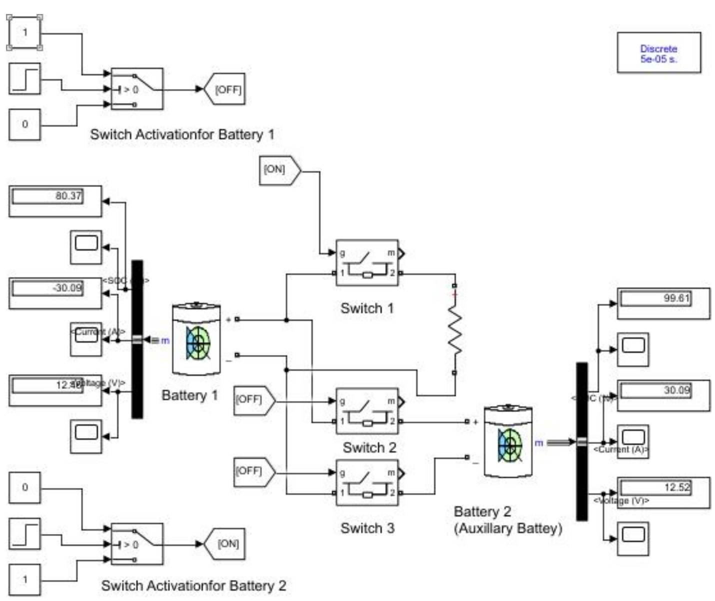

Figure 18: Simulink circuit for battery charging using auxiliary source

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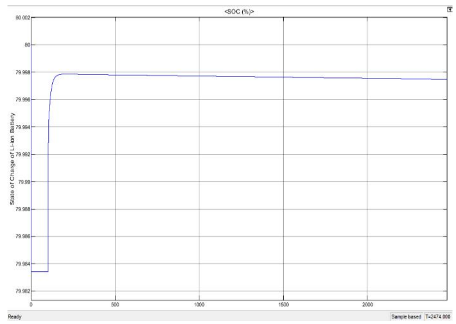
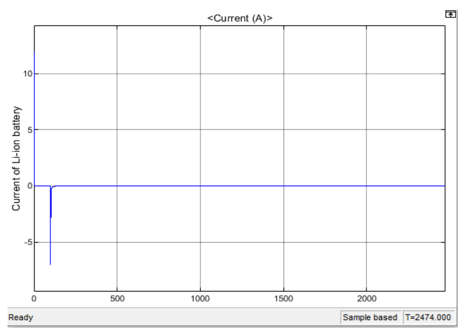
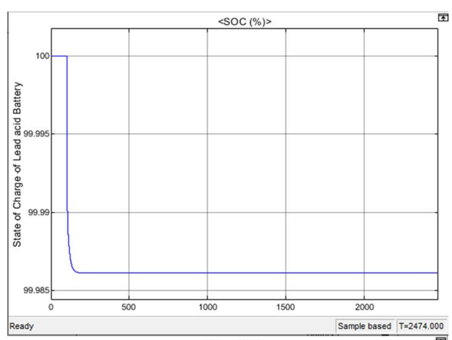
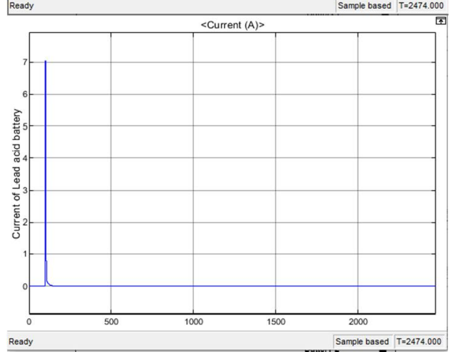
Table 8: Simulink circuit results for battery charging using auxiliary source

For working battery (lithium-ion battery) vs auxiliary battery (Lead acid battery)









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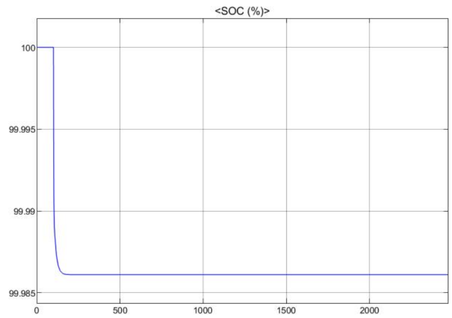

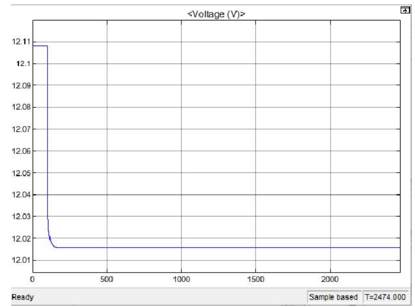

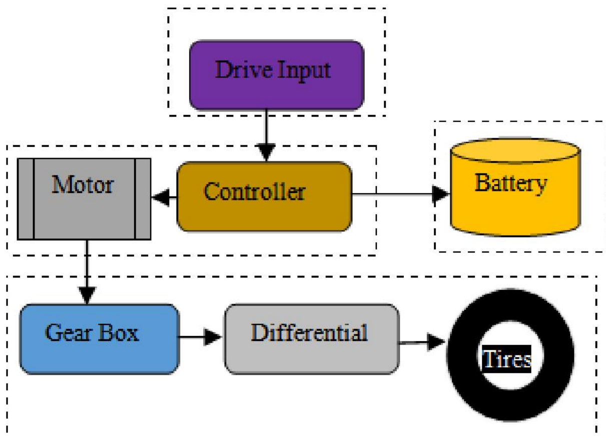

Figure 19: Block diagram of the Simulation on e-bicycle

Table 9: List of Parameters required for Simulation using MATLAB / Simulink

Battery Parameters	Nominal voltage	12 V
	Rated capacity	20 AH
	Initial stage of charge	100%
Vehicle parameters	Mass	100kg
	No of wheels per axle	2
	Horizontal Distance from CG to front axle	0.7m
	Horizontal Distance from CG to rear axle	0.7m
	CG height above ground	0.5m
	Gravitational Acceleration	9.81m/s^2
	Drag coefficient	2
	Air Density	1.18 kg/m^3
Gear, differential and motor parameters	Carrier to drive shaft teeth ratio	4
	Follower to base teeth ratio	2
	Inductance	12e^{-6} H
	No Load speed	6000 rpm
	Rated speed	5000 rpm
	Rated Load	1 kW
	Rated DC supply	24 V

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Simulation: (Time of simulation study for 2474 seconds)

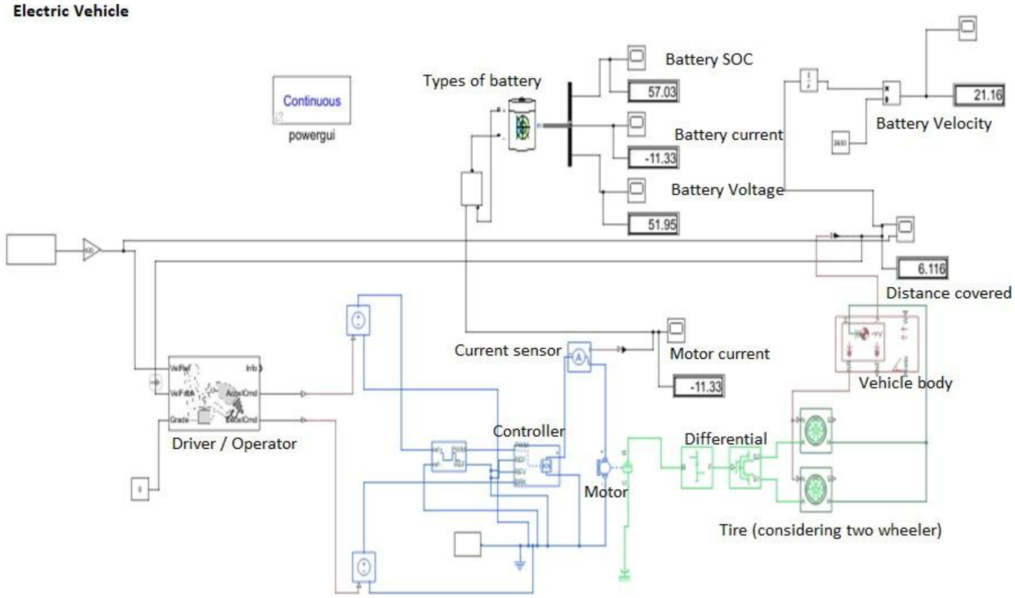
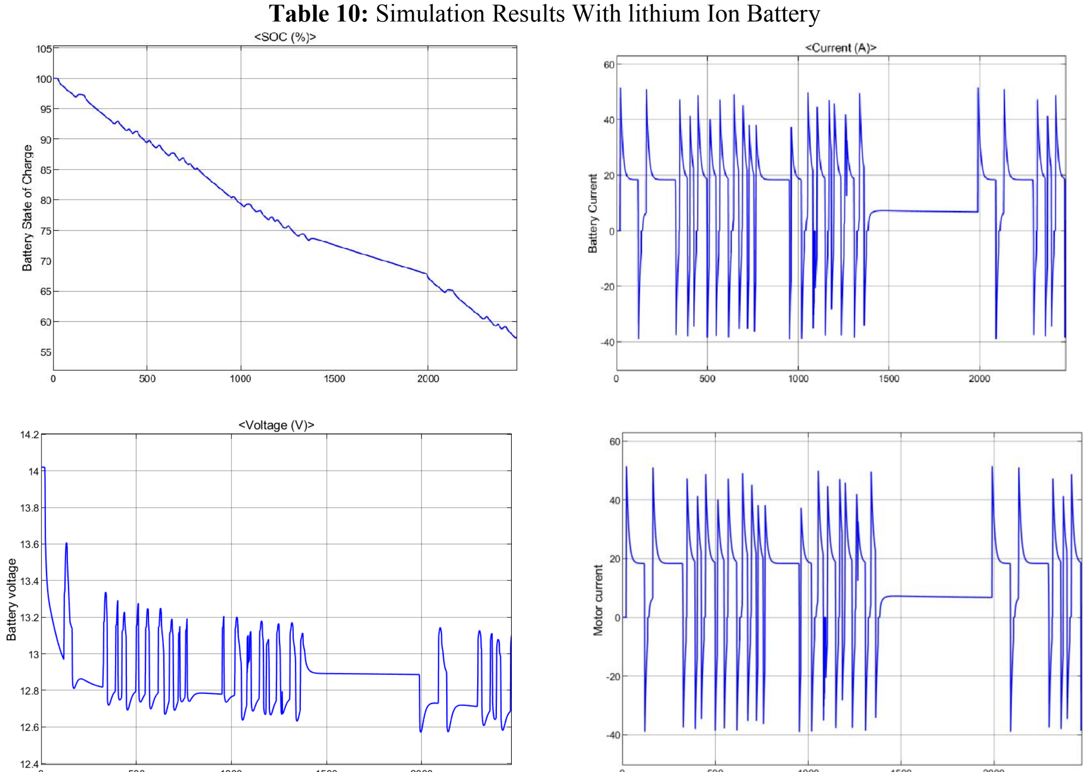


Figure 20: Simulink model of E-Bicycle using MATLAB / Simulink

Table 10: Simulation Results With lithium Ion Battery



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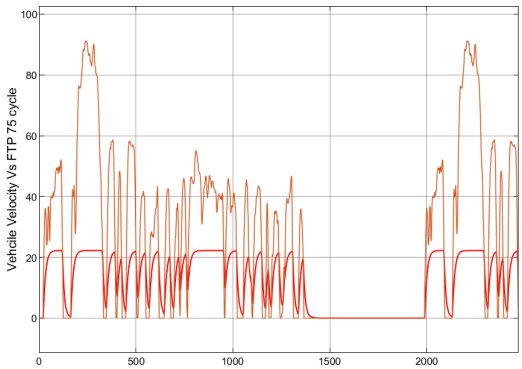


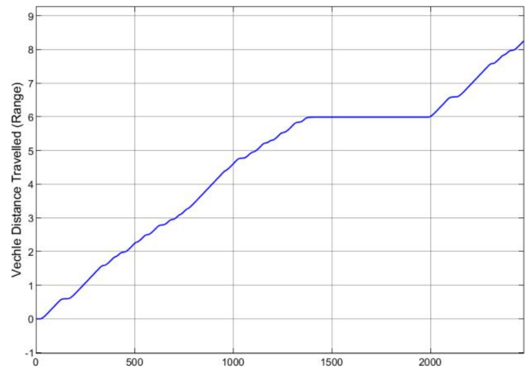
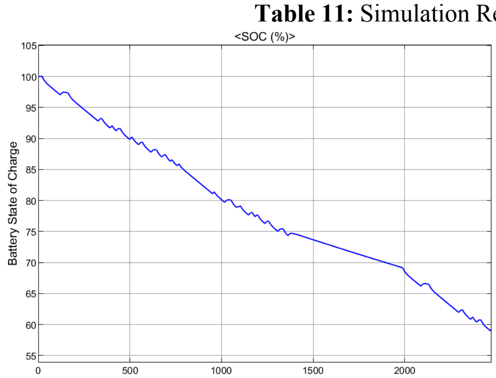
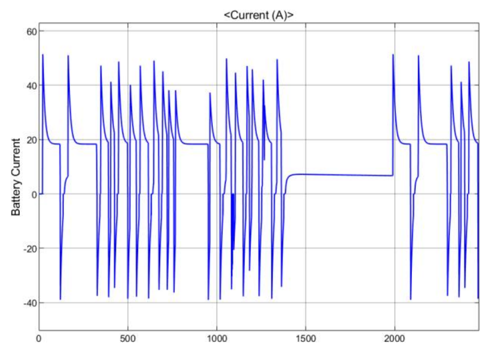
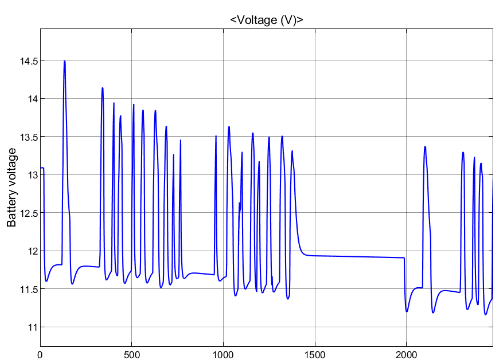
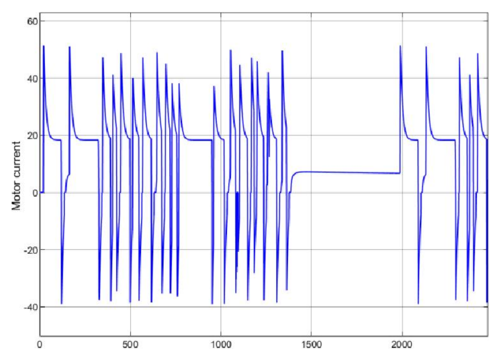


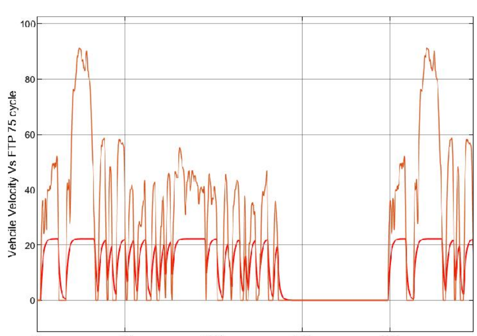
Table 11: Simulation Results With lead acid Battery











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Similar simulation is performed using different types of batteries and results are summarized below.

Table 12: Simulation results of different batteries for performance parameters

Types of Battery	SOC in %	Current in A	Voltage in V	Velocity in	Distance in Km
Li-ion	57.53	22.98	13.1	12.61	8.255
Lead acid	59.23	22.98	12.96	12.61	8.254
Nickel Cadmium	62.62	22.98	13.08	12.61	8.254
Nickel metal hydride	60.56	22.98	13.3	12.61	8.254

IV. EXPERIMENTAL SET UP

For experimental analysis two batteries i.e., lead acid and li-ion have been used. the bicycle is manufactured from scrap/old bicycle which has been run after converting it into e-bicycle initially with lead acid battery, then with lithium-ion battery and finally with combination of both as shown in following table.

Table 13: Cost Estimation of the experimental set up

Sr. No.	List of Component	Specifications	Quantity	Price (Rs.)
1	Bicycle	General light weight	01	1500
2	Battery Pack	Lithium-ion battery cells of 3.7 V and 2.5 A. 3 in series and 8 in parallel	24	3000
3	Battery	Lead acid 24 V 28 A	01	1600
3	Controller	Voltage: 24V±1. Current Limit: 30A ±1.	01	2000
4	BLDC Motor	36V, 80% Efficiency, 750W class B	01	4500
5	Throttle r Charger	Charger 20 A	01	2000
6	Display Unit	Voltmeter and Ammeter	01 each	500
7	Other wiring connections, solder, wire	Color, Black; Material, Aluminum Yed Electric; Current Rating; Brand, Ampere, 3 A	As per requirement	1000
Total cost				**16100**

Figure 21: Experimental set up

Table 14: Comparative analysis of lead acid and lithium-ion battery

Sr. No.	Type of battery	SOC (%)	Current (A)	Voltage (V)	Velocity (Km/hr)	Distance (Km)
1	Lithium ion	50	5.5	10	3	18
2	Lead acid	60	6	9.5	2.8	18
3	Combination of	55	5.8	10	3	17.5

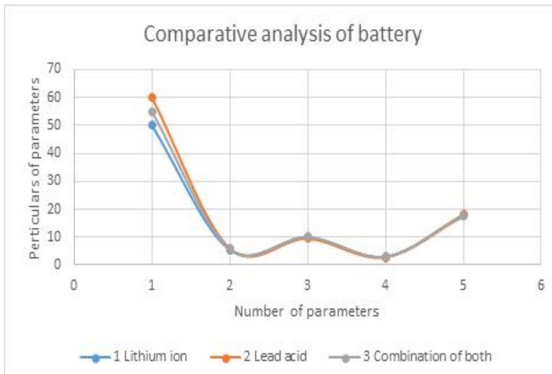

Figure 22: Experimental comparative analysis of lead acid and lithium-ion battery

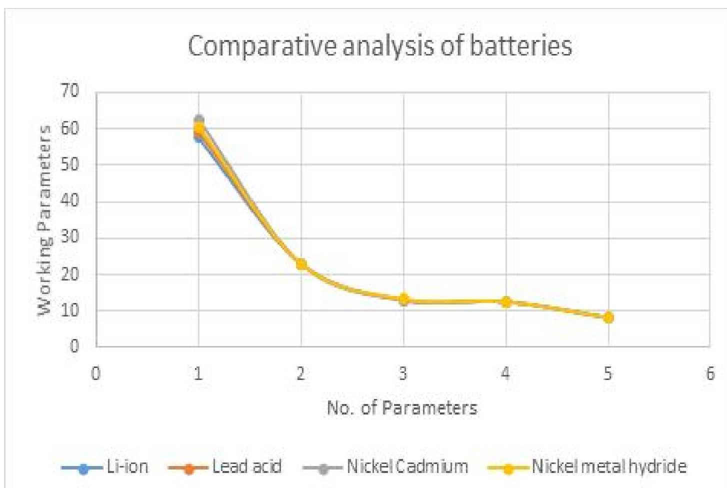

Figure 23: Simulated comparative analysis of different battery parameters

I. V. CONCLUSIONS AND FUTURE SCOPE

Conclusions

- Literature survey shows that much work has been done on foreign road conditions and automobile applications, mush work need to focus on Indian road conditions as well as energy sector considerations.
- The calculation for energy recovery mechanism for the proposed set found that approximately = 313.678 W of energy can be recovered by paddling for approximately 2 hours.
- The simulation was carried for different connections for li-ion battery, it is found that

1. series connection increased the voltage whereas parallel connection of battery cells increases the capacity, therefore to have efficient solution we need to implement both connections, in this project we have use 3 series and 8 parallel battery cells.

2. While charge some variation is found in voltage and current of different battery cells, to avoid this active and passive balancing is studies through simulation and finally active balancing is utilized in battery pack for experimental set up through battery management system which is also used for controlling overcharging and thermal issues in battery pack.
3. Simulation of charging and discharging circuit gives satisfactory results using graphical analysis.
4. simulated and experimental results of pure li-ion battery, lead acid battery and combination of both will be better solution for Indian road conditions due to shortages of charging stations, we can use two different batteries and energy storage device so that one will charge other during actual operation. Further second can be recharged either proposed paddling energy mechanism or through regenerative breaking.

- Comparative analysis of lithium-ion battery with other batteries shows that approximately same velocity and distance achieved with slight difference in state of charge. But if we go to the charging and discharging cycle and other efficient parameters of those batteries, lithium-ion finds the best suited solution for e-mobility.
- Simulation and experimental results on manufactured e-bicycle shows some interrupted and discrete results for variation in working parameters like current, voltage, state of charge, velocity and distance covered by the vehicle, which can be further improved by more optimized battery pack, controller and motor selection and connections.

Future Scope

- Further work proposed for different types of batteries simulation and its experimental analysis for results validation of EV battery parameters like SOC, Temperature, current and voltage variation w.r.to time.
- The work can be implemented for other types of light vehicles of two-wheeler or three-wheeler as well as for heavy transport vehicle and four wheelers for further getting effective solution for e-mobility and towards reducing the dependency on petroleum fuels and its harmful effects on human beings.
- Experimental set up can be further modified with other energy storage systems or combination of one or more batteries.

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